RESEARCH ARTICLE

PROSPECTS OF COMMERCIAL HYBRIDS OF SUGARCANE (*SACCHARUM* SPP.) FOR BIOMASS AND BIOENERGY PRODUCTION POTENTIAL

S. Vasantha*, S. Venkataramana, K. Hari and R. Arun kumar

Abstract

Sugarcane crop is an efficient harvester of solar energy. As a renewable energy resource crop, assessment of energy production potential of sugarcane commercial hybrids, gives an estimate of energy availability as whole biomass or bagasse alone. The energy production potential was estimated in six popular varieties, whose photosynthetic rate and, light interception were more or less similar. The biomass production varied during different phenophases of the crop. The varietal difference was smoothened for total dry matter production at harvest, indicating compensatory ability of the hybrids in partitioning of the biomass to stalk. The estimated energy production potential (116322 kcal/m^2 (Co 86032) to 18856 kcal/m^2 (Co 62175)) corresponding to the biomass as a whole is very high, while the bioenergy that can be obtained from stalk bagasse (14352 kcal/m^2 to 16671 kcal/m^2) still indicate variation for varieties, implying, varietal variability for energy purpose is strong. The leads are clear and the data emphasizes the importance of varietal identification for higher bioenergy production, efficiency as well as sustainability of commercial hybrids as dual purpose types.

Key words: Energy potential, dual purpose cane, *Saccharum* commercial hybrids, biomass.

Introduction

Sugarcane, a high solar energy trapper, is cultivated under varied climatic and soil conditions. Despite its capacity as high biomass producer its full potential has not been realized as energy crop. Much of the biomass as dry leaves and young stalks and trash is wasted by *in situ* burning. Commercial cultivars, combine both high biomass production and sucrose potential. Commercial varieties with higher allocation of dry biomass to stem invariably will produce high energy output.

Bioenergy crops are dependable renewable energy sources for the future. Bioenergy refers to energy produced from biological materials, specifically photosynthetic organisms. Bioenergy crops are already the fourth largest energy source producing about > 55 EJ yr^{-1} (Hall and House, 2004). Photosynthesis is the process that green plants use to convert solar energy into chemical energy and photosynthetic process is responsible for the synthesis of sugars from atmospheric CO_2 and water. In many developing countries, bioenergy supplies contribute 35 - 70% of the energy requirements (Sims *et al*., 2001). This process can be used more efficiently on a large scale in the form of co-generation, which refers to the production of electricity and heat energy. Plants can be used as a source of fermentable sugars for the production of ethanol or other low molecular weight alcohols. The fermentable sugars needed for the production of ethanol can be obtained from the juice of sweet sorghums, sugarcane, or crops such as sugar beets or sweet potatoes and also via hydrolysis of starch from maize, sorghum or wheat grain. Also, ethanol or methanol can be produced from fermentation or chemical catalysis of biomass. Therefore, bioenergy has the potential

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to have a large contribution towards energy needs in the immediate future. Bioenergy crops can be used as a good option to sequester atmospheric CO_2 by increasing biomass productivity which can be incorporated in to existing energy alternatives to improve energy use efficiency. One of the advantages of bioenergy crops is that above ground biomass can be used to produce energy through combustion without increasing net CO_2 emission (Zan *et al.,* 2001).

Since sugarcane is an indigenous species, it is reasonable to believe that breeding and selection will provide suitable 'climate- and soil-matched' genotypes for tropical and subtropical agricultural climates. The current challenges are to find methods to screen germplasm rapidly for the traits related to high biomass production. Thus, bioenergy crops have the potential to supply a significant portion of global needs while reducing the enrichment of atmospheric CO_2. The atmospheric CO_2 concentration has increased by 30% since the industrial era (IPCC, 2001). Enhanced carbon sequestration and energy cropping could have the potential to offset 1000 to 2000Mt C yr^{-1} (Cannell, 2003) and thus sugarcane and other bioenergy crops can improve soil quality, enhance nutrient cycling, apart from sequestering carbon.

Sugarcane is focused as energy crop, as it produces high biomass. In this perspective it is essential to understand the contribution towards biomass from millable cane stalks, tops, green leaves and dry leaves. Sugarcane has a significant advantage over most other potential biomass crops because of its long history of industry research and development and the existing infrastructure that is currently used for traditional sugar production. Extensive breeding research and development programs produce new sugarcane varieties improved for yield and to overcome problems associated with existing varieties.

The energy cane is reported to produce 69% millable stalks, 17% immature cane tops and leaves and 14% dry leaves (Alexander, 1985). Sugarcane has the potential of fixing higher CO_2 per unit time and produces more biomass per unit area than any other crop species (Elawad *et al.,* 1980). Early generation hybrids maintained higher biomass in plant as well as ratoon crops as compared to cultivars of *Saccharum* (Legendre and Burner, 1995). This study reports the information on the biomass, bioenergy of cane varieties and stresses the need of careful selection for bioenergy production.

Materials and Methods

The promising varieties identified for cultivation, combining high sugar and cane yields, were selected for the study. The varieties *viz*., Co 86032, Co 99004, Co 94008, Co 62175, Co 0218 and Co 0314 combine high yield and sucrose levels with varying phenotypic characteristics, were planted in six rows each in a randomized block design with three replications and an inter row spacing of 90 cm. The crop was raised following recommended cultural practices. The experiments were conducted for four consecutive years from 2011-15 at ICAR-SBI, research farm.

Plant characteristics *viz*., Plant height, No of tillers, Shoot population were recorded during formative (90 to 150 days), Grand growth (150 to 240 days) and Maturity phase (240 to 360 days). Leaf area was recorded in LA meter (LI-3100, LI COR-Inc., USA), Biomass was estimated following standard protocol and Photosynthetic rate (PAR) was recorded with portable Photosynthetic system (ADC, LCA-4, UK) photosynthetic system. CGR was worked out from biomass data collected at different growth phases. Energy estimation was carried out in a bomb colorimeter (IKA-C2000) from dried and powdered samples of leaf, sheath and stem of all the varieties at different growth stages. The energy values were integrated with biomass data to arrive at energy production potential of cultivars per unit area.

Results and Discussion

Weather parameters

Maximum and minimum temperature prevailed during the experimental trials is depicted in fig.1. The (mean) maximum temp., was highest in the months of March, April in all the years of the study coinciding with summer months. There was a minor peak observed during August - September. During the same months minimum temperature was also high (Fig. 1). Nevertheless, the rainfall was erratic and two years *viz.*, 12-13, 13-14 were drought years registering less than 40% rainfall while, the years 2011-12 and 2014-15 received normal rainfall. The high temperature coupled with scanty rainfall impacted cane growth and yield during drought years. All the varieties recorded moderate reduction in yield during these two years.

Photosynthetic rate, light interception and crop growth rate

Photosynthetically active radiation was high (1153 to 1291 µmol m^{-2} s^{-1}) in all the varieties during active growth stages i.e., formative and grand growth phase of the crop (Fig. 2). Photosynthetic rate ranged from 19 to 21.1 CO_2 µmol m^{-2} S^{-1} during formative phase and at grand growth phase it increased marginally and ranged from 19.8 to 23.6 µmol CO_2 m^{-2} S^{-1} (Fig. 3). The crop growth rate (CGR) at grand growth phase (240 DAP) ranged from 14 g m^2 day^{-1} in Co 86032 to 29 g m^2 day^{-1} in Co 0314 (Table 1). Variety Co 86032 is the major variety cultivated in peninsular region of Indian subcontinent over past few decades, while Co 0314 is the recent one. Daily integrals of photosynthesis expressed per unit leaf area basis, leaf and biomass has much to explain the growth variations in crop species (Eric *et al.*, 2006). CGR at harvest reduced in Co 94008, Co 99004 and Co 0314 while it increased in Co, 86032, Co 62175 and Co 0218. The higher dry biomass coupled with early high CGR renders the variety (Co 0314) as an efficient harvester and converter of solar energy in to energy harvestable parts. On

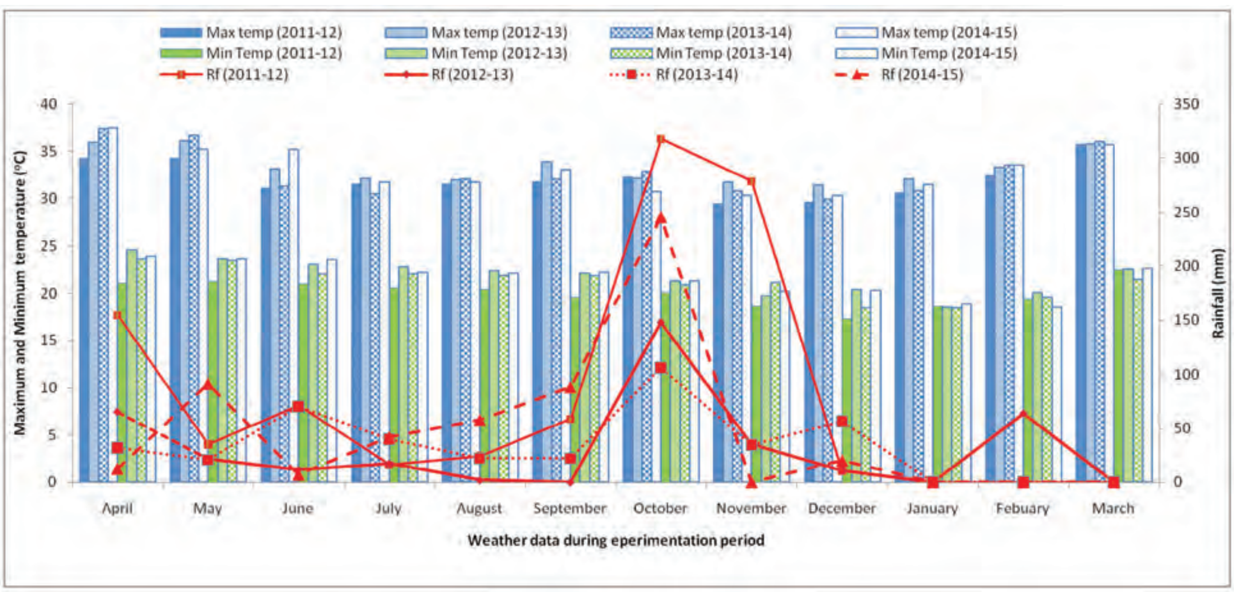

Fig. 1. Weather data during cropping season (2011-15)

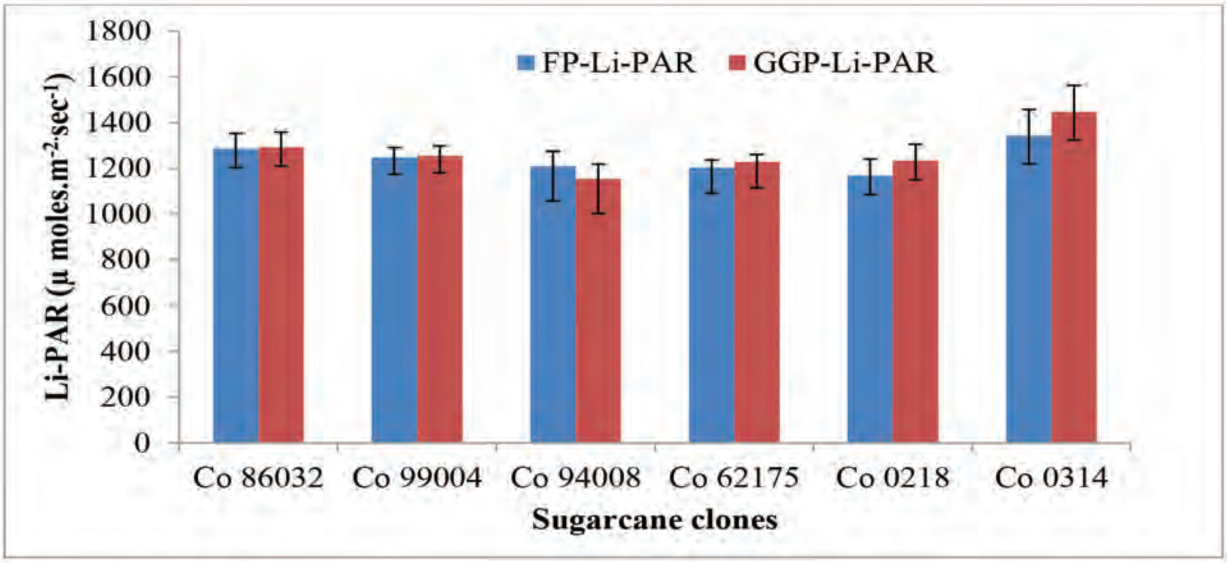

Fig. 2. Photosynthetically active radiation (µmol m^{-2} s^{-1}) recorded during formative phase and grand growth phase and the vertical bars represent the standard deviation

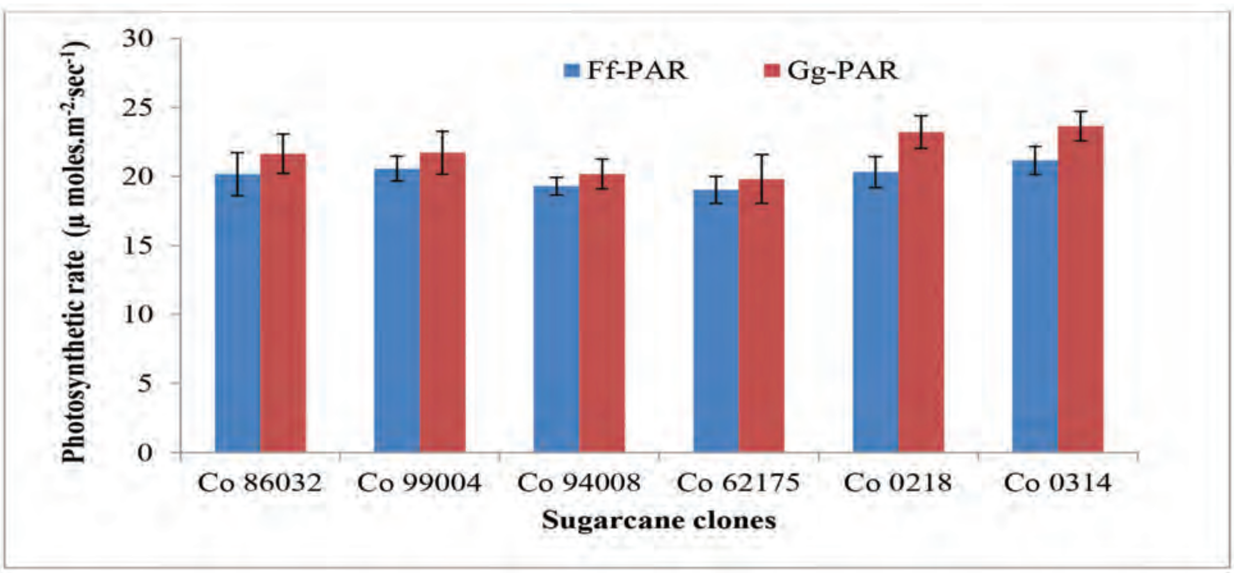

Fig. 3. Photosynthetic rate (µmol m^{-2} s^{-1}) during formative phase and grand growth phase (vertical bars represent the standard deviation).

the contrary, more time to mature, higher biomass allocation to stalk, higher fiber content (data not shown) at harvest are indications of high energy production potential as evidenced in varieties Co 0218 and Co 62175.

Biomass production and partitioning

The biomass production potential in sugarcane depends on the photosynthetic efficiency and like other economically important large-stature grasses, which include maize (*Zea mays*) and sorghum (*Sorghum bicolor*). Sugarcane being a C_4 plant, the theoretical maximum efficiency of the photosynthetic process of converting solar energy into biomass is estimated to be 6 - 7%. In sugarcane, biomass yields have reached about

Table 1. Crop growth rate and biomass production during active growth phases

Variety	Crop Growth Rate ($g,m^2 day^{-1}$)		Biomass production ($kg m^{-2}$)		
	GGP	At Harvest	FF	GGP	At harvest
Co 86032	14.23	16.75	1.378	2.232	4.243
Co 99004	23.15	15.62	1.358	2.747	4.622
Co 94008	24.35	17.49	1.178	2.639	4.738
Co 62175	18.98	20.04	1.176	2.315	4.720
Co 0218	15.01	23.21	1.152	2.053	4.839
Co 0314	29.00	12.66	1.149	2.889	4.409
SEd	-	-	0.207	0.200	0.282
CD (0.5%)			NS	0.428	NS

half the theoretical maximum (Moore *et al.*, 1997; Moore and Ming, 2011) particularly in highly managed agricultural fields. Various researchers have studied radiation interception and biomass accumulation in sugarcane grown under irrigated tropical conditions (Muchow *et al.,* 1994).

Total biomass production ranged from 1.149 kg m^2 (Co 0314) to 1.378 kg m^2 (Co 86032) at formative phase and biomass production in the early stage of growth (up to 150 DAP) indicated variation in early vigour of the crop for producing the tiller population (Table 1). During grand growth phase (240 DAP) the biomass production varied from 2.053 kg / m2 (Co 0218) to 2.889 kg / m^2 (Co 0314). At harvest the total biomass produced was the least (4.243 kg / m^2) in Co 86032 and a high of 4.839 kg/m^2 (Co 218). A clear trend of uniform biomass at harvest at maturity stage indicated the self-compensatory mechanism for total biomass, while stalk biomass still showed a difference of about 600g / m^2 more in Co 0218 as compared to Co 86032 (4.243 kg / m^2). This has implications in the energy productivity, as far the present times only the bagasse obtained from crushed stalk is used for co-generation. In spite of least difference in the biomass among the varieties studied, stalk weight would contribute for difference in energy productivity. The biomass allocation varied widely among the varieties (Fig. 4) with Co 86032 registering 70 % and Co 0314 a high of 89 % towards stalk. The biomass partitioning efficiency was high in Co 0314.This single factor perhaps impacts energy production potential through high yield of bagasse, sucrose and other components of economic value for energy production.

Theoretically, sugarcane can produce about 565 t/ha of plant biomass in one year which when partitioned into cane yield, a theoretical maximum cane yield of 339 tonnes/ha could be possible to harvest in an annual irrigated sugarcane crop (Naidu and Venkataramana, 1988). The average fresh-weight yield of sugarcane on a worldwide basis is approximately 65 mg $ha^{-1}yr^{-1}$. This translates to roughly 17 mg total solids (8 mg sugar, 9 mg DW fiber $ha^{-1}yr^{-1}$), overlooking the leafy trash which is either burned or left to decompose in the field.

Sucrose % juice and cane yield

Sucrose % juice and cane yield % at harvest, varied significantly among the varieties, while CCS% was not. Cane yield is one of the major contributor for energy production as evidenced from table 2. Among varieties Co 62175 registered higher fibre as well as cane yield followed by Co 0218 and

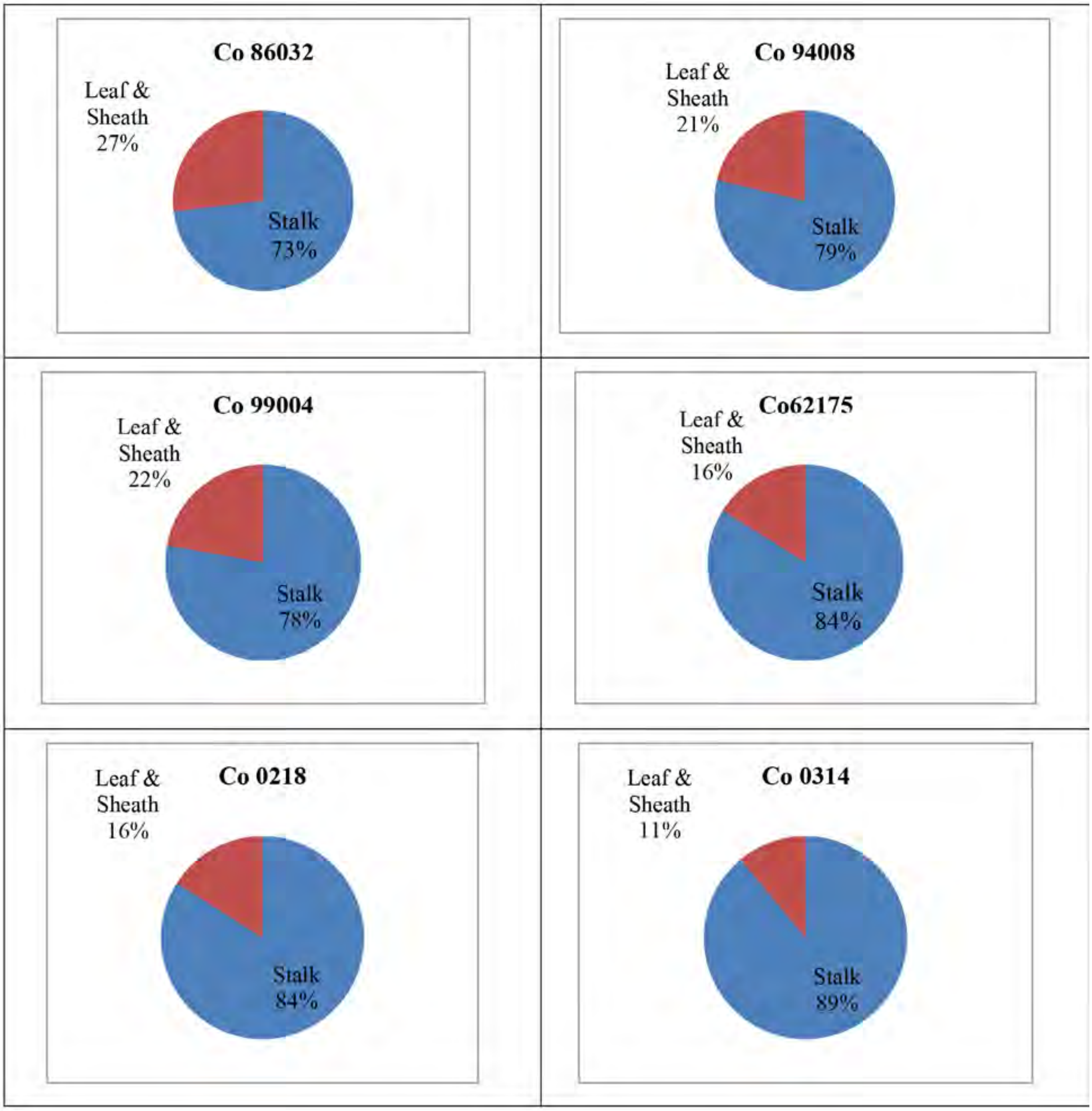

Fig. 4. Biomass (dry) partitioning to stalk, leaf and sheath at harvest in the varieties

Co 94008. Nevertheless on dry biomass basis Co 62175 and Co 0218 outperformed the rest with high energy potential (Table 2).

Bioenergy production potential and productivity

Bioenergy production potential during early growth phase (150 DAP) ranged from 1361 k cal/m^2 (Co 0218) to 2735 k cal/m^2 (Co 94008) with stem portion recording higher energy values (3351 kcal/m^2) compared to leaf and sheath (1901 kcal/m^2 and 914 kcal/m^2 respectively, data not shown). At harvest the total energy productivity ranged from 116322 kcal/m^2 (Co 86032) to 18856kcal/m^2 (Co 62175). The stalk alone recorded 14352 kcal/m^2 to 16671 kcal/m^2 (Table 3).

Energy values calculated based on the dry biomass yield (stalk alone) and worked out based on the economic products yield is depicted in table 4. The energy content of biomass on dry ash free basis is similar for all plant species lying in the range of 17-21 MJ/kg (Peter McKendry, 2002).

Table 2. Sucrose % and other economic characters of commercial hybrids

Varieties	Sucrose % juice	CCS%	Cane yield (t ha^{-1})
Co 86032	19.42	13.53	91.34
Co 94008	18.72	12.95	132.88
Co 99004	20.36	14.17	111.39
Co 62175	17.09	13.26	137.32
Co 0218	19.41	13.65	134.41
Co 0314	19.68	13.81	126.44
Mean	19.14	13.56	122.90
SEd	0.584	0.485	14.90
CD (0.05)	1.245	NS	31.75

Despite minor errors in both the methods of working out energy potential the values obtained varied little, and the varietal variation amounts to 177 GJ/ha in dry biomass yield (estimated by bomb colorimeter) while in the economic product yield method the difference among varieties was 226 GJ/ha.

Conclusion

Varietal selection for biomass production, sugar and fibre content needs further emphasis as selection for individual characters leads to specialized varieties while pre breeding materials and inter specific hybrids combine most of the desirable characters to cater the needs of the industry in a multidimensional way (Bakshi Ram and Singh, 2014; Manjunatha Rao and Rajeswari, 2014; Govindaraj and Nair, 2014). A multipurpose variety meets the requirements of the industry in the form of additional fibre content as well as yield and sucrose. In this context, the varietal variation for the said parameters as evidenced in the present work establishes the variation existing among the commercial hybrids which if exploited would improve the varietal use efficiency.

Despite limited number of varieties used in the present study, varietal effect is worthwhile mentioning for variations evidenced for biomass production and allocation to stalk at harvest are remarkable. This clearly suggest varietal selection needs to be multifaceted as a handful of varieties with better management can yield optimum sugar as well as sizeable bio energy and special purpose varieties cogeneration can further improve the energy production potential.

Table 3. Energy Production Potential (kcal/kg/m^2) of different plant parts of varieties

Varieties	Leaf	Sheath	Stem	Total
Co 86032	1206	764	14352	16322
Co 94008	1327	622	15777	17726
Co 99004	1064	1064	16671	18799
Co 62175	1601	863	16392	18856
Co 0218	1515	994	16319	18828
Co 0314	1044	678	15757	17479
Sem	220.87	119.15	1514.10	1437.15
CD(.05)	NS	253.97	NS	NS

Table 4. Energy production potential based on calorific estimation and product values among the varieties

Varieties	Energy values based on stalk biomass			Energy values based on product output			
	Stalk dry weight (kg ha^{-1})	Energy Potential* (kcal kg^{-1})	Energy equivalent (MJ ha^{-1})	Estimated dry bagasse yield (kg ha^{-1})	Residual sugar in the bagasse**	Sugar yield (kg ha^{-1})	Energy equivalent (MJ ha^{-1})
Co 86032	31000	4023	505402	13701	2284	10500	450245
Co 94008	37290	4036	630249	19932	3322	15281	655112
Co 99004	36000	4024	606633	16708	2847	12809	550188
Co 62175	39610	4080	676753	20598	3433	15792	676991
Co 0218	40830	3996	683235	20161	3360	15457	662626
Co 0314	39440	3980	657333	18966	3161	14540	623373
Varietal mean	Energy value=626.600 GJ/ha			Energy value=603.089 GJ/ha			

*Estimated in bomb calorimeter, **@ 2.5% (kg ha^{-1})

Acknowledgements

The authors thank the Director, ICAR-SBI, for constant encouragement and support for carrying out the work.

References

Alexander AG (1985) The energy cane alternative. Amsterdam, Elsevier Science Publishers B.V. 509 p.

Bakshi Ram, Singh BD (2014) Sugarcane fibre-a potential source of renewable energy. In: Viswanathan R, Bhaskaran A, Hemaprabha G, Ramasubramanian T, Nair NV, (Eds.). Proceedings of Symposium on Bioenergy for Sustainable Development – The potential role of sugar Crops. pp. 51-54.

Cannell MGR (2003) Carbon sequestration and biomass energy offset: Theoretical, potential, and achievable capacities globally, in Europe and the UK. Biomass and Bioenergy, 24(2): 97 -116.

Elawad SH, Gascho GJ, Shih SF (1980) The energy potential of sugarcane and sweet sorghum. In: Klass DL, Weatherly JW, (Eds). Energy from biomass and wastes IV. Chicago, IL, USA: Institute of Gas Technology, 65–105.

Eric AC, Kruger L, John C Volin (2006) Reexamining the empirical relation between plant growth and leaf photosynthesis, Functional Plant Biology, 33: 421–429.

Govindaraj P, Nair V (2014) Energy cane option for sugar complex: augmenting feedstock supply to cogeneration plants. In: Viswanathan R, Bhaskaran A, Hemaprabha G, Ramasubramanian T, Nair NV, (Eds.). Proceedings of Symposium on Bioenergy for Sustainable Development – The potential role of sugar Crops. pp. 65 - 67.

Hall DO, House JI (2004) Biomass energy development and carbon dioxide mitigation options. Biomass Energy Development.

Online: http://www, uccee.org/ Copenhagen Conference /hall.ht*m*

IPCC. (2001). Climate Change 2001: Impacts. Adaptation and Vulnerability.IPCC Thirtt Assessment Report. Intergovernmental Panel in Climate Change.On line: http://www.ipcc.ch/

Legendre BL, Burner DM (1995) Biomass production of sugarcane cultivars and early-generation hybrids. Biomass and Bioenergy, 8(2): 55-61.

Manjunatha Rao S, Rajeswari S (2014) Development of multipurpose varieties for energy. In: Viswanathan R, Bhaskaran A, Hemaprabha G, Ramasubramanian T, Nair NV, (Eds.). Proceedings of Symposium on Bioenergy for Sustainable Development – The potential role of sugar Crops. pp. 60 – 61.

Moore PH, Ming R (2011) Sugarcane breeding and biotechnology to feed the emergent sugarcane bio refinery industry. Tropical Plant Biology, 4:1-2.

Moore PH, Botha FC, Furbank R, Grof C (1997) Potential for overcoming physio biochemical limits to sucrose accumulation. In: Keating BA, Wilson JR (Eds.) Intensive sugarcane production: meeting and challenges beyond 2000. CAB Int. Wallingford, UK. pp 141-155.

Muchow RC, Spillman MF, Wood AW (1994) Radiation interception and biomass accumulation in a sugarcane crop grown under irrigated tropical conditions. Australian Journal of Agricultural Research, 92(2–3):119–135.

Naidu MK, Venkataramana S (1988) Physiological basis of yield in sugarcane. Proc. of International Congress of Plant Physiology, New Delhi, India, Feb.15-20, 1988.pp389-397.

Peter McKendry (2002) Energy production from biomass (Part 1): Overview of Biomass. Bio-resource Technology, 83: 37-46.

Sims R (2001) Bioenergy - a renewable carbon sink. Renewable Energy, 22(1-3):31–7.

Zan CS, Fyles JM, Girourard P, Samson RV (2001) Carbon sequestration in perennial bioenergy. Annual corn and uncultivated systems in Southern Quebec. Agricultural Ecosystem and Environment, 86: 135-144.

Received: Oct, 2018; Revised & Accepted: Dec, 2018