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Manufacturing and Performance Evaluation of a Sugarcane Node Cutting Machine

Elwakeel, A. E.[1*]; A. M. Zein Eldin[2]; A. A. Tantawy[3]; S. M. A. Mohamed[4] and H. A. A. Mohamed [5]

[1] Department of Agric. Eng., Faculty. of Agric., and Nat. Res. Aswan U., Egypt.
[2] Department of Agric. Eng., Faculty. of Agric., Alexandria U., Egypt.
[3] Department of Crops, Faculty of Agric., Minia U., Egypt.
[4] Faculty. of Agric., Cairo U., Egypt.
[5] Department of Horticulture, Faculty. of Ag., Al-Azhar U., Assuit, Egypt.

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ABSTRACT

Sugarcane node cutting machine was manufactured and tested in the department of Agronomy, Faculty of Agriculture, El-Minia University, El-Minia, Egypt, to facilitate the process of cutting nodes that are used in transplanting sugarcane, the machine parts were designed using "SolidWorks" software, and then manufactured and constructed by using the low-cost available materials in local markets. The machine is used to separate the nodes from the sugarcane stalks and leave the internodes for industrial processes. The machine consists of reciprocating blades powered by a 3-phase AC motor. Field experiments were conducted for four groups of stalk diameters to study the effect of stalk diameters and cutting speeds on the machine performance. Results of the field tests for C9 sugarcane variety showed that the average diameter (cm), stalk weight (g), stalk length (cm), and the number of nodes per stalk of the tested samples ranged from (1.38 to 3.28 cm), (405.11 to 1206.67 g), (181.67 to 197.78 cm), and (12.56 to 14.33), respectively. Also, the results showed that the cutting efficiency was ranged between (83.67– 100%), maximum machine productivity was 3944 node/ha and the total operating cost ranged between 55.07 to 115.96 EGP/Fedd according to the cutting speed and stalk dimeters. It could be concluded from this study that the designed node-cutter prototype is profitable, handy and cost-effective to assist small-scale sugarcane farmers under Egyptian conditions.

Keywords: Sugarcane, Node Cutting, Machine Productivity, Operating Cost.

INTRODUCTION

Sugarcane represents the main cash crop in Upper Egypt. The cultivated area with sugarcane is estimated to be over 300,000 Fedd with an average production of 48 t/Fedd and total production may reach 16 million tons per year (Elwakeel, 2017; Zein El-den *et al*., 2020a; Zein El-den *et al*., 2020b). Sugarcane planting and mechanization are the development trend of the industry (Yadav *et al*., 2003). Sugarcane is planted commercially using stalk cuttings or setts (25-30 cm stalk pieces having 2-3 buds each). This method is gradually becoming uneconomical as the cost of seed cane used for replanting accounts for over 20 % of the total cost of production. In the conventional system prevailing in Egypt, about 5 – 6 t of seed cane /feddan (1 Fedd = 4200 m^2) is used as planting material. This large mass of planting material imposes hardship in transport, handling, and storage. It also undergoes rapid deterioration that could reduce buds' viability and subsequently their germination percentage in the field (Narasimha, 1977; Galal, 2016). An efficient and reproducible protocol for the regeneration of plantlets at a high frequency was developed by using sugarcane buds (Vázquez Molina, *et al*., 2014). In the traditional planting method, great human force, and a high volume of sugarcane stalk in hectares are required (Phapale *et al*., 2017). Transplanting the healthy seedlings of the sugarcane in the permanent field gave a high cane yield (60.96 t/Fedd), which was 10.96 % higher than that of conventionally planted sugarcane crop (54.94 t/Fedd) (Ahmad *et al*., 2020). It has been observed in rural areas that most of the sugarcane buds cut are done manually. This consumes a lot of sugarcane and time to cut the buds (Pujar *et al*., 2017; Patil *et al*., 2018).

Bosoi *et al*. (1996) reported that the sugarcane cutting force depends on the physical and mechanical properties of the sugarcane stalk. El-Nakib *et al*. (1996) performed tests on the Egyptian sugarcane variety C9, and they found that the average diameter of the stalk was 2.3 cm, and the cane stalk hardness was 775 N. Abdel-mawla *et al*. (2014) made an experiment and they found that the average measurements during five years as follow: Average stalk diameter ranged between 2.2 to 2.7 cm, average stalk weight ranged between 0.79 to 0.86 kg, and Average cutting force ranged between 840 to 886 N. Elwakeel (2017) and Zein El-den *et al*. (2020) reported that the average cutting force for Egyptian sugarcane variety C9 was 863 N when the average stalk diameter was 2.45 cm. The objectives of this research were therefore to:

1- Determine the physical properties of sugarcane (C9 Variety).
2- Manufacture and construct a prototype sugarcane seed cutting machine to reduce the human effort to cut the buds from the sugarcane stalks for sowing purposes.
3- Test and evaluate the performance of the machine in the field.
4- Make an economical evaluation of the machine.

MATERIALS AND METHODS

Materials:

To achieve the proposed objectives for the current work, an experimental sugarcane seed cutting machine was

* **Corresponding author.**
E-mail address: abdallah_elshawadfy@agr.aswu.edu.eg
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manufactured at a local workshop in El-Minya governorate - El-Minya - Egypt, 2021. This experimental machine was designed for cutting on both sides as well as to be compatible with a wide range of stalk diameters and cutting speeds, as shown in Fig. (1).

Figure 1. Isometric view of the prototype sugarcane seed cutter machine.

Description of the experimental sugarcane seed cutting machine:

The entire experimental sugarcane seed cutter was subjected to standard design methodology. The machine consists of three main parts: machine frame, cutting system, power supply, as shown in Fig. (2).

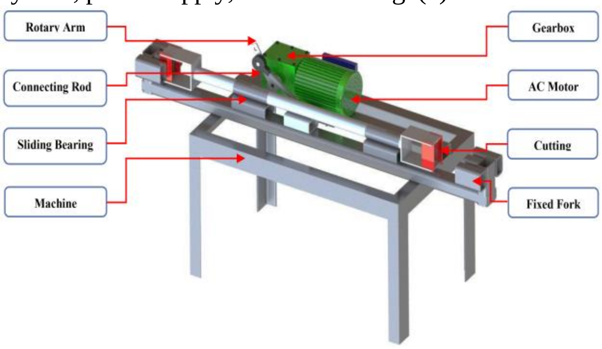

Figure 2. The main components of the prototype sugarcane seed cutter machine.

1. Machine frame:

The machine frame support and carry out the cutter bar, electrical motor, and power transmission system, as shown in the detailed views Figure No. (3). the machine frame was constructed out of both angle bars (3*2*0.25 in [6.72*5.08*0.635 mm]) and rectangular tube (3*2*0.25 in [6.72*5.08*0.635 mm]). The machine frame's main dimensions are 80 cm in height, 165 cm in length, and 60 cm in width.

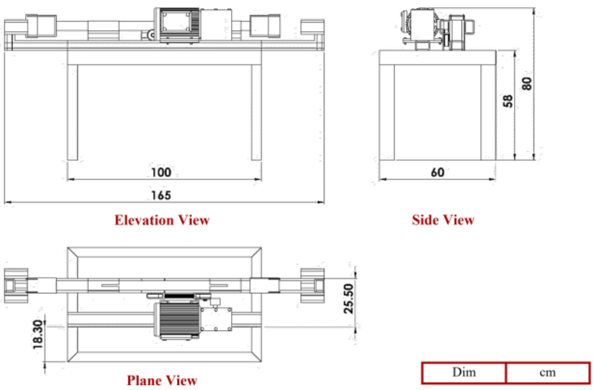

Figure 3. Detailed views of the experimental machine.

2. Cutting system:

The cutting system consists of two main parts, a cutting bar, and a fixed fork. The cutting bar is used for cutting sugarcane stalks (Fig. 4), and it is welded at the top of the machine frame. The cutter bar slips on the upper surface of the machine frame using two sliding bearings for minimizing the friction forces and also maintaining the cutting directions for increasing the cutting efficiency.

The cutting bar consists of two groups of blades, one for each side and each group contains two stainless plates of steel blades 12 cm in length * 8 cm in width * 0.2 cm in thickness with 3.5 cm spacing between them because of the desired cutting nodes was 3.5 cm, as shown in Fig. (4). The cutting force of the blades is provided by a connecting rod and rotary arm that are used to convert the rotary motion of the AC motor to reciprocating motion for the cutting bar.

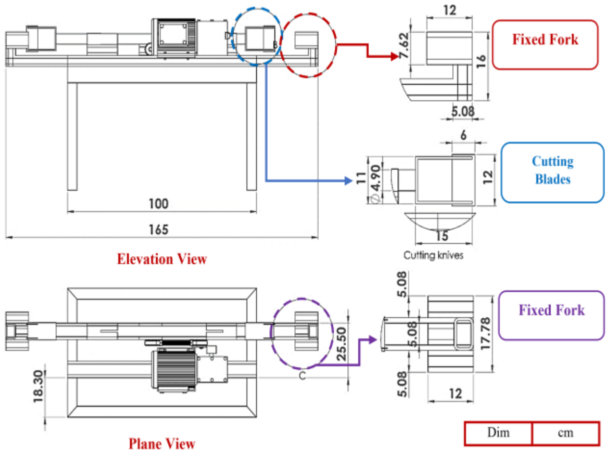

Figure 4. Detailed views of the cutting system.

3. Power supply:

The experimental sugarcane seed cutting machine is powered by a 3-phase electrical AC motor (0.55 kW). The specification of the electrical motor is indicated in Table (1). The rotational speed of the AC motor was reduced from 360 rpm to 56 rpm by using a gearbox.

Table 1. Specification of the power supply (3-phase electrical AC motor.).

Type	WA30DT80KA/ASD1 (Germany)
Speed	360/56 rpm
Current	3.05 – 1.75 A
Power	0.55 kW
Gearbox reduction ratio	20 : 1
Output Torque	93.3 N.m

The power transmission mechanism (Fig. 5) is provided with a rotary arm that has three holes with spacing 7, 4, and 4 cm from center, between each one for controlling cutting force and linear speed of cutting bar, and the rotary arm was fixed with the electrical motor. The cutting force and speed can be changed by adjusting the connecting rod between the electrical motor and the cutting bar for the suitable rotary armholes, so as to control the cutting force and speed of the cutting bar, as shown in Table (2).

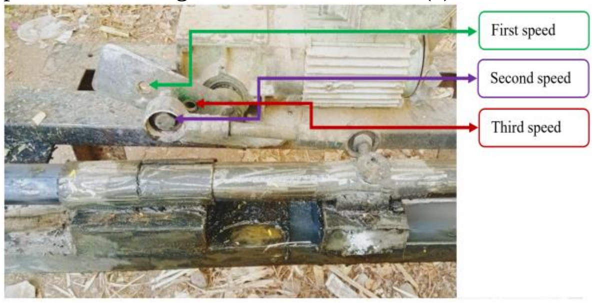

Figure 5. The different operation speeds.

The tabulated data in Table (2), showed the linear speed and cutting force for the cutting bar at each gearbox rotational speed, where the values presented in the same table were calculated mathematically with neglecting the friction force.

Table 2. The linear speed, cutting force, and cutting stroke for each speed.

Speed	Cutting Force, N	Linear speed, m/s	Cutting Stroke, cm
S1	1341	0.41	7.00
S2	853	0.65	11.00
S3	626	0.88	15.00

Machine description and performance:

The labor holds the sugarcane stalk and moves it until the node became between the cutting blades and the fixed fork, after connecting the machine with the 3-phase power supply then the labor presses the switch bottom that switch on the electrical motor and create the reciprocating motion of the cutting bar when the cutting bar strongly presses the sugarcane stalk and cut the node with the shear force. The labor repeats this action to continuously separate the nodes.

After cutting all nodes, nodes and internodes still on the ground surface under the machine as shown in Figures (6 and 7), the labor after that separates all nodes for the planting, and the internodes are still malleable and could be used for juicing or sugar distillation process. Sugarcane nodes of commercial variety C9 separated by the seed cutting machine were planted in plastic trays in a greenhouse as shown in Fig (8), on 12 September 2021, in the Research Farm - Department of Agronomy – Faculty of Agriculture – El-Minia University - El-Minia - Egypt.

Figure 6. Field experiments of the experimental machine.

Figure 7. The experimental machine after testing with nodes and internodes underneath.

Figure 8. Planting the separation nodes in plastic trays in a greenhouse.

Methods:

Performance Tests and Evaluation of proposed sugarcane Node cutting unit:

The prototype sugarcane seed cutting machine was tested in the department of Agronomy – Faculty of Agriculture – El-Minia University - El-Minia - Egypt.

Field tests were carried out in order to:

- ✓ Evaluate the physical characteristics of the clean whole sugarcane stalks.
- ✓ Estimate the machine performance in terms of:
- ❖ Machine productivity, Node/h.
- ❖ Cutting efficiency, %.
- ❖ Operation cost, EGP/Fedd.

Experiment design:

Field tests were conducted to evaluate the performance of the experimental unit by studying the following variables:

I. **Stalk diameters:** (G1, G2, G3, and G4) group.
II. **Blade (cutting) speed:** (S1, S2, and S3) speed.

1. Machine productivity:

The machine was operated by experienced laborers. The nodes and timed consumed were estimated for each whole stalk, then the machine productivity (Q) was computed as No. nodes/h, by using the following equation, (Mahmoud and Abu El-maaty (2021):

$$Q = Nb_{actual} / t$$

Where: Nb_{actual} = Actual number of buds per minutes at time t, (h).

2. Cutting efficiency:

The cutting efficiency (η_c) was determined after cutting each whole stalk. The nodes were then separated into those that were completely cut correctly, and those that were cut incorrectly or not cut. The cutting efficiency was calculated according to the following formula (Zein El-den *et al.*, 2020; Mahmoud and Abu El-maaty, 2021):

$$\eta_c = N_c / N_t \times 100$$

Where: N_c = number of nodes completely cut.
N_t = the total number of sugarcane nodes per the whole stalk.

3. Cost estimation of owning and operating the proposed machine:

Formulas developed by the American Society of Agricultural and Biological Engineers (ASABE) are used to calculate the operation costs for the experimental machine. All costs are based on buying a new proposed prototype of the sugarcane seed cutting machine, owning the machine for 5 years, and using it 150 hours per year.

4. Statistical analysis:

The statistical analysis was carried out using IBM SPSS statistics 25, PC statistical software. Each experiment in triplicate repeated and the values presented in terms of standard division (±) (Sanchez-Hermosilla *et al.*, 2011).

RESULTS AND DISCUSSION

1. Physical properties of sugarcane stalks:

Physical properties of sugarcane stalks that affect mechanical cutting were measured from the average of four random sampling groups, as shown in Fig. (9), in Center of Experiments and Agricultural Research, Faculty of Agriculture, El-Minia University, and sugarcane farm that all grow sugarcane variety C9.

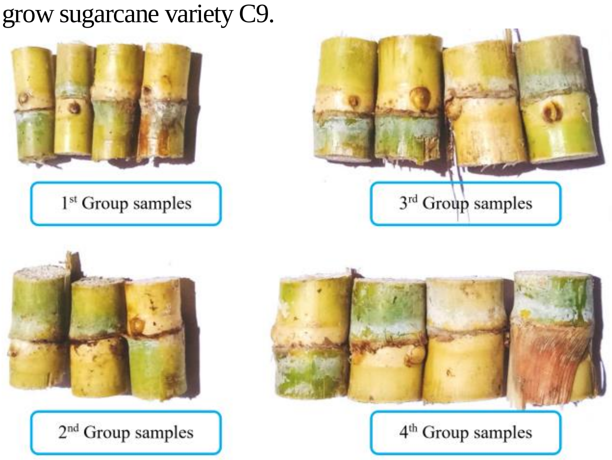

Figure 9. Four groups of sugarcane stalk sampled with different diameters.

Tested samples of 36 whole stalks had taken randomly after cleaning and branching. The cleaned stalks were divided into four groups depending on the stalk diameters, as shown in Table (3). Table (3) and Fig. (10), show the average diameters of the experimental sugarcane stalks at a different position in the whole stalks.

Table 3. The average diameters of the experimental sugarcane stalks at a different position in the stalks.

Group No.	Stalk diameter, cm		
	Node location on the stalk		
	Bottom	Middle	Top
G1	1.48	1.39	1.30
G2	2.00	1.93	1.79
G3	2.69	2.63	2.47
G4	3.43	3.29	3.11

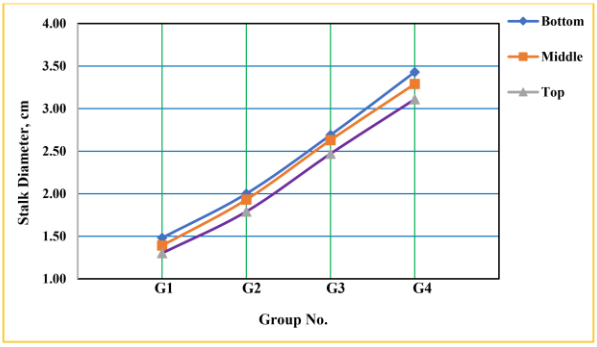

Figure 10. The average diameters of the experimental sugarcane stalks at a different position in the stalks.

Table (4) and Fig. (11), show average values of physical properties of clean sugarcane stalks. The average diameter of branched stems ranged from 1.48 to 3.43 cm depending on the stalking group at the base and ranged from 1.30 to 3.11 cm at the top.

Table (4) and Figures (11 and 12), illustrates average values of physical properties of clean sugarcane stalks. The average stalk diameters were ranged from 1.38 to 3.28 cm and the average weight of branched stems were also ranged from 405.11 to 1206.67 g. The length of branched stems ranged from 181.67 to 197.78 cm and the Average Number of nodes per stalk were ranged from 12.56 to 14.33 node/stalk depending on the testing group.

Table 4. Average values of physical properties of sugar cane stalks.

Group No.	No. of Stalks	Average stalk Diameter, cm	Average Stalk weight, gm	Average Stalk length, cm	Average No. of nodes per stalk
G1	9	1.38 ± 0.15	405.11 ± 77.08	181.67 ± 15.76	12.56 ± 1.94
G2	9	1.91 ± 0.11	802.00 ± 154.90	185.67 ± 25.60	12.89 ± 3.06
G3	9	2.60 ± 0.20	1019.67 ± 122.54	192.56 ± 17.66	14.78 ± 2.22
G4	9	3.28 ± 0.18	1206.67 ± 218.83	197.78 ± 19.22	14.33 ± 2.18

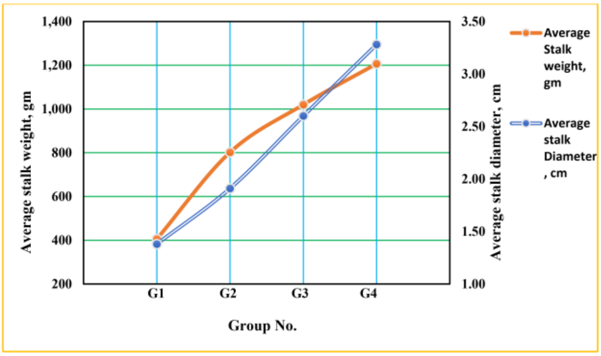

Figure 11. The average stalk diameters and stalk weights of the experimental groups.

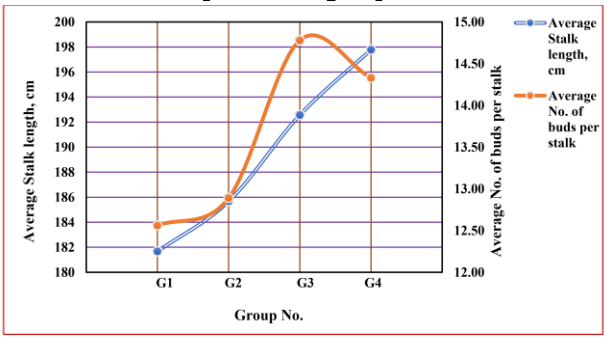

Figure 12. The average stalk length and number of nodes of the experimental groups

2. Separated nodes properties:

The measurements of separated nodes after a separation show that the average node weight percentage ranged from 24.73 to 30.77 % of the total average weight of the nodes. There is a little difference in the percent of the average weight of nodes between the different groups under testing.

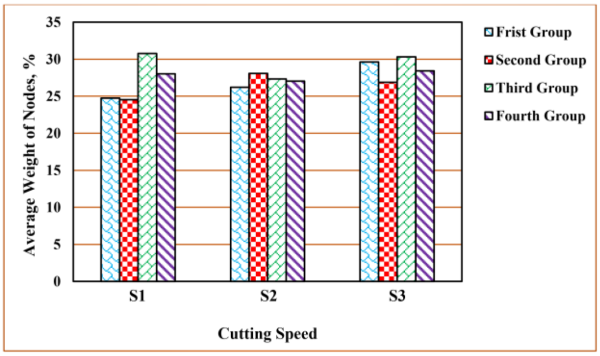

Figure 13. Average weight of nodes for each stalk for each group.

3. Cutting efficiency:

Table (5) and Fig. (14), represent the effect of cutting speed on cutting efficiency. Results show that the highest cutting efficiency (100 %), and was observed in the first group, which includes the average sugarcane stalk diameters 1.38 ± 0.15 cm for all cutting speeds. On the other hand, it was found that increasing the cutting speed and average stalk diameters led to decrease the cutting efficiency for all groups. Many reasons led to a decrease in the cutting efficiency, such as small cutting stroke led to miss some feeding times and increase the time required for cutting the whole stalk and decreasing the available cutting force led to uncut some nodes and sometimes machine stopped (Elwakeel, 2017; Mahmoud and Abu El-maaty, 2021). Various types of nodes damage during machine testing, as shown in Figure (15), included broken nodes, diseased nodes, and damaged nodes as a result of human error in feeding.

Table 5. The prototype performance at different stalk diameters and cutting speeds.

Group No.	Cutting Speed	Average Weight of Nodes, %	Cutting Efficiency, %	Machine Productivity, node/h	Operation Cost, EGP/Fedd
	S1	24.73 ± 2.93	100.0 ± 0.00	3857 ± 309.1	56.31
G1	S2	26.20 ± 5.82	100.0 ± 0.00	2268 ± 184.2	95.77
	S3	29.61 ± 2.32	100.0 ± 0.00	1972 ± 81.30	110.14
	S1	24.53 ± 1.87	96.47 ± 0.00	3656 ± 214.6	59.41
G1	S2	28.07 ± 2.15	97.21 ± 3.05	2610 ± 245.6	83.22
	S3	26.87 ± 5.38	100.0 ± 0.0	2015 ± 125.2	107.79
	S1	30.77 ± 3.60	94.67 ± 4.04	3944 ± 390.8	55.07
G1	S2	27.33 ± 3.32	95.22 ± 6.25	2178 ± 88.20	99.72
	S3	30.30 ± 0.81	97.67 ± 4.04	1873 ± 149.9	115.96
	S1	28.03 ± 2.80	83.67 ± 3.51	3820 ± 491.8	56.86
G1	S2	27.03 ± 3.50	84.67 ± 8.51	2354 ± 263.0	92.27
	S3	28.43 ± 2.22	89.12 ± 4.00	1895 ± 187.7	57.31

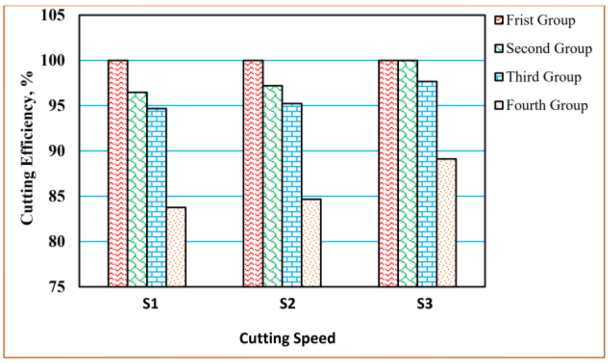

Figure 14. Effect of cutting speed on the cutting efficiency.

Figure 15. Different types of nodes damage during machine testing.

4. Machine productivity:

The machine was operated by experienced laborers and the consumed time was recorded, for cutting three stalks for each group at each cutting speed. The separated nodes were counted then the machine productivity was computed as node/h. The maximum production of the machine under the conditions of the test was about 3944 nodes/h for the third group & first speed. Table (5) and Fig. (16), show the results of machine operation. It could be noticed that the machine productivity was decreased with increasing the cutting speed where the highest machine productivity was recorded for the first speed while the lowest machine productivity was recorded for the third speed (Elwakeel, 2017; Mahmoud and Abu El-maaty, 2021).

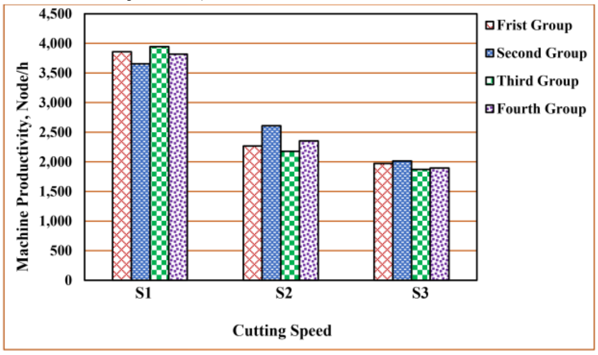

Figure 16. Effect of cutting speed on the machine productivity.

5. Operation cost:

Results in Table (5) and Fig. (17) show that increasing total operating costs from (55.07 to 115.96 EGP/Fedd) decreases the machine productivity from (3944 to 1873 node/h).

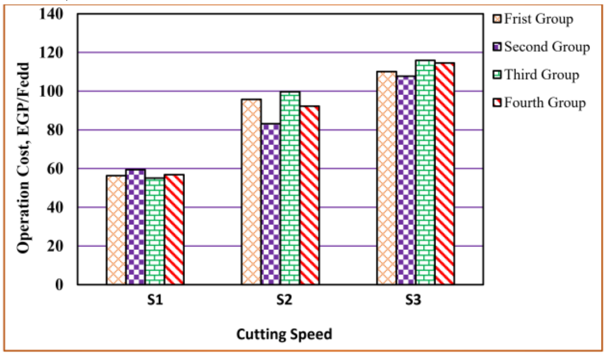

Figure 17. Effect of cutting speed on the operation cost.

CONCLUSION

Sugarcane seed cutting machine is used to cut nodes (buds or eyes) from sugarcane which can be used as seeds for planting purposes to beneficially help farmers to grow sugarcane to reduce wastage of sugarcane when planting again. The main purpose of this study was to design and produce a prototype node cutter suitable for working under Egyptian conditions.

The main recommendations of this study could be concluded as follows:

1. Using the first cutting speed gave maximum machine productivity and minimum total operation costs for all sugarcane stalk diameters.
2. Increasing the cutting speed and average stalk diameters led to a decrease in the cutting efficiency for all sugarcane stalk diameters.

To sum up, the main contribution of this paper is to design and field evaluation of a sugarcane node cutting machine, which can save time, reduce labor intensity, and be safe and stable. It can provide a reference for the design and development of a sugarcane node/bud cutting system. The cutting equipment can meet the agricultural needs of sugarcane seed production.

Declaration of Competing Interest:

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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تصنيع وتقييم الأداء لآلة تقطيع عقل قصب السكر

عبدالله الشوادفي الوكيل[1]*، عبدالله مسعد زين الدين[2]، أبوبكر عبدالوهاب طنطاوي[3]، ساهر محمود عبدالرحمن محمد[4] و حسن أحمد علي محمد[5]

[1] قسم الهندسة الزراعية ـ كلية الزراعة والموارد الطبيعية – جامعة أسوان – مصر

[2] قسم الهندسة الزراعية ـ كلية الزراعة – جامعة الإسكندرية – مصر

[3] قسم المحاصيل ـ كلية الزراعة – جامعة المنيا – مصر

[4] كلية الزراعة – جامعة القاهرة – مصر

[5] قسم البساتين – كلية الزراعة – جامعة الأزهر – مصر

من أجل تسهيل عملية تقطع العقل المستخدمة في زراعة قصب السكر بطريقة الشتل، تم تصميم آلة لتقطيع عقل قصب السكر وإختبارها في قسم المحاصيل – كلية الزراعة – جامعة المنيا – المنيا – مصر. تم تصميم أجزاء الآلة المختلفة بإستخدام برنامج (SolidWorks)، حيث تم تصنيع الآلة وتجميعها باستخدام المواد منخفضة التكلفة والمتوفرة في السوق المحلي. الآلة تستخدم لتقطيع أو فصل العقل من أعواد قصب السكر ثم استخدام السلميات في عمليات التصنيع. الآلة تتكون من شفرات أو سكاكين تتحرك حركة ترددية تأخذ حركتها من محرك كهربي ثلاثي الطور. تم إجراء التجارب الحقلية علي أربعة مجموعات مختلفة من أقطار عيدان قصب السكر وثلاثة سرعات للقطع وذلك من أجل دراسة تأثير أقطار العيدان وسرعات القطع علي أداء الألة. أظهرت نتائج الاختبار الحقلي لأصناف قصب السكر C9 ,أن متوسط الأقطار، الوزن والطول لعيدان القصب المستخدمة في الاختبار وكذلك متوسط عدد البراعم أو العقل لكل عود قصب سكر من العينات المستخدمة كان يتراوح من (1.38 – 3.28 سم)، (405.11 – 1206.67 جم)، (181.67 – 197.78 سم) و (12.56 – 14.33) على التوالي. النتائج أيضاً أظهرت أن أقصي قدرة إنتاجية للآلة كانت 3944 عقلة/ساعة وكذلك تكاليف التشغيل الكلية للآلة تراوحت بين 55.07 الي 115.96 جنيه/فدان، طبقاً لسرعة القطع المستخدمة وأقطار عيدان قصب السكر. من هذه الدراسة يمكن الاستنتاج أن النموذج الأولي المصمم لآلة تقطيع عقل قصب السكر مربح ومفيد وفعال من حيث التكلفة لمساعدة صغار مزارعي قصب السكر في ظل الظروف المصرية.

الكلمات المفتاحية: قصب السكر، تقطيع العقل، إنتاجية الآلة، تكاليف التشغيل.