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AICRP Reporter: A web-based reporting system for the trials of AICRP on sugarcane

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ABSTRACT

All India Coordinated Research Project (AICRP) on Sugarcane regularly conducts multi-location trials of breeding material, production techniques, and pest / disease management strategies at AICRP centres located in five zones of India. Data generated out of these trials is analysed and various reports are compiled by Investigators, Centre Incharges, Principal Investigators and Project Coordinator. An effective coordination, communication, data analysis and documentation are required to achieve the objectives of AICRP. Use of Information and Communication Technologies (ICT) based data management can improve the efficiency of such systems. The problem was discussed in AICRP Workshop held in 2015 at Rajendra Agricultural University, Pusa, Bihar. It was recommended to develop software for recording and reporting AICRP trials data using a web based application software. Paper gives brief information about AICRP Reporter software developed at ICAR-Indian Institute of Sugarcane Research, Lucknow to address the issue.

Key words: AICRP Reporter, Web Application, Data Management

INTRODUCTION

All India Coordinated Research Project (AICRP) on Sugarcane was set up in 1970 with the objective to evaluate varieties under location specific conditions in addition to multi-location testing of production and protection technologies developed at various research stations. Trials are conducted for evaluation of these technologies every year at over 22 AICRP centres located in North-East, North-West, North-Central, East Coast and Peninsular Zones of India. Further 15 voluntary centres are also involved in these trials (Shukla *et al.* 2018). Trials are conducted at these centres with the help of Centre Incharges, Investigators and Technical staff. Monitoring teams of experts are formed to monitor the trials and to share views for effective trial execution. Project Coordinator and Principal Investigators monitor overall progress of AICRP trials and formulate future plans with the help of centre's staff and experts. Data generated out of these trials are analysed and various reports are compiled by Investigators, Centre Incharges, Principal Investigators and Project Coordinator for monitoring, evaluation and planning of AICRP trials. An effective coordination, communication, data analysis and documentation is required to achieve the objectives of AICRP. But existing data management system has many issues such as:

- Resources consuming information communication
- Delayed reporting
- Inconsistent data formats
- Re-entry of data at various stages
- Data security issues
- Repeated and inconsistent data analysis
- Poor documentation
- Poor decision support and planning
- No historic data availability
- Need ample experts for monitoring trials
- Difficult peer group consultation

Information and Communication Technologies (ICT) based data management techniques can improve the efficiency of such systems. Web based applications enable recording of data and accessibility of reports thereof from remote locations over the Internet (Castells 2014). Keeping in view, the potential of ICT, it is advisable to switch over to ICT based data management techniques for AICRP trials (Mahant *et al.* 2012). The problem was also discussed in AICRP Workshop held in 2015 at Rajendra Agricultural University, Pusa, Bihar. It was recommended to develop software for recording and reporting AICRP trials data using a web based application software. Paper gives brief information about AICRP Reporter software developed at ICAR-Indian Institute of Sugarcane Research, Lucknow to address the problem.

ABOUT AICRP REPORTER

AICRP Reporter is a web based application developed to provide an effective data recording and reporting platform to stakeholders of AICRP on Sugarcane. Application works in client-server architecture, where client get access of the software and database from server (Oluwatosin 2014). Software has been developed using Java and Hyper Text Markup Language (HTML) and hosted on server along with relevant database. To achieve objectives, software modules have been developed to manage data profiles generated under AICRP project.

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Data Profiles in AICRP Reporter

Sugarcane varieties and production / protection technologies requiring multi-location trials are proposed by research centres during AICRP Group Meeting / Workshop (Sinha *et al.* 2016). Discussions are held on these proposals under four disciplines of Crop Improvement, Crop Production, Entomology, and Plant Pathology headed by respective Principal Investigators. Consequently technical programme is finalized under these disciplines for multi-location trials of proposed technologies. Seed material and other testing material are supplied to respective centres to conduct trials. Trial observations along with analysed results are communicated by centres to respective Project Investigator and Project Coordinator for further compilation and documentation of trial results. Reports of trials are used in various meetings / workshops for trial recommendations and future planning.

Based on literature review and discussion with AICRP officials, a number of profiles to be managed by the software, has been identified as Project, Experiment, Centre, Official, Treatment, Character, Treatment Schedule, Character Observation Schedule, Trial, Observation, and Remark. Brief information about profiles being managed and used by AICRP Reporter are as follows:

Project: Information about projects managed in AICRP under disciplines of Crop Improvement, Crop Production, Entomology and Plant Pathology.

Centre: Maintain profiles of AICRP centres along-with agro-climatic conditions, states and zone they belong to.

Official: Official profiles are record of officials engaged in planning, management and execution of trials under user roles of Project Coordinator, Centre Incharge, Principal Investigator, Investigator (Project Leader) and Technical, *etc.* Further, system also allow guest user to have information about AICRP activities and achievements.

Treatment: This is repository of all technologies / varieties tested under AICRP.

Character: This is repository of characters for which observations may be recorded under AICRP trials.

Experiment: Experiment is the key operational entity in the software. Experiments are added / initiated in the software under various projects after finalization of technical programme in AICRP Workshop. Individual experiments are initiated in the software every year under respective project and centre.

Trial: Field information about trials conducted under an experiment at the centre.

Treatment Schedule: Varieties / technologies to be tested under experiments with respect to technical program. These are finalized during AICRP Workshop and are maintained in the system as technical program for the trials.

Character Observation Schedule: Characters to be observed under experiments with respect to technical program. These are also finalized as technical program during AICRP Workshop.

Events / Activities: AICRP Reporter enables recording of events / activities of field trials. These are useful for monitoring of trials and interpretation of results.

Observations: It is repository of observations recorded in field trials.

Remarks: Remarks are recorded along with trial observations for interpretation of results. Comments are also made by experts on trials during monitoring and AICRP Workshop.

Major software components

AICRP Reporter software provides data management and reporting platform for entire cycle of AICRP trial management. Various components of the software are profile management; activity dashboard; observation recording; analysis and knowledge hub; report generation; security management and settings.

Profile Management: Software manage data profiles with the help of Profile Management tools *viz.* Project, Experiment, Centre, Official, Trial, Treatment, Character, Treatment Schedule, Character Observation Schedule, and Event/ Activity, Remarks, *etc.* Profile record may be added, updated, removed, searched and listed using modules available in the system.

Activity Dashboard: Activity Dashboard is working area of AICRP Reporter software to provide access of software tools to users. Quick Links in dashboard give access to frequently used modules of the software. Some of the quick links are Project, Experiment, Treatment, Character, Centre, Official, Treatment Schedule and Character Observation Schedule. Activity Space area of dashboard incorporates space for queries and listing of results. Records appear in this area for view, selection, addition, modification, deletion and relation-setting activities. On logging into the system user land into his dashboard.

Observation Recording: System enables two modes of observation recording *viz.* online through Observation Recording Screen and offline through Excel File generation.

Analysis & Knowledge: Analysis and Knowledge hub hosts modules to carry out data analysis, data mining and knowledge discovery from the system. It is the key feature incorporated in the system to be used for planning and decision support for AICRP trials.

Security Management: Security mechanism has been integrated in the software for secured access of the software modules and AICRP data. System incorporates three level of security mechanism *viz.* user registration and authentication, role-based access to software modules, and data filtering rules.

Report Generation: Report Generation modules are used to view reports of Projects, Experiments, Trials, Officials, Centres, Characters, Treatments, Treatment Schedule, Character Observation Schedule, Observation, Events, etc.

Settings: It allows setting relationship among various profiles. Assignment of user roles to registered officials are made by modules under this category. Further, modules are available for accessibility and display setting of AICRP experiments and trial data.

Observation recording through AICRP Reporter

There are two ways of trial observation recording *viz.* online and offline mode. In online mode of observation recording, data is uploaded through online data entry interface. Steps to upload data in online mode are as follows:

1. Select the experiment for which trial observations to be uploaded
2. Select the treatment / entries
3. Select the characters
4. Record the data in observation recording screen
5. Save the data recorded

In offline mode, MS Excel file is generated by the system. Data is recorded in downloaded Excel File and uploaded into the software through uploading module. Steps to upload data using Excel File are as follows:

1. Select the experiment for which trial observations to be uploaded
2. Select the treatment / entries
3. Select the characters
4. Create and download Excel File
5. Record the data in downloaded Excel File
6. Upload above Excel File

Figure 1-3 show few screen shots of observation recording in AICRP Reporter.

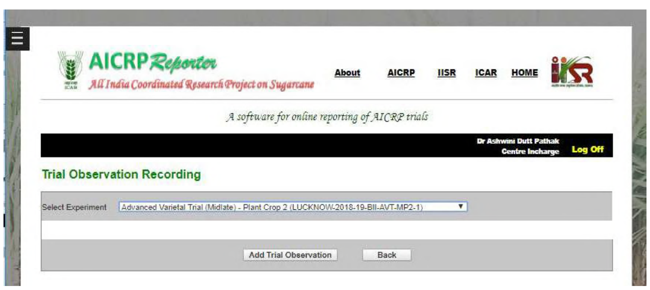

Fig 1. Screen shot for selection of experiment for which observations to be uploaded

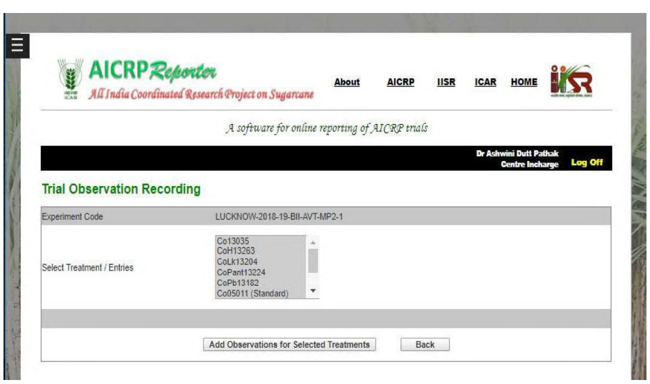

Fig 2. Screen shot for selection of treatments

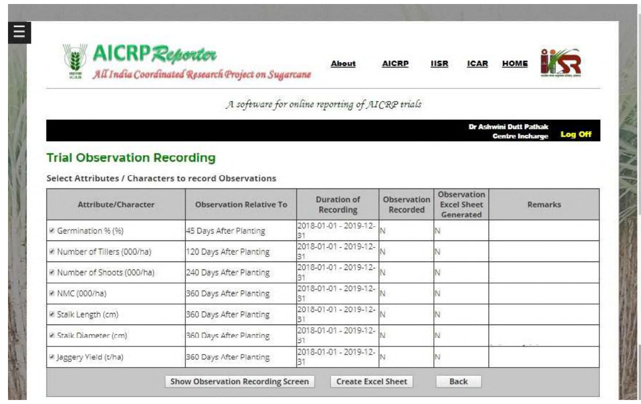

Fig.3 Screen shot for selection of characters

IMPLEMENTATION OF AICRP REPORTER

AICRP Reporter is a web based application and therefore requires web server to host it. Open source technologies have been utilized for development and hosting of the application (Heron *et al.* 2013). Apache Tomcat 6.0.48 web server has been used to host the application and to provide access to its users. Software needs a reliable and secure database support to manage data profiles, which has been achieved using MySQL 5.7 database server. Further, domain for the application has been registered with ICAR Data Centre. Application and database has been uploaded on ICAR Server.

User can access the software over the Internet using URL https://iisr.icar.gov.in/iisr/aicrp/software/index.jsp. Web server accepts user requests, executes server-side scripts, establish connectivity with database server to access AICRP data and finally create client-end html scripts to be executed on user's computer.

CONCLUSION

AICRP Reporter provides web based access to AICRP data resources over the Internet for reporting of trial data and reports thereof. Common data recording formats used in the system improve the consistency and reliability of data reported. Being ICT based technologies, it will reduce the cost of data recording, compilation and documentation. Remote monitoring of trials and knowledge sharing is possible through this system. Data once recorded may be utilized with historical perspective for new knowledge discovery. Free and open source technologies has been used for development of the software, thus it costs nothing on development end. Further, design of the system is generic, *i.e.* software can be implemented for other such crop based AICRP projects with few changes in database.

Intensifying and extending the networking facility and information generation for transfer of technology to the farmers and sugar industry is one of the mandates of AICRP on sugarcane. System successfully fulfils the mandate of AICRP along with providing better coordination, communication, analysis and documentation facility to its stakeholders.

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Evaluation of introduced sugarcane varieties (*Saccharum* spp. hybrid) for yield and quality characteristics in Southern Ethiopia

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ABSTRACT

Sugarcane varieties play a pivotal role by their cane yield and quality in the success of new sugar factories with respect to sugar recovery and production. Promising sugarcane varieties are needed to be identified with high cane yield and quality for new sugar factories being established at Omo-Kuraz, Southern Ethiopia. Hence, a study was undertaken to evaluate the performance of introduced sugarcane varieties for cane yield and quality characteristics. The materials consisted of fourteen sugarcane varieties, ten introduced, *viz.,*'B 49/224', 'B 49/338', 'B 53/165', 'B 57/371', 'Co 842', 'Co 945', 'Co 978', 'Co 1001', 'CP 72/2083', 'PR 1007', and four grown by farmers, *viz., 'Habesha', 'Nech Habesha', 'Shelle Habesha'* and *'Wonji'*. Field experiment with these varieties was planted in randomized complete block design with two replications. Plot size was three rows of 3.0 m spaced 1.45 m apart. Varieties differed significantly for cane yielding and quality characteristics, cane yield and sugar yield. Number of cane stalks and millable canes were high in varieties, 'PR 1007', *'Wonji'*, 'B 53/165' and 'Co 978'. Cane height was more in the varieties, *'Wonji'*, 'B 49/338', 'B 53/165' and 'B 49/224', Canes were medium thick in *'Shelle Habesha'* and medium in the varieties, *'Nech Habesha'*, *'Habesha'*, 'B 49/224','Co 842' and 'B 53/165'. Cane weight was more in the varieties, 'B 49/224', *'Shelle Habesha'*, 'B 49/338' and 'Co 842' and 'B 53/165'. Estimated cane yield was high in the varieties, *'Wonji'*, 'B 53/165', 'Co 978', 'PR 1007' and 'B 49/338'. Pol in juice was high in the varieties, 'PR 1007', 'CP 72/2085', 'B 57/371' and 'B 49/224'. Sugar recovery per cent was high in the varieties, 'PR 1007', 'CP 72/2083', 'Co 842', 'B 57/371' and 'Co 1001'. Estimated sugar yield was high in the varieties, 'PR 1007', 'Co1001', 'B 49/224', 'Co 978', 'B 49/338' and 'B 53/165'. On the basis of cane and sugar yields, seven varieties, 'PR 1007', 'Co 1001', 'B 49/224', 'Co 978', 'B 49/338', 'B 53/165' and *'Wonji'* were found promising, which were suggested to be further tested for their specific and wide area adaptation in Southern Ethiopia.

Key words: Sugarcane varieties, Cane yield, Cane quality, Sugar yield, Ethiopia

INTRODUCTION

Sugarcane is an important sugar crop of subtropical and tropical countries and belongs to genus *Saccharum* of the family, *Poaceae (Gramineae)*. The matured sugarcane stems or millable canes are milled and their extracted juice is processed for crystallization of sugar in sugar factories along with other valuable by-products like bagasse, molasses, ethanol, co-generation of electricity and filter press mud. Its green tops are used as fodder for cattle. Sugarcane production in Ethiopia was undertaken on 5000 hectares of land initially at Wonji during 1950s and the first sugar factory was commissioned in 1954-55. Later, sugarcane production was extended to Shoa, Metahara, Finchaa and Tendahoe states where sugar factories were established. The present sugar production in the country is able to meet 60 percent demand of the people. Notwithstanding this, the per capita consumption of sugar is 5 to 6 kg, whereas it is 16.5 kg in Africa and 24 kg in the world (Shimelis *et al.* 2011; ISO, 2012; Firehun *et al.* 2013). In order to meet the sugar consumption demand, the Ethiopian Government has launched an ambitious project for increasing sugarcane and sugar production by establishment of ten new sugar factories and expanding the crushing capacity of existing sugar mills. Sugarcane plantations are being developed at three new sugar projects, namely, Omo-Kuraz, Tana Beles, and Wolkayit. Sugarcane plantation is planned in 150,000 hectares at Omo-Kuraz, Southern Ethiopia where six sugar factories are being established with a production capacity of 556,000 tons (EIA, 2012; ESIP, 2017).

Sugar cane varieties play an important role in sugarcane and sugar production due to their inherent potential for cane yield and quality, resistance to diseases and insect pests and adaptability to different agro-climatic conditions (Getaneh *et al.* 2013a; Getaneh *et al.* 2013b; Tadesse *et al.* 2009). Sugarcane varieties in Ethiopia have been introduced from different countries, of which promising ones have been selected for cultivation (Negi and Damtie 2009; Tadesse *et al.* 2014). Improved sugarcane varieties are the derivatives of inter-species hybrids (*Saccharum* spp. hybrid) involving cultivated species *(S. officinarum, S. barberi* and *S sinense*) and wild species (*S. spontaneum* and *S. robustum*). Nobel clone (*S. officinarum)* was hybridized with wild species (*S. spontaneum*)

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and first inter-species hybrid became a success in India. The two-species hybrids were nobilized and also crossed with other Indian cultivated clones (*S. barberi*) for improvement in cane yield and quality, disease resistance and tolerance to stress environments. Later, improved tri-species hybrid varieties were used as breeding materials and were hybridized with other tri-species hybrids as well as others with complementary characters to evolve improved varieties with high cane and sugar yields, resistance to biotic and abiotic stresses and adaptability to different agro-climatic conditions in India, Indonesia, Barbados, USA and other countries (Nair 2009; Srivastava 2009; Bischoff and Gravois 2004; Moore *et al.* 2014). Introduced sugarcane varieties were needed to be evaluated for identifying promising ones for new sugar factories establishing site at Omo-Kuraz. Arba Minch University is near to Omo-Kuraz and represents warm agro-climatic conditions similar to that at new Omo-Kuraz sugar project. The present investigation was, therefore, undertaken to evaluate the performance of sugarcane varieties for yield and quality characteristics in plant crop at Arba Minch, Southern Ethiopia

MATERALS AND METHODS

Study area and meteorological data

Current study was carried out at Arba Minch University, Ethiopia located at 6.04 ^{0}N latitude, 37.36 ^{0}E and altitude of 1218 m. Average proportions of sand, silt and clay particles in the soil of the experimental field were 12.0, 37.30 and 50.70%, respectively. The pH of soil was 7.8. The soil was rated as clay and slightly alkaline (Murphy 1968). The average monthly maximum (31^{0}C) and minimum (18^{0}C) temperatures, relative humidity (62%) and rainfall (220 mm) during April, 2018 were suitable for sprouting of buds in cane setts planted. There were moderate temperatures, relative humidity and sunshine hours at tillering, cane stalks and millable canes formation during subsequent months up to September, 2018. Mean maximum and minimum temperatures were over 33 ^{0}C to 39.3^{0}C and 16.9 ^{0}C to 18.5^{0}C with declining relative humidity and non-sunny days during November, 2018 to February, 2019. Temperatures were also high during March-April, 2019 which could have affected growth and development and ripening or maturity of sugarcane.

Materials

The materials for the investigation consisted of 14 sugarcane varieties, ten introduced *viz.,* 'B 49/224', 'B 49/338', 'B 53/165', 'B 57/371', 'Co 842', 'Co 945', 'Co 978', 'Co 1001', 'CP 72/2083', 'PR 1007', and four grown by farmers, *viz., 'Habesha', 'Nech 'Habesha', 'Shelle Habesha' and 'Wonji'*. Initial alphabets of names of varieties indicate the country of breeding, *viz.,* B, Barbados, Co-Coimbatore, India, CP-Canal Point, Florida, USA, PR-Puerto Rico, and *'Habesha', 'Nech Habesha' and 'Shelle Habesha'* are early introductions resembling noble canes and *'Wonji'* appeared inter-species hybrid from Ethiopian Sugar Corporation, *'Wonji'*. The seed canes of introduced varieties were collected from Metahara Research Centre of Ethiopian Sugar Corporation and of 4 locally grown cane varieties from village, Shara near to Arba Minch University.

Experimental design and procedures

The experiment was planted with 14 varieties in randomized complete block design with two replications on April, 4, 2018. Plot size was 3 rows of 3.0 m length spaced 1.45 m apart. Nine 3-budded sets were planted in 3.0 m long row of each plot. Experiment was fertilized @ 150 kg Urea and 250 kg Diammonium phosphate (DAP) per hectare which was equivalent to 114 kg N and 115 kg P per hectare. Full dose of DAP was applied at the time of planting. Urea was applied in three split doses, one third at planting time, one- third at 30 days after planting and the remaining one third at 90 days after planting as per recommended practice. The setts were treated with Tilt 250 EC (Propiconazole) @ 1 ml per litre for a minute before placing in the furrows. Water emulsion of Ethiozinone 60 EC insecticide was sprayed on the setts @ 43 ml in 10 litre of water emulsion in 100 m furrow length after placement in furrows and covered with 5 cm layer of soil to control insect damage as per recommended practice. Light irrigation was given in furrows after planting the same day. After two days of irrigation, the exposed setts from soil were covered with soil in the field. The required cultural practices for raising sugarcane crop like irrigation, weeding, hoeing, earthing up and tying up of sugarcane stalks were done as and when required.

Recording of data

Data on yield characteristics was recorded at different growth periods. Sprouting of buds in cane setts was recorded at 45 days after planting as per standard practice. Numbers of tillers including primary sprout were recorded per plot at 75 days after planting. Cane formed stalks per plot were recorded at 8 month after planting. Number of millable canes with visible nodes and internodes with length greater than 1.0 m were recorded at 10 months after planting. Cane characteristics, cane stalk length and diameter, number of internodes and cane weight were recorded on random sample of 6 cane stalks from the plot at 9 month after planting. Cane diameter or thickness was classified as:<2.0 cm thin, 2-2.5 cm medium thin, 2.5-3.0 cm medium, 3.0 3.5 medium thick and >3.5 thick (Akhtar *et al.* 2001). Cane yield was estimated by multiplying number of number millable canes per plot with average cane weight of 6 millable canes sample per plot at 12 month after planting.

Quality characters data on °Brix, Pol and purity% juice were recorded from the composite juice of five random cane stalk samples crushed in a three roller cane crusher. Quality characteristics, °Brix, pol (sucrose) and purity per cent juice were determined by indirect method following standard procedures at Sugar Quality Laboratory, Ethiopian Sugar Corporation, Wonji at 12 months after planting. °Brix in juice was recorded using Rudolf Automatic Refractometer made by Rudolf Research Analytical, USA which gives direct reading of refromatric dry substance °Brix or soluble solids from the refraction angle. Pol per cent juice was determined by using Autopol 880 Automatic Saccharimeter made by Rudolf Research Analytical, USA by polarizing the clear filtered juice after precipitation of non-sugars by addition of basic lead (1.0 g/100ml) and Celite filtering aid and filtering through Whatman 91 filter paper. Pol or apparent sucrose per cent juice was noted from the table corresponding to pol reading and °Brix reading. Purity per cent juice was derived from ratio of pol over °Brix readings multiplied by 100 (Hundito 2009).

Estimated recoverable sugar percent cane was estimated using Winter Carp indirect method for cane quality analysis followed at Ethiopian Sugar Corporation as follows (James and Chung 1993):

$$ERS(\%) = [Pol\% - (Brix\% - Pol\%) * NSF] - CF$$

where, ERS = estimated recoverable sucrose per cent, NSF= non sugar factor (0.70) and CF = cane factor (0.57) (Hundito *et al.* 2009).

Estimated sugar yield was calculated as follows:

ESY (t / ha) = CYH (t / ha) x ERS (%)

Where, ESY = estimated sugar yield, CYH = cane yield per hectare, ERS = estimated recoverable sucrose per cent (Hundito 2009).

Statistical analysis

The data were subjected to statistical analysis for analysis of variance in randomized complete block design using SAS software version 9.00, 2004 (SAS 2004). Variety means for the characters were compared for significant differences with least significance difference (LSD) at 5% probability level.

RESULTS AND DISCUSSION

Bud sprouting, number of tillers, cane stalks and millable canes

Bud sprouting differed significantly (P<0.01) among varieties at 45 days after planting and varied from 79.63 to 237.04 per cent. Bud sprouting beyond 100 per cent included formation of tillers in the primary shoots in varieties (Table 1). Maximum and significantly higher bud sprouting was recorded in variety, *'Wonji'* than that in 13 other varieties. The next significantly higher bud sprouting was observed in variety, *'Nech Habesha'* but it was statistically at par with varieties, 'PR 1007', 'B 49/224', 'Co 978', *'Habesha'*, 'Co 945', 'B 49/338', 'B 53/165', 'Co 1001', 'B 57/371' and *'Shelle Habesha'*. The lowest bud sprouting occurred in varieties, 'Co 842' and 'CP 72/208'. As in present study, varietal differences for sprouting of buds were observed by others (Ali 2009; Khan *et al.* 2016). Besides the inherent genotypic differences, bud sprouting was affected by several factors such as crop age, portion of stem and condition of bud of seed canes, soil moisture and temperature (Ali 2009).

Number of tillers at 75 days after planting was maximum and significantly higher in variety, *'Wonji'* than other 13 varieties. The next significantly higher tillers were observed in variety B 49/338, which were at par with that of varieties, 'PR 1007', 'Co 978', 'Co 1001', 'Co 945', 'B 49/224' and 'B 49/224'. Tillers in latter variety were at par with 'B 53/165'. Significantly low number of tillers were formed in the remaining 6 varieties with lowest being in varieties, '*Habesha'* and *'Shelle Habesha'* Results indicated that locally grown variety, *'Wonji'* had highest number of tillers, whereas the other locally grown varieties, *'Habesha'* and *'Shelle Habesha'* had lowest number of tillers. As in present study, differences among varieties for tiller numbers were reported by other workers (Getaneh *et al*. 2015; Khan *et al.* 2016). Tillers arise at the base of newly developed plant from the axillary buds on the nodes of short internodes below the ground. Tiller arising from the bud of primary shoot plant at the base is known as primary tiller and the tiller developing from primary tiller is known as secondary tiller and so on. Tiller numbers vary with varieties and thus tillering is a varietal characteristics. Later some tillers develop into cane stalks by expansion of visible internodes on its culm and others die due to competition among tillers for light and nutrition (Bell and Garside 2005; Bonnet 2014).

Number of cane stalks differed significantly (P<0.01) among varieties at 8 month crop age. Number of cane stalks (thousand per hectare) were significantly higher in varieties, *'Wonji'* and 'PR 1007' than 12 other varieties. Next significantly high number of cane stalks was recorded in varieties, 'B 53/165', 'Co1001', 'Co 978', 'Co 945' and 'B 49/338', which were at par with 'B 57/371' and 'B 49/224'. Significantly low number of cane stalks were found in remaining 5 varieties with lowest in *'Shelle Habesha'* Number of millable canes differed significantly among varieties at 10 month age. Number of millable canes in variety, PR 1007 were maximum and significantly higher than 12 other varieties but were on par with variety, *'Wonji'*. Next significantly high number of millable canes was recorded in varieties, 'B 53/165', 'Co 978', 'Co 1001', 'B 49/338' and 'Co 945', which were on par with each other. Millable canes in the latter variety were also at par with 'B 57/371'. Significantly less number of millable canes were found in the remaining 6 varieties with the lowest number in variety, *'Shelle Habesha'*. It could be noted that the number of millable canes among varieties were less than the number of cane stalks. It could occur due to mortality of some cane stalks due to competition among cane stalks for light, nutrition and the shading effect of fast developing stalks on the slow growing stalks. Differences in number of cane stalks and millable canes among varieties indicated that there were inherent genotypic differences for these characters which were important component of cane yield (Gitaneh *et al.* 2015; Soomro *et al.* 2006; Shingles and Smit 2009; Inman-Bamber2014; Khan *et al.* 2016).

Table 1 Mean bud sprouting % and number of tillers, cane formed stalks and millable canes in sugarcane varieties in plant crop during 2018/19 at Arba Minch, Southern Ethiopia

Varieties	Bud sprouting % at 45 days	No. of tillers ('000/ha) at 75 days	No. of cane stalks ('000/ha) at 8 months	No. of millable canes ('000/ha) at 10 months
'B 49/224'	124.08^{bcd}	129.1^{bcd}	94.2^{bcd}	86.9^{ef}
'B 49/338'	107.41^{bcd}	169.3^{b}	109.1^{b}	100.7^{cde}
'B 53/165'	103.74^{bcd}	122.6^{cde}	114.1^{b}	113.7^{bc}
'B 57/371'	94.45^{bcd}	89.2^{def}	99.9^{bc}	93.8^{def}
'Co 842'	88.89^{cd}	83.9^{def}	83.1^{cde}	78.9^{fg}
'Co 945'	109.26^{bcd}	142.1^{bc}	111.8^{b}	99.9^{cde}
'Co 978'	124.07^{bcd}	147.5^{bc}	111.8^{b}	111.4^{cd}
'Co 1001'	94.43^{bcd}	146.7^{bc}	113.4^{b}	108.4^{cd}
'CP 72/2083'	79.63^{d}	91.9^{def}	72.0^{de}	66.2^{gh}
'PR 1007'	140.43^{bc}	165.1^{bc}	140.6^{a}	133.7^{a}
'Habesha'	114.81^{bcd}	75.8^{f}	61.6^{ef}	55.5^{h}
'Nech Habesha'	142.61^{b}	82.3^{ef}	65.9^{ef}	59.7^{h}
'Shelle Habesha'	90.72^{bcd}	48.2^{f}	40.2^{f}	36.3^{i}
'Wonji'	237.04^{a}	271.2^{a}	149.8^{a}	131.0^{ab}
General Mean	117.96	126.1	97.7	91.2
SE (±)	17.45	14.8	8.4	6.2
LSD	53.33^{**}	45.3^{**}	25.9^{**}	19^{**}
CV%	20.92	16.62	12.29	9.68

^{NS} = Non significant: ** = Significant at 1 % level (P < 0.01); Means with the same alphabet in column are not significantly different

Cane characteristics and cane yield

Sugarcane varieties differed significantly for cane height (P<0.05) and cane diameter, number of internodes and cane weight (P<0.01) at 9 month crop age (Table 2.). Maximum and significantly higher cane height was in the variety, *'Wonji'* than 9 other varieties but it was at par with 'B 49/338', 'B 53/165' and 'B 49/224'. Next group of the varieties with cane height at par were 'Co 978', 'Co 842', 'B 57/371', 'Co 1001', 'Co 945', 'PR 1007', *'Habesha'* and *'Nech Habesha'*. Significantly lowest cane height was recorded in the varieties, 'CP 72/2083' and *'Shelle Habesha'*. Higher cane height is an indication of higher cane yield if it matches with the cane weight. Cane length is an important component of cane yield expressed on fresh mass basis (Inman-Bamber 2014). Cane stalk length, cane diameter and weight have been found positively associated with cane yield (Soomro *et al.* 2006). Cane diameter was maximum and significantly higher the in variety, *'Shelle Habesha'*. This indicated that *'Shelle Habesha'* formed medium thick canes (Akhtar *et al.* 2001). Cane thickness was medium in the varieties, *'Habesha'*, *'Nech Habesha'*, 'B 49/224', 'Co 842', 'Co 1001', *'Wonji'*, 'B 49/338' and 'CP 72/2083'. Cane thickness in remaining 5 varieties was significantly less with lowest in variety 'PR 1007' indicating that these varieties formed medium thin canes (Akhtar *et al.* 2001).

Number of internodes was significantly higher in the varieties, *'Habesha'* and *'Nech Habesha'* than the other 12 varieties. The next significantly high internode number was in the variety, *'Wonji'*, which was on par with 'B 49/338', 'Co 1001', 'Co 842', 'B 49/224'. Internodes in canes of remaining 7 varieties were significantly less with the lowest being in variety, 'Co 978'. Internode length depends on cane length and number of internodes. Accordingly, dividing cane length by internode number indicated that short internodes were formed in *'Habesha'*, *'Nech Habesha'* and *'Shelle Habesha'* (9.2 cm to 10.46 cm), whereas, relatively longer internodes were formed in the varieties, 'Co 978', 'B 53/165' and *'Wonji'* (14.03 cm-13.47 cm).

Cane weight was maximum and significantly higher in the variety, 'B 49/224' than 10 other varieties but it was at par with the varieties, *'Shelle Habesha'*, 'B 49/338' and 'Co 842'. It could be mentioned that these varieties with higher cane weight had higher cane diameter indicating that cane weight was related to cane diameter. The next significantly higher cane weight was recorded in the varieties, 'B 53/165', 'Co 978', 'Co 1001', 'CP 72/2083', *'Nech Habesha'* and *'Wonji'*. These varieties had relatively less cane diameter supporting the observation that cane weight was directly related to cane diameter. Significantly low cane weight was found in the varieties, 'Co 945' and 'B 57/371', 'PR 1007' and *'Habesha'*. Low cane weight in a variety was also caused by drying or senescing of leaves of growing top due to sensitivity or susceptibility to water deficit and ambient high temperature stress.

Estimated cane yield was maximum and significantly higher in variety, *'Wonji'* than other 8 varieties but it was at par with that of 'B 53/165', 'Co 978', 'PR 1007' and 'B 49/338'. Cane

Table 2 Mean cane height, cane diameter and number of internodes at 9 month and cane weight and cane yield at 12 month crop age of sugarcane varieties in plant crop during 2018/19 at Arba Minch, Southern Ethiopia

Varieties	Cane height (cm)	Cane diameter (cm)	No. of internodes	Cane weight (kg)	Estimated cane yield (t/ha)
'B 49/224'	211[abc]	2.7[bcd]	16.5[bcd]	1.79[a]	155.9[bc]
'B 49/338'	217.5[ab]	2.6[cdef]	17.5[bc]	1.63[ab]	163.8[ab]
'B 53/165'	214[ab]	2.35[fg]	15.5[de]	1.55[b]	176.6[ab]
'B 57/371'	191.5[bcd]	2.3[g]	15.5[de]	1.26[c]	118.0[de]
'Co 842'	200.5[bcd]	2.7[bcd]	16.5[bcd]	1.6[ab]	126.2[cd]
'Co 945'	184.5[bcd]	2.45[defg]	15.5[de]	1.27[c]	127.1[cd]
'Co 978'	203.5[bcd]	2.4[efg]	14.5[e]	1.53[b]	169.0[ab]
'Co 1001'	187[bcd]	2.65[cde]	17[bcd]	1.53[b]	165.9[ab]
'CP 72/2083'	174.5[cd]	2.65[cde]	15.5[de]	1.53[b]	101.4[def]
'PR 1007'	189[bcd]	2.25[g]	15.5[de]	1.25[c]	167.1[ab]
'Habesha'	185.5[bcd]	2.75[bc]	20[a]	1.25[c]	69.6[fg]
'Nech Habesha'	184.5[bcd]	2.95[ab]	20[a]	1.51[b]	90.6[efg]
'Shelle Habesha'	167.5[d]	3.15[a]	16[cde]	1.65[ab]	64.0[g]
'Wonji'	242.5[a]	2.7[bcd]	18[b]	1.51[b]	197.5[a]
General Mean	196.64	2.61	16.67	1.49	135.2
SE (±)	12.16	0.08	0.56	0.07	11
LSD	37.16*	0.26**	1.71**	0.22**	33.7**
CV%	8.74	4.72	4.75	6.89	11.56

*= Significant at 5% level (P<0.05);** = Significant at 1% level (P <0.01); Means with the same alphabet in column are not significantly different

yields of latter varieties were also at par with 'B 49/224'. Cane yield in remaining 7 varieties were significantly low with the lowest being in *'Nech Habesha'*, '*Habesha*' and *'Shelle Habesha'*. This indicated that cane yield was a genetic characteristic and varied with the varieties. As in present study differences among the varieties for cane yield were reported by several workers (Tadesse *et al*. 2014; Getaneh *et al.* 2015; Tyagi and Naidu 2016; Naidu *et al.* 2017; Islam and Begum 2012).

Cane quality characteristics and sugar yield

°Brix per cent in cane juice differed significantly (P<0.05) among the varieties at 12 months after planting (Table 3). It was maximum and significantly higher in the variety, 'PR 1007' than other 9 varieties but it was at par with 'B 57/371', 'CP 73/2083', 'B 49/224' and 'Co 1001'. The next significantly high °Brix was in the variety, 'B 49/338' followed by 'Co 978', 'Co 842' and 'B 53/165'. Remaining 5 varieties had significantly low °Brix with the lowest observed in 'Co 945'. Varieties differed significantly (P <0.01) for pol and purity per cent juice, sugar yield per cent cane and sugar yield per hectare at 12 month age (Table 3). Pol or sucrose in juice was significantly higher in the varieties, 'PR 1007' than the other 12 varieties but was at par with 'CP 72/2083'. Pol in latter variety, however, was at par with 'B 57/371', 'B 49/224', 'Co 1001' and 'Co 842'. Next high pol in juice was in *'Nech Habesha'*, 'Co 978' and 'B 49/338'. Remaining 5 varieties had significantly low sucrose in juice with the lowest in *'Wonji'* and *'Habesha'*. It may be mentioned that top 5 varieties with respect to °Brix were also the top for pol per cent juice. Purity per cent juice was maximum and significantly higher in the variety, 'PR 1007' than other 4 varieties but it was statistically at par with 'CP 72/2083', *'Nech Habesha',* 'Co 842', 'B57/371', 'Co 945','B 49/224', 'Co 978', 'Co1001' and *'Shelle Habesha'*. It was noted that the 5 varieties with high juice purity per cent had high pol in juice. Significantly lower juice purity was in the varieties, *'Habesha'* and *'Wonji'*. The results showed that the °Brix, pol or sucrose and purity per cent juice varied with the varieties. As in present study, differences among varieties for quality characteristics were reported by others also (Soomro *et al*. 2006; Islam and Begum 2012; Khaled *et al*. 2014; Khan *et al*. 2017; Shitahun *et al*. 2018).

Estimated recoverable sugar or sugar recovery per cent was maximum and significantly higher in the variety, 'PR 1007' than the other 12 varieties at 12 month age but was at par with 'CP 72/2083'. However, the latter variety was at par with 'Co 842', 'B49/224', 'B 57/371', 'Co 1001' and *'Nech Habesha'*. Remaining 7 varieties had significantly low sugar recovery per cent with the lowest in *'Habesha'* and *'Wonji'*. It may be mentioned that 7 varieties with high pol and purity in juice had high sugar recovery per cent. Thus pol and purity were important cane quality parameters for sugar recovery per cent cane (Getaneh *et al*. 2013b; Shitahun *et al*. 2018; Shrivastava and Solomon 2009).

Table 3 Mean °Brix, pol and purity %, estimated recoverable sugar % cane and estimated sugar yield at 12 month age in sugarcane varieties in plant crop during 2018/19 at Arba Minch, Southern, Ethiopia

Varieties	°Brix (%)	Pol (%)	Purity (%)	Estimated recoverable sugar(%)	Estimated sugar yield (t/ha)
'B 49/224'	17.79abc	14.96bcd	84.09abc	9.73bcd	15.1bc
'B 49/338'	17.09bcd	13.99cdef	81.91bcd	8.87cd	14.5bc
'B 53/165'	16.47bcde	13.43defg	79.45cde	8.25de	14.5bc
'B 57/371'	18.24ab	15.49bc	84.95abc	9.73bcd	11.4de
'Co 842'	16.74bcde	14.73bcde	87.99ab	9.99bc	12.6cd
'Co 945'	15.22e	12.8fgh	84.28abc	8.34de	10.6de
'Co 978'	16.74bcde	14.11cdef	84.39abc	8.72cd	14.7bc
'Co 1001'	17.72abc	14.9bcd	84.09abc	9.69bcd	15.9b
'CP 72/2083'	18.25ab	16.07ab	87.79ab	10.9ab	10.9de
'PR 1007'	19.21a	17.07a	88.71a	11.67a	19.5a
'Habesha'	17.28de	11.87h	76.54de	6.92e	4.8f
'Nech Habesha'	17.28cde	14.24cdef	86.83ab	9.53bcd	8.5e
'Shelle Habesha'	17.28cde	13.29efgh	82.97abcd	8.54cd	5.4f
'Wonji'	17.28cde	11.93gh	74.04e	6.74e	13.2bcd
General Mean	16.97	14.2	83.43	9.11	12.2
SE (±)	0.58	0.51	2.14	0.42	0.9
LSD	1.79*	1.55**	6.57**	1.61**	2.9**
CV%	4.89	5.08	3.64	8.19	10.96

*= Significant at 5% level (P< 0.05); **= Significant at 1 % level (P < 0.01); Means with the same alphabet in column are not significantly different

Estimated sugar yield per hectare was maximum and significantly higher in the variety, 'PR 1007' than the other 13 varieties. The next high sugar yield was recorded in the variety, 'Co 1001' but it was at par with that in varieties, 'B 49/224', 'Co 978', 'B 49/338', 'B 53/165' and *'Wonji'*. Remaining 7 varieties recorded significantly low sugar yield with the lowest being in varieties, *'Shelle Habesha'* and *'Habesha'*. Therefore, the locally cultivated variety, *'Wonji'* was more economical than *'Habesha'*, *'Nech Habesha'* and *'Shelle Habesha'*. However, the rind or outer epidermal covering of canes of latter varieties was thin and soft making them suitable for chewing. These varieties are specially cultivated for selling their canes for chewing by the people. The present studies indicated that five varieties were high cane yielding, namely, *'Wonji'*, 'N 53/165', 'Co 978', 'PR 1007' and 'B 49/338'. Seven varieties were high sugar yielding, *viz.*, 'PR 1007', 'Co 1001', 'B 49/224', 'Co 978', 'B 49/338', 'B 53/165' and *'Wonji'*. It was, therefore, concluded that the latter seven high sugar yielding varieties were promising for cultivation. However, these varieties could be further tested for their specific and wide area adaptation in Southern Ethiopia, and identification and recommendation accordingly for cultivation in Ethiopia.

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Genetic variation in sugarcane crosses and their reciprocals for some economically important traits

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ABSTRACT

In sugarcane and many other crops, crossing of varieties is the best way to generate variations for selection and crop improvement. The present study was aimed to examine the performance of a few reciprocal crosses in comparison to their bi-parental crosses for different agronomical traits. Twenty four bi-parental crosses were evaluated in a randomized complete design, at the breeding nursery of Sugarcane Research Institute, Yunnan Academy, China. The results showed significant differences among many entries for all the traits studied. High values of GCV (genotypic coefficient of variation) and PCV (phenotypic coefficient of variation) were associated with moderate heritability for number of stalks, while moderate estimates were exhibited for stalk length with high heritability. The results showed that reciprocal crosses R3 ('ROC25' × 'ROC22') and R6 ('CYZ02-588' × 'ROC22') out classed their crosses for all studied traits, which suggests their relevance for sugarcane breeding and selection purposes.

Key words: Heritability, Coefficient of variation, Seedling, Genotype, Breeding, Selection

INTRODUCTION

Sugarcane (*Saccharum* spp. hybrid) is cultivated in an area of more than 20 million hectares in tropical and subtropical regions of the world, producing up to 1.3 billion metric tonnes of crushable stalks. Sugarcane accounts for nearly 80% of the total white sugar production in the world, the rest being contributed by sugar beet. China is one of the original producers of sugarcane and the third largest sugar producing country in the world after Brazil and India (Anon. 2019; Liu *et al.* 2013). Sugarcane improvement involves hybridization followed by evaluation of the seedlings obtained from the fluff and selection of improved clones in the clonal stages. Bi-parental crosses, which involve only 2 parents, polycrosses (PCs), which involve a group of known parents and General Collections (GCs) where pollen from several unknown parents pollinate a single arrow of the female parent are the matings usually attempted in sugarcane (Tew and Pan 2010). Reciprocal crosses are also made based on the bi-parental crosses. New sugarcane varieties are derived through hybridization of superior parents and selection of superior clones. Probably due to the genomic complexities reported, prediction of the performance of clones derived from any specific cross is difficult in this crop.

In interspecific hybrids of *S. officinarum x S. spontaneum, S. officinarum* as the egg parent is known to contribute the diploid number of chromosomes. In reciprocal crosses, *S. officinarum* contributes the unreduced number through its sperm (Raghavan 1951). Their gross identity between reciprocal crosses is not indicative of cytoplasmic inheritance (Raghavan 1951, 1953, 1954). There is reason to suspect the presence of cytoplasmic inheritance as being an interaction between the genes and maternal cytoplasm. For this, we need to study some reciprocal crosses.

Raghavan (1956a) illustrated that 'P 8331' is a sugarcane genotype now being increasingly used in hybridization for improving the juice quality. Likewise 'Co 605' gives uniformly good seedlings with high yield. Reciprocal crosses of the above parents were made with a significant increase in cane genotypes to be studied. In the combination where P 8331 was utilized as the female parent, about 80% of the seedlings showed high °Brix (Raghavan 1956b). In the cross where 'Co 605' was used as the female parent, nearly 80% of the seedlings showed high yield; the number of seedlings having high sucrose was comparatively low. The seedling behavior with regards to both the characters was significantly different in the reciprocal crosses.

In Brazil, Carneiro *et al.* (2011) reported a high performing newly released variety that was derived from the reciprocal cross. This suggests the relevance of reciprocal crosses in sugarcane breeding as an important source of genetic variation. The current study therefore, aimed to estimate the genetic variations in a few bi-parental crosses and their reciprocal crosses for different agronomic traits in sugarcane.

MATERIAL AND METHODS

The study was carried out at the breeding nursery of

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Sugarcane Research Institute, Yunnan Academy, China. The experimental material (*Saccharum* spp. hybrid) was composed of twenty four bi-parental crosses, *i.e.* twelve crosses and their reciprocal crosses which could be considered as representative of the breeding material used in China (Table 1). The true seeds (fuzz) were germinated in the greenhouse in March 2015 and after three months, a total of twenty four families were transplanted in field in June, 2015. Plant cane and first ratoon were harvested in January 2016 and 2017, respectively. The field was irrigated right after planting and all other agronomic practices were carried out as recommended.

Experimental design and data collection

The experiment was laid out in a completely randomized design (CRD) with 24 families comprising different numbers of seedlings. Each family was grown in four rows of 6 m in length with 1 m of row spacing.Within each family, the following traits were measured: (i) number of stalks per stool, (ii) stalk length from soil surface to the visible dewlap, (iii) stalk diameter at mid stalk, (iv) °Brix (percent of soluble solids) determined with a refractometer.

Statistical analysis

The analysis of variance was performed on data collected according to Gomez and Gomez (1984) using MSTAT-C computer package by Freed *et al.* (1989). The comparison among means was done using the least significant difference (LSD) test at 5% level of probability. For comparisons between sugarcane crosses and their reciprocal crosses, a one-way ANOVA procedure was used.

Variance components

Variance components were calculated by equating appropriate mean squares for the differences among genotypes to their expectations and solving for the components. Broad-sense heritability (H%) was estimated using variance components following the formula (Allard, 1960):

$H\% = (\sigma^2 g / \sigma^2 ph) \times 100$

Where, $\sigma^2 g$ and $\sigma^2 ph$ are genotypic and phenotypic variances respectively.

Genotypic and phenotypic components of variance were estimated according to the following formulae:

Genotypic variance ($\sigma^2 g$) = gMS– EMS

Phenotypic variance ($\sigma^2 p$) = $\sigma^2 g$ + EMS

Where, gMS refers to genotypic mean squares and EMS to error mean squares.

Coefficients of variation

Both genotypic and phenotypic coefficients of variation were computed for each character according to Burton and De Vane (1953) as follows:

Genotypic coefficient of variation (GCV) = (σg/general mean) × 100%.

Phenotypic coefficient of variation (PCV) = (σp/general mean) × 100%.

Where, σg = genotypic standard deviation and σp = phenotypic standard deviation.

RESULTS AND DISCUSSION

Comparison of mean squares between sugarcane crosses and their reciprocal crosses is shown in Table 2. The analysis of variance revealed significant differences among many evaluated entries for all studied traits, not only for crosses but also for a number of reciprocal crosses.

For stalk number, only one cross (no. 3) showed significant difference ($p<0.05$) with its reciprocal cross, whereas, six crosses (no. 1, 3, 5, 7, 9 and 12) showed significant differences in mean squares with their reciprocal crosses for stalk length. Only two crosses (no. 10 and 12) showed highly significant differences ($p<0.01$) with their reciprocal crosses for stalk diameter.

Five crosses (no. 2, 3, 5, 7 and 8) showed highly significant differences ($p<0.01$) with their reciprocal crosses for Brix percentage. Significant differences among genotypes were observed for most of the traits, indicating enough genetic variations within the crosses and reciprocals.

Reciprocal crosses might have increased the variations among the genotypes, so that the best performing ones to be selected could be derived from these crosses.

Table 1 Sugarcane crosses and their reciprocal crosses used in the study

No.	Crosses (C)	Reciprocals (R)
1	‘CGT00-122’× ‘CYN73-204’	‘CYN73-204’× ‘CGT00-122’
2	‘CYT93-159’× ‘ROC22’	‘ROC22’× ‘CYT93-159’
3	‘ROC22’× ‘ROC25’	‘ROC25’× ‘ROC22’
4	‘CDZ93-88’× ‘ROC25’	‘ROC25’× ‘CDZ93-88’
5	CYT99-66× ‘CYZ94-343	‘CYZ94-343’× ‘CYT99-66’
6	‘ROC22’× ‘CYZ02-588’	‘CYZ02-588’× ‘ROC22’
7	‘CGT00-122’× ‘CYT91-976’	‘CYT91-976’× ‘CGT00-122’
8	‘L75-20’× ‘CFN02-6427’	‘CFN02-6427’ × ‘L75-20’
9	‘CFN02-6427’× ‘CGT00-122’	‘CGT00-122’× ‘CFN02-6427’
10	‘CYZ89-7’× ‘ROC25’	‘ROC25’× ‘CYZ89-7’
11	‘CYT91-976’× ‘ROC22’	‘ROC22’× ‘CYT91-976’
12	‘CYZ94-343’× ‘CNJ00-118’	‘CNJ00-118’× ‘CYZ94-343’

Table 2 Results of the analysis of variance regarding sugarcane crosses and their reciprocal crosses for different agronomic traits

Crosses and reciprocals	Number of stalks		Stalk length		Stalk diameter		°Brix	
	MS	Prob.	MS	Prob.	MS	Prob.	MS	Prob.
C1 vs R1	32.27	NS	5226.67	**	0.31	NS	0.19	NS
C2 vs R2	26.32	NS	1100.88	NS	0.04	NS	43.61	**
C3 vs R3	42.22	*	1281.67	**	0.22	NS	23.15	**
C4 vs R4	10.84	NS	19.38	NS	0.21	NS	1.06	NS
C5 vs R5	10.28	NS	311.49	**	0.02	NS	44.76	**
C6 vs R6	12.15	NS	150.42	NS	0.01	NS	0.82	NS
C7 vs R7	45.04	NS	3620.18	*	0.58	NS	51.79	**
C8 vs R8	16.02	NS	1372.82	NS	0.28	NS	57.43	**
C9 vs R9	0.27	NS	3172.02	**	0.04	NS	2.05	NS
C10 vs R10	1.72	NS	476.85	NS	1.32	**	0.80	NS
C11 vs R11	3.29	NS	516.44	NS	0.02	NS	0.72	NS
C12 vs R12	3.38	NS	5060.01	*	1.67	**	4.48	NS

*, **Entry means differ at the 0.05 and 0.01 probability levels by F-test, respectively.

Performance of sugarcane crosses and their reciprocals

Table 3 shows the variability within crosses and their reciprocal crosses for each of the four agronomic traits investigated (number of stalks, stalk length, stalk diameter and °Brix). Significant differences between crosses and their reciprocals ($P<0.05$) were also observed for each of these traits.

The highest number of stalks/stool (16) was recorded in the reciprocal crosses R6 and R7, whereas the highest values for stalk length and stalk diameter were recorded in the crosses C12 (265 cm) and C6 (4.10 cm), respectively.

Higher Brix percentage was observed in the crosses C7, C8 and reciprocal cross R11, with the values 25.2, 25.0 and 25.0% respectively.

Higher average for stalk number/stool (6.4 and 6.3) were recorded in crosses C12 and R3 which were followed by reciprocal crosses R12 and R7 (Table 4). Regarding this trait, higher values of standard deviation were obtained in reciprocal crosses R12 and R7, which suggest enough genetic variations inherent to reciprocal crosses for breeding purpose. Crosses C10, R3 and R12 exhibited higher average stalk lengths with 213.3, 2121.7 and 212.7 cm respectively. For stalk diameter, the crosses C1, C10, R4 and R1 gave higher average values with of 2.9, 2.9, 2.8 and 2.8 cm respectively. For °Brix, four crosses (C5, C7, C8 and C 12) and one reciprocal cross (R12) gave higher average values (> 22%). The above results showed that reciprocal cross R12 ('NEIJIANG00'-118 × 'YUNZHE94-343') gave a better performance for all the traits, with higher values of standard deviation which suggest its relevance for breeding purpose.

Variance components

Genetic variance is important as it describes the amount of genetic variation present for the trait. Table 5 shows that estimates for phenotypic coefficient of variation (PCV) were higher than that of genotypic coefficient of variation (GCV) for all the traits, suggesting that the apparent variation was not only due to genetics but also due to environmental factors. However, differences between PCV and GCV for most of the traits were small, indicating high potential of genetic progress through sugarcane breeding and selection under our conditions of investigation.

Higher GCV and PCV values were associated with moderate heritability for stalk number, while moderate estimates were associated with high heritability for stalk length. Lower estimates of both the coefficients were associated with moderate heritability recorded for stalk diameter, and °Brix. However, differences between both the coefficients were small for all the studied traits, suggesting their relatively high heritability and therefore, enough potential for genetic progress in selection under our conditions of investigation. Similar findings in terms of GCV and PCV of small differences were reported by many authors (Masri *et al.* 2016; Mehareb *et al.* 2017; Mehareb and Galal 2017; Mehareb *et al.* 2018; Abo-Elenen *et al.* 2018).

Higher broad sense heritability estimates were obtained for stalk length and °Brix, with 82.8 and 82.61%, respectively, which shows the importance of genetic variations over the total variations observed regarding these traits and their relevance in sugarcane improvement. Similar findings were reported in sugarcane by Masri *et al.* (2016) and Abo-Elenen *et al.* (2018).

Table 3 Variability within sugarcane crosses and their reciprocals for different agronomic traits

Crosses and reciprocals	Range	Stalks number/stool	Stalk length (cm)	Stalk diam. (cm)	ºBrix
C1	Maximum	11	250	3.80	23.80
	Minimum	1	135	2.40	17.80
R1	Maximum	15	215	3.40	22.80
	Minimum	1	135	2.00	17.40
C2	Maximum	9	220	3.50	23.80
	Minimum	1	110	2.00	17.20
R2	Maximum	11	200	3.30	21.40
	Minimum	2	100	1.80	16.00
C3	Maximum	9	180	3.00	21.00
	Minimum	1	100	1.90	16.00
R3	Maximum	14	250	3.30	22.80
	Minimum	1	175	1.90	19.60
C4	Maximum	13	230	3.20	24.00
	Minimum	1	120	2.20	19.80
R4	Maximum	11	210	3.70	23.80
	Minimum	1	115	1.80	18.00
C5	Maximum	12	210	3.10	24.00
	Minimum	2	80	1.80	20.00
R5	Maximum	13	240	3.90	23.80
	Minimum	1	175	2.10	18.80
C6	Maximum	9	230	4.10	23.20
	Minimum	1	125	2.00	19.80
R6	Maximum	16	200	3.00	24.00
	Minimum	1	130	1.80	20.00
C7	Maximum	15	245	3.50	25.20
	Minimum	1	155	2.10	17.40
R7	Maximum	16	230	3.30	24.40
	Minimum	1	135	1.80	16.40
C8	Maximum	15	205	3.50	25.00
	Minimum	1	140	1.20	15.00
R8	Maximum	11	240	3.60	23.00
	Minimum	1	145	1.80	17.40
C9	Maximum	13	255	3.50	24.00
	Minimum	1	125	1.60	18.00
R9	Maximum	10	225	3.20	23.80
	Minimum	1	125	2.10	18.80
C10	Maximum	15	250	3.70	23.00
	Minimum	1	170	2.20	18.20
R10	Maximum	9	250	3.20	22.40
	Minimum	1	105	1.60	17.40
C11	Maximum	13	245	3.40	23.00
	Minimum	2	110	1.90	18.40
R11	Maximum	13	230	3.60	25.00
	Minimum	1	155	2.00	18.40
C12	Maximum	15	265	3.20	24.00
	Minimum	2	100	2.20	20.00
R12	Maximum	15	250	3.10	24.70
	Minimum	1	150	2.50	20.90
LSD at 0.05		0.70	8.18	0.09	0.43

C: crosses; R: reciprocal crosses.

Table 4 Descriptive statistics of sugarcane crosses and their reciprocals for different agronomic traits

Crosses and reciprocals	Number of clones/cross	Stalk number/ stool		Stalk length (cm)		Stalk diameter (cm)		°Brix	
		Average	SD	Average	SD	Average	SD	Average	SD
C1	30	4.20	2.40	199.50	30.83	2.95	0.40	20.78	1.21
R1	30	5.67	3.51	180.83	22.17	2.81	0.35	20.67	1.27
C2	30	4.10	2.51	170.50	22.76	2.63	0.38	20.79	1.75
R2	23	5.52	3.06	161.30	23.75	2.58	0.41	18.96	1.37
C3	12	3.75	2.60	144.17	25.83	2.47	0.30	19.15	1.43
R3	15	6.27	3.01	212.67	20.17	2.65	0.46	21.01	1.06
C4	26	5.12	3.25	173.65	31.58	2.70	0.24	21.37	1.18
R4	30	4.23	2.47	174.83	22.65	2.82	0.42	21.09	1.52
C5	26	6.19	3.21	163.85	27.40	2.60	0.36	22.52	1.40
R5	30	5.33	2.48	202.03	18.74	2.63	0.36	20.73	1.22
C6	30	4.40	2.46	173.33	23.39	2.49	0.47	21.57	0.99
R6	30	5.30	3.97	176.50	17.92	2.51	0.34	21.81	0.99
C7	30	3.90	2.81	196.17	24.16	2.70	0.38	22.33	1.84
R7	21	5.81	4.96	179.05	28.88	2.48	0.43	20.29	1.98
C8	30	4.67	3.42	176.43	14.48	2.50	0.42	22.52	2.10
R8	30	3.63	2.24	186.00	23.10	2.63	0.47	20.57	1.38
C9	30	4.70	2.93	210.97	38.94	2.56	0.45	21.95	1.54
R9	30	4.83	2.41	181.33	26.32	2.61	0.31	21.58	1.15
C10	23	4.91	3.29	213.26	17.88	2.88	0.31	19.97	1.30
R10	18	4.50	2.12	206.39	36.89	2.52	0.45	20.26	1.57
C11	22	5.91	3.26	202.05	35.11	2.68	0.34	20.83	1.33
R11	30	5.40	3.09	195.67	20.12	2.71	0.32	20.59	1.36
C12	14	6.43	3.41	189.64	47.33	2.73	0.27	22.47	1.40
R12	30	5.83	3.65	212.67	23.73	2.81	0.38	22.88	1.98
Mean		5.03		186.78		2.63		21.07	

C: crosses; R: reciprocal crosses.

Table 5 Variance components, heritability, phenotypic and genotypic coefficients of variation for agronomic traits in sugarcane

Statistical parameters	Stalks number	Stalk length	Stalk diameter	°Brix
$\sigma^2 e$	0.49	66.02	0.01	0.18
$\sigma^2 g$	0.51	316.82	0.02	0.87
$\sigma^2 ph$	1.00	382.84	0.03	1.05
Heritability%	51.15	82.76	66.81	82.61
GCV%	14.36	9.53	5.02	4.42
PCV%	20.08	10.48	6.14	4.86

e: error; g: genotypic; ph: phenotypic

CONCLUSION

The present study showed that reciprocal crosses R3 ('ROC25'×'ROC22') and R6 ('CYZ02-588'×'ROC22') out classed their crosses for all agronomic traits investigated, namely stalk number/stool, stalk length, stalk diameter and °Brix, suggesting their relevance in sugarcane breeding and varietal improvement.

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Assessing the efficacy of 'Fungbact sugarcane kit' in economizing nutritional need and reducing the incidence of pests and diseases in sugarcane cultivation

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ABSTRACT

Experimental results indicated that the increasing doses of recommended doses of fertilizers (RDF) from 25% to 75% + 'Fungbact sugarcane kit' (FBS kit) (@ 3.0 kit/ha) successively increased the no. of tillers, length, width and weight of cane, no. of millable canes and cane yield significantly. The above growth and yield attributes of cane under T_3 were statistically at par with and T_8 treatments. It thus showed that 25% RDF could be economized with the application of FBS kit in sugarcane cultivation. Moreover, 100% RDF with FBS kit either at 3.0 or 5.0 kit/ha significantly out-yielded all the treatments including T_3 and T_4 treatments. Treatments T_5 and T_6 being statistically at par with each other produced higher cane yield to the tune of 17.04%, 13.11%, 24.03% and 31.01% as compared to T_4, T_3, T_2, and T_1 treatments, respectively. Quality of cane either CCS % or purity % did not yield any significant difference due to different treatments in the study. Incidence of different insect pests and diseases of sugarcane was recorded in plots treated with 'Fungbact sugarcane kit' along with recommended and reduced doses of fertilizers (Table 1). The incidence of top borer II Brood T_5 (4.47%) and T_6 (3.73%), III brood T_5 (7.97%) and T_6 (6.90%) were low. Incidence of internode borer was low in all treatment except plots were given only 100 per cent recommended doses of fertilizers (standard) (Table 2). It showed that 'Fungbact sugarcane kit' helps in reducing the incidence of top borer and internode borer. No diseases were observed in experimental plots.

Key words: Sugarcane, Fertilizer use efficiency, Incidence of pests and diseases, Quality of cane, Soil micro-organisms

INTRODUCTION

Sugarcane is the most important agro-industrial crop grown under tropical and sub-tropical parts of the country. In the Indo-Gangetic Plain region of the sub-tropical belt, the crop is grown in the major production system of rice-wheat-sugarcane. The extensive cereal-based cropping system, lack of legumes in the crop rotations and poor soil manuring have led the soils of the Indo-Gangetic Plains become poor in organic carbon content (Singh *et al.* 2007). Sugarcane is a very demanding crop as for cane yield of 100 t/ha it removes about 205 kg N, 55 kg P_2O_5, 275 kg K_2O and a large amount of micro-nutrients from the soil. In order to sustain productivity, major nutrients are provided each year at the recommended application rates, which in the sub-tropical part of India are 150 kg N/ha for the sugarcane plant crop and 220 kg N/ha for its ratoon crop and 60 kg each of P_2O_5 and K_2O/ha for both the plant and ratoon crops. However, the efficiency of sugarcane to utilize N ranges between 16% and 45% as large quantities of applied N leach down through the soil layers due to irrigation. Deterioration in the physico-chemical and biological properties of the soil is considered to be the prime reason for the declining sugarcane yield and productivity. Moreover, sugarcane being a long duration crop having tropical plant characteristics that faces a large number of pests and diseases. The crop is liable to attack by these pests right from planting till harvest and thus causes enormous losses both in tonnage and recovery of sugar in the mill. To address these problems, the indiscriminate use of synthetic pesticides is followed which leads to the potential danger to agro-ecosystem. Integrated management of plant nutrients (balanced use of chemical fertilizers, manures and biofertilizers) and other organically produced microbial agents (alternative eco-friendly pesticides) are considered a promising agro-technique to sustain crop yields, increase fertilizer use efficiency, restore soil fertility and protect the crop from attacking pests at the threshold level (Singh *et al.* 2008) . Microbial agents are products containing living cells of microorganisms having the ability to convert nutritionally important elements from unavailable to available form by producing certain essential enzymes and hormones through biological process in the soil rhizosphere. Although these eco-friendly microbes are found in our soil, but their population are decreased from time to time due to adverse conditions in soil. If such microbes are replenished in soil rhizosphere through organic amendments then they will be helpful in enhancing sugarcane growth and yield with economized use of plant nutrients and reduced incidence of pests and diseases by inducing resistance to cane plants. 'Fungbact sugarcane kit' having nutritive, as well as protective microbes, may prove worthy in sugarcane farming for better production and protection of the crop over the conventional system. Keeping these points in view, the present study was, therefore, undertaken.

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Table 1 Experimental results of contract research programme at ICAR- IISR, Lucknow during crop seasons of 2012-2013 and 2013-14

Treatment	Germination %		No. of tillers (000/ha)	Length of cane (cm)	Width of cane (cm)	Single cane weight (kg)	No. of millable canes (000/ha)	Cane yield (t/ha)	Quality parameters	
	30 DAP	45 DAP							CCS %	Purity (%)
T_1 : 25% RDF + 'Fungbact sugarcane kit' (3.0 kit/ha)	39.32	42.96	151	189	2.07	0.65	98	58.52	11.07	85.79
T_2 : 50% RDF + 'Fungbact sugarcane kit' (3.0 kit/ha)	36.41	44.03	166	201	2.15	0.74	107	64.44	11.28	87.26
T_3 : 75% RDF + 'Fungbact sugarcane kit' (3.0 kit/ha)	31.65	42.74	198	215	2.23	0.86	115	73.70	11.53	89.96
T_4 : 100% RDF	34.71	44.07	204	219	2.22	0.88	119	70.37	11.26	88.13
T_5 : 100% RDF + 'Fungbact sugarcane kit' (3.0 kit/ha)	38.48	43.29	236	231	2.33	0.97	128	83.70	11.33	88.19
T_6 : 100% RDF + 'Fungbact sugarcane kit' (5.0 kit/ha)	40.26	41.35	250	242	2.37	0.98	129	85.93	11.20	86.37
T_7 : 100% RDN, 100% P and 100% K + 4.0 kg/ha *Azotobacter* bioculture each at 30 and 60 DAP	34.52	43.70	205	212	2.20	0.81	118	71.11	11.18	85.40
T_8 : 75% RDN, 100% P and 100% K + 6.0 kg/ha *Acetobactecr* bioculture at the time of planting and tillering phase	39.32	40.51	210	214	2.22	0.83	119	72.59	11.21	86.29
CD (P=0.05)	NS	NS	13.40	10.73	0.08	0.08	7.61	5.23	NS	NS

RDF: Recommended dose of fertilizers RDN: Recommended dose of nitrogen CCS: Commercial cane sugar

MATERIALS AND METHODS

A field experiment with the objectives of studying the effect of 'Fungbact sugarcane kit' in economizing the nutritional need of sugarcane and also in reducing the incidence of pests and diseases in sugarcane was planted in the spring season of 2012-13 and 2013-14 with sugarcane variety 'CoSe 92423' at the research farm of the Indian Institute of Sugarcane Research, Lucknow (26^0 56 N, 80^0 52 E and 111 m above mean sea level) in a loamy soil having pH value of 7.1. The climate of the region is subtropical and characterized by hot dry summer and cold winters. The average annual rainfall is 900 mm. The soil of experimental plot was low in available N (210.5 kg/ha) and medium in available P (14.6 kg/ha) as well as K (235.0 kg/ha). Sugarcane was planted as per the technical program of the experiment. Sugarcane was harvested at the age of twelve months. The crop received the doses of NPK (150:60:60 kg) per hectare as per the scheduled treatments. Full doses of P and K and one-third dose of N were given in furrows at planting and the remaining N was applied in two equal splits at tiller initiation and maximum tillering stage. The crop was grown as per the recommended package of practices of the region. Observations were recorded as per schedule at the growth and harvesting stages. Per cent commercial cane sugar was calculated as per procedure mentioned by Spencer and Meade (1955). Five millable cane were randomly taken from observation on yield attributes and juice quality.

RESULTS AND DISCUSSION

Experimental results indicated that the germination of cane buds did not differ significantly due to different treatments tested. However, increasing doses of recommended doses of fertilizers (RDF) from 25% to 75% + 'Fungbact sugarcane kit' (FBS kit) (@ 3.0 kit/ha) successively increased the no. of tillers, length, width and weight of cane, no. of millable canes and cane yield significantly. The above growth and yield attributes of cane under T_3 were statistically at par with and T_8 treatments. It thus showed that 25% RDF could be economized with the application of FBS kit in sugarcane cultivation. Moreover, 100% RDF with FBS kit either at 3.0 or 5.0 kit/ha significantly out-yielded all the treatments including T_3 and T_4 treatments. Treatments T_5 and T_6 being statistically at par with each other produced higher cane yield to the tune of 17.04%, 13.11%, 24.03% and 31.01% as compared to T_4, T_3, T_2, and T_1 treatments, respectively. Quality of cane either CCS % or purity % did not yield any significant difference due to different treatments in the study. Incidence of different insect pests and diseases of sugarcane was recorded in plots treated with 'Fungbact sugarcane kit' along with recommended and reduced doses of fertilizers (Table 1). The incidence of top borer II Brood T_5 (4.47%) and T_6 (3.73%), III brood T_5 (7.97%) and T_6 (6.90%) was low. Incidence of internode borer was low in all treatment except plots were given only 100 per cent recommended doses of fertilizers (standard) (Table 2). It showed that 'Fungbact sugarcane kit' helps in reducing the incidence of top borer and internode borer. No diseases were observed in experimental plots.

Table 2 Effect of 'Fungbact sugarcane kit' on incidence of insect pests and diseases of sugarcane

Treatments	Incidence of Top borer (%)			Incidence Internode borer (%)
	II brood	III brood	IV brood	
T1	14.72	14.40	7.77	10.53
T2	8.20	11.61	8.22	12.72
T3	7.46	11.55	8.59	7.28
T4	17.35	15.42	8.47	16.40
T5	4.47	7.97	8.14	8.84
T6	3.73	6.90	6.57	8.93
T7	8.51	13.68	9.33	10.00
T8	10.25	14.64	10.60	11.27

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Isolation of endophytic bacteria associated with sugarcane and their *in vitro* antagonistic activity against red rot pathogen *Colletotrichum falcatum*

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ABSTRACT

Red rot is one of the most threatening diseases of sugarcane crop that adversely affects the yield and productivity. In the present study, *in vitro* antagonistic activity of endophytic bacteria isolated from the stalk of the sugarcane variety 'CoS 767' was assessed against red rot pathogen (*Colletotrichum falcatum* Went). The findings revealed that 21 isolates were obtained by proper sterilization technique. The isolates when checked for dual culture *in vitro* antagonism against pathogen; only 18 isolates were able to inhibit the mycelial growth of the pathogen. However, of these 18 isolates, 11 isolates exhibited strong antagonism with more than 70% inhibition. The high effectiveness of these 11 isolates in the inhibition of fungus mycelium might be due to the production of various metabolites and other related compounds that needs to be explored. Therefore, these effective endophytic bacterial isolates could be further exploited as bio-agents for the management of red rot disease of sugarcane.

Key words: Red rot, *Colletotrichum falcatum*, Endophytic bacteria, Antagonism

INTRODUCTION

Sugarcane (*Saccharum* spp. hybrid) commands an important position among the various commercial crops of India. It is the second most important agro-industrial crop, next only to cotton (Jayashree *et al.* 2010). The crop is mainly cultivated in most of the states of India. Globally, sugarcane is an important source of commercial sugar accounting for 75% of world sugar production and almost 100% of sugar production in India (Srivastava and Lal 2019). More recently, it has been exploited for the production of renewable bio-fuel ethanol for blending with petrol. Consequently, sustaining and enhancing the growth and yield of sugarcane is an important aspect of research. The growth and performance of the crop in the field is adversely affected by a number of abiotic and biotic factors. About one hundred diseases of sugarcane have been reported from different parts of the world (Rott *et al.* 2000; Sharma and Tamta 2015). In India, the estimated loss in crop production due to fungal diseases is 18-31% (Jayashree *et al.* 2010). Generally, fungi, bacteria, virus and phytoplasmas are responsible for causing serious threat to sugarcane cultivation (Viswanathan and Rao 2011; Lal 2016). It has been also estimated that sugarcane diseases alone reduce the crop yield by 20% every year (Lal 2019). Red rot, wilt, smut and sett rot are the main fungal diseases causing significant loss to sugarcane production.

Red rot is an important disease of sugarcane caused by the fungus *Colletotrichum falcatum* Went. It causes severe losses in yield and quality of the sugarcane in the Indian sub-continent (Satyavir 2003; Duttamajumder 2008). It can reduce cane weight up to 29% and loss in sugar recovery by 31% (Hussnain and Afghan 2006). Although several commercial varieties have been developed with higher cane and sugar yield; but they cannot be cultivated continuously due to frequent development of new pathotypes of the pathogen resulting in knockdown of varieties (Viswanathan 2017). Current management strategies involve the use of resistant varieties and fungicide applications. However, the efficacy of both the control measures are limited, and there is an urgent need for novel and environmentally sound strategies to manage the disease. In recent years, the uses of biological agents is the only cost-effective and promising method for the management of this devastating disease. Currently, endophytic microorganisms (fungi and bacteria) are attaining a most prestigious approach for the management of plant diseases. The endophytes comprise of two Greek words "endon" meaning within, and "phyton" meaning plant. Thus, endophytic microorganisms can be defined as such fungi and bacteria that reside in the plant endosphere during all or part of their life cycle without causing any harm to the host plant (Dobereiner 1992, Wilson 1995). Endophytic bacteria are generally regarded as untapped resource of novel metabolites exhibiting antifungal and plant growth-promoting traits (Lodewyckx *et al.* 2002, Rosenblueth *et al.* 2006). They have also shown beneficial effects as an antagonist against various

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plant pathogens besides enhancing crop growth as well as yield. The main modes of their action are nitrogen fixation, production of phytohormones, antifungal compounds and induced systemic resistance (Kuklinsky-Sobral *et al.* 2004, Compant *et al.* 2005). Various endophytic bacteria such as *Bacillus, Burkholderia, Enterobacter, Pseudomonas* and *Serratia* have also been demonstrated as an effective microorganism in suppressing the growth of pathogenic microorganisms either *in vivo* or *in vitro* conditions (Mercado-Blanco and Lugtenberg 2014, Esmaeel *et al.* 2016, Kandel *et al.* 2017a, Kandel *et al.* 2017b). Sugarcane being a vegetatively grown crop, endophytic bacteria if once established inside the crop, would provide beneficial effect to the plant (Viswanathan *et al.* 2003). The study conducted by Viswanathan *et al.* (2003) demonstrated the inhibitory action of various bacterial endophytes against *C. falcatum*. Endophytes are source of active resources that needs to be further explored for the effective exploitation for crop benefits.Therefore, the overall goal of this study was to isolate endophytic bacteria from sugarcane and assess their *in vitro* antagonistic activity against red rot pathogen (*C. falcatum*) that were associated with sugarcane crop.

MATERIALS AND METHODS

Isolation and purification of test pathogen and endophytic bacteria

Healthy clumps of sugarcane variety 'CoS 767' were collected from the farm of ICAR-Indian Institute of Sugarcane Research (IISR), Lucknow in sterilized zip-lock poly-pouches and endophytic bacteria were isolated from the internal stalk tissues following the modified protocol of Viswanathan *et al.* .(2003). The tissue cylinders of stalks were taken off by using sterile corkborer and placed in different conical flasks containing 25 ml of sterile distilled water. It was then shaken vigorously for 2 min. After, that, cylinders were washed with 0.1% mercuric chloride ($HgCl_2$) for 2 min. and subsequently several times washed with sterile distilled water. The tissues were then finally placed in separate flasks containing 25 ml sterile distilled water. Flasks were then shaken for 1 hour at 150 rpm. One hundred µl suspension from the flasks were spread onto Luria Bertani (LB) agar plates and incubated at 28±2ºC for 48-72 hr. The 0.1 ml of last aliquots of washing the stalk tissue was also spread on LB plates for sterility check. If colony appeared on the media then the samples were discarded. After, isolation, bacterial colonies obtained were further purified on the LB agar medium and stored at 4ºC. The pathogen *C. falcatum* was isolated on Oat Meal Agar (OMA) medium from infected stalks of 'CoS 767' showing typical symptoms of red rot and maintained at 4ºC for further studies.

Evaluation of antagonistic activity in dual culture

Dual culture antagonism test of isolated endophytic bacteria was performed against the test pathogen on Potato Dextrose Agar (PDA) plates. For this, 5 mm disc of fungal pathogen was placed in the center of the plate and the antagonistic isolated endophytic bacteria was streaked on the corner of plates approximately 2 cm away from the fungus (Viswanathan *et al.* 2003). After this, the plates were incubated for 7-10 days at 28ºC. The per cent inhibition was calculated employing the following formula, *i.e.*, C-T/C x 100, where, C is the radial colony growth of fungal pathogen in control, and T is the radial colony growth in dual culture. The selected efficient endophytic isolates were repeated for their antagonistic activity on Oat Meal Agar (OMA) medium.

Characterization of efficient endophytic isolates

The selected efficient antagonistic endophytic bacteria were also morphologically characterized by the Gram's staining. This helps in the characterization of isolates as gram positive and gram negative.

RESULTS AND DISCUSSION

A total of 21 endophytic bacteria were isolated from the healthy stalk tissues of 'CoS 767' variety. Isolation of endophytic bacteria requires a proper sterilization technique which is the utmost requirement of the protocol. In the present study; the plates incubated with the last aliquots obtained after washing of stalk cylinder was found to have no bacterial colony; thus, it was considered that the bacterial colony obtained from the isolation was the true endophytic bacteria (Fig.1). Further, all the 21 isolates were tested for their antagonism against the pathogen on the potato dextrose agar medium. Out of 21 isolates evaluated,11 isolates (SE-1, SE-2, SE-6, SE-7, SE-9, SE-12, SE-15, SE-17, SE-18, SE-19, SE-21) exhibited strong *in vitro* antagonism against *C. falcatum*

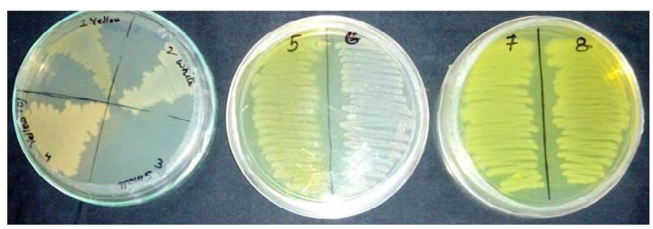

Fig. 1. Some isolates of selected antagonistic endophytic bacteria

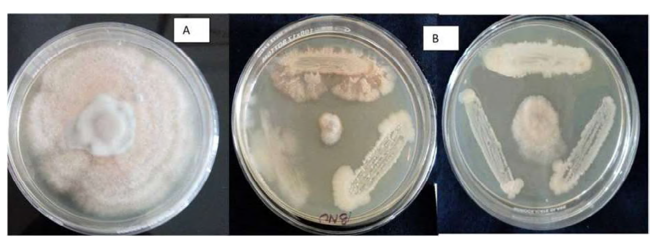

Fig. 2. Bacterial isolates showing *in vitro* dual culture antagonism against *C. falcatum* on PDA plate; (A) Control (B) Plate with antagonistic endophytic bacteria with centrally placed fungal pathogen disc

resulting in more than 70% inhibition, while the remaining 10 isolates (SE-3, SE-4, SE-5, SE-8, SE-10, SE-11, SE-13, SE-14, SE-16, SE-20) showed 42.22 to 68.92 per cent inhibition of the pathogen (Table 1, Fig. 2). The reason attributed for their strong inhibition might be due to the presence of multiple antagonism mechanisms that contribute towards the suppression of pathogen mycelial growth. Furthermore, it is also known that bio-control strains of bacteria release different metabolic compounds including antibiotics, and lytic enzymes effective in growth inhibition of phytopathogenic fungi or oomycetes (Compant *et al.* 2005; Gagne-Bourgue *et al.* 2013; Pageni *et al.* 2014).

Table 1 Per cent inhibition of *C. falcatum* by endophytic bacteria on PDA and OMA medium

Isolates code	% inhibition on PDA medium	% inhibition on OMA medium
SE-1	72.42	71.32
SE-2	74.12	76.62
SE-3	45.55	45.23
SE-4	47.56	43.76
SE-5	62.44	60.43
SE-6	70.43	70.53
SE-7	79.64	77.94
SE-8	53.89	56.78
SE-9	78.35	79.45
SE-10	-	-
SE-11	48.92	36.33
SE-12	72.52	70.62
SE-13	-	-
SE-14	54.51	56.12
SE-15	72.32	78.62
SE-16	46.65	45.67
SE-17	73.36	71.66
SE-18	76.80	74.50
SE-19	75.98	73.56
SE-20	-	-
SE-21	77.76	77.77

The same isolates were also evaluated for antagonism on oat meal agar medium (Table 1, Fig.3). No significant difference was observed in the antagonism on OMA medium, however, some of the isolates showed higher inhibition on OMA when

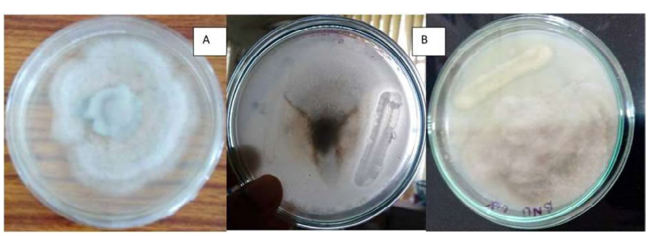

Fig. 3. Some of the isolates showing *in vitro* dual culture antagonism against *C. falcatum* on OMA plate; (A) Control (B) Plate with antagonistic endophytic bacteria with centrally placed fungal pathogen disc

compared with PDA, while other isolates showed lower inhibition. Our study was found congruent with the findings of Viswanathan *et al.* (2013). The idea of repeating the dual antagonism activity on OMA medium was to check the *in vitro* efficiency of isolates to inhibit the pathogen on OMA (as this media supports the sporulation of the pathogen more effectively than PDA). However, in spite of the difference in the media; the isolates in the present study were able to cause inhibition in both the media strongly.

Eighteen bacterial isolates were also selected for morphological studies. The morphological study of the selected isolates revealed that most of isolates (15 out of 18) were gram positive, while rest 3 isolates were gram negative bacteria (Table 2). The study was also found congruent with Viswanathan *et al.* (2003) where, gram positive endophytes were found in much higher proportion.

Table 2 Gram staining reaction of selected antagonistic endophytic bacteria

Types of reaction	Isolates
Gram positive	SE-1, SE-2, SE-3, SE-4, SE-6, SE-9, SE-11, SE-12, SE-14, SE-15, SE-16, SE-17, SE-18,SE-19, SE-21
Gram negative	SE-5, SE-7, SE-8

The present study further demonstrated the advantage of endophytic bacteria over bacteria surviving in the rhizosphere. As endophytic ones inhabitate inside the plant's tissue, they have a strong affinity with the plants cell and also exert more beneficial effect (Santoyo *et al.* 2016). Endophytic bacteria colonize an ecological niche where they can interact more intimately with the host plant (Viswanathan *et al.* 2003). Bacterial endophytes in a single plant host are not restricted to any single species but comprise of several genera and species (Rosenblueth and Martínez-Romero 2006). The most commonly isolated bacterial genera are *Pseudomonas, Bacillus, Enterobacter and Agrobacterium* (Hallmann et al. 1997). Bacterial endophytes are able to reduce or prevent the deleterious effects of certain pathogenic organisms. This study was able to select potentially active antagonistic bacteria to act against red rot disease.The findings of de, Almeida Lopes *et al.* (2018) suggested that *Bacillus* and *Burkholderia* species were the most effective in controlling fungal pathogens *in vitro*, and the activity was mainly due to peptides.The beneficial effects of bacterial endophytes on their host plant appear to occur through various mechanisms (Ryan *et al.* 2008). Certain mechanisms responsible for antagonism includes antibiosis (antibiotic production), induction of systemic resistance, parasitism, competition and signal interference (quorum sensing) (Jorjani *et al.* 2011; Mansoori *et al.* 2013). Many biocontrol bacterial endophytes display a combination of several of these mechanisms (Ongena *et al.* 2007).

The selected antagonistic endophytic bacteria from this study require more investigation on their plant growth beneficial traits in future as endophytes also help in plant growth promotion along with alleviation of various stresses. Thus, together as a source of potent antagonistic isolates having various growth promoting factors, the promising endophytic bacteria would help in combating the abiotic as well as biotic stresses in sugarcane.

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Enhancing income of small land holding farmers of sub-tropical India through sugarcane based integrated farming system approach

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ABSTRACT

A field experiment was conducted on sugarcane based integrated farming system (S-IFS) approach consecutively during 2016-2017 to 2018-19 (three years) at ICAR-Indian Institute of Sugarcane Research, Lucknow, with the objectives to enhance the income of small land holding farmers and their livelihoods. The different components of the farming system included were cultivation of different horticultural crops (*banana, papaya*, and *karonda* planting), bee-keeping (apiculture), mushroom cultivation and intercropping of high value crops (Potato, Maize, Fenugreek, Garlic and Coriander) with autumn planted sugarcane. Allocation of farm land was kept to meet minimum essential annual requirements of food and fodder of a household with 7 family members and overall improvement in livelihood. Impact of different treatments on yield and income through different models of farming systems was evaluated. The farming systems developed were Agri (0.7 ha)-horti (0.2 ha) system (Net income: Rs. 5,00,474/ha), Agri (0.7 ha)-api (0.05 ha) system (Net income: Rs. 4,15,614/ha), Agri (0.7 ha)-mushroom farming(0.05 ha) system(Net income: Rs. 4,13,614/ha), Agri (0.7 ha)- horti (0.2 ha)- api system (Net income: Rs. 5,03,473/ha), Agri (0.7 ha)- horti (0.2 ha)- mushroom farming (0.05 ha) system (Net income: Rs. 5,01,473/ha), Agri (0.7 ha)-api (0.05 ha)- mushroom farming (0.05 ha) system (Net income: Rs. 4,16,614/ha), Agri (0.7 ha)-horti (0.2 ha)- api (0.05 ha)- mushroom (0.05 ha) farming system (Net income: Rs. 5,04,473/ha).The net income from sole sugarcane was observed to be Rs.164154/ha. The different intercropping systems with sugarcane recorded the higher cane equivalent yield (119.0 to 247.9 t/ha) and B: C ratio (2.48 to 4.77). From the results of the experiments, it can be inferred that sugarcane based integrated farming systems hold promise in increasing the net income of the farmers by 2-3 times to the sole sugarcane.

Keywords: B:C ratio, Cane equivalent yield, Integrated farming system, Intercropping, Farmers' income, Sugarcane

INTRODUCTION

Sugarcane occupies an important position in agrarian economy of India. It is grown in diversified cropping systems under varying edaphic and climatic conditions. As a result, not only the sugarcane production fluctuates over the years, but cost of cultivation of the crop also varies considerably. The goal of sugarcane farming system is to produce sugarcane as per requirement of sweeteners, food, energy and bio-fuels without compromising the ability of future generations to meet their own needs. Practitioners of sustainable sugarcane farming seek to integrate three main objectives into their work: a healthy environment, economic profitability, and social and economic equity. Every person involved in the food system-growers, sugar industry, food processors, distributors, retailers, consumers, and waste managers can play a role in ensuring a sustainable cane farming system (Singh *et al*. 2018). About 7 million farmers, their dependents and large number of agricultural labourers are involved in the cane farming. Besides, being an important agro-industrial annual crop sugarcane involves more than 50 million skilled and unskilled workers in India for various activities. The area under sugarcane cultivation during 2017-18 was 5.04 million ha and produced 411 million tonnes of cane with an average productivity of 81.5 tons/hectare (ISMA 2019). Weakening of the traditional joint family concept combined with unchecked linear growth in human population has led to indiscriminate fragmentation of land holdings. Per capita availability of land in India has declined from 0.5 ha in the year 1950-51 to 0.12 ha in the year 2015-16 (Singh *et al*. 2018). Small and fragmented land holdings do not allow a farmer to keep independent farm resources and other sophisticated machineries for various cultural operations. Further, most of the inputs have become costly and out of reach of these resource poor farmers, which has resulted in farming being an uneconomic and unsustainable enterprise. Farming system under sugarcane agribusiness may hold promise to mitigate such problems and may prove as resource management strategy to enhance the income and sustain production of farm households, while preserving resource base and maintaining a high level environmental quality.

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In view of changing market scenario, consumers' preferences and global competitions, new income generating opportunities need to be created through crop diversification in sugarcane 'Produce to Product Chain' (Lal and Singh 2004; Singh *et al.* 2017).This would help in increasing the land utilization efficiency, reducing the production cost, economizing the use of costly inputs to be purchased from market and making sugarcane based farming system much sustainable. "Farming System is a complex inter-related matrix of soil, plants, animals, implements, power, labour, capital and other inputs controlled in parts by farming families and influenced to varying degrees by political, economic, institutional and social forces that operate at many levels" (Mahapatra 1992). The term "Farming System" refers to a particular arrangement of farming enterprises that are managed in response to physical, biological and socio-economic environment and in accordance with farmers' goals, preferences and resources (Shaner *et al.* 1982). "The household, its resources and the resource flows and interactions at the individual farm levels are together referred to as a farm system" (FAO 2001).The Farming System, as a concept, takes into account the components of soil, water, crops, livestock, labour, capital, energy and other resources with the farm family at the centre managing agricultural and related activities. The farm family functions within the limitations of its capability and resources, the socio-cultural setting, and the interaction of these components with the physical, biological and economic factors. Apart from sugarcane based intercropping systems, components of the farming systems *viz.* horticulture, apiary, and plantation crops *viz*., banana, papaya *etc*. along with intercropping in sugarcane crop may increase net profit significantly. This in turn, raises the socio-economic status of small and marginal, resource constrained farmers and generates employment especially for rural women and youths, which also help accomplish the goal of doubling the farmers' income. The information of sugarcane based intercropping with cereals, pulses and oilseeds are available, however, researches on intercropping of high value crops and its integration with other agricultural enterprises are meagre. Considering above points in view, the present investigation was taken into consideration with the objective to develop different sugarcane based farming system models for enhancing the farmer's income and livelihoods.

MATERIALS AND METHODS

A field experiment for three consecutive years starting from 2016-17 to 2018-2019 was conducted at ICAR-Indian Institute of Sugarcane Research, Lucknow located at 26^0 50´N, 80^0 52´E. The soil of the experimental site was categorized as neutral in reaction (pH 7.5), low in organic carbon (0.44%) and available N (222.6 kg ha^{-1}), medium in available P (49.8 kg ha^{-1}) and K (238.5 kg ha^{-1}). Texture of experimental field was sandy loam of *Gangetic* alluvial origin. The technical programme of the integrated farming system model including different treatment is given as below:

- Area of the IFS model : One ha
- Family Size : Seven members

Sugarcane based intercropping systems – Components of IFS Model:

- Sugarcane(Sole)/Intercropping with cereals/pulses/ oilseeds/ vegetables >(0.6ha) : >60% area
- Mushroom, beekeeping & land for house (0.1ha)
- Horticulture -banana, papaya (0.1 ha each)
- Food/fodder/vegetable and other crops for household uses (0.1 ha)
- *Karonda* (*Carissa carandas*) as boundary plantation (0.1 ha)

During the autumn season, thirteen cropping systems *viz*. Sugarcane (Sole)-'CoPk 05191', Sugarcane + Potato ('*Kufri Chandramukhi'*), Sugarcane + Pea ('*Azad P-3'*), Sugarcane + Maize ('VMH-174'), Sugarcane + French bean (*'Arun'*), Sugarcane + Broad bean (*'SWS 1 white'*), Sugarcane + Fenugreek (*'Rajendra Kranti'*), Sugarcane + Garlic (*'Polish white'*), Sugarcane + Coriander ('Co.2'), Sugarcane + Lentil ('PL-639'), Sugarcane + Turnip (*'Purple Top sultan'*), Sugarcane + Radish (*'Clear white'*), Sugarcane + Sugar beet ('LS-6') were tested and respective yield and economic gain were analysed. The above experiment was laid out in randomized block design with three replications. The recommended dose of N: P: K for sugarcane was 150:60:60 kg ha^{-1}. The sources of nutrients were through urea (46.6%N), di-ammonium phosphate (18% N and 46% P) and muriate of potash (60% K). Full amount of P and K fertilizers and one-third N were applied as basal dose beneath cane setts at the time of planting. Chlorpyriphos 20% EC @ 5.0 L ha^{-1} was sprinkled over setts before covering them with soil to safeguard against insect–pests. Remaining amount of the N was applied in two equal splits at initial (60 days after planting-DAP) and (120 DAP) final stage of tillering. The fertilizers in different intercrops were applied as per their recommendations. Irrigations were given as per the requirement of intercrops. Results were statistically analysed following the procedures of Cochran and Cox (1957). The data on cane equivalent yield (CEY), which is the conversion of monetary benefit gain from the yield of intercrops, equated to the yield of sugarcane.

Under banana field, there were three intercropping systems *viz*. Banana + Tomato (*Mansuri*), Banana + Brinjal (*Pusa purple long*), Banana + Maize ('VMH -125*'*) which were tested and respective yields and economic gains were analysed. Under apiculture farming, two jangi start type (*Apis mellifera*) boxes were maintained. Under mushroom farming, oyster mushroom was produced.

RESULTS AND DISCUSSION

Sugarcane based intercropping systems

From the result, it is evident that significantly highest autumn sugarcane yield (97.2 t/ha) was recorded under

Table 1 Productivity and profitability of autumn sugarcane based intercropping systems (pooled data of 2017-18 &2018-19)

Intercropping systems	Sugarcane Yield (t/ha)	Intercrop Yield (q/ha)	Cost of cultivation (Rs/ha)	Gross Income (Rs/ha)	Net Income (Rs/ha)	Cane equivalent yield- CEY (t/ha)	B:C Ratio
Sugarcane (Sole) 'CoPk 05191'	91.40	-	1,23,756	2,87,910	1,64,154	92.30	2.33
Sugarcane + Potato (*'Kufri Chandramukhi'*)	96.00	252.50	2,14,746	5,54,900	3,40,154	176.20	2.59
Sugarcane + Pea (*'Azad P-3'*)	90.35	71.00	1,57,955	3,91,103	2,33,148	124.15	2.48
Sugarcane + Maize ('VMH-174')	84.50	83000**	1,55,646	5,15,175	3,59,530	163.55	3.31
Sugarcane + French bean (*'Arun'*)	95.15	19.70	1,84,007	5,16,423	3,32,416	163.95	2.81
Sugarcane + Broad bean (*'SWS 1 white'*)	94.45	72.20	1,68,840	4,41,918	2,73,078	140.30	2.62
Sugarcane + Fenugreek (*'Rajendra Kranti'*)	97.20	*127.85/18.30	1,56,327	7,44,880	5,88,553	236.45	4.77
Sugarcane + Garlic (*'Polish white'*)	97.05	86.40	1,90,561	7,80,908	5,90,347	247.95	4.10
Sugarcane + Coriander ('Co.2')	85.50	*233.45/7.30	2,07,683	6,92,500	4,84,817	219.80	3.34
Sugarcane + Lentil ('PL-639')	80.65	15.10	1,53,242	3,74,848	2,21,606	119.00	2.45
Sugarcane + Turnip (*'Purple Top sultan'*)	90.90	222.40	1,58,463	5,08,735	3,50,262	161.50	3.21
Sugarcane + Radish (*'Clear white'*)	91.50	228.55	1,60,105	5,16,775	3,56,670	164.05	3.23
Sugarcane + Sugar beet ('LS-6')	87.05	83.65	1,70,589	5,25,158	3,54,569	166.75	3.08
CD (P=0.05)	11.24	-	170.63	279.52	214.46	18.67	1.12

Rate of different commodities: Sugarcane- Rs. 3,150/t; Potato-Rs.1,000/q**;** Pea-Rs. 1,500/q; Maize-Rs.3/cobs
French bean-Rs.11,000/q; Broad bean-Rs.2,000/q; Fenugreek- Rs. 2,000/q (Green leaf), Rs. 10,000 /q (Grains); Garlic-Rs. 5,500/q; Coriander- Rs.1,500/q (Green Leaf), Rs. 10,000 /q (Spice Grains); Lentil-8,000/q;
Turnip- Rs.1,000 /q; Radish-Rs. 1,000/q; Sugar beet-3,000/q
*Yield of green leaves
**Number of green cobs

sugarcane + fenugreek intercropping system, which was closely followed by sugarcane + garlic (Table 1). The yield of sugarcane was significantly reduced under sugarcane + lentil (80.65 t/ha) and sugarcane + maize (84.50 t/ha) intercropping systems. The dual purpose fenugreek and coriander recorded 127.85 and 233.45 q/ha green leaves yield along with 18.30 and 7.30 q/ha grains yield, respectively. Intercropping of autumn sugarcane + garlic fetched significantly highest net income of Rs. 5,90,347/ha. The next best treatment was sugarcane + fenugreek (Rs.5,88,553/ ha). The other intercropping systems *viz.,* sugarcane + coriander (Rs.4,84,817/ha), sugarcane + maize (Rs.3,595,30/ha) and sugarcane + radish (Rs. 3,56,670/ha) were found highly remunerative with respect to net income obtained from either of the system. The net income from sole sugarcane was observed to the tune of Rs.1,64,154/ha. All the sugarcane based intercropping systems recorded significantly higher income than that of sole sugarcane. The above systems also produced higher cane equivalent yield (119.00 to 247.95 t/ha) and B: C ratio (2.48 to 4.77). The data on cane equivalent yield (CEY) showed significant increase under all the intercropping systems. Significantly, the highest CEY (247.95 t/ha) was observed for sugarcane + garlic intercropping system, closely followed by sugarcane + fenugreek (236.45 t/ha). The significantly highest Benefit: Cost ratio (4.77) was recorded by sugarcane + fenugreek intercropping system, however, sugarcane + garlic fetched B: C ratio of 4.10. The results clearly indicated that autumn sugarcane based intercropping systems hold promise in increasing the net income of 2-3 times more than that of sole sugarcane. The researches on intercropping systems have confirmed that small farmers in developing countries make efficient use of resources and generally provide yield advantage as compared to sole cropping (Willey 1979). The inclusion of vegetables as intercrops in sugarcane holds promise in enhancing the income of the farmers (Singh *et al.* 2018). The experimental findings of on-farm trials also indicated viability of sugarcane based crop diversification options (Singh and Lal 2007).

Horticultural crop based systems

Data presented in Table 2 clearly indicates that banana + tomato system fetched the highest net income of Rs. 4,39,296/ ha followed by banana + maize (Rs. 4,19,499/ha**)** and banana +

Table 2 Productivity and profitability of banana based intercropping systems

Intercropping systems	Banana Yield (q/ha)	Intercrop Yield (q/ha)	Cost of cultivation (Rs/ha)	Gross Income (Rs/ha)	Net Income (Rs/ha)	Banana Equivalent yield-BEY (q/ha)	B:C ratio
Banana Sole (‘*Grand Nain-G 9’*)	462	-	1,71,191	4,62,000	2,90,809	462.0	2.70
Banana + Tomato (‘*Mansuri’*)	462	151.5	2,04,504	6,43,800	4,39,296	519.7	3.15
Banana + Brinjal (‘*Pusa purple long’*)	460	156.9	2,03,213	6,17,000	4,13,787	509.8	3.04
Banana + Maize (‘*VMH - 125’*)	453	*58000	2,07,501	6,27,000	4,19,499	508.2	3.02

Rate of different commodities: Banana- Rs. 1,000/q; Tomato- Rs. 1,000/q; Brinjal -Rs. 1,000/q; Maize-Rs. 3/cob;

brinjal (Rs.4,13,787/ha). The above systems also recorded higher banana equivalent yield (508.2 to 519.7 q/ha) and B: C ratio (3.02 to 3.15) as compared to others. The papaya crop was intercropped with brinjal, onion, radish, french bean, broad bean, fenugreek and dill (*soa*). The intercropping of fenugreek and dill recorded yield of 270.6 and 147.7 q/ha respectively. The *karonda* (*Carrissa carandas*) plantation along with the field boundary progressed well and recorded 110 kg of the fruits in two years of this study. Under apiculture farming, two jangi start type (*Apis mellifera*) boxes were maintained and 16 kg of honey was produced. Under mushroom farming, 17 kg of oyster mushroom was produced. From the earlier researches, it was emphasised that farming system is a resource management strategy to achieve economic and sustained production to meet diverse requirements of farm households while preserving the resource base and maintaining a high level environmental quality (Lal and Millu 1990). The spatial and temporal changes of land use, cropping patterns and cattle keeping under banana based farming systems were assessed and showed positive results (Baijukya *et al*. 2005).

Farming systems developed

The important agricultural enterprise combinations assessed through computing their net profit as presented in Table 3. The above study developed the following new farming

Table 3 Income from different farm enterprises

S. No.	Cropping/Farming systems*	Income (Rs) from one ha farm land
1.	Agri (0.7 ha)- horti (0.2 ha) System Agri: Sugarcane + Fenugreek : Rs. 5,88,553/ha So, for 0.35ha = Rs. 2,05,993 Agri : Sugarcane + Garlic : Rs. 5,90,347/ha So, for 0.35 ha = Rs.2,06,621 Total = Rs. 4,12,614 Horti: Banana + Tomato: Rs. 4,39,296/ha So, for (0.2 ha): Rs. 8,78,59 Total = Rs. 5,00,474	5,00,474
2.	Agri (0.7 ha) – api (0.05 ha) System Rs. 4,12,614 + Rs. 3,000 = Rs. Rs. 4,15,614	4,15,614
3.	Agri (0.7 ha) – mushroom farming (0.05 ha) Rs. 4,12,614 + Rs.1,000 =Rs. 4,13,614	4,13,614
4.	Agri (0.7 ha) – horti (0.2 ha) – api System Rs. 4,12,614 + Rs. 8,78,59 + Rs. 3,000 =Rs. 5,03,473	5,03,473
5.	Agri (0.7 ha) – horti (0.2 ha) – mushroom (0.05 ha) Rs. 4,12,614 + Rs. 8,78,59 + Rs. 1,000 = Rs. 5,01,473	5,01,473
6.	Agri (0.7 ha) – api (0.05 ha) – mushroom (0.05 ha) Rs. 4,12,614 + Rs. 3,000 + Rs. 1,000 = Rs. 4,16,614	4,16,614
7.	Agri (0.7 ha)- horti (0.2 ha)- api (0.05 ha)-mushroom (0.05 ha) system: Rs. 4,12,614 + Rs. 8,78,59 + 3,000 + 1,000 = Rs. 5,04,473	5,04,473
8.	Income from Sole Sugarcane =Rs. 1,64,154/ha	1,64,154

*Agri-Agricultural crop (Sugarcane); Horti-Horticulture (Horticultural crops); api-apiculture (bee keeping) systems on the basis of net returns obtained:

1. Agri (0.7 ha)-horti (0.2 ha) system: (Rs. 5,00,474)
2. Agri (0.7 ha)-api (0.05 ha) system: (Rs. 4,15,614)
3. Agri (0.7 ha)-mushroom farming (0.05 ha): (Rs. 4,13,614)
4. Agri(0.7 ha)-horti (0.2 ha)-api system: (Rs. 5,03,473)
5. Agri (0.7ha)-horti (0.2ha)- mushroom farming (0.05 ha): (Rs. 5,01,473)
6. Agri (0.7 ha)-api (0.05 ha)- mushroom farming (0.05 ha): (Rs. 4,16,614)
7. Agri(0.7 ha)-horti (0.2 ha)-api(0.05 ha)-mushroom(0.05 ha) system: (Rs. 5,04,473)

The net income of Rs.1,64,154/ha was observed from sole sugarcane. From the results, it is clearly evident that income from farming systems was two to three times more than that of sole sugarcane. The findings of the Srivastava (2018) are also in close-conformity with the results. Singh *et al.* (2006)also opined that integrated farming system models hold promise in enhancing the income of farmers. Integrated farming systems offer unique opportunities for maintaining and extending biodiversity. The emphasis on such systems is for optimization of resource utilization rather than maximization of individual elements in the systems (Soni *et al*. 2014).

CONCLUSION

Due to conversion of valuable irrigated agricultural lands for non-agricultural purposes *viz*., residential houses, industrial and business establishments and fragmentation of holdings, the per capita availability of land is declining day by day. Therefore, no single farm enterprise is able to meet the growing demands of food and other necessities of the small and marginal land holding farmers. Hence, there is an utmost necessity of adoption of "farming systems approach" by these vulnerable sections of sugarcane farming community. Sugarcane based integrated farming systems hold promise in increasing the net income 2-3 times to the sole sugarcane.

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Agrotechniques for productivity enhancement of sugarcane raised with single node seedlings

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ABSTRACT

A field experiment was conducted for three consecutive years (2015-16 to 2017-18) on sandy loam with clay base soil at RARS, Anakapalle, Andhra Pradesh to find out the optimum age of seedlings, plant density and nitrogen dose for enhancing yield and quality of sugarcane raised with single node seedlings. The treatments consisted of age of seedlings (30 days, 45 days and 60 days age), population densities (18,500, 24,700 and 37,000 seedlings/ha) and nitrogen levels (150 % and 200 % recommended dose of nitrogen). The experiment was laid out in split-split plot design with age of the seedlings in main plots, population densities in sub plots and nitrogen levels as sub-sub plots. The results of the study revealed that, planting of 30 days old seedlings (76.93 t/ha) or 45 days old seedlings (75.97 t/ha) registered higher cane yield as compared to 60 days old seedlings (68.47 t/ha). Among population densities, planting of 24,700 seedlings /ha registered higher cane yield of 76.20 t/ha and found on par with 18,500 seedlings /ha (74.33 t/ha) while at higher population density of 37,000/ ha, the cane yield reduced considerably (71.23t/ha). Seedlings responded upto 200 % RDN and recorded relatively higher cane yield (75.17 t/ha) as compared to 150% RDN (72.17 t/ha). Quality of cane in terms of juice sucrose percent and commercial cane sugar was not affected due to age of the seedlings, population densities and nitrogen levels.

Key words: Age of the single node seedlings, Nitrogen levels, Population density

INTRODUCTION

In Andhra Pradesh sugarcane is grown in an area of 1.00 lakh ha with a production of 80 lakh tonnes. In recent years, farmers are preferring single node seedlings as planting material due to less cost towards seed material as compared to three bud sett planting. Generally, 30 days aged seedlings are more suitable for planting in January and February months, but due to delay in land preparation after paddy or due to coincidence of planting and harvesting operations in sugarcane, timely transplanting of single node seedlings at right age is not being done. So, farmers are forced to transplant overaged seedlings which may lead to poor tillering, reduced millable cane population and ultimately the low cane yields. Hence, it was felt essential to find out optimum age of seedlings, plant density and nitrogen dose for improving yield of sugarcane raised with single node seedlings.

MATERIALS AND METHODS

A field experiment was laid out at Regional Agricultural Research Station, Anakapalle (Andhra Pradesh) on sandy loam with clay base soil for three years during 2015-16 to 2017-18. An early maturing sugarcane variety '2001A63' (*Kanaka Mahalakshmi*) was planted during spring season (February-March). The experimental soil was low in available nitrogen (207.7 kg N/ha), medium in available phosphorus (35.8 kg P_2O_5 /ha) and high in available potassium (350.2 kg K_2O/ha). The treatments consisted of age of seedlings (30 days, 45 days and 60 days age), population densities (18,500 seedlings/ha, 24,700 seedlings/ha and 37,000 seedlings/ha) and nitrogen levels (150% and 200 % recommended dose of nitrogen). The experiment was laid out in split-split plot design keeping age of the seedlings in main plots, population densities in sub plots and nitrogen levels in sub - sub plots. Irrigations were accorded once in 3 days up to 15 days after planting and thereafter once in six days during formative phase and once in three weeks during maturity phase i.e. from November to harvest. Seedlings were planted in treatment plots by letting water into the furrows. FYM @ 25 t/ha and phosphorus @ 100 kg P_2O_5/ha were applied uniformly in furrows before transplanting of single node seedlings. Potassium @ 120 kg K_2O/ha was applied in split doses along with nitrogen. Nitrogen @ 168 kg and 224 kg under 150 and 200% RDN, respectively was applied as per treatments in 4 split doses at planting, 30, 60 and 90 DAP (days after planting) by pocketing method. Other cultural operations *viz*. weeding, inter-cultivation, earthing up and trash twist propping were done at appropriate time.

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RESULTS AND DISCUSSION

Yield attributes

Millable cane population at harvest

Number of millable canes was recorded at harvest in all the treatment plots and analyzed statistically and presented in Table 1. Number of millable cane varied considerably due to ages of seedlings, population densities and nitrogen levels. Planting of 30 days old seedlings registered higher number of millable canes (67,994/ha) as compared to 60 days old seedlings (61,048/ha) but found comparable to 45 days old seedlings (66,146/ha). Higher number of millable canes (67,552/ha) were registered at higher population density of 37,000 seedlings / ha when compared to lesser population density of 18,500 seedlings/ha (63,266/ha). Irrespective of age of the seedlings and population densities, higher millable canes were recorded at 200% recommended dose of nitrogen (66,180/ha) than at 150% recommended dose of nitrogen (62,699/ha). This may be due to fast establishment and more tillering ability of tender seedlings when compared to overaged seedlings. Similar results were also reported by Chitkala Devi *et al.* (2012) and Sarala (2017).

Length of millable canes

Considerable differences in length of millable canes were not observed due to age of the seedlings, plant densities and nitrogen levels. However, comparatively higher cane length (229.2 cm) was obtained in 30 days old seedlings than 60 days old seedlings (213.2 cm). Similarly longer canes were recorded at higher population density of 37,000 seedlings/ha (225.6 cm) as compared to 18,500 seedlings/ha (216.1 cm). Levels of nitrogen did not influence the length of millable cane appreciably (Table 1).

Quality of cane

Quality of cane was studied in terms of percent juice sucrose and CCS% and data are presented in Table 2. Percent juice sucrose values did not vary considerably due to different treatments and the mean percent juice sucrose values ranged from 17.43 to 17.79. However, at higher level of nitrogen dose i.e. 200% RDN comparatively lesser percent juice sucrose values (17.48 %) were registered as compared to 150% RDN (17.79%). Similarly the CCS% was also not influenced by age of seedlings, plant density and N levels and it ranged from 12.81 to 12.95 in different treatments.

Yield

Cane yield

Cane yield at harvest differed significantly due to age of the seedlings and plant densities during all the years of investigation (Table 3). Planting of 30 days old seedlings recorded significantly higher cane yield when compared to 60 days old seedlings but gave at par yields with 45 days old seedlings. A mean cane yield of 76.93 t/ha and 75.97 t/ha was registered with 30 and 45 days old seedlings, respectively, while, it was 68.47 t/ha with 60 days old seedlings accounting to cane yield reduction of 11.0% over 30 days old seedlings. Higher yield with 30 days old seedlings might be due to more number of tillers and population of millable canes at harvest. These results are in corroboration with Chitkala Devi *et al.* (2012), Sarala (2017). Similarly, planting of seedlings at a population density of 24,700 seedlings/ha registered higher mean cane yield of 76.20 t/ha and found comparable to 18,500 seedlings/ha (74.33 t/ha), but superior over higher population density of 37,000/ha (71.23 t/ha). Reduction in yield at higher plant density might be due to thinner canes and less cane weight due to competition among tillers/shoot for nutrients

Table 1 Yield attributes of sugarcane as influenced by age of the seedlings, population densities and nitrogen levels under seedling cultivation

Treatment	Number of millable canes/ha				Length of millable canes (cm)			
	2015-16	2016-17	2017-18	Mean	2015-16	2016-17	2017-18	Mean
Age of seedlings:								
A1:30 Days	75747	66574	61660	67993	281.4	210.1	196.0	229.2
A2:45 Days	73227	65491	59721	66146	276.9	193.3	186.3	218.8
A3:60 Days	68615	58589	55940	61048	271.0	186.7	182.0	213.2
C.D (0.05)	3028	4339	NS	-	NS	NS	NS	-
Population Densities:								
S1:18,500 Seedlings / ha	70785	62219	56794	63266	272.2	188.2	188.1	216.1
S2:24,700 Seedlings / ha	72296	64456	58996	65249	276.4	195.3	186.5	219.4
S3:37,000 Seedlings / ha	75105	66018	61532	67551	280.5	206.7	189.7	225.6
C.D (0.05)	2,785	3350	3438	-	6.7	NS	NS	-
Nitrogen Levels:								
N1:150% RDN	68116	61996	57984	62698	274.3	192.7	191.3	219.4
N2:200% RDN	73204	65105	60231	66180	278.5	200.7	184.9	221.3
C.D (0.05)	3231	2705	NS	-	NS	7.8	6.3	-
Interaction	NS	NS	NS	-	NS	NS	NS	-

Table 2 Quality parameters as influenced by age of seedlings, plant densities and nitrogen levels under seedling cultivation

Treatment	Percent sucrose				Commercial cane sugar %			
	2015-16	2016-17	2017-18	Mean	2015-16	2016-17	2017-18	Mean
Age of seedlings:								
A1:30 Days	16.29	15.96	20.92	17.72	11.30	12.07	15.48	12.95
A2:45 Days	15.78	15.78	20.93	17.50	11.42	11.81	15.40	12.88
A3:60 Days	16.59	15.85	20.77	17.74	11.59	11.90	15.31	12.93
C.D (0.05)	NS	NS	NS	-	NS	NS	NS	-
Population Densities:								
S1:18,500 Seedlings / ha	16.51	15.90	20.91	17.77	11.43	11.91	15.42	12.92
S2:24,700 Seedlings / ha	15.65	15.74	20.89	17.43	11.41	11.71	15.43	12.85
S3:37,000 Seedlings / ha	16.47	15.96	20.81	17.75	11.47	11.89	15.33	12.90
C.D (0.05)	NS	NS	NS	-	NS	NS	NS	-
Nitrogen Levels:								
N1:150% RDN	16.42	16.10	20.85	17.79	11.35	12.09	15.35	12.93
N2:200% RDN	15.91	15.63	20.89	17.48	11.53	11.45	15.44	12.81
C.D (0.05)	NS	0.20	NS	-	NS	0.38	NS	-
Interaction	NS	NS	NS	-	NS	NS	NS	-

Table 3 Cane and sugar yields of sugarcane as influenced by age of seedlings, plant densities and nitrogen levels under seedling cultivation

Treatment	Cane yield (t/ha)				Sugar yield (t/ha)			
	2015-16	2016-17	2017-18	Mean	2015-16	2016-17	2017-18	Mean
Age of seedlings:								
A1:30 Days	83.8	72.5	74.5	76.93	9.5	8.7	11.5	9.90
A2:45 Days	82.4	71.3	74.2	75.97	9.4	8.4	11.4	9.73
A3:60 Days	74.5	63.2	67.7	68.47	8.6	7.5	10.4	8.83
C.D (0.05)	4.3	4.3	5.1	-				
Population Densities:								
S1:18,500 Seedlings /ha	80.2	70.2	72.6	74.33	9.2	8.4	10.2	9.27
S2:24,700 Seedlings /ha	82.6	71.7	74.3	76.20	9.4	8.4	11.5	9.77
S3:37,000 Seedlings /ha	78.3	66.0	69.4	71.23	9.0	7.8	10.6	9.13
C.D (0.05)	3.4	3.7	4.1	-				
Nitrogen Levels:								
N1:150% RDN	78.1	68.0	70.4	72.17	8.9	8.2	10.8	9.30
N2:200% RDN	82.5	70.2	72.8	75.17	9.5	8.0	11.2	9.57
C.D (0.05)	3.1	NS	NS	-				
Interaction	NS	NS	NS	-				

and other resources. Sarala (2017) reported that planting of 30 to 45 days old seedlings using 18,500 seedlings/ha (60/120x60 cm) was optimum for realizing higher yields in sugarcane under bud chip seedling cultivation. Among different nitrogen levels, higher mean cane yield was obtained with 200% RDN (75.17 t/ha) than at 150% recommended dose of nitrogen (72.17 t/ha). This might be due to high response of seedlings to applied nitrogen (Chitkala Devi *et al.* 2012). The interaction effects were found to be non significant.

Sugar yield

Higher mean sugar yield was recorded with planting of 30 days old seedlings (9.90 t/ha) which was closely followed by 45 days old seedlings (9.73 t/ha). When 60 days old seedlings were transplanted, the sugar yield was drastically reduced (8.83 t/ha) due to reduction in cane yield with 60 days old seedlings. At population density of 24,700 seedlings/ha higher sugar yield of 9.77 t/ha was recorded as compared to higher population density of 37,000 seedlings/ha (9.13 t/ha). Similarly, increase in sugar yield was noticed at 200% RDN (9.57 t/ha) when compared to 150% recommended dose of nitrogen application (9.30 t/ha) and this may be attributed to higher cane yield at 200% RDN.

CONCLUSIONS

The results of the three years study indicated that single node seedlings can be transplanted upto 45 days age without considerable yield reduction, whereas, planting of 60 days old seedlings reduced the cane yield and sugar yield to the tune of 8.46 t/ha and 1.07 t/ha, respectively over 30 days old seedlings. A population density of 24,700 seedlings/ha can be adopted to realize higher cane yield (76.2 t/ha) as cane yield gets reduced with higher plant density of 37,000 seedling/ha (71.23 t/ha). Similarly, a nitrogen dose of 200% RDN can be suggested to maximize cane yield (75.17 t/ha) as compared to 150% RDN (72.17 t/ha) as cane yield increased to an extent of 3.0 t/ha with additional dose of 50% N over 150% RDN.

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Halosulfuron- methyl 75% WG-A new post emergence herbicide for management of sedges (*Cyperus rotundus*) in sugarcane under seedling cultivation

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ABSTRACT

A field experiment was carried out at Regional Agricultural Research Station, Anakapalle for two consecutive years during 2015-16 and 2016-17 on a sandy loam soil to evaluate the efficacy of halosulfuron-methyl 75% WG against sedges in sugarcane under seedling cultivation. Twelve treatments consisting of post-emergence (PoE) application of halosulfuron @ 50, 60, 70 and 80 g a.i. ha^{-1} applied at 30 and 45 days after planting; PoE application of metribuzin @ 0.75 kg a.i. ha^{-1} + 2,4-D sodium salt @ 1.5 kg a.i. ha^{-1}; pre-emergence (PE) application of atrazine @ 2.5 kg a.i. ha^{-1} along with conventional hand weeding and weedy check were tested in a randomized block design with three replications. Experimental results indicated that the conventional hand weeding thrice at 30, 60 and 90 days after planting controlled the weeds effectively, favoured good crop growth and resulted in lower weed density, higher weed control efficiency, higher millable cane population (87137 ha^{-1}), cane yield (111.7 t ha^{-1}) and sugar yields (13.26 t ha^{-1}) over weedy check. Among the herbicides, PoE application of halosulfuron-methyl @ 80 g a.i. ha^{-1} at 30 or 45 days after planting was found effective over other treatments and recorded higher mean WCE (49.2% at 60 DAP and 65.4% at 90 DAP) and cane yield (102.7 t ha^{-1}) over weedy check (77.9 t ha^{-1}). No phytotoxicity effect was observed with post emergence weedicides on sugarcane seedlings.

Key words: Halosulfuron-methyl, Phytotoxicity, Weed control efficiency, Weed management index, Weed index

INTRODUCTION

Sugarcane is an important commercial crop cultivated in the state of Andhra Pradesh and mostly grown with three bud setts as seed material. However, cultivation of sugarcane using single node seedlings is becoming popular as a seed and labour saving technology as it requires one ton of cane to raise seedlings required for one acre and 5-6 labour are sufficient to transplant the pro tray seedlings. Frequent irrigations provided to ensure good establishment of seedlings favours rapid growth of weeds which compete for moisture and nutrients. Among different weeds infesting sugarcane at early stages of crop growth, *Cyperus rotundus* is the predominant and problematic weed in sugarcane growing areas. Commonly used PE herbicides like atrazine and PoE weedicides like metribuzin + 2,4 D sodium salt or 2,4 D amine etc., are found less ineffective against *Cyperus rotundus* as it regenerates within a short period of its application. Hoeing though checks the *Cyperus* effectively, its impact is temporary as it regenerates at a faster rate after hoeing from the underground rhizomes present in deeper layers. Non availability of labour, high labour wages and poor efficiency of manual weeding warrants an effective herbicide against *Cyperus rotundus* especially under seedling transplantation as its problem is more severe at early stages of establishment of the crop.

MATERIALS AND METHODS

A field experiment was carried out at Regional Agricultural Research Station, Anakapalle for two consecutive years during 2015-16 and 2016-17 to recommend optimum dose and time of application of halosulfuron-methyl for the control of sedges *Cyperus rotundus* in sugarcane under seedling cultivation. The experimental site was a red sandy loam, neutral in P^H (7.63), low in available N (143Kg N ha^{-1}), medium in available phosphorus (40.5 kg P_2O_5 ha^{-1}) and high in available potassium (289 kg K_2O ha^{-1}). The experiment was laid out in a randomized block design with twelve treatments and replicated thrice. The treatments consisted of PoE application of halosulfuron-methyl 75% WG at four doses (50, 60, 70 & 80 g a.i. ha^{-1}) and two times of application (30 DAP & 45 DAP), metribuzin + 2, 4-D (0.75 and 1.5 kg a.i. ha^{-1} respectively) at 30 DAP, PE application of atrazine @ 2.5 kg a.i. ha^{-1} integrated with hand weeding at 60 DAP, and hand weeding thrice at 30, 60 and 90 DAP along with weedy check. An early maturing sugarcane clone 2007A81 was used as test variety. Single bud seedlings raised in pro trays were transplanted at 30 days age at a row spacing of 90 cm and plant to plant spacing of 45cm. Irrigation was provided at 5-6 days interval till the establishment of seedlings. Phosphorus and potassium @ 100 and 120 kg ha^{-1} in the form of single super phosphate and muriate of potash, respectively

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were applied basally in planting furrows. Nitrogen @ 168 kg ha^{-1} was applied in three splits at 30, 60 and 90 DAP by pocketing. Weedicide halosulfuron-methyl was sprayed as per treatments using spray volume of 500 Lha^{-1}. PE weedicide atrazine @ 2.5 kg a.i.ha^{-1} using 500 L of water volume ha^{-1} was sprayed on 2nd day of planting and hand weeding was done at 60 days after planting. The data on seedling survival at one month after planting and shoot population at 120 DAP were recorded.

The length and girth of millable canes, no. of millable canes and cane yield were recorded at harvest. Quality parameters like brix and sucrose % were recorded with Sucrolyzer at harvest. CCS% at harvest was calculated based on Brix and sucrose % and sugar yield was computed. The replicated data were analyzed in RBD as suggested by Snedecor and Cochran (1968). The data on weed density were recorded at 30, 60 and 90 days after planting. Phytotoxicity was recorded by visual scoring at 15 days after application. Based on weed density different weed control parameters viz., Weed Control Efficiency (WCE), Weed Management Index (WMI) and Weed Index (WI) were calculated as detailed below.

Weed Control Efficiency (WCE)

Weed control efficiency was calculated as suggested by Mani *et al.* (1973) as a derived parameter out of weed density per unit urea in control and treatment plots.

$$\text{Weed Control Efficiency (WCE)} = \frac{WD_C - WD_T}{WD_C} \times 100$$

Where, WD_C is Weed density in control plot and WD_T is Weed density in treatment plot.

Weed Management Index (WMI)

Weed management index was calculated as a derived parameter of % yield increase to % weed control over weedy check as suggested by Mishra and Misra (1997).

$$\text{Weed Management Index (WMI)} = \frac{\text{\% increase in crop yield}}{\text{\% control of weeds}}$$

$$\text{Weed Management Index (WMI)} = \frac{\text{\% crop yield over control}}{\text{\% control of weeds}}$$

Weed Index / weed competition Index (WI / WCI)

Weed Index is a derived parameter from the crop yields obtained across the treatments and was calculated with the following formula as suggested by Gill and Vijaykumar (1969).

$$\text{Weed Index / Weed Competition Index (WI)} = \frac{Ywf - Yt}{Ywf} \times 100$$

Where, Ywf is the crop yield in weed free plot and Yt is the crop yield in treatment plot.

RESULTS AND DISCUSSION

Effect of different weed control treatments on weed control parameters, seedling survival, shoot population, yield attributes, quality parameters and yield are presented in Table 1 to 6 and results are furnished here under.

Effect on weed control parameters

Weed Flora

Major weed flora observed in the experimental field were *Cyperus rotundus, Dactyloctenium aegyptium, Panicum repens, Cenchrus ciliaris, Echinochloa crusgalli* among monocots and *Euphorbia geniculata, Ipomoea pestigritis* and *Rothia trifoliata* among dicots. Out of all the weeds *Cyperus rotundus* was the predominant sedge (60-70%) observed in the experimental field.

Weed Density

Weed density per unit area was recorded at 30, 60 and 90 DAP and the data are presented in table 1. Weed density nos. m^{-2} increased with the advancement of crop age upto 60 DAP and reduced at 90 DAP. All the treatments recorded more or less equal weed density at 30 DAP except in PE application of atrazine @ 2.5 kg a.i. ha^{-1} which recorded relatively less weed density (213.84 m^{-2}) over the weedy check (249.34 m^{-2}). Weed density varied considerably at 60 and 90 DAP. Lowest weed density of 189.65 m^{-2} was recorded with PoE application of halosulfuron- methyl @ 80 g a.i. ha^{-1} sprayed at 30 DAP followed by PoE application of same at 45 DAP while maximum weed density was noticed in weedy check (405.17 nos. m^{-2}). At 90 DAP, lowest weed density was observed with PoE application of halosulfuron- methyl @ 80 g a.i. ha^{-1} at 30 DAP (89.67 m^{-2}).

Weed Control Efficiency (WCE)

The data on wed control efficiency given in table 2 indicated that the conventional practice of hand weeding thrice at 30, 60 and 90 DAP proved effective and recorded highest weed control efficiency of 55.7% at 60 DAP. Among the herbicide treatments, PoE application of halosulfuron-methyl @ 80 g a.i. ha^{-1} at 45 DAP (54.9%) or PoE application of metribuzin + 2,4 – D at 30 DAP (54.3%) recorded weed control efficiency similar to hand weeding and proved superior over other herbicides. At 90 days after planting PoE application of halosulfuron-methyl @ 80 g a.i. ha^{-1} at 30 DAP recorded highest weed control efficiency of 70.45% which was higher than traditional hand weeding treatment (40.55%) as *Cyperus rotundus* weed regenerated under hand weeding plotsSimilar results were also observed by Luke (2007) who reported that halosulfuron-methyl controlled the purple nut sedge to an extent of 44% at 2 weeks after treatment and 80% at 4 weeks after treatment. Meher Chand *et al.* (2014) opined that halosulfuron methyl 75% WG @ 67.5 g a.i. ha^{-1} applied at 35-45 DAP was found to be the optimum dose and time for effective control of *Cyperus rotundus* in sugarcane.

Weed Management Index (WMI)

Weed management Index represents the magnitude of yield increase to the magnitude of weed control. The data on WMI embedded in table 2 revealed that WMI was higher at 60 DAP than at 90 DAP indicating the most critical stage of weed

Table 1 Weed density (no./m^{-1}) at different growth stages of sugarcane as influenced by weed control treatments

Treatments	Weed density (no. m^{-2})								
	30 DAP			60 DAP			90 DAP		
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean
T_1- PoE application of Halosulfuron methyl at 30 DAP @ 50g a.i. ha^{-1}	14.18 (201.33)	17.90 (320.00)	16.04 (260.67)	17.13 (292.33)	12.30 (150.67)	14.72 (221.50)	12.18 (165.33)	8.22 (66.67)	10.20 (116.00)
T_2- PoE application of Halosulfuron methyl at 45 DAP @ 50g a.i. ha^{-1}	14.46 (216.00)	16.62 (288.00)	15.54 (252.00)	17.84 (317.33)	11.07 (125.33)	14.46 (221.33)	13.31 (177.33)	7.85 (61.33)	10.58 (119.33)
T_3- PoE application of Halosulfuron methyl at 30 DAP @ 60g a.i. ha^{-1}	14.09 (204.00)	16.73 (280.00)	15.41 (242.00)	18.05 (325.33)	10.86 (118.67)	14.46 (222.00)	12.27 (154.67)	8.14 (66.67)	10.21 (110.67)
T_4- PoE application of Halosulfuron methyl at 45 DAP @ 60 g a.i. ha^{-1}	15.28 (236.00)	16.08 (260.00)	15.68 (248.00)	18.53 (342.67)	10.63 (114.67)	14.58 (228.67)	13.15 (174.67)	7.51 (57.33)	10.33 (116.00)
T_5- PoE application of Halosulfuron methyl at 30 DAP @ 70g a.i. ha^{-1}	14.40 (218.67)	14.64 (218.67)	14.52 (218.67)	16.70 (278.67)	13.48 (181.33)	15.09 (230.00)	12.62 (160.00)	6.90 (46.67)	9.76 (103.34)
T_6- PoE application of Halosulfuron methyl at 45 DAP @ 70g a.i. ha^{-1}	15.18 (232.00)	15.54 (242.67)	15.36 (237.34)	17.29 (300.00)	11.43 (130.67)	14.36 (215.34)	13.53 (183.33)	6.74 (45.00)	10.14 (114.17)
T_7- PoE application of Halosulfuron methyl at 30 DAP @ 80g a.i. ha^{-1}	15.62 (244.00)	14.59 (216.00)	15.11 (230.00)	16.60 (276.00)	10.16 (103.30)	13.38 (189.65)	11.54 (134.67)	6.68 (44.67)	9.11 (89.67)
T_8- PoE application of Halosulfuron methyl at 45 DAP @ 80g a.i. ha^{-1}	15.87 (258.67)	15.89 (257.33)	15.88 (258.00)	17.13 (293.33)	9.80 (96.00)	13.47 (194.67)	14.09 (198.67)	6.40 (42.00)	10.25 (120.34)
T_9- PoE application of Metribuzin @ 0.75 kg a.i. ha^{-1} +2,4, D Sodium salt @ 1.5 kg a.i. ha^{-1} at 30 DAP	15.85 (253.33)	15.50 (246.67)	15.68 (250.00)	16.29 (266.67)	10.92 (118.67)	13.88 (192.67)	13.96 (194.67)	7.28 (52.00)	10.62 (123.34)
T_{10}- Hand Weeding thrice	15.30 (238.67)	16.41 (270.67)	15.86 (254.67)	16.37 (268.00)	10.44 (109.00)	16.93 (288.67)	14.05 (197.33)	12.75 (162.67)	13.40 (180.00)
T_{11}-Weedy check	16.29 (266.67)	15.10 (232.00)	15.70 (249.34)	21.63 (467.67)	18.51 (342.67)	20.07 (405.17)	17.48 (304.00)	17.36 (301.33)	17.42 (302.67)
T_{12}- PE application of atrazine @ 2.5 kg a.i. ha^{-1}+ Hand Weeding at 60 DAP	12.67 (161.00)	16.36 (266.67)	14.52 (213.84)	17.83 (317.00)	13.76 (189.33)	15.80 (253.17)	14.99 (224.00)	12.00 (144.00)	13.50 (184.00)
SEm±	1.48	1.2		0.68	0.68		0.73	0.60	
CD (0.05)	NS	NS		2.00	2.01		2.15	1.77	

* Original values are in parenthesis

Table 2 Weed Control Efficiency (WEC), Weed Management Index and Weed Index as influenced by different weed control treatments

Treatment	Weed control efficiency % (WCE)						Weed Management Index						Weed index		Mean
	60 DAP			90 DAP			60 DAP			90 DAP					
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	
T_1-PoE application of Halosulfuron methyl at 30 DAP @ 50g a.i. ha^{-1}	38.0	56.0	47.00	45.6	77.9	61.75	0.40	0.00	0.20	0.33	0.00	0.16	7.24	30.02	18.63
T_2- PoE application of Halosulfuron methyl at 45 DAP @ 50g a.i. ha^{-1}	32.0	63.6	47.80	41.7	79.6	60.65	0.31	0.32	0.32	0.24	0.26	0.25	11.1	25.20	18.15
T_3- PoE application of Halosulfuron methyl at 30 DAP @ 60g a.i. ha^{-1}	31.0	65.3	48.15	49.1	77.9	63.50	0.36	0.21	0.29	0.22	0.18	0.20	10.5	29.20	19.85
T_4- PoE application of Halosulfuron methyl at 45 DAP @ 60 g a.i. ha^{-1}	27.2	66.5	46.85	42.6	81.0	61.80	0.37	0.57	0.47	0.23	0.47	0.35	11.38	14.25	12.82
T_5- PoE application of Halosulfuron methyl at 30 DAP @ 70g a.i. ha^{-1}	40.8	47.2	44.00	45.2	84.5	64.85	0.36	0.64	0.50	0.32	0.36	0.34	7.76	19.03	13.40
T_6- PoE application of Halosulfuron methyl at 45 DAP @ 70g a.i. ha^{-1}	36.3	61.8	49.05	39.5	85.1	62.30	0.18	0.37	0.28	0.17	0.27	0.22	14.06	16.40	15.23
T_7- PoE application of Halosulfuron methyl at 30 DAP @ 80g a.i. ha^{-1}	41.4	45.5	43.45	55.7	85.2	70.45	0.42	0.99	0.71	0.32	0.53	0.43	5.27	10.19	7.73
T_8- PoE application of Halosulfuron methyl at 45 DAP @ 80g a.i. ha^{-1}	37.8	72.0	54.90	34.6	86.1	60.35	0.14	0.82	0.48	0.15	0.69	0.42	15.31	1.35	8.33
T_9- PoE application of Metribuzin @ 0.75 kg a.i. ha^{-1} +2,4, D Sodium salt @ 1.5 kg a.i. ha^{-1} at 30 DAP	43.3	65.3	54.30	36.0	82.7	59.35	0.16	0.57	0.37	0.19	0.45	0.32	13.89	14.89	14.39
T_{10}- Hand Weeding thrice	43.1	68.2	55.70	35.1	46.0	40.55	0.56	0.89	0.73	0.69	1.33	1.01	-	-	-
T_{11}- Weedy check	0.0	-	0.00	0.0	0.0	0.00	-	-	-	-	-	-	19.44	32.06	25.75
T_{12}- PE application of atrazine @ 2.5 kg a.i. ha^{-1}+ Hand Weeding at 60 DAP	32.7	44.8	38.75	26.3	52.2	39.25	0.44	1.04	0.74	0.55	0.83	0.69	7.76	11.07	9.42

Table 3 Seedling survival and shoot population at 120 DAP in sugarcane as influenced by different weed treatments

Treatment	Seedling survival %			Shoot population at 120 DAP		
	2015-16	2016-17	Mean	2015-16	2016-17	Mean
T_1- PoE application of Halosulfuron methyl at 30 DAP @ 50g a.i. ha^{-1}	94.7	96.7	95.70	49893	98010	73952
T_2- PoE application of Halosulfuron methyl at 45 DAP @ 50g a.i. ha^{-1}	96.7	96.1	96.40	47607	92057	69832
T_3- PoE application of Halosulfuron methyl at 30 DAP @ 60g a.i. ha^{-1}	95.3	93.3	94.30	50964	108723	79844
T_4- PoE application of Halosulfuron methyl at 45 DAP @ 60 g a.i. ha^{-1}	93.3	99.0	96.15	50714	107930	79322
T_5- PoE application of Halosulfuron methyl at 30 DAP @ 70g a.i. ha^{-1}	95.3	95.7	95.50	51321	108326	79824
T_6- PoE application of Halosulfuron methyl at 45 DAP @ 70g a.i. ha^{-1}	94.3	98.6	96.45	49893	105946	77920
T_7- PoE application of Halosulfuron methyl at 30 DAP @ 80g a.i. ha^{-1}	93.3	99.0	96.15	58464	106342	82403
T_8- PoE application of Halosulfuron methyl at 45 DAP @ 80g a.i. ha^{-1}	96.1	94.3	95.20	55821	103168	79495
T_9- PoE application of Metribuzin @ 0.75 kg a.i. ha^{-1} +2,4, D Sodium salt @ 1.5 kg a.i. ha^{-1} at 30 DAP	93.9	99.6	96.75	55250	113485	84368
T_{10}- Hand Weeding thrice	99.0	99.0	99.00	102857	148800	125829
T_{11}-Weedy check	91.9	97.6	94.75	42587	94042	68315
T_{12}- PE application of atrazine @ 2.5 kg a.i. ha^{-1}+ Hand Weeding at 60 DAP	98.1	99.0	98.55	75964	148800	112382
SEm±	1.7	1.84	-	2437	7169	-
CD(0.05)	NS	NS	-	7086	20835	-
C.V.%	3.1	3.3	-	6.9	10.8	-

competition and impact of weed control on yield. At 60 days after planting the WMI was higher with PE application of atrazine @ 2.5 kg a.i. ha^{-1} + hand weeding at 60 DAP (0.74) followed by hand weeding thrice at 30, 60 and 90 DAP (0.73). At 90 DAP hand weeding thrice recorded higher weed management index of 1.01 followed by PE application of atrazine @ 2.5 kg a.i. ha^{-1} + hand weeding at 60 DAP (0.69). Among the halosulfuron treatments PoE application of halosulfuron-methyl @ 80 g a.i. ha^{-1} sprayed at 30 DAP recorded relatively higher WMI of 0.71 and 0.43 at 60 DAP and 90 DAP, respectively.

Weed Index

Weed index which indicates the magnitude of yield reduction with weed competition. Weed index was lowest (7.73) with PoE application of halosulfuron-methyl at 30 DAP @ 80g a.i. ha^{-1} while it was maximum in weedy check (25.75) disclosing the fact that the yield reduction in these treatments was minimum and maximum, respectively when compared to weed free condition maintained by conventional hand weeding at critical period of weed competition. Kalaiyarasi (2012) also reported lower weed index in herbicide applied plot compared to control.

Phytotoxicity

Phytotoxicity on visual scoring recorded at 15 days after application indicated that there was no phytotoxicity effect of halosulfuron-methyl applied at both the stages of growth in terms of leaf discoloration, chlorosis, wilting, stunted growth, at any of the dose tested in the study indicating that the halosulfuron is safe to sugarcane crop. Similar observatiopns were also recorded by Meher chand *et al.* (2014) and Suganthi *et al* (2013).

Effect on yield attributes and yield

Seedling survival

Seedling survival % recorded at one month after planting did not differ significantly among different weed control treatments and it ranged from 94.3 to 99.0 % (Table 3).

Shoot population at 120 DAP

Shoot population at 120 DAP was influenced by weed control treatments (Table 3). The highest mean shoot population was recorded under conventional practice of hand weeding thrice at 30, 60 and 90 DAP (1,25,829 ha^{-1}) and proved superior over rest of the treatments. Among the herbicide treatments, PE application of atrazine @ 2.5 kg a.i. ha^{-1} followed by hand weeding at 60 DAP registered higher shoot population of 112382 ha^{-1} than PoE application of halosufuron-methyl

Table 4 Millable cane characters at harvest as inflenced by different weed control treatments.

Treatment	Length of Millable Canes at harvest (cm)			Girth of Millable Canes at harvest (cm)			Number of internodes / millable cane at harvest		
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean
T_1- PoE application of Halosulfuron methyl at 30 DAP @ 50g a.i. ha^{-1}	267.7	288.2	277.95	2.49	2.43	2.46	26.7	27.4	27.1
T_2- PoE application of Halosulfuron methyl at 45 DAP @ 50g a.i. ha^{-1}	258.6	287.5	273.05	2.38	2.45	2.42	25.9	27.0	26.5
T_3- PoE application of Halosulfuron methyl at 30 DAP @ 60g a.i. ha^{-1}	275.8	290.1	282.95	2.40	2.53	2.47	27.9	26.5	27.2
T_4- PoE application of Halosulfuron methyl at 45 DAP @ 60 g a.i. ha^{-1}	297.7	308.2	302.95	2.48	2.63	2.56	29.5	27.7	28.6
T_5- PoE application of Halosulfuron methyl at 30 DAP @ 70g a.i. ha^{-1}	269.5	303.8	286.65	2.54	2.53	2.54	28.5	28.1	28.3
T_6- PoE application of Halosulfuron methyl at 45 DAP @ 70g a.i. ha^{-1}	265.5	289.8	277.65	2.57	2.49	2.53	26.3	26.5	26.4
T_7- PoE application of Halosulfuron methyl at 30 DAP @ 80g a.i. ha^{-1}	267.7	286.6	277.15	2.60	2.64	2.62	26.3	26.3	26.3
T_8- PoE application of Halosulfuron methyl at 45 DAP @ 80g a.i. ha^{-1}	277.7	297.4	287.55	2.77	2.58	2.68	26.3	27.7	27.0
T_9- PoE application of Metribuzin @ 0.75 kg a.i. ha^{-1} +2,4, D Sodium salt @ 1.5 kg a.i. ha^{-1} at 30 DAP	277.5	310.8	294.15	2.48	2.51	2.50	26.5	28.3	27.4
T_{10}- Hand Weeding thrice	274.6	303.1	288.85	2.47	2.56	2.52	28.4	28.2	28.3
T_{11}-Weedy check	292.5	284.7	288.60	2.51	2.46	2.49	30.5	25.9	28.2
T_{12}- PE application of atrazine @ 2.5 kg a.i. ha^{-1}+ Hand Weeding at 60 DAP	260.0	297.9	278.95	2.42	2.61	2.52	28.6	26.7	27.7
SEm$\pm$	10.24	11.73	-	0.10	0.07	-	1.20	0.88	-
CD(0.05)	NS	NS	-	NS	NS	-	NS	NS	-
C.V.%	6.5	6.8	-	6.8	4.83	-	7.5	5.56	-

(82403 ha^{-1}) or metribuzin + 2, 4 –D (84368 ha^{-1}) at 30 DAP. Lowest shoot population was recorded in weedy check (68315 ha^{-1}). Maintenance of weed free environment by resorting by hand weeding at critical stages of weed competition in conventional hand weeding treatment might have favoured the crop to utilize growth resources more effectively and resulted in highest shoot production at 120 DAP. Highest shoot production at 120 days after planting recorded with combined application of halosulfuron-methyl and chlorimuron-ethyl which was comparable with PE application of atrazine and two times hand weeding at 30 and 60 DAP (Suganthi *et al.*, 2013).

Millable cane characters at harvest

Length of millable cane at harvest was not influenced by different weed control treatments considerably and more or less similar cane length was recorded in all the treatments. Mean length of millable cane varied from 273.05 to 302.95 cm in different treatments. The diameter / girth of millable cane was also not influenced by weed control treatments and it ranged from 2.42 to 2.68cm in different treatments. (Table 4). The data on number of internodes / millable cane furnished in table 4 revealed that the mean internodes per millable cane at harvest did not vary considerably and it ranged from 26.3 to 28.6 in different treatments.

Millable cane population at harvest

Millable cane population at harvest differed significantly with weed control treatments during both the years of study (Table 5). Higher mean millable canes were registered in conventional hand weeding (87137 ha^{-1}) while weedy check recorded lower millable cane population of 63686 ha^{-1}. Among the herbicidal treatments PoE application of halosulfuron-methyl @ 80 g a.i. ha^{-1} sprayed at 45 DAP produced higher number of millable canes (81141 ha^{-1}) over its application at lower concentrations. Irrespective of the concentration of halosulfuron-methyl its application at 45 DAP was found to be effective and resulted in relatively higher millable cane population than at 30 DAP. These findings are in agreement with Singh *et al* (2011) who reported favourable influence of

Table 5 Millable cane population, cane and sugar yields as influenced by different weed control treatments

Treatment	NMC/ha at harvest			Cane yield (t/ha)			Sugar yield		
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean
T_1- PoE application of Halosulfuron methyl at 30 DAP @ 50g a.i. ha^{-1}	67089	67042	67066	89.7	78.7	84.2	11.64	9.99	10.82
T_2- PoE application of Halosulfuron methyl at 45 DAP @ 50g a.i. ha^{-1}	65005	79451	72228	85.6	93.9	89.8	10.16	11.56	10.86
T_3- PoE application of Halosulfuron methyl at 30 DAP @ 60g a.i. ha^{-1}	64589	70746	67668	86.5	88.7	87.6	9.95	11.14	10.55
T_4- PoE application of Halosulfuron methyl at 45 DAP @ 60 g a.i. ha^{-1}	63338	92414	77876	85.7	107.8	96.8	9.67	12.48	11.08
T_5- PoE application of Halosulfuron methyl at 30 DAP @ 70g a.i. ha^{-1}	68339	71117	69728	89.2	101.5	95.4	10.44	11.77	11.11
T_6- PoE application of Halosulfuron methyl at 45 DAP @ 70g a.i. ha^{-1}	64172	77784	70978	83.1	95.6	89.3	9.69	13.06	11.38
T_7- PoE application of Halosulfuron methyl at 30 DAP @ 80g a.i. ha^{-1}	69173	90007	79590	91.6	113.2	102.4	11.12	13.49	12.31
T_8- PoE application of Halosulfuron methyl at 45 DAP @ 80g a.i. ha^{-1}	67089	95193	81141	81.9	124.1	103.0	9.65	14.68	12.17
T_9- PoE application of Metribuzin @ 0.75 kg a.i. ha^{-1} +2,4, D Sodium salt @ 1.5 kg a.i. ha^{-1} at 30 DAP	68756	84451	76604	83.3	106.9	95.1	10.52	12.98	11.75
T_{10}- Hand Weeding thrice	75006	99267	87137	96.7	125.6	111.1	11.78	14.73	13.26
T_{11}-Weedy check	59588	67783	63686	77.9	78.00	77.9	9.05	9.51	9.28
T_{12}- PE application of atrazine @ 2.5 kg a.i. ha^{-1} +Hand Weeding at 60 DAP	68505	81673	75089	89.2	111.7	100.4	9.55	13.50	11.53
SEm±	3380	4100	-	2.8	5.02	-	0.49	0.14	-
CD(0.05)	9792	12292	-	8.0	15.05	-	1.43	0.43	-
C.V.%	8.8	6.18	-	5.4	5.98	-	8.3	7.04	-

Table 6 Quality parameters as influenced by different weed control treatments in sugarcane under seedling cultivation

Treatments	Brix at harvest			Sucrose % at harvest			CCS %		
	2015-16	2016-17	Mean	2015-16	2016-17	Mean	2015-16	2016-17	Mean
T_1- PoE application of Halosulfuron methyl at 30 DAP @ 50g a.i. ha^{-1}	19.6	20.32	19.96	17.94	16.63	17.29	12.96	11.36	12.16
T_2- PoE application of Halosulfuron methyl at 45 DAP @ 50g a.i. ha^{-1}	20.5	19.51	20.01	16.68	17.59	17.14	11.87	12.31	12.09
T_3- PoE application of Halosulfuron methyl at 30 DAP @ 60g a.i. ha^{-1}	20.8	19.81	20.31	16.22	17.59	16.91	11.53	12.53	12.03
T_4- PoE application of Halosulfuron methyl at 45 DAP @ 60 g a.i. ha^{-1}	20.3	22.59	21.45	15.12	17.49	16.31	11.29	11.59	11.44
T_5- PoE application of Halosulfuron methyl at 30 DAP @ 70g a.i. ha^{-1}	19.2	20.71	19.96	16.24	16.93	16.59	11.77	11.57	11.67
T_6- PoE application of Halosulfuron methyl at 45 DAP @ 70g a.i. ha^{-1}	20.0	20.11	20.06	16.07	17.60	16.84	11.61	12.44	12.03
T_7- PoE application of Halosulfuron methyl at 30 DAP @ 80g a.i. ha^{-1}	19.3	22.03	20.67	16.69	17.68	17.19	12.13	11.96	12.05
T_8- PoE application of Halosulfuron methyl at 45 DAP @ 80g a.i. ha^{-1}	19.9	21.04	20.47	16.39	17.30	16.85	11.77	11.85	11.81
T_9- PoE application of Metribuzin @ 0.75 kg a.i. ha^{-1} +2,4, D Sodium salt @ 1.5 kg a.i. ha^{-1} at 30 DAP	19.0	19.60	19.30	15.86	17.16	16.51	11.39	12.14	11.77
T_{10}- Hand Weeding thrice	19.7	19.30	19.50	17.09	16.68	16.89	12.20	11.73	11.97
T_{11}-Weedy check	21.5	20.10	20.80	16.50	17.38	16.94	11.61	12.22	11.92
T_{12}- PE application of atrazine @ 2.5 kg a.i. ha^{-1}+ Hand Weeding at 60 DAP	19.0	19.76	19.38	15.30	17.17	16.24	10.72	12.09	11.41
SEm±	0.67	1.09	-	0.72	0.43	-	0.55	0.39	-
CD(0.05)	NS	NS	-	NS	NS	-	NS	NS	-
C.V.%	5.8	9.17	-	7.6	4.26	-	8.1	5.6	-

weed control treatments on yield attributes like number of millable canes, cane length and diameter. Mehar chand *et al* (2017) also reported higher millable stalk population with halosulfuron-methyl sprayed at 45 days after planting.

Cane yield

Cane yield varied considerably in different weed control treatments and the data are presented in table 5. The conventional hand weeding at 30, 60 and 90 DAP provided highest mean cane yield of 111.1 t/ha while weedy check registered lowest yield (77.9 t ha^{-1}). Weeds reduced the cane yield by 29.8 % over weed free condition at critical stages of crop growth. Among the herbicide treatments PoE application of halosulfuron-methyl @ 80 g a.i. ha^{-1} sprayed at 45 DAP (103.0 t ha^{-1}) or at 30 DAP (102.4 t ha^{-1}) or PE application of atrazine @ 2.5 kg a.i. ha^{-1} + hand weeding at 60 DAP (100.4 t ha^{-1}) recorded more or less comparable cane yields and proved superior over other herbicide treatments. Ramesh and Sundari (2006), Suganthi *et al*, (2013), Mehar chand *et al* (2017) also reported higher cane yields with PoE application of halosulfuron-methyl due to effective control of *Cyperus sps.* PoE application of halosulfuron either at 30 or 45 DAP @ 80g a.i. ha^{-1} was found to be more effective over other doses. Effective control of weeds by hand weeding or post-emergence application of halosulfuron @ 80g a.i. ha^{-1} at 30 DAP or 45 DAP might have controlled the *Cyperus rotundus* effectively and created favourable environment for good growth and tiller production which ultimately resulted in higher no. of millable canes and cane yield. Rathika *et al* (2013) reported higher weed control efficiency and cane yield with halosulfuron-methyl @ 60 g a.i. ha^{-1} which was on par with PE application of atrazine + hand weeding and earthing up at 60 DAP. Mehar Chand *et al* (2017) reported that halosulfuron-methyl 75% WG @ 67.5 g a.i. ha^{-1} applied at 35-45 days after planting at optimum soil moisture provided higher WCE of *Cyperus rotundus*, cane yield and benefit: cost ratio over PE application of atrazine followed by PoE application of 2,4 D at 45 DAP.

Effect on Quality parameters and sugar yield

Brix and Sucrose

The data presented in table 6 on quality parameters indicated that the brix and sucrose % did not vary appreciably due to weed control treatments. Brix % ranged from 19.3 to 21.45 while sucrose % ranged from 16.24 to 17.29 in different treatments indicating that there was no adverse effect of herbicides on quality parameters at harvest.

CCS%

The commercial cane sugar % at harvest was not influenced by weed control treatments significantly and the mean CCS% ranged from 11.41 to 12.16 under different treatments.

Sugar yield (t/ha)

Sugar yield was computed by multiplying cane yield with commercial cane sugar %. Sugar yield followed similar trend as that of cane yield. The conventional hand weeding recorded highest sugar yield of 13.26 t ha^{-1} while lowest sugar yield was recorded with weedy check (9.28 t ha^{-1}). Among the herbicide treatments, PoE application of halosulfuron-methyl @ 80 g a.i. ha^{-1} at 30 DAP (12.31 t ha^{-1}) or at 45 DAP (12.17 t ha^{-1}) registered higher sugar yield (Table 5) owing to higher cane yield.

CONCLUSION

The two years study revealed that the conventional practice of hand weeding thrice at 30,60 and 90 DAP was effective in control of sedges and produced higher number of millable canes, cane and sugar yields with higher weed control efficiency and lower weed index. Among the herbicides PoE application of halosulfuron methyl 75% WG @ 80 g a.i. ha^{-1} at 30 or 45 days after planting was found to be effective in controlling the sedge *cyperus* sp. at early stages of seedling growth and resulted in higher number of millable canes and cane yield over other doses of application and found similar to conventional practice of hand weeding thrice at 30, 60 and 90 DAP with no phytotoxicity effect on sugarcane seedlings.

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Effect of arrowing/flowering on juice quality of sugarcane

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ABSTRACT

Arrowing or flowering is an undesirable trait of sugarcane from the growers and millers point of view. This problem is quite severe in many cane growing countries,including India. Arrowing depends upon various factors such as varieties under cultivation,cultural practices and environmental parameters in a given experimental year. The sugarcane varieties show varied response with respect to flowering under different types of environment and therefore, some varieties are less prone to flowering as compared to others. To investigate the impact of flowering on juice quality of sugarcane, a study was carried out at UPCSR, Shahjahanpur with six non flowering *viz*; 'CoS 96260', 'CoS 88230', 'CoS 92263', 'CoS 88216', 'CoS 91269', 'Co 1148' and six flowering *viz*; 'S.9/76', 'S.2/87', 'CoA 7602', 'S. 2820/77', 'UP1', 'UP16' varieties/ genotypes. Floral initiation started in September and full flowering was completed in December. A detailed study on juice quality parameters with respect to flowering revealed that from October to February the sucrose percent was increased in both flowered and non-flowered varieties. There was a steep decline in juice quality in flowered canes from March onwards; however, the deterioration in juice quality was less after March in non-flowered varieties. The study suggests that arrowing would not affect the sugar recovery if the canes are harvested within a period of four months after initiation of the flowering.

Key words: Arrowing, Flowering, Sugarcane, Flowered, Non-flowered and Varieties

INTRODUCTION

Flowering in sugarcane is influenced by a number of plant and environmental factors like photoperiod, temperature, moisture and nutrition (Moore and Nuss 1987). In sub-tropical cane growing belt, flower initiationis usually observed in the second week of September, whereasin tropical belt, it commences in second week of August. Flowering is known to affect the productivity of cane and sugar. Although flowering in sugarcane is essential for breeding, uncontrolled flowering in commercial fields poses a serious problem for sugarcane farmers and millers with a considerable loss of cane and sugar yield (Rao and Kumar 2003). The reduction in cane tonnage due to flowering varies with the percentage of flowering and the age of the crop at flowering. Miah and Sarkar (1981) reported that the fresh weight of non-flowered stalks was superior over the flowered ones, while Singh(1980) reported that the weight of flowered canes after 35 to 45 days of inflorescence emergence was superior to the non-flowered canes in the varieties 'Co 1158' and 'Co 740'. Flowering reduced the sucrose content in cane especially when there is a high percentage of flowering. Hes (1951) reported that flowering reduced the purity of the juice, if the crop was harvested after four or more months. Insub-tropical cane growing belt,growth of cane practically ceases with the fall in mean maximum and minimum temperature between 25ºC and 10ºC, respectively, whether they have flowered or are still in vegetative phase. Therefore, under such conditions, difference in cane yield as a result of flower inhibition is usually not observed. Contrary to this, in the peninsular or tropical cane growing regions, cane continues to grow throughout the year due to favourable conditions. Improvement in cane yield under such conditions has been observed in profusely flowering varieties (Panje *et al.* 1968, Panje 1969). The flowering in sugarcane is influenced by many internal and external factors which include climatic factors like rainfall, temperature, sunshine hours, humidity etc. Besides climate, the soil fertility is another factor which influences flowering in sugarcane. A sugarcane crop shows early flowering in infertile soil as compared to the one grown in fertile soil. The objective of this study was to determine the effect of flowering on juice quality of sugarcane varieties in different months.

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MATERIAL AND METHODS

A field study was conducted to determine the effect of flowering on juice quality with six non flowering *viz*; 'CoS 96260', 'CoS 88230', 'CoS 92263', 'CoS 88216', 'CoS 91269', 'Co 1148' and six flowering *viz*; 'S.9/76', 'S.2/87', 'CoA 7602', 'S. 2820/77', 'UP1', 'UP16' varieties/genotypes. The canes were planted in the month of February at the Farm of Sugarcane Research Institute, Shahjahanpur (27.83ºN, 79.82ºE) in randomized block design (RBD) with three replications. The floral initiation in the flowering varieties started in the month of September and full flowering was completed during the third week of November. Brix, Sucrose and Commercial cane sugar percent in cane was estimated in both flowering and non-flowering varieties from the month of October to April in upper, middle and lower as well as in the whole cane. Ten mature canes were randomly selected in each replication and stripped free of leaves and sheath. In the case of flowering varieties, only flowered stalks were sampled. Brix% was determined by Brix Hand Refractometer, and Pol% juice was determined by Rudolph Automatic Polarimeterby following standard juice clarification method. CCS% juice was determined by using formula: CCS% juice =1.022 Pol% juice-0.292 Brix%. All the data were statistically analysed by using the standard statistical methods.

RESULTS AND DISCUSSION

In this study, the floral initiation in the flowering varieties started in the month of September and full flowering was completed during the third week of November. The flowering intensity varied from 50 to 80 per cent among the flowering varieties. The results showed that the sucrose percent in the flowered cane increased from October until the month of February in upper, middle and lower parts of the cane by 18 to 23 percent (Table 1). The average increase was 20.6 percent with the highest in upper part (23%) of all varieties/genotypes. Although, the sucrose percentage was not affected until February the increase was found to be less as compared to non-flowered varieties where the average increase in sucrose was 25 percent with highest in the upper part of the cane (27%). These findings were in agreement with the reports of Rao (1977) that the available sucrose in the non-flowered canes of the plant crop was significantly higher than that of the flowered canes. The studies carried out by Long (1976) and Rao (1977) were also in agreement with the present findings.

The sucrose percent was found to decrease in both the groups with the increase in temperature, however, the decline was much higher in flowered varieties (3.5%) from March onwards till April with highest decline in the upper part of the cane (7.06%). The decline in non-flowered varieties was observed from April onwards, however, the average decline was only by 1.03% (Table 1). Similar trend was observed in commercial cane sugar percent of both flowered and non-flowered varieties where the steep decline was spotted in flowered varieties from February onwards, whereas, in non-flowered decline was nominal from April onwards (Table 2).

Table 1 Sucrose percent in flowered and non-flowered genotypes in different months

Varieties	Part of cane	Months						
		Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
Non-flowered	Upper part*	11.70	13.86	14.08	15.00	15.88	16.24	16.03
	Middle part*	12.14	14.23	14.75	15.34	16.06	16.40	16.28
	Lower part*	12.57	14.66	15.39	15.89	16.36	16.48	16.30
	Mean	12.14	14.25	14.75	15.41	16.10	16.37	16.20
	CD	0.14	0.13	0.32	0.19	0.08	0.10	0.12
Flowered	Upper part*	11.76	13.70	14.26	15.18	15.28	14.80	14.20
	Middle part*	12.18	14.01	14.50	15.34	15.32	15.17	15.02
	Lower part*	12.57	14.43	14.70	15.38	15.38	15.22	15.77
	Mean	12.17	14.05	14.48	15.30	15.32	15.06	14.79
	CD	0.06	0.13	0.06	NS	NS	0.09	0.36

*Mean of the values

Table 2 Commercial cane sugar percent (CCS %) in flowered and non-flowered genotypes during different months

S. No.	Varieties/ Genotypes	Months						
		Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
1.	'CoS 96260'	8.99	10.11	10.58	10.73	11.28	11.35	11.10
2.	'CoS 88230'	9.15	10.09	10.46	11.17	11.59	11.78	10.69
3.	'CoS 92263'	7.28	9.68	9.88	10.25	10.44	11.10	10.75
4.	'CoS 88216'	8.30	9.62	9.91	10.25	10.93	11.04	10.82
5.	'CoS 91269'	6.82	8.78	9.07	9.44	10.00	10.86	10.88
6.	'Co 1148'	7.25	9.25	9.71	10.13	10.83	11.24	10.62
	Mean	7.96	9.58	9.93	10.29	10.84	11.41	10.78
1.	'S.9/76'	8.98	10.11	10.23	10.55	10.60	10.48	9.22
2.	'S.2/87'	8.10	9.46	9.90	10.17	10.22	10.03	8.88
3.	'CoA 7602'	7.90	8.93	9.28	9.95	10.08	9.78	9.46
4.	'S. 2820/77'	7.58	9.56	9.84	9.90	9.84	9.76	9.60
5.	'UP 1'	7.78	9.00	9.56	10.02	10.04	9.86	9.49
6.	'UP 16'	8.56	9.75	10.07	10.67	10.77	10.64	10.55
	Mean	8.11	9.46	9.81	10.21	10.25	10.09	9.53
	CD	0.56	0.48	0.38	0.50	0.38	0.54	0.39

Hes (1951) reported that flowering reduced the purity of the juice, if the crop was harvested after four or more months. Rao (1982) reported no difference in available sucrose content between flowered and non-flowered canes by suppressing flowering through photoperiodic treatment. Studies (Thulijaram1964) reported that arrowing does not affect yield or quality if the cane is harvested within a period of three months.

CONCLUSION

This study on juice quality parameters with respect to flowering revealed that for initial period of four months after initiation of tassel, the juice quality was not deteriorated, although the increase was less as compared to non-flowered varieties.Also,with the rise in temperature juice quality started deteriorating faster in both flowered and non-flowered varieties. Generally the farmers and factory do not prefer flowering varieties, however in the present study it was found that the juice quality of the flowered variety was at par with the non-flowered varieties up to the month of February. So, if the varieties are processed within this period there will be no adverse effect on the recovery. Hence, it is suggested to process flowered crop before the non-flowered one to obtain optimum sugar recovery.

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Ploidy level diversity, cytotype identification and fertility characteristics of *S. spontaneum* genotypes

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ABSTRACT

Twenty two genotypes of *S. spontaneum* with varying morphology, biological pattern and photoperiods, representing different geographical adaptations of India, were studied with respect to somatic chromosome number, meiotic chromosome pairing pattern and pollen fertility analysis as essential added information for sugarcane breeders to select them as suitable parents for interspecific hybridization programmes. A lot of variability existed for these attributes among the studied genotypes. All the clones revealed preponderant bivalent formation and good pollen fertility. Based on their ploidy levels, 8 cytotype groups were identified with ploidy levels ranging from 2n = 48 - 112. Since the various forms of *S. spontaneum* are inter-crossable as well as adapted to different eco-geographical conditions, these cytotypes might have originated by hybridization among various ploidy levels providing them better adaptation to different ecological backgrounds.

Keywords: Diplodization, Cytotypes, Germplasm, Ploidy level, Sugarcane, Wild species

INTRODUCTION

The genus *Saccharum* comprises of mainly three cultivated species (*S. officinarum, S. barberi* and *S. sinense*) and two wild species (*S. robustum* and *S. spontaneum*). Several hypotheses pertaining to the origin of different species have been given based on morphological and cytological parameters (Srivastava *et al.* 2000). Evolving improved varieties of sugarcane through interspecific hybridisation has long been practiced in sugarcane breeding. In fact, sugar cane (*Saccharum* spp. hybrid) is one of the crops for which interspecific hybridization has provided a major breakthrough in its genetic improvement (Sreenivasan *et al.* 1987). Species hybridisation in *Saccharum* was first suggested by Wakker in 1893 (Bremer 1923) for evolving genotypes with high sugar content and improved resistance towards disease. In the late nineteenth century, Soltwedel, the first director of the Sugar Experiment Station "Midden Java" tried to obtain Sereh disease resistant cane varieties by species hybridization to save the sugar cane which was heavily affected by this disease (Bremer 1923). The first species hybrids of *Saccharum officinarum* x '*Kassoer*' (considered to be a wild species) were obtained by Wakker in 1893. Later, '*Kassoer*' was proved to be the first product of nobilization with 2n = 136 chromosome number, arising from a spontaneous hybridization between *S. officinarum* (2n = 80) and *S. spontaneum* clone wild 'glagah' (2n=112) from cytological investigations by Bremer (1921) and morphological investigations by Jeswiet (1925). Barber (1916) crossed *S. officinarum* 'Vellai' with *S. spontaneum* 'Coimbatore' and the resultant F1 hybrid was released for commercial cultivation in Northern India as 'Co 205' at Sugarcane Breeding Institute, Coimbatore, India (Nair, 1975).

Modern commercial sugarcane varieties (*Saccharum* spp. hybrids) are derived from interspecific hybridization pioneered in Java (Price 1963) and are aneuploids of complex polyploid interspecific lineage (hybrids of two to three species) with chromosome numbers ranging between 2n = 100 -130 (Sreenivasan *et al.* 1987; Srivastava and Srivastava 2002; Srivastava and Gupta 2004; Srivastava *et al.* 2013; Srivastava *et al.* 2019). The narrow genetic base of modern sugarcane cultivars and the need to introgress specific genes from hitherto unused genetic resources are a matter of concern for all sugarcane breeders and justify the pursuance of identification of newer gene resources. With accessions at hand from at least 31 separate expeditions, deposited in the two sugarcane world collections as genetic reservoirs at Miami, Florida, USA and Kannur, India, sugarcane breeders have long understood that germplasm diversity is indispensable for sustained crop improvement (Paterson 2012). Obviously, there is a large reserve of untapped genetic potential because only a limited proportion of the total available basic germplasm has been utilized in breeding work and scope for progress is substantial (Roach, 1971; Shrivastava and Srivastava, 2016; Srivastava 2000). Successful exploitation of the genetic resources of sugarcane requires careful characterization and evaluation of the available germplasm, using different methods including morphological, cytological, physio-biochemical and molecular tools along with the evaluation for economic attributes and stress tolerance. Interspecific/intergeneric hybridization among *Saccharum* species clones is fraught with difficulties arising from

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asynchronous and erratic flowering in some species, low fertility of hybrids, genetic complexity resulting from high ploidy levels, peculiar chromosome transmission and meiotic irregularities, low intergenomic recombination, unfavourable linkage groups and authenticity of true hybrids (Srivastava 2006).

Saccharum spontaneum L. a wild species of genus *Saccharum* belongs to the family Gramineae, tribe Andropogoneae. India is considered to be the centre of origin for this species. This wild species has already received considerable attention from sugarcane geneticists and breeders world over due to key role it played in the make-up of the present day cultivated sugarcane varieties. The clones of *S. spontaneum* exhibit striking diversity of form and habit and provide an excellent material to study morphology, taxonomy and cytology of the grass family along with its breeding behaviour and its stress tolerance characteristics (Shrivastava and Srivastava, 2016). Over 600 *S. spontaneum* accessions from different eco-geographical locations are available in the Indian Germplasm Collection, most of which have been characterized for morphological and agronomic attributes (Kandasami *et al.* 1983; Sreenivasan *et al.* 2001). Genetically distant forms were identified from a collection of *S. spontaneum* genotypes being maintained at Indian Institute of Sugarcane Research, Lucknow using RAPD and SSCP-SSR markers, in order to augment sugarcane breeding through the use of diverse parents facilitating the selection of hybrids with maximum genetic diversity and hybrid vigour (Srivastava *et al.* 2011). The chromosome numbers of wild *S. spontaneum* species differ extensively. The chromosome structure, meiotic behaviour and chromosome transmission of these *S. spontaneum* genotypes have largely remained unravelled; only a few karyotypes of *S. spontaneum* have been successfully identified and utilized, while the majority of karyotypes of *S. spontaneum* have not been used effectively. With this in view, *S. spontaneum* clones available at ICAR-IISR, Lucknow which belonged to different regions of India and represented different geographical adaptations in their morphology, biological pattern and had varying photoperiods depending upon their area of colonization, were characterized for their cytological behaviour in terms of chromosome number and meiotic attributes as an essential added information for the plant breeders to select them as suitable parents for interspecific hybridization programmes of sugarcane.

MATERIAL AND METHODS

Twenty two genotypes of *S. spontaneum viz.* 'BG 2', 'BG 5', 'BG 6', 'BG 9', 'BG 13', 'BG 14', 'BG 20', 'SES 24', 'SES 32A', 'SES 65', 'SES 69', 'SES 72', 'SES 129A', 'SES 267A', 'SES 519', 'SES 597', 'SES 605', '*Bazpur*-2', '*Bazpur*-6', '*Gadarpur* 2', '*Kans local*', and 'IS 76 164' were used for cytological studies with respect to somatic chromosome number, meiotic chromosome pairing pattern and pollen fertility analysis. The samples were fixed and processed as per Srivastava (1995). Briefly, single budded setts of *S. spontaneum* genotypes were grown in sand culture in trays at 28-30 °C in the BOD incubator and left until roots were about 1-2 cm long. Actively growing healthy root-tips were cut, pre-treated with 1:1 v/V 0.002 M solution of *8-hydroxyquinoline* (Merck) and saturated aqueous solution of *p-Dichlorobenzene* (Merck) adding a pinch of *aesculin* (Hi-media) for 5 min at 0 °C on ice, followed by 3 h at 12 °C. The root tips were washed thoroughly in DD water and transferred to Carnoy's 6:3:1 fixative (Alcohol: Chloroform: Acetic Acid) solution for at least 16 h at room temperature, and then transferred to fresh fixative for 24-48 h followed by preservation in 70% ethanol and stored at 10 - 12 °C. The root tips were hydrolysed in 1N HCL at 60 °C and stained in 2% Aceto-orcein. The mitotic index and chromosome numbers were determined from the chromosome squash preparations of hydrolysed root tips in a drop of 45% acetic acid.

For meiotic studies, immature inflorescences of these genotypes were fixed between 900-1100 hrs. in Carnoy's 6:3:1 fixative with a pinch of mordant for 24-48 h and transferred to 70% ethanol and stored at 10 - 12 °C. The anthers were squeezed in a drop of 45% acetic acid and pollen mother cells (PMCs) were stained in 2% Aceto-carmine. Data on chromosome pairing and segregation were recorded at diakinesis, metaphase-I and anaphase stages respectively, from 150-200 PMCs belonging to at least 10 random spikelets for each genotype. Both the somatic and meiotic chromosome squash preparations were examined under phase contrast trinocular research microscope (Nikon Optiphot 2) and only clear stained plates were taken into consideration while scoring.

RESULTS AND DISCUSSION

The twenty two genotypes of *S. spontaneum* consisting of seven genotypes of BG group ('BG 2', 'BG 5', 'BG 6', 'BG 9', 'BG 13', 'BG 14' and 'BG 20'), ten genotypes of SES group ('SES 24', 'SES 32A', 'SES 65', 'SES 69', 'SES 72', 'SES 129A', 'SES 267A', 'SES 519', 'SES 597' and 'SES 605'), two genotypes of *Bazpur* group ('*Bazpur*-2' and '*Bazpur*-6'), and one genotype each of '*Gadarpur* 2', '*Kans local*', and 'IS 76 164' were subjected to cytological studies with respect to somatic chromosome number, meiotic chromosome pairing pattern and pollen fertility analysis.

Ploidy level and cytotype identification among S. spontaneum genotypes

The studied *Saccharum spontaneum* genotypes showed a lot of variability among themselves for cytological attributes. The somatic chromosomes number of these genotypes ranged from 2n = 48 to 112. Based on the their ploidy levels, these genotypes were grouped into 8 cytotype groups (table 1) having 2n chromosome numbers of; 2n = 48 (4 genotypes), 2n = 52 (4 genotypes), 2n = 54 (3 genotypes), 2n = 56 (3 genotypes), 2n = 64 (5 genotypes) and 2n =80, 96 and 112 (1 genotype of each respectively). The *S. spontaneum* clones with ploidy level of 2n = 64 have the widest distribution and are adapted to an extensive range of ecological conditions and altitudes, and they exhibit wide-ranging phenotypic differences in correspondence to these wide habitats. In comparison, the 2n = 80 forms have restricted distribution. The five genotypes of same ploidy level (2n = 64) in current study also showed wide morpho-physiological variability (data not presented here). A clone with 2n = 80 was also reported during the present study. 2n = 80 forms have been reported from Assam and Meghalaya in the north, Gujarat in the middle and the mid-western Ghats in Peninsular India. Panje and Babu (1960) reported the occurrence of 2n = 80 cytotypes of *S. spontaneum* from the central sector of India. The two clones showing high ploidy levels among the studied genotypes, with 2n = 112 ('SES 519') and 2n = 96 ('SES 597') may be a product of natural hybridization or autotetraploidization of 2n = 56 and 2n = 48 cytotypes of *S. spontaneum* respectively.

India is considered to be a major centre of diversity for species of *Saccharum* and related genera. The wild species *S. spontaneum* occurs pan India from the remotest sub-Himalayan region to the southern peninsula covering all types of eco-geographic adaptations. The first comprehensive research on cytogenetics of *S. spontaneum* was done by Janaki Ammal (1936 and 1939) and Janaki Ammal and Singh (1936). She postulated the origin of certain chromosome types. Subsequently several cytologists reported chromosome numbers of a large number of clones. The species shows interesting cytological variations (Parthasarathy and Subba Rao 1946). Six cytotypes designated as C1, C2, C3, C4, C5 and C6 with chromosome numbers n = 20, 21, 22, 27, 28, 36 respectively were detected from the part of the Indo-gangetic plane under Haryana and Punjab states of India (Mehra and Sood 1974). There existed both qualitative as well as quantitative morphological differences amongst the six cytotypes investigated. They concluded that there are floating chromosomes within the populations of *S. spontaneum*. Panje and Babu (1960) documented the location and 2n chromosome numbers from 443 clones of *S. spontaneum* ranging from 2n = 40 -128 (40, 48, 50, 52, 54, 56, 58, 60, 62, 64, 66, 68, 70, 72, 74, 76, 78, 80, 82, 88, 90, 92, 96, 100, 104, 112, 116, 124 and 128). *S. spontaneum* clones having eight different ploidy levels of 2n = 40, 48, 54, 64, 80, 88, 92 and 96, coming from Tibet of China, Nepal, the Irrawaddy River and the Salween River of Myanmar were subjected to genetic diversity studies using SRAP markers (Yu *et al.* 2019). In the cluster diagram of *S. spontaneum* samples, they observed that the clones with the same chromosome numbers tended to cluster together. Further, the Nei genetic distance between 2n = 48 and 2n = 80 types was the smallest (0.09), whereas, the genetic distances between 2n = 64 and 2n = 96 as well as between 2n = 80 and 2n = 92 were both 0.1, indicating that there is a close phylogenetic relationship between these types. The genetic distances among *S. spontaneum* with different ploidy levels were different, and hypoploids and hyperploids showed a mesh-type relationship, indicating that the ploidy evolution of *S. spontaneum* germplasms might be a mesh-type development rather than a single direction (Yu *et al.* 2019). This clearly reflects that since the various forms of *S. spontaneum* are inter-crossable as well as adapted to different eco-geographical conditions, the new cytotypes might have originated by hybridization among various ploidy levels. This type of development might provide better adaptation to different ecological environments.

Table 1 Cytotype diversity in *S. spontaneum* genotypes

Genotype	Ploidy level
'BG 2' 'BG 5' 'BG 6'	2n = 54
'BG 9' 'BG13' 'BG 20' 'SES 605'	2n = 48
'SES 72' 'SES 32 A' 'SES 65' 'SES 69' *'Gadarpur 2'*	2n = 64
'SES 519'	2n = 112
'SES 597'	2n = 96
'Bazpur 2' *'Bazpur* 6' 'BG 14' '*Kans Local*'	2n = 52
'IS 76 164' 'SES 129 A' 'SES 267 A'	2n = 56
'SES 24'	2n = 80

Meiotic chromosome pairing pattern, segregation and pollen fertility

To study the chromosome pairing behaviour and segregation during meiosis, the anthers from fixed inflorescences were squashed. Chromosomes at diakinesis and metaphase I showed variation in association among different genotypes. All the clones revealed preponderant bivalent formation (figure 1). Average meiotic configurations of different cytotype groups of *S. spontaneum* genotypes are given in table 2. The number of bivalents per cell ranged from 23.1 to 54.2 depending upon their 2n chromosome numbers. Maximum numbers of bivalents were present in 'SES 519' (54.20 II / cell) and minimum numbers of bivalents were present in 'BG 9' and 'SES 605' (23.1 II / cell). Bivalents were predominantly of ring type. There were relatively less univalents per cell (0 -3.6) and their frequencies varied the genotypes. Presence of B chromosomes was also noticed in approximately 7 % cells of one genotype *viz*. 'BG 9'. The chromosome segregation at anaphase was almost normal. A few chromosomal aberrations were noticed in low frequency in all the genotypes studied, however, they did not affect the pollen fertility of these clones which was very good (more than 90%) in all the genotypes.

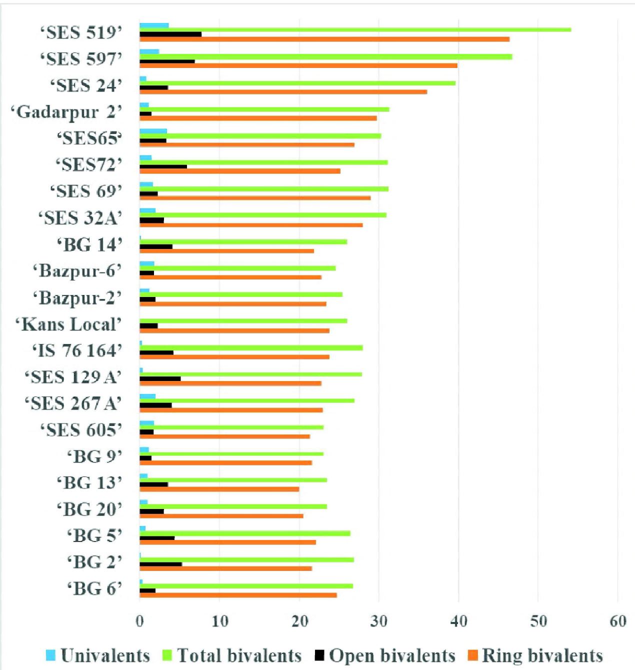

Fig 1. Mean meiotic configuration of *S. spontaneum* genotypes

Sreenivasan and Jagathesan (1975) also studied meiosis in several clones of *Saccharum spontaneum* with chromosome numbers ranging from 2n=40 to 2n=126. Meiotic abnormalities such as occurrence of univalents, pseudo bivalents, multivalents, heteromorphic or unequal bivalents, chromosome mosaicism, secondary association of bivalents, and complement fractionation were recorded. Bielig *et al.* (2003) found formation of 2n gametes during meiosis and showed that the frequencies of 2n gametes produced during meiotic separation were 0.5% and 0.8% in *S. spontaneum* and in tropical species, respectively, and that the frequency of hybrids ranged from 0.9 to 4.4%. While examining meiosis in 31 wild *Saccharum* relatives including 14 clones of *S. spontaneum*, Burner (1991) found that chromosome number for seven clones ('Djatiroto' 2n=58, 'Molokai 5099' 2n=80, 'SES 84/58' 2n=58, 'SES 114' 2n=64, 'SES 260' 2n=64, 'Taiwan 100' 2n=112, and 'US 57-11-2' 2n=60) differed from their published counts (2n=112, 86-100, 64, 60, 60, 96, and 30, respectively). Predominant bivalent chromosome pairing was observed in all the clones similar to what we observed in current study. Further, he observed that errors in chromosome association and synapsis (numerical aberrations, univalents, multivalents, and telophase II micronuclei) owing to high chromosome number led to differences in levels of meiotic stability and was reflected in their taxonomic groupings. Preferential Chromosome pairing and preponderant bivalent formation was also observed by Srivastava and Srivastava (2001) among elite sugarcane clones of subtropical India. Among the clones studied in present study, one clone, 'SES 519'showed a high chromosome number 2n = 112, another clone 'SES 597' had 2n = 96 and one clone, 'SES 24' had 2n = 80. The clones with 2n = 112 and 2n = 96 may be natural autotetraploids of 2n = 56 and 2n = 48 cytotypes of *S. spontaneum* respectively, but looking at their meiotic behaviour of preponderant bivalent formation (Table 2), it seems that they are a product of natural hybridization between two different cytotypes of *S. spontaneum* with ploidy levels of 2n = 56 and 2n = 48 respectively.

Table 2 Average meiotic configuration of different ploidy groups* of *S. spontaneum* genotypes

2n Chromosome number	Bivalents			Univalents
	Ring	Open	Total	
48	20.88	2.43	23.31	1.24
52	22.98	2.53	25.51	0.78
54	22.83	3.9	26.73	0.41
56	23.2	4.43	27.63	0.88
64	27.8	3.18	30.98	1.92
80	36.1	3.5	39.6	0.8
96	39.9	6.9	46.8	2.4
112	46.4	7.8	54.2	3.6

*Genotypes in different ploidy groups are as given in table 1.

In another study, in the cross progeny of *S. officinarum* '*Kaludai Boothan*' x *S. spontaneum* '*Imp*. 212', *S. spontaneum* '*Imp*. 212' (2n=61) was assumed to have contributed gametes with n = 30 to give rise to the 110-chromosome in the hybrids (assuming that 80 chromosomes are coming from *S. officinarum* parent owing to 2n gamete formation) (Nair 1972). The univalent was found to be mostly eliminated at the end of the first division of meiosis in '*Imp*. 212' and probably this results in majority of the pollen with n = 30 (Nair 1972). Yu *et al.* (2019) studied the genetic variation of *S. spontaneum* clones with eight different ploidy levels of 2n = 40, 48, 54, 64, 80, 88, 92 and 96 from Tibet of China, Nepal, the Irrawaddy River and the Salween River of Myanmar and found significant genetic diversities among different ploidy levels of *S. spontaneum*. The coefficient of gene differentiation (Gst) and gene flow (Nm) of different ploidy levels of *S. spontaneum* were 0.31 and 1.11 among different karyotypes, indicating that genetic differentiation among *S. spontaneum* from different geographical sources is significant and that gene communication exists among different types of *S. spontaneum* resulting into gene exchanges among *S. spontaneum* with different ploidy levels. Cluster analysis showed that

S. spontaneum of the same ploidy level tended to cluster together, and variance analysis showed that the genetic variation within species was 83% and that among species was 17%, indicating that intra-specific variation was significantly higher than inter-specific variation in *S. spontaneum* with different ploidy levels and found that the variation within and between species was significant. Mehra and Sood (1974) also concluded that there was a definite evidence of structural changes in the chromosome complement of the various cytotypes as evidenced by differences in karyotypes of euploid or dysploid taxa.

The present day sugarcane varieties have chromosome numbers in the range of 2n = 100 -130. The persistence of high chromosome numbers under selection suggests an advantageous balance between the contributions of *S. officinarum* and *S. spontaneum* in spite of ample opportunities for chromosome losses through meiotic irregularities. A series of new lines have been bred in China using Yacheng *S. spontaneum* (2n = 80) and Yunnan *S. spontaneum* '75-2-11' (2n = 64), which provided important parental species for sugarcane breeding (Chen *et al.* 2010). Since, India has the most abundant *S. spontaneum* resources in the world, such cytological studies coupled with molecular insights into this rich germplasm resource will provide a scientific foundation for its utilization for sugarcane variety improvement strategies and parental species selection programme.

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Studies on intercropping of winter vegetables with autumn planted sugarcane (*Saccharum* sp. hybrid) under real farming situations

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ABSTRACT

Results of an on-farm field trial conducted consecutively during autumn seasons of 2010-12, 2011-13 and 2012-14 at *Dhanuansand* village under *Mohanlalganj* block of Lucknow district in Uttar Pradesh clearly indicated that the intercropping of potato with autumn planted sugarcane increased the cane yield significantly as compared to rest of the intercropping treatments including cane alone. The potato as intercrop with autumn cane improved the cane yield by 8.25% while, cane + cauliflower, cane + cabbage, cane + knol-khol and cane + turnip treatments being statistically at par with the cane yield obtained under sole cane, exhibited minor reduction in cane yield to the tune of 4.03%, 3.49%, 4.42% and 4.75%, respectively than that of cane alone. Cane equivalent yield under different treatments produced the same trend as that of cane yield. Economics of different treatments indicated that the cane + potato intercropping system was found to be the most remunerative and thus, gave highest B:C ratio of 1.97 followed by 1.58, 1.65, 1.62 and 1.41 under cane + cauliflower, cane + cabbage, cane + knol-khol, cane + turnip, cane + carrot and cane + radish treatments, respectively as against 1.10 obtained under cane alone. The vegetable *viz*., carrot and radish as intercrop with autumn cane decreased the cane yield by 6.87% as compared to other vegetables (cauliflower, cabbage, knol-khol and turnip) in the intercropping system, but the values of net returns and B:C ratio were higher as compared to cane alone. CCS% cane as an indicator of cane quality did not alter significantly due to different treatments.

Key words: Autumn sugarcane, Intercropping, Winter vegetables, Potato, Commercial cane sugar

INTRODUCTION

Autumn planting of sugarcane invariably yields 15-20% higher sugarcane as also more sugar recovery than spring planted cane (Singh and Rai 1996). Research on intercropping cereals, oilseeds, pulses and spices with autumn planted cane has been intensified recently to understand the biological validity of the system by way of possible increase in yield, efficient use of solar energy and better land use resulting in higher net returns (Verma *et al*. 1981). The traditional agriculture aimed at increasing the production through two dimensions *viz*., expanding the cultivated area and increasing the potential yield per unit area of the crop. The modern agriculture stresses on efficient use of resources-land, light, water and nutrients. With this objective, it is need of the hour to utilize the resources within a given time by raising two or more crops simultaneously by exploiting the space more effective by planting crops of varying architecture.

The consumption of winter vegetables is increasing at faster rate in modern time as these are protective foods in human nutrition. Their cultivation is of utmost importance to the growers of north-central India because it offers tremendous potential of brining higher income per unit area and time. It is a general practice of the farmers to take spring cane after winter vegetables which leads to loss in cane yield and quality. The information for wider adoptability of intercropping of short duration winter vegetables with autumn planted cane with respect to yield potential and economic return is very much lacking particularly in north-central India where farmers grow vegetables and sugarcane in plenty under winter vegetables-spring sugarcane cropping sequence. In the light of above, the present investigation was planned and carried out in farmer's field of Lucknow district under north-central India.

MATERIALS AND METHODS

With a view to study the effect of intercropping winter vegetables with autumn cane on yield and economic potential, an on-farm field trial was conducted during autumn seasons of 2010-12, 2011-13 and 2012-14 at *Dhanuansand* village under *Mohanlalganj* block of Lucknow district in Uttar Pradesh under north-central India. The experimental field was sandy loam in texture, moderately alkaline in reaction (pH 7.8), low in organic carbon and medium in available nitrogen, phosphorus and potash. The experiment was laid-out in randomized block design with four replications keeping test variety of sugarcane 'CoSe 92423'. Intercrops selected for the study were cauliflower, cabbage, knol-khol, turnip, carrot, radish and potato. Sole crop of sugarcane was included to compare the yield potential and economics of intercropping systems. In all, eight treatments were formulated. Agronomic practices adopted for raising different intercrops are given in Table 1.

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Table 1 Details of variety, row arrangement, date of sowing/harvesting, seed rate and fertilizer application for different intercrops during 2010-12, 2011-13 and 2012-14 cropping seasons

Intercropped vegetables	Test variety	No. of rows in between two cane rows	Date of sowing	Date of harvesting	Plant to plant distance (cm)	Seed rate (kg/ha)	Fertlizer rate (kg/ha)		
Cauliflower (*Brassica oleracea* var.botrytis L.)	PSB-16	Two	11-23 Nov.	01-09 Feb.	45	0.35 (for nursery)	80	40	40
Cabbage(*Brassica oleracea* var.Capitata *F.alba*)	Pride of India	Two	10-23 Nov.	27 Jan-10 Feb.	45	0.40 (for nursery)	80	40	40
Knol-khol (*Brassica oleracea* var.Caulopra O.C. Linn.)	King of North	Three	09-23 Nov.	05-23 Jan.	20	0.45 (for nursery)	60	30	30
Turnip (*Brassica rapa* L.)	PTWG	Three	08-24 Nov.	06-25 Jan.	20	0.80	40	20	20
Carrot (*Daucus carota* L.)	Pusa Kesar	Three	08-25 Nov.	11 Jan-01 Feb.	10	3.50	60	30	30
Radish (*Raphanus sativus* L.)	Jaunpuri	Three	08-11 Nov.	05 Jan-01 Feb.	10	7.00	40	20	20
Potato (*Solanum tuberosum* L.)	C-3797	Two	11-02 Dec.	09-13 March	20	2200	160	80	80

Sugarcane was planted in furrows 90 cm apart keeping one-three budded setts @ 30 cm row length in the first fortnight of October during all the three seasons of experimentation. Sugarcane was fertilized with 150 kg N/ha (1/3 at planting as basal dressing + 2/3 in two equal split doses as top dressing after harvesting of intercrops at proper moisture) while, intercrops were given half of the total N + full doses of P_2O_5 and K_2O at their respective sowing times and remaining half of N was top dressed after 30 days of sowing as per Table 1.

Agronomic data on number of tillers, millable canes along with yield of intercrops and cane were recorded at their respective growth and harvesting stages and got analyzed statistically. Juice samples were drawn in the first week of December and got analyzed for ^{0}Brix and sucrose per cent. Per cent commercial cane sugar was calculated as per procedure mentioned by Spencer and Meade (1955). The data thus recorded during three years of experimentations were got pooled analysed statistically to work out the economic feasibility of treatments. Mean of cane equivalent yield and economic return of different intercropping systems were worked out on the basis of prevailing market prices during the course of experimentation.

RESULTS AND DISCUSSION

A perusal of data summarized in Table 2 clearly revealed that the intercropping treatments had no significant effect on the germination percent of cane buds at 45 days after planting. It vividly indicates that intercrops caused no adverse effect on germination percent of cane buds because plants of intercrops were very small during the germination phase of sugarcane.

Data presented in Table 2 further indicated that significantly higher numbers of tillers were recorded under the treatment of cane + potato as compared to other treatments but, it was statistically at par with cane alone. The reduction in number of tillers was lower under cane + cauliflower, cane + cabbage, cane + knol-khol and cane + turnip treatments (statistically at per among themselves) while maximum reduction was noticed due to intercropping of carrot and radish than that of cane alone treatment. The reduction in number of tillers may be due to dense canopy formed by the above intercrops. The number of tillers under cane + potato treatment which were significantly higher as compared to cane alone may be attributed to the deep hoeing of the field due to ridge planting, earthling up and digging of potato tubers which caused for proper soil aeration and weeds free condition to the cane plants. These results are in agreement with the findings of Verma *et al.* (1981). The number of millable canes was significantly higher under the treatment of cane + potato as compared to other treatments during all the three years of experimentation and followed almost the same trend as tillers. The number of tillers and millable canes were relatively higher under the intercropping of cauliflower, cabbage, knol-khol and turnip as compared carrot and radish vegetables. It was due to ample spaced planting and sparse population under cole crops resulted to lesser shading effect on sugarcane plants. Data presented in Table 2 evidently indicated that the intercropping of potato with autumn planted sugarcane increased the cane yield significantly as compared to rest of the intercropping treatments including cane alone. The potato as intercrops with autumn cane improved the cane yield by 8.25% while, cane + cauliflower, cane + cabbage, cane + knol khol and cane + turnip treatments, being statistically at par among themselves reduced the cane yield to the tune of 4.03% , 3.49%, 4.42% and 4.75%,

Table 2 Effect of vegetables intercropping on sugarcane growth, yield potentials, quality and economics returns (pooled data of 2010-12, 2011-13 and 2012-14)

Treatments	Germination (%)	No. of tillers in June (000/ ha)	No. of millable canes (000/ha)	Yield of intercrops (q/ha)	Yield of cane (t/ha)	CCS% cane	Cane equivalent yield (t/ha)	% decrease in cane yield over cane alone	% increase in cane equivalent over cane alone	Cost of cultivation (Rs/ha)	Net returns (Rs/ha)	B:C ratio
T_1-Autumn cane alone	38.73	315	134	-	94.50	10.20	94.50	-	-	121715	133395	1.10
T_2-Autumn cane+cauliflower	40.15	253	129	201.20	90.69	10.14	137.10	4.03	45.08	143623	226547	1.58
T_3- Autumn cane+cabbage	39.13	254	126	225.40	91.20	10.12	141.15	3.49	49.37	143715	237525	1.65
T_4- Autumn cane+knol-khol	37.68	257	122	245.20	90.50	10.31	139.54	4.42	47.66	143709	232941	1.62
Autumn	41.03	248	121	280.00	90.01	10.41	129.78	4.75	37.33	145634	204826	1.41
T_6- Autumn cane+carrot	37.80	215	111	182.50	85.15	10.60	123.81	9.89	3.50	145579	188681	1.30
T_7- Autumn cane+radish	39.42	229	113	305.00	83.60	10.44	113.06	11.53	19.64	143810	161560	1.12
T_8- Autumn cane+potato	40.85	341	139	245.05	102.30	10.29	179.44	(+)8.25	89.88	163098	321282	1.97
CD (P=0.05)	NS	30.71	6.85	-	4.05	NS	-	-	-	-	-	-

respectively than that of cane alone. Such reduction in the yield of cane due to intercrops may be attributed to the competition for space and light between cane plants and the plants of these intercrops. Higher cane yield reduction due to intercropping of carrot and radish may be due to taller plants accompanied with dense canopy formed under these intercrops resulting in severe smothering of cane plants. Similarly, the lower cane yield reductions under the intercropping of cole crops may be due to relatively lower plant height, ample spaced canopy and symbiotic association with cane plants. Contrary to this, the growing of potato as intercrops with autumn cane increased the yield of cane to the tune of 8.25% as compared to cane alone. It may be attributed to the lesser competition for light and space and moreover, deep hoeing of the field due to ridge planting, earthling up and digging of potato tubers which caused for proper soil aeration and weeds free condition to the cane plants. Apart from this, potato as intercrops was given 160 kgN/ha and perhaps did not utilize the applied fertilizer form deeper soil layers because of sparse and shallow rooting. Later on, the residual N thus left was utilized by sugarcane crop which enjoys extensive deep root systems. Verma and Yadav (1988) also indicated favourable influence of companion cropping of potato on cane yield. CCS% in case did not alter significantly due to different intercropping treatments (Table 2). The economics of different treatments presented in Table 2 shows that all the intercropping systems exhibited higher net returns as compared to cane alone. The system of cane + potato produced the highest B:C ratio of 1.97 followed by cane + cabbage (1.65), cane + knol khol (1.62), cane + cauliflower (1.58), cane + turnip (1.41), cane + carrot (1.30) and cane + radish (1.12) as against 1.10 obtained under cane alone treatment.

CONCLUSION

From the results obtained during three years of experimentation, it is clearly evident that the intercropping of winter vegetables *viz*., potato, cauliflower, knol-khol, cabbage, turnip, carrot and radish with autumn planted cane produced 58.48%, 41.12%, 43.84%, 42.73%, 34.87% and 17.43%, respectively more net returns and showed effective utilization of resources as compared to sole crop of cane and is, therefore, worth adopting by sugarcane growers specially small and marginal ones where the farming is generally done by their own family members.

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Indian Journal of Sugarcane Technology **34(02)**: 104-106, December 2019 **Short Communication**

In silico comparison of kinase RGA markers in red rot resistant and susceptible sugarcane genotypes

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Sugarcane, an important cash crop of grass family Poaceae is cultivated in around 120 countries of the world not only for the production of sugar but also for green energy. Several pathogens encompassing bacteria, fungi, phytoplasma, virus and insect pests are accountable for decreased productivity of sugarcane (Agnihotri 1983; Dangl *et al.* 2013). Among these, the red rot disease of sugarcane caused by a hemibiotrophic fungal pathogen, *Colletotrichum falcatum* is responsible for causing this dreaded disease in sugarcane and is a major constraint for more than 100 years in India. (Singh and Singh 1989). Currently, the management of red rot disease is achieved through the deployment of new varieties, various field practices, biological control and the chemicals. Varietal breeding takes approximate 10-12 years to develop a red rot resistant genotype and several ruling varieties succumb to the disease in a few years due to varietal breakdown (Duttamajumder 2002). The plants have two layered immune system that is facilitated by the resistance genes (Jones and Dangl 2006; Thomma *et al.* 2011; Spoel and Dong 2012). First layer of innate immunity is called pathogen triggered immunity (PTI) which is facilitated by surface localized pattern recognition receptors (PRRs). PRRs can be categorized into two surface localized receptors *viz.* receptor like kinases (RLKs) and receptor like proteins (RLPs). Some RLKs and RLPs facilitate abiotic stress and symbiosis also (Tang *et al.* 2017).

The development of disease resistant cultivars through the use of resistance genes (R-genes) could be an important method to counter red rot disease of sugarcane. The majority of the R-genes cloned and sequenced until now are part of the conserved nucleotide binding site-leucine rich repeat (NBS-LRR) gene family. P-loop, RNBS-A, kinase 2, RNBS-B, RNBS-C, GLPL, and RNBS-D are also highly conserved motifs generally present in the NBS domain of the R genes. Hence, plant resistance genes are characterized by conserved domains and motifs. Degenerate primers are designed based on conserved domains of known resistance genes (R-genes) and have been subsequently used successfully as PCR primers in combinations to amplify resistance gene analogues (RGAs) in various plant species such as rice, potato, *Sorghum,* taro, turmeric, common bean and sugarcane (Dezhsetan *et al.* 2020; Glynn *et al.* 2008; Joshi *et al.* 2010; Kumar *et al.* 2017a & 2017b; Mago *et al.* 1999; Mutlu *et al.* 2006; Nath *et al.*, 2013; Rody *et al.* 2019; Srivastava *et al.* 2017; Totad *et al.* 2005; Yadav and Srivastava 2016). Using this approach, five RGA markers similar to kinase resistance gene were isolated from red rot resistant and susceptible sugarcane genotypes: *Saccharum spontaneum* clone 'SES 594' (resistant-R), *Saccharum* spp. hybrid cultivars 'CoS 96268' (moderately resistant-MR), 'CoS 767' (moderately susceptible-MS) 'CoJ 64' (susceptible-S), and 'Co 419' (highly susceptible-HS). The nucleotide sequences of these RGAs were submitted in NCBI Gen bank (www.ncbi.nih.gov) under the accession numbers ranging from LC388887-LC388891. For their application to develop red rot resistant cultivars, an *in silico* comparative study was done among these RGAs similar to kinase resistance gene and previously characterized kinase RGAs (FR 797980-FR 797981) in sugarcane red rot resistant cultivar HSF 240 (Hammed et al. 2015). The multiple sequence alignment of these RGAs with the help of T-Coffee alignment program (https://www.ebi.ac.uk/Tools/msa/tcoffee/) revealed that these kinase RGAs from red rot resistant, moderately resistant, moderately susceptible, susceptible and highly susceptible sugarcane genotypes were highly conserved at nucleotide level (Figure 1). The nucleotide identities of these sequences from multiple sequence alignments predicted through Blosum matrix are given in Table 1. The identity % among kinase RGAs ranged from 86.54% to 99.18 %. The identity coefficient between RGAs identified from red rot resistant and moderately resistant genotypes was 99.18% while the sequence identity ranged from 97.82% to 98.68% among kinase RGAs identified from the three red rot susceptible genotypes. The Kinase RGAs from SES 594 (R) genotype has 93.1% mean identity with resistant cultivar HSF 240 and other kinase RGA from CoS 96268 (MR) variety has 93.04 mean identity with cultivar HSF 240 (R). Analysis suggests that kinase RGAs among sugarcane genotypes are though quite conserved at nucleotide level in genotypes of sugarcane (family Poaceae) but may differ functionally due to co-evolutionary process of plant-pathogen interaction. Therefore, kinase RGAs identified in red rot resistant varieties could be helpful in development of resistant varieties of red rot resistant varieties.

The research in the area of RLK-genes which facilitate disease resistance in plants, is in progressive stage and

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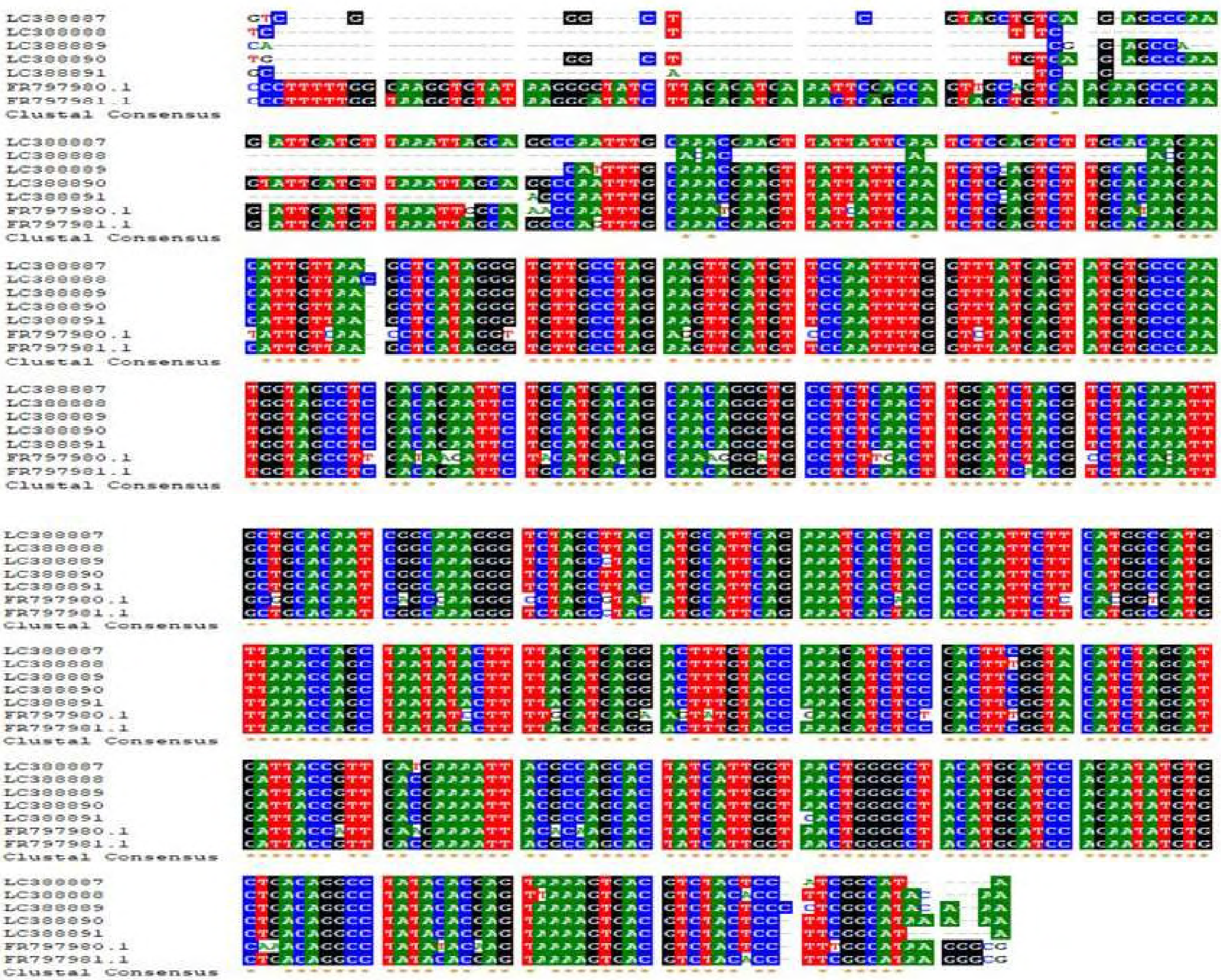

Fig. 1. Multiple alignment of nucleotide sequences of Kinase RGAs from sugarcane genotypes

Table 1. Nucleotide identity matrix of kinase RGAs of sugarcane genotypes

LC388887	100%						
LC388888	97.82%	100%					
LC388889	98.02%	97.82%	100%				
LC388890	99.18%	98.32%	98.03%	100%			
LC388891	98.45%	98.06%	98.66%	98.68%	100%		
FR797980	88.03%	86.54%	86.90%	87.93%	87.64%	100%	
FR797981	98.17%	97.60%	97.38%	98.16%	97.79%	88.38%	100%
	LC388887	LC388888	LC388889	LC3888890	LC3888891	FR797980	FR797981

information about RLKs signaling has increased over the years, but reporting of kinase like RGAs in sugarcane crop is very limited, probably due to complex genomic organization and polyploidy. The genetic control and mechanism underneath red rot resistance in sugarcane are still not well understood despite the fact that the role of resistance genes could be crucial to manage the disease. The current study indicated that it is possible to use sequence homology from conserved motifs of known R-genes to amplify putative resistance genes analogues from sugarcane. The kinase RGAs identified in the present study could be helpful in filling the gap of knowledge and may help in work on resistance gene identification in sugarcane. These sequences can be used as guidelines to detect, map and eventually isolate numerous R-genes in sugarcane.

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1.d Research articles submitted for publication should have direct relevance with the sugarcane, sugar and other sugar producing crops and technologies.

1.e The author should indicate the period (years) of conducting the experiment and the article should be submitted immediately after the completion of the experiment.

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