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Physical Properties of Sugarcane Pertaining to the Design of a Whole Stalk Sugarcane Harvester

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Abstract

Sugarcane crop plays a vital role in nation's economy, being one of the most commercialised crops in India. The production cost of sugarcane is increasing year after year which reduces the profit margin of sugarcane growers and sugar industry. Harvesting is one of the key operations responsible for increase in sugarcane production cost. Hence a tractor mounted whole stalk sugarcane harvester suitable for small and medium farmers is highly essential. The physical properties of sugarcane pertaining to de-topping, de-trashing and conveyance are studied for the designing of a whole stalk sugarcane harvester. The various physical parameters for the major varieties of sugarcane are measured in the farmers' field. The farmers' grow CO 86032 sugarcane at a row spacing of 75 to 100cm, and the spacing is increased to 150 and 200cm wherever harvesting is done by self propelled combine harvesters. The average number of cane per meter varied from 27 to 30. The length of the millable cane varies between 1200mm and 2700mm. The maximum and minimum diameters are 40 and 20mm respectively. The trash content at the time of harvesting was 38.56 percent where the regular de-trashing processes were completely skipped by farmers

Keywords: Sugarcane, physical properties, trash content

Introduction

Sugarcane, *Saccharum officinarum L.*, one of the most important crops of India, is a renewable, natural agricultural resource providing sugar and bio-fuel besides a myriad of by-products like, fibre and fertilizer. Sugarcane crop plays a vital role in nation's economy, being one of the most commercialised crops in India. It provides income to the grower, and employment for numerous farm workers throughout the year. Sugarcane occupies about 2.5 percent of the gross cropped area in India and provides raw material to more than 450 sugar mills.

The production cost of sugarcane is increasing year after year which reduces the profit margin of sugarcane growers and sugar industry. Harvesting is one of the key operations responsible for increase in sugarcane production cost. In India, harvesting of sugarcane is mostly done manually. Hence mechanization of sugarcane harvesting is essential not only for reducing the production cost but also for reducing drudgery involved in manual harvesting operations, and also to ensure quality produce.

Hence a tractor mounted whole stalk sugarcane harvester suitable for small and medium farmers is highly essential. Keeping the above factors in view study the physical properties of sugarcane pertaining to de-topping, de-trashing and conveyance is conducted for the designing of a tractor mounted whole stalk sugarcane harvester. The design of the major unit operations such as de-topping, base cutting, de-trashing and conveyance are depends upon the above properties. Physiology of sugarcane at the time of harvest is very important for the development of a tractor operated whole cane combine harvester. Hence the various physical parameters such as length and diameter of millable cane, node characteristics, leaf characteristics and amount of trash for the major varieties of sugarcane are measured. These properties are mainly depending upon the morphology of the sugarcane.

Blackburn (1984) describes sugarcane as a tall tropical grass with a single un-branched stem of average height in the range of 3 to 4m with a stem

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diameter ranges from 3 to 5cm depending on the species.

Moore and Nuss (1987) states that sugarcane is a large tropical grass that produces multiple stems or culms each of which consist of a series of nodes separated by internodes. After germination, the terminal vegetative bud of each shoot lays down a series of nodes, each with a dormant bud and one or more rows of root primordial and a growth ring. The internodes consist of sucrose storing parenchyma cells and vascular tissue.

The stalk of sugarcane is the major storage area for photosynthate (sucrose) within the sugarcane plant, rather than fruit or seed structures. Stalk is also known as "millable cane". The top of the stalk is relatively low in sucrose and therefore is of little value to the mill.

The stalk consists of segments called joints. Each joint is made up of a node and an internode. The node is the place where the leaf attaches to the stalk.

Moore and Nuss (1987) reported that the node consists of a growth ring or intercalary meristem, the root band (containing root primordial) and a bud above the leaf scar where the leaf sheath attaches, which delimits the node from the internode. The transverse cross section through an internode reveals vascular bundles surrounded by parenchyma cells with a thick outer epidermis covered in an external layer of wax.

Bull (2000) reported that internode length can reach over 30cm, depending on growth conditions, and stems normally reach two to three metres in the normal growing season.

Miller and Gilbert (2009) describe the cross section of an internode shows tissues *viz.*, epidermis, cortex or rind and ground tissue with embedded vascular bundles from the outside to the center. The cells of the rind are thick-walled and lignified. These cells help in strengthening the stalk. More towards the center, the ground tissue contains the vascular bundles with the xylem and phloem. The xylem tissue conducts water and its dissolved minerals upward from the roots and phloem conductive tissue transports plant- manufactured nutrients and products downward toward the roots.
According to Miller and Gilbert (2009), the length and diameter of the joints vary widely with different varieties and growing conditions. In general, however the joints at the base are short and inter-nodal length gradually increases toward the top.

The leaf of the sugarcane plant is divided into two parts: sheath and blade, separated by a blade joint. The sheath, as its name implies, completely sheaths the stalk, extending over at least one complete internode.

Bull (2000) reported that as the stem develops, the leaves emerge, one leaf per node, attached at the base of the node, forming two alternate ranks on either side of the stem. At the top of the stem is an apical meristem set on top of a number of very short internodes. Mature stems consist of seven leaves still enclosed in the leaf spindle, a dozen or so green leaves and a number of senescent leaves, increasing in number with increasing age of the plant. New leaves emerge and expand over a period of between one and three weeks.

According to Miller and Gilbert (2009), the leaves are usually attached alternately to the nodes, thus forming two ranks on opposite sides. The mature sugarcane plant has an average total upper leaf surface of about 0.5 square metres and the number of green leaves per stalk is around ten, depending on variety and growing conditions.

According to Anon. (2010), the ripening and maturation phase in a twelve-month crop lasts for about three months starting from 270-360 days. Sugar synthesis and rapid accumulation of sugar takes place during this phase and vegetative growth is reduced. As ripening advances, simple sugars (monosaccharide *viz.*, fructose and glucose) are converted into cane sugar (sucrose, a disaccharide). Cane ripening proceeds from bottom to the top and hence bottom portion contains more sugars than the top portions. Ample sunshine, clear skies, cool nights and warm days (*i.e.*, more diurnal variation in temperature) and dry weather are highly conducive for ripening.

Materials and methods

Physiology of sugarcane at the time of harvest is very important for the development of a prototype de-topper and de-trasher cum conveyer that can be attached to a tractor operated whole cane combine harvester. Hence the various physical parameters such as length and diameter of millable cane, node characteristics, leaf characteristics and amount of trash for the major varieties of sugarcane are measured in the farmers' field at Sirugamani in

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Tiruchirapalli district, Telungupalayam in Coimbatore district and Gobichettipalayam in Erode district. To assess the mass flow through the machine to be developed, the crop geometry such as row spacing, weight and number of millable cane per meter length of the row are also measured in the same field.

Length of the cane

The length of matured cane has significant influence on the design of the de-topper mechanism for a sugarcane combine harvester. The de-topper blade assembly has to be raised or lowered to cut the top of the cane precisely to avoid the loss of the millable cane at the time of harvest. The millable cane length in the farmers' field is measured using a 3m measuring tape and is recorded. The maximum and minimum length of the millable cane was selected from the observed data for the design of the de-topper lifting and lowering mechanism, such that the harvester was able to de-top the sugarcane at different heights in the field.

Diameter of the cane

Sugarcane diameter usually varies from top to bottom and the variations depended upon the variety and the climatic conditions which prevailed in the growth phase of the sugarcane. The diameter has an important role in the determination of base cutting and de-topping energy requirement. The minimum and maximum diameter has also to be considered in the design of the conveyor system, such that the design system is able to accommodate the variation in the diameter of the cane without reducing the forward movement of the sugarcane through the conveyor system. The diameter of the sugarcane is determined at three different locations of the cane *viz.*, top, middle and bottom. The data are tabulated and the maximum value is considered in the design of de-topper system, whereas as the maximum and minimum values are considered in the design of the conveyor system to accommodate the variations in the sugarcane diameter.

Trash content

Trash content of the cane at the time of harvest varies depending upon the variety and the agricultural practices adopted. As per the package of practice of sugarcane, it is to be de-trashed at regular interval for the removal of dried, yellowish green, bottom leaves. This operation is skipped by the farmers nowadays due to the drudgery involved in the job and lack of labours. Hence, the trash content at the time of harvest will vary depending upon the practices adopted by the farmers. The trash available at the time of harvest is removed mainly by two operations *viz.*, de-topping and de-trashing. The amount of trash available at the time of harvest is assessed at different farmers' field and expressed as the trash content per millable cane for the uniformity of representation. The trash content removed by de-topping and de-trashing are tabulated separately. Number of leaves at the time of harvest, leaf blade and sheath parameters and nodal characteristics are also measured and tabulated.

Row spacing

The main consideration in the design of a harvesting system is the amount of crop that is to be harvested and conveyed through the conveying system per meter run of the machine. This decides the capacity of the machine with respect to the width of the operation. In a crop situation where row cultivation is practiced, the width of the machine is directly linked with the crops row spacing. Hence, the present investigation is done on the existing pattern of cultivation with respect to row spacing.

The optimum spacing for planting of sugarcane as reported by Hunsigi (1993) is 0.9 to 1.0m between rows. In subtropical India, where growth of the plant is restricted due to climatic parameters, a row spacing of 0.75m is adopted. Even though there are different planting systems for sugarcane, the ridges and furrows system of planting is very common in South India. The fields at different locations are studied for finding out the existing row spacing of the crop, to decide the optimum spacing of the crop divider and the effective width of the base cutter.

Number of millable canes

The study of the number of plants in the field and the distribution of stalks along the row are required for designing a sugarcane harvester. The number of canes at the time of harvest in a meter length of a row is an important factor in deciding the capacity of the machine and in turn required in the design of the de-trashing with conveying system of a combine harvester. The design is made such that, each system is capable of handling the maximum amount of cane available per meter length of row(s) which is cut by the base cutting system.

Sugarcane grows in clumps and the number of shoots per clump depends on the variety of cane, planting method, soil type, time of planting *etc.* Usually 90,000 to 1, 00,000 eye buds ha^{-1} (30,000 three-eye bud sets or 50,000 two-eye bud sets) are planted.

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Normally, a well-managed crop in peninsular India has 80 per cent germination, which results in the bud population of 72,000 to 80,000 per ha. The average tillering is 2.5 tillers per bud and the initial shoot population is 1, 80,000 to 2, 00,000 shoots ha^{-1}. As the crop grows, there may be some tiller mortality due to lack of sunlight, water, and genetical constraints. Finally, the number of millable canes (NMC) of the present cultivars was 1, 00,000 to 1, 20,000 ha^{-1} (Hunsigi, 2001).

To evaluate the number of millable canes (NMC) per meter length, sugarcane is counted randomly at different location of a field and also in different fields.

Results and discussion

Physical parameters and crop geometry of the sugarcane at the time of harvest were studied for the development of a proto type de-trasher cum conveyer, that can be attached to a tractor operated whole cane combine harvester. The various physical parameters such as length, diameter and weight of millable cane, leaf characteristics, nodal characteristics and amount of trash content were studied at Sirugamani in Tiruchirapalli district, Telungupalayam in Coimbatore district and Gobichettipalayam in Erode district. Sugarcane crop geometry such as row spacing and number of millable cane per meter length of the row were also studied in the same fields.

Length of mature cane

Matured cane lengths were observed in the three fields. In all fields the most popular sugarcane variety in Tamil Nadu, CO 86032 was cultivated. The maximum and minimum operating height of the de-topper mechanism was decided based on the length of the millable cane. The length of the millable cane at Sirugamani varied between 1700mm and 2100mm, the same at Telungupalayam varied between 1200mm and 1800mm and at Gobichettipalayam ranged between 1800mm and 2700mm. The data is furnished in Table 1.

Table 1. Length of matured cane at different locations

Parameter (mm)		Location			Over all
		Sirugamani	Telungupalayam	Gobi	
Length	Max.	2100	2000	2700	2700
	Min.	1700	1500	1800	1500

Diameter of canes

The diameter of the matured sugarcane was observed in the said fields. The diameter of the sugarcanes were determined at three different positions *viz*., top, middle and bottom and is tabulated in Table 2.

Table 2. Diameter of sugarcane stalks at different locations

Diameter of cane (mm)		Location			Over all
		Sirugamani	Telungupalayam	Gobi	
Top	Max.	34.0	22.2	35.0	35.0
	Min.	27.8	20.0	20.5	20.0
Middle	Max.	39.5	29.5	37.5	39.5
	Min.	28.5	19.0	23.5	19.0
Bottom	Max.	39.0	28.5	40.0	40.0
	Min.	28.5	19.5	28.5	19.5

The diameter varied from top to bottom and the variations depended upon the soil type and the climatic conditions prevailing in the growth phase of the sugarcane. From the data, it is clear that the crop growth is less in the dry land conditions (Telungupalayam) than the wet land conditions (Sirugamani) and irrigated conditions (Gobichettipalayam). The maximum and minimum diameters are 40 and 20mm respectively. These data were considered in the design of the de-topper and de-trasher with conveyor systems.

Trash content

The amount of trash available at the time of harvest was evaluated at different locations and expressed as the trash content per millable cane for uniformity of representation. Trash content after de-topping and de-trashing were separately calculated and tabulated. Number of leafs at the time of harvest, leaf blade's length, width and thickness, sheath's length and thickness and the nodular characteristics of the stalks were also measured and is presented in Table 3.

Table 3. Morphological characteristics of sugarcane at different locations

Parameters		Location		
		Sirugamani	Telungupalayam	Gobi
No of green leaves (leaf/stem)	Mean	17.81	13.23	18.5
	SD	1.604	1.56	2.35
Node distance B (mm)	Mean	112.7	108.7	115.5
	SD	20.23	11.23	20.32
Node distance M (mm)	Mean	110.0	98.5	110.2
	SD	16.72	10.23	19.85
Node distance T (mm)	Mean	91.14	93.5	100.5
	SD	9.12	9.45	15.83
Leaf sheaf length	Mean	332.2	NA	285.5

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B (mm)	SD	33.36	NA	29.5
Leaf sheaf length M (mm)	Mean	322.2	245.6	286.8
	SD	20.04	23.5	31.5
Leaf sheaf length T (mm)	Mean	320	246.5	278.6
	SD	31.13	28.6	26.5
Leaf total length B (mm)	Mean	1285	NA	1456
	SD	185	NA	165
Leaf total length M (mm)	Mean	1656	1523	1578
	SD	73.39	95.3	97.5
Leaf total length T (mm)	Mean	1842	1735	1885
	SD	113	102.5	125
Leaf width B (mm)	Mean	39.92	NA	42.5
	SD	5.12	NA	5.26
Leaf width M (mm)	Mean	50.04	35.5	51.6
	SD	3.62	3.56	6.51
Leaf width T (mm)	Mean	56.61	36.8	54.8
	SD	4.12	3.48	6.78
Leaf sheaf thickness B (mm)	Mean	10.05	NA	11.25
	SD	0.31	NA	0.28
Leaf sheaf thickness M (mm)	Mean	12.26	9.3	12.46
	SD	0.30	0.25	0.35
Leaf sheaf thickness T (mm)	Mean	14.42	10.1	15.68
	SD	0.31	0.75	0.43
Leaf blade thickness B (mm)	Mean	2.11	NA	2.45
	SD	0.02	NA	0.03
Leaf blade thickness M (mm)	Mean	2.22	2.0	2.68
	SD	0.04	0.05	0.04
Leaf blade thickness T (mm)	Mean	2.44	2.1	2.78
	SD	0.03	0.04	0.06
Trash content (%)	Mean	33.52	22.38	38.56
	SD	9.45	6.50	9.85
Trash content after de-topping (%)	Mean	6.58	4.12	8.52
	SD	2.32	2.50	3.12

NA – not available since already de-trashed,
T-top, M-middle, B- bottom

Trash content of the cane at the time of harvest depends upon the variety and the agricultural practices adopted by the farmers. At Gobi and Sirugamani the regular de-trashing process were completely skipped by farmers. In Telungupalayam the same was done two times in the initial stages. Thus the variations of trash content at Telungupalayam may be due to the different agricultural practices adopted by the farmers.

Row spacing

The row spacing at the farmers fields varied from 90 to 150cm. Closer row spacing was adopted under low fertility status, shy tillering varieties, delayed planting and drought conditions. Narrow spacing is considered beneficial for high bio-mass yield. But the cost of seed cane, difficulties in carrying out the agricultural practices and harvesting are its drawbacks. Closer row spacing of 75 to100cm is common in these areas. The row spacing is wider (>1.2m) where mechanized cultivation is practiced.

Traditional practice consist of closer row spacing of 75 to 90cm in areas where harvesting is done manually. In order to accommodate mechanical harvesters, farmers have adopted wider row spacing of 120 to 150cm.

Number of millable canes

The number of millable canes along the ridge at the time of harvest was observed in three fields as mentioned above. It was observed that, the number of canes per metre length of the ridge was highly varying from field to field.

Among the three fields, the field at Gobi showed the maximum number of 30 canes per metre. The other two fields the number of plants per metre length was much lesser.

Conclusion

A study was undertaken to understand the requirements of sugarcane harvester and the field conditions. The various physical parameters such as length, diameter and weight of millable cane, leaf characteristics, nodal characteristics and amount of trash content were studied at Sirugamani in Tiruchirapalli district, Telungupalayam in Coimbatore district and Gobichettipalayam in Erode district. Crop geometry such as row spacing and number of millable cane per meter length of the row were also studied in the sugarcane fields. This envisaged the basis for the development of a prototype tractor operated whole cane combine harvester.

1. The farmers' at Sirugamani in Tiruchirapalli district, Telungupalayam in Coimbatore district and Gobichettipalayam in Erode district grow CO 86032 sugarcane at a row spacing of 75 to 100cm, and the spacing is increased to 150 and 200cm wherever harvesting is done by self propelled combine harvesters.
2. The average number of cane per meter varied from 27 to 30. The length of the millable cane varies between 1200mm and 2700mm. The maximum and minimum diameters are 40 and 20mm respectively.

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3. Trash content of the cane at the time of harvesting depends upon the variety and the agricultural practices adopted by the farmers. The trash content at the time of harvesting was 38.56 percent where the regular de-trashing processes were completely skipped by farmers.

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