International Research Journal of Agricultural Science and Soil Science (ISSN: 2251-0044) Vol. 1(7) pp. 227-233 September 2011
Available online http://www.interesjournals.org/IRJAS

Full Length Research Paper

Development and performance evaluation of a leafy vegetable harvester

[1]C.O. Olowojola, [2]*T. Faleye and [3]L.A.S. Agbetoye

[1]Engineering Services Department, Ministry of Agriculture, Alagbaka, Akure
[2*] National Centre for Agricultural Mechanisation (NCAM) P.M.B. 1525, Ilorin, Kwara State
[3]Department of Agricultural Engineering, Federal University of Technology Akure

Accepted 13 June, 2011

A leafy vegetable harvester was developed to enhance mechanized production of herbaceous vegetables such as *amaranthus*. The harvester was powered from the tractor's Power – Take – Off (PTO). The ground wheel of the harvester powered the conveyor, which transmits power to the conveyor belts for transporting the harvested vegetable from the cutting unit to the storage bin. The machine was tested under operational and agronomic parameters: knife speeds, forward speeds and vegetable heights. Regression analysis and ANOVA at 0.05 significant level were used to analyse the effects of the parameters on the performance of the harvester. Results during tests indicated that the field capacity of the machine increases linearly with increase in knife speed and forward speed. At 447 rpm knife speed and 5.04 km/hr, the field capacity was 0.18 ha/hr and the harvesting efficiency was 68%. At a reduced forward speed, the field capacity and harvesting efficiency increased to 0.20 ha/hr and 92% respectively. At high vegetable height (average of 69.60 cm), the harvesting efficiency reduced considerable largely due to the frame of the machine which tends to push "standing" vegetables away from the reach of the cutting unit.

Keywords: Leafy vegetable, harvester, field capacity, field efficiency and tractor mounted.

INTRODUCTION

Vegetables are raised for both human and animal consumption largely because of their minerals, vitamins and fibre contents. *Amaranthus*, a typical example of a leafy vegetable, are raised for human consumption (Oke, 1980; Oliveira and de Carvalho, 1975), forage crop (Fitterer *et al.,* 1975), Ornamental purposes (Iturbide and Gispert, 1994) and pigment production (Piatelli *et al.,* 1969). Kaul and Egbo (1985) noted that the history of harvesting crops is as old as the history of human itself. This important operation is labour consuming and its cost has gone up considerably in the recent years due to increase in the area of cultivation and unavailability of labour (Ojha and Michael, 2003). Cho *et al.* (2002) reported that researchers in rural development administration investigated input labour per hour of greenhouse lettuce in each stage of task and reported that 47% of the total working hours applied to harvesting. Buchmaster (2006) also asserted that harvesting machinery and associated labour costs is often the single largest contributor to the cost of producing and delivering forages. Acquiring western designed harvester which could be adapted for harvesting *amaranthus* is practically impossible because of the high cost of the machine, sophistication of its operation and maintenance; its suitability to the local terrain and the fragmentation (farm holdings) of our farming land.

The structural complexities of a harvester depend on a lot of factors. These include plant architecture, end use of the crop (human or animal consumption) and agronomic characteristics (Dingke et al., 2007; Glancey, 2007; Jakeway, 2003; Savoie et al., 2006). Other factors that should be considered include ergonomics, soil and weather conditions during harvesting operational parameters.

*Corresponding author email: topeleye@yahoo.com

Vegetables, until recently, have been planted locally in a small scale for domestic consumption. This could account for the draught of specialized machines for vegetable harvesting. In areas where *amaranthus* are planted as forage crops, in which case lacerations of leaves are stems are permissible to some degree, forage equipments are used for its harvesting. Where *amaranthus* are grown for human consumption, efforts are made to preserve the quality of the vegetable by carefully cutting and handling it to reduce lacerations and bruising of the edible leaves and stems. So far, this had been done by manual means. Due to increase in the area under cultivation for *amaranthus*, Akande (2004) attempted to mechanize the operation by designing a mechanical harvester for the vegetable. His machine lacerates and bruises the vegetable and thereby reduces its quality. Also, provision was not made to collect harvested vegetable. The specific objectives are to: design a cost effective vegetable harvester, fabricate the harvester using locally sourced materials and carry out the performance evaluation of the harvester.

MATERIALS AND METHODS

Description of the machine

The major components of the machines include the cutting unit (reciprocating cutter bar), the slider crank mechanisms, the reel, conveyor, storage bin and the frame. The machine is designed to be fully mounted on a tractor. The reel pushes the standing vegetable toward the cutting unit and gently placed the cut vegetable on the conveyor for transporting into the storage bin. The cutting unit, a reciprocating cutter bar, consists of 2 sets of knives – one stationary and the other moving to and fro in scissors-like manner, cut the vegetable through a shear action. The slider mechanism is an arrangement of crank and connecting rod (pitman) which convert the rotary motion supplied by the tractor's PTO to reciprocating motion of the cutter bar. The conveyor is inclined at a convenient angle for transporting the cut vegetable into the storage bin. It is powered by pulley arrangements which take drive from the ground wheel. All these components are attached to the frame which was designed to be rigid and sturdy to be able to absorb all the induced stresses generated during the operation of the harvester.

Design consideration

In order to ensure efficiency and reliability, the machine was designed to meet the following assumptions:

i. It should be able to harvest vegetable with minimum bruise or laceration on its leaves and stems,

ii. It should reduce drudgery and reduce labour requirements in the harvesting of vegetable,

iii. It should harvest at a rate higher than human method of harvesting,

iv. All the materials used for the fabrications are locally available,

v. It should be simple in design and be able to operate and maintain with farmers.

Design Procedures

Slider Crank Mechanism

The interest is to use the mechanism to convert rotary power supplied by the PTO into reciprocating motion of the cutter bar and determined the knife speed. The formula given by Celik (2006) was used to determine the knife speed as follows:

$$V_k = \frac{Sn}{30} \qquad (1)$$

Where V_k = Knife speeds (m/s)
S = length of stroke (m)
N = Crank speed in rpm

Power requirements of the cutting Unit

The procedure used by Celik (2006) and Richey et al., (1961) was used to determine the minimum power requirements of the cutting unit.

Chain and Sprocket/Belt and pulley

The design procedure given by (Khurmi and Gupta, 2005) was used for the design and selection of the chain/sprockets and belt/pulley system to achieve desired functions.

Shaft design

Considering the horizontal and vertical loading on the shaft its diameter was obtained using equation: (ASAE, 1998).

$$d^3 = \frac{16}{\pi S_s}\sqrt{(K_b M_b)^2 + (K_t M_t)^2} \qquad (2)$$

Fabrication and Machine Evaluation

The harvester was fabricated at the engineering

Figure 1. The picture of the vegetable harvester after fabrication

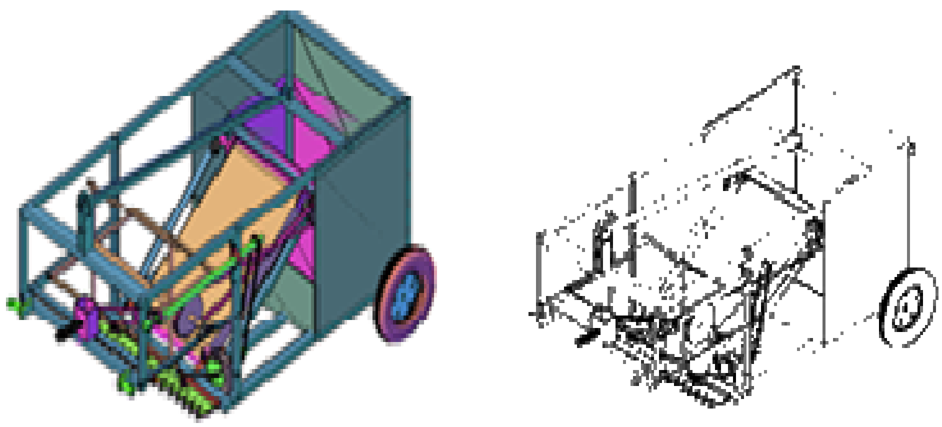

Figure 2. The model and isometric view of the vegetable harvester using CAD

workshop of the Ondo State Ministry of Agriculture, Akure, Nigeria. . The planter was fabricated and sized based on the designed dimensions shown in the prototype drawing using AUTOCAD.

Richey (1961) observed that performance of cutter bar is linearly influenced by knife speeds. Forward speeds of the harvester as determined by the speed of the tractor used during harvesting and different vegetable heights were the factors used to evaluate the effective field capacity and efficiency of the harvester.

The experimental plot was located close to River Ogbese, about 15km away from Akure, the Ondo State Capital. The area of the experimental plot was 0.18Ha as determined using the GPS. The designed harvester was tested using Massey Ferguson Tractor 435 model. The knife speeds was varied at different engine speeds and this was measured using Lutron digital tachometer. The forward speeds of the harvester by measuring the time taken for the harvester to specific distances. The differences in vegetable heights were achieved by varying the date of planting of the vegetable so that at the time of harvesting, their ages were 3, 7 and 10 weeks respectively (Figure 1 and 2).

ANOVA and regression analysis procedures were employed in the processing of the data obtained during the testing of the machine. The parameters used for the testing of the machine namely knife speeds, forward speeds and vegetable heights all influenced the effective field capacity and the efficiency of the harvester.

RESULTS AND DISCUSSIONS

Effect of knife speeds on the performance of the harvester

The effect of knife speeds on the harvesting field capacities was evaluated by operating the harvester at 447 rpm and 297 rpm. The effective field capacities at the two operating knife speeds are tabulated in Table 6. Single-way ANOVA procedures was used to statistically determine whether there is a significant difference in the means effective harvesting capacities of the harvester at 447 rpm (μ_{sk1}) and 297 rpm (μ_{sk2}).

The hypotheses are stated below:

H_o: $\mu_{sk1} = \mu_{k2}$ (The effective field capacity means are the same)

H_a: The Effective Field Capacity means are different.

As shown in Table 6, since F (calculated) is greater than F_c (critical), there is a very strong difference among the mean of effective field capacities at different operating knife speeds. The probability that this procedure will lead to Type 1 error (conclude that there is a difference among the means when in fact they are equal) is 0.05. This implies that the knife speeds affect the performance of the harvester. Increase in knife speed would considerable increase the rate of harvesting of the harvester.

F = 9.122503192 and F_c = 3.554557146 (From table 6).

Effects of forward speeds on the performance of the harvester

The results shown in table 1 – 4, the effect of forward speeds on effective capacity of the harvester were statistically analyzed using Regression Analyses procedures. Generally there is a strong positive linear relationship between the forward speeds of the machine and the field capacities. That is, the field capacity (ha/h) increases as the forward speed (km/h) increases. This was obvious in the values of R^2 (Coefficient of determination) which represented the proportion of the sum of squares of deviations of the field capacities values about their mean that can be attributed to a linear relationship between field capacities and forward speeds. The values were very high for all the cases tested; 0.771 when the average height of the vegetable was 26.57 cm, 0.59 when the average height of the vegetable was 40.9 cm and 0.814 when the 69.6 cm. High time loss during operation was responsible for the decrease in the coefficient of determination when the vegetable was 40.9 cm high. This was due to operating conditions which were rather not favourable during the time of testing at this height. However when the forward speed is increased beyond certain range, some vegetable would be left un-harvested. This implies that there is a speed limit for the harvester to function effectively.

Effect of vegetable heights on the performance of the harvester

The effective field capacities of the harvester were determined when the vegetable was at different stages of development: 3 weeks after planting; 6 weeks after planting and 10 weeks after planting. The results are tabulated in table 7 below. A one-way ANOVA procedure was used to evaluate whether there is a significant difference in the effective field capacities means.

The hypotheses are stated below:

H_o: $\mu_{ca(eff)1} = \mu_{ca(eff)2} = \mu_{ca(eff)3}$ (the effective field capacities means at different heights are equal)

H_a: At least two Effective Field Capacity means are different.

Refer to the Table 8, since F (calculated) is greater than F_c (critical), then there is a very strong difference among the mean of effective field capacity at different vegetable heights. The probability that this procedure will lead to Type 1 error (conclude that there is a difference among the means when in fact they are equal) is 0.05. This shows that vegetable height affect the performance of the harvester.

F = 26.19266 and F_c = 4.747225 (From table 8).

CONCLUSIONS

A tractor mounted leafy vegetable harvester was designed, fabricated from locally sourced materials, and tested under some operational and crop parameters namely: knife speed, forward speed and vegetable height.

The Performance of the harvester was satisfactory during testing and it would meet the requirements of targeted local farmers. The optimum performance of the machine was achieved when it was operated at 3.27km/h forward speed and the knife moving at crank speed of 447rpm. This translated to effective field capacity of 0.27 ha/hr and efficiency of 92%. At this operating condition and alongside 3 – 5 labour/day who will be packaging harvested vegetable into sizes, the machine could harvest 1.6ha of *amaranthus* farm per day. This same task would have required between 30 – 40 labour per day if entirely done manually.

The performance of the harvester reduced considerably at vegetable height of 68 cm and above. This was due to the fact that the machine was designed to rear mounted to the tractor. Besides this, the harvester performed satisfactorily.

Table 1. Machine Performance 3 WAP and at 447 rpm Knife Speed

Test	S_f	Ca_t (ha/hr)	$Ca_{(eff)}$(ha/hr)	Efficiency (%)
1	1.97	0.12	0.10	85
2	2.40	0.15	0.10	80
3	2.62	0.16	0.12	75
4	2.70	0.16	0.11	90
5	2.75	0.17	0.11	75
6	3.22	0.20	0.13	73
7	3.30	0.20	0.15	80

Ca_t = Theoretical field capacity
$Ca_{(eff)}$ = Effective Field capacity
S_f = Forward speed

Table 2. Machine Performance 6 WAP and at 447 rpm Knife Speed

Test	S_f	Ca_t (ha/hr)	$Ca_{(eff)}$(ha/hr)	Efficiency %
1	2.88	0.18	0.15	85.56
2	2.95	0.18	0.11	73.67
3	3.15	0.19	0.15	78.74
4	3.27	0.20	0.14	91.55
5	3.60	0.22	0.15	77.81
6	4.40	0.27	0.17	64.43
7	5.04	0.31	0.18	67.91

Ca_t = Theoretical field capacity
$Ca_{(eff)}$ = Effective Field capacity
S_f = Forward speed

Table 3. Machine Performance 10 WAP and at 447 rpm Knife Speed

Test	S_f	Ca_t (ha/hr)	$Ca_{(eff)}$(ha/hr)	Efficiency %
1	1.20	0.07	0.06	91.37
2	1.58	0.10	0.08	84.67
3	1.69	0.10	0.09	95.77
4	2.08	0.13	0.10	77.64
5	2.49	0.15	0.13	85.26
6	2.78	0.17	0.11	78.76
7	3.09	0.19	0.13	70.26

Ca_t = Theoretical field capacity
$Ca_{(eff)}$ = Effective Field capacity
S_f = Forward speed

Table 4. Machine Performance 6 WAP and at 297 rpm Knife Speed

Test	S_f	Ca_t (ha/hr)	$Ca_{(eff)}$(ha/hr)	Efficiency %
1	1.20	0.07	0.06	0.80
2	1.80	0.11	0.09	0.88
3	1.94	0.12	0.09	0.82
4	2.06	0.13	0.09	0.86
5	2.70	0.16	0.12	0.76
6	2.88	0.18	0.11	0.69
7	3.05	0.19	0.10	0.53

Ca_t = Theoretical field capacity
$Ca_{(eff)}$ = Effective Field capacity
S_f = Forward speed

Table 5. Effective Field Capacities at 6 WAP at 447 rpm and 297 rpm Knife Speed

Test	$Ca_{(eff)22}$	$Ca_{(eff)21}$
1	0.15	0.06
2	0.11	0.09
3	0.15	0.09
4	0.14	0.09
5	0.15	0.12
6	0.17	0.11
7	0.18	0.10

$Ca_{(eff)21}$ = Effective Field Capacity (ha/h) at S_k = 297 rpm when veg. = 40 days old, $Ca_{(eff)22}$ = Effective Field Capacity 0. 76m/s knife speed (ha/h) when veg. = 40days old

Table 6. ANOVA of Knife Speeds on Machine Performance

Source of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	0.00885417	2	0.004427085	9.122503192	0.001837464	3.554557146
Within Groups	0.00873527	18	0.000485293			
Total	0.01758944	20				

Table 7. Effective Field Capacities at Various Stages of Development and at 0.76 Knife Speed

Test	**Effective field capacity (ha/hr) at 3WAP**	**Effective field capacity (ha/hr) at 6WAP**	**Effective field capacity (ha/hr) at 10WAP**
1	0.10	0.15	0.06
2	0.10	0.11	0.08
3	0.12	0.15	0.09
4	0.11	0.14	0.10
5	0.11	0.15	0.13
6	0.13	0.17	0.11
7	0.15	0.18	0.13

Table 8. ANOVA of Difference in Heights on the Performance of the Harvester

TSource of Variation	***SS***	***df***	***MS***	***F***	***P-value***	***F crit***
Between Groups	0.012912	1	0.012912	26.19266	0.000254	4.747225
Within Groups	0.005916	12	0.000493			
Total	0.018828	13				

REFERENCES

Akande AL (2004). Development of a Mechanical Harvester for *Amaranthus*. Unpublished M.Eng. Project Report, Fed. Univ. of Tech., Akure. Pp 5-6.

Buckmaster DR (2006). A System Approach to Forage Harvesting Operations. Paper No. 061087. *(ASABE)* St. Joseph, Michigan, USA. 12-14

Celik A (2006). Design and Operating Characteristics of a Push Type Cutter Bar Mower. J. Can. Biosys. Eng. 48(2):23-2.27.

Cho SI, Chang YY, Kim KJ (2002). Development of a Three-Degree-of Freedom for Harvesting Lettuce using Machine Vision and Fuzzy Logic Control. Biosys. Eng. J. 82 (2):143-149.

Dingke Z, Yinggang O, Zhiwei L, Canquan H (2007). Research and Analysis on the Hydraulic Driving System of the Whole-Stalk Sugarcane Harvester. (ASAE). Meeting Presentation. St. Joseph Michigan USA. Paper Number: 071068. Pp. 2-6.

Fitterer SA, Johnson BL, Schneither AA (1996). Grain Amaranth Harvest Timeliness in Eastern North Dakota. In Janick, J. (eds). Progress in New Crops ASHS Press, Alexandria, V.A. 2: 11-12

Glancey J (2007). Once-Over Mechanical Harvesting of Several Leafy Greens for Processing. (ASABE) St. Joseph Michigan, USA. Paper No: 071140. p. 4.

Hall AS, Holowenko MS, Laughlin GH (2004). Shaum's Outline of Theory and Problems of Machine Design SI (Metric) Ed. Tata McGraw-Hill Publishing Company Limited. Fourth Reprint. Pp 113-115.

Iturbide GA, Gispert M (1994). Grain Amaranth. In Hernando, B and Leon J (eds), Plant Production and Protection Series. No. 26. FAO, Italy Pp. 93-101.

Jakeway LA (2003). Application of Cane and Forage Harvesters For Biomass Fuel Recovery. (ASAE) International Conference on Crop Harvesting and Processing. Paper Number: 701P1103e, ed.

Kaul RN, Egbo CO (1985). Introduction to Agricultural Mechanisation. Macmillan. Pp. 116-121.

Khurmi RS, Gupta JK (2006). A Textbook of Machine Design. Eurasia Publishing House (PVT.) LTD. New Delhi. 14th Ed. P. 759 – 775.

Ojha TP, Micheal AM (2003). Principles of Agricultural Engineering, 4th eds. Jains rothers, New Delhi Pp 420-433.

Oke OL (1980). Amaranth in Nigeria. In Proceedings of the Second Amaranth Conference, Rodale Press Emmaus, P.A. P.22.

Oliveira JS, de Carvalho MF (1975). Nutritional Value of Some Edible Leaves used in Mozambique. Economic. Botany, 29:255.

Piatelli M, Denicola M, Castrogiovanni V (1969). Photocontrol of Amaranthin Synthesis in *Amaranthus* tricolor, *Phytochemistry* 8:731.

Richey CB, Jacobson P, Hall CW (1961). Agricultural Engineer's Handbook. McGraw-Hill Book Company. N.Y.

Savoie P, Amours D, Lavoie F, Lechasseur G, Joanis H (2006). Development of a Cutter- Shredder-Baler to Harvest Long-Stem Willow. (ASABE) St. Joseph Michigan USA. Paper No: 061016. Pp 4-6.