Determination of optimum critical operating parameters of stripping rice harvester in a rural area

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Abstract

One of the vital challenges for future years in agricultural production is developing and adopting new technology for different farming systems. Stripper harvester though has been developed and tested in places like Britain, some Asian countries and Europe, its performance on rice harvesting was highly affected by setting of its critical operating parameters, therefore not yet practically accepted in most of these places. Optimum operational condition of a 30cm width self propelled prototype pedestrian controlled grain stripper header produced was determined for rice harvesting in a Nigeria farming system to replace the prevalent manual harvesting. The optimum setting of critical operating parameters of the stripper was at best when the machine settings was at 270mm rotor height, stripper rotor speed was 17.55m/s and forward speed was 3km/h. The machine performed better on row planted rice field than on spot planted field in overcoming tyre rolling resistance and wheel slip problems caused by crop stalks.

Keywords: Operational, optimum, settings, critical, stripper.

1 Introduction

Agricultural system in Nigeria is mostly rural production which provides employment for about 30% of her population as of 2010 (Nigerian Bureau of Statistics, 2015) is now being transformed by commercialization at small, medium and large- scale enterprise levels (Olomola, 2007). Designing sustainable agricultural production systems for a changing world even in rural area is essential to determine methods and application of modern technological development including machines to replace the traditional tools (Dogliotti et al, 2014). Nigeria Government with objective of developing and testing plan of significantly increasing production of crops like rice, cassava, maize, wheat etc, has a renew and growing recognition of self- reliance as a strategy for economic development, Patel (1989). To contribute to food security and import substitution, Oloruntoba et al (2007) reported that the Nigeria Government launched the New Rice for Africa (NERICA) in June 2005, which aimed at increasing local rice production. Rice farming in a system of small scale which is generally and predominantly cultivated manually from planting to post harvesting in Nigeria. Carruthers (1985) reported that up to 40 % of the total cultivation input under manual field operation was expended on harvesting, hence there was need to introduce a mechanical harvester that can reduce operational cost, time, harvest losses and improve produce quality.

Present trend of combine harvester development is of increasing capacity (size), reducing harvester losses, high level of sophistication, high machine cost which is also resulting in soil compaction problem with modern farming system, Klinner et al (1987). Nigeria farmers' small farm size holdings, low technical skill, low per capital income and fragile top soil condition, cannot afford to own and operate the conventional large harvester. A vital challenge for future years is not only perfecting existing technology, but also developing new ones and better methods of harvesting as required for a farm location and farming system, (Freye, 1988).

In China the stripping header was developed and adapted to harvesting of wheat and rice that was planted as inter-ridge with corns to match the country's planting system, Yulai et al (1999). The main practical problems were that of consumer acceptability and operator's restricted operating environment. In Nigeria, Elegbeleye et al, (2003) worked on the effect of tractor mounted stripper peripheral speeds (100 to 260 rpm) at two tractor forward speeds 3km/hr and 5km/hr on some header parameters, this required further design and investigation for Nigeria rice field conditions. This paper was based on determining optimum settings at critical operating parameters of a developed self propelled prototype stripper harvester meant for Nigeria's small farm size and intercropped farming pattern, Adisa (2008).

2 Methodology

2.1 Description and Working Principle of the Developed Self Propelled Grain Stripper

In a conventional combine harvester, its operation is crop gathering, cutting, threshing and crop conveying Douthwaite et al (1993). Operation of the stripper rotor of the harvester simultaneously carried out four functions of crop lifting, harvesting, partial threshing and grain transporting in one operation. Figure 1 is showing the eight stripping comb-like resilient elements made of a rubber material with keyhole- shaped recess slots between each pair of teeth root which were mounted horizontally on an upward rotating drum. These rotor elements engaged crop stalks as machine advances forward and detaches ears and grains at high speed from the stalk and throws the materials that was removed into the grain box. The grains were later discharged by an auger conveyor located at the lower backward end of the grain box for final threshing/cleaning. Figure 2 is the developed 30cm width grain stripping harvester.

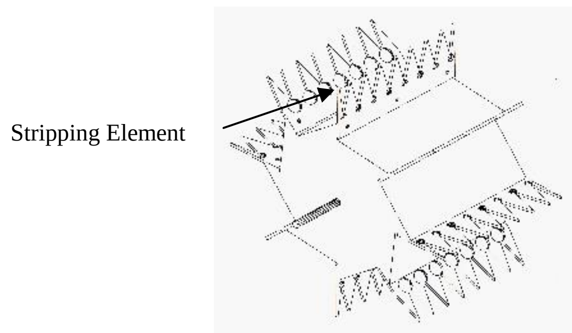

Fig. 1: Stripper Rotating Drum

Furrow dividers were coupled to both sides of the stripping header to provide clear demarcation between stripped and unstripped rows. Dislodging mechanism was incorporated to dislodge the lodged crop which was made of three L shaped iron rod that were hanged on the front end of the hood nose, ahead of stripping unit.

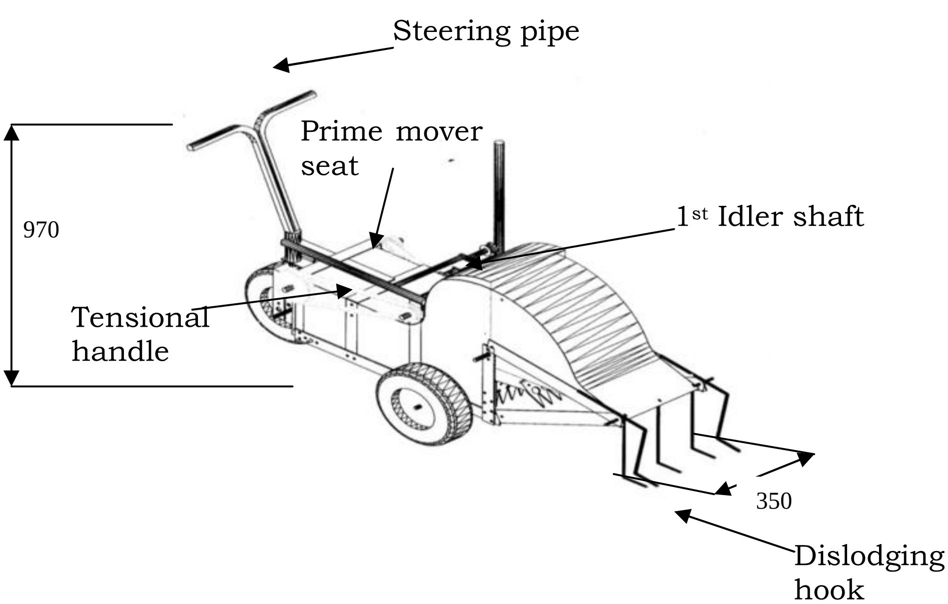

Fig. 2: Isometric View of the Stripper Harvester

This stripping harvester is a self propelled machine which moved within human walking speed (pedestrian speed, averagely 3.6km/h) and controlled by the steering unit. Machine traction unit was made of two tyres in front and single one at the rear which was connected directly to the steering unit for easy maneuverability on small field. The machine was powered by a 5h.p. (3.71kw) petrol engine.

2.2 Preliminary Field Experiment

Trial tests were conducted to determine the machine's forward speeds on both spot planted and row planted rice fields, rotor speeds and conveyor speeds. The actual ground speeds of the harvester was obtained by running the machine through a marked distance and timed. Soil moisture content and that of the crop were determined on wet basis from time to time until appropriate rice crop harvesting moisture content of 20% average was obtained. This machine performance testing was carried out where the rice field was spot planted at 25cm average spacing on level ground of loamy silt sand soil (rain fed upland rice field). The rice variety was *faro* 44 which is one of the NERICA varieties, locally called '*kwadala*', planted at Basawa village, Samaru, Zaria, Nigeria.

2.3 Experimental Design

Klinner et al (1986) identified the following four stripper machine settings, rotor height, forward speed, nose height and rotor speed as the one that affects it performance. This study was to determine effect of combination of machine settings like rotor height, forward speed and rotor speed on field performance of the rice stripping harvester and establish combination with best performance result in Nigeria rice field condition.

2.4 Experimental Procedure

A randomized complete block design (RCB) was adopted to study the rotor speeds at various harvester forward speeds, a nose height (fixed), and rotor heights on field losses and field efficiency. The 2 x 5 x 5 factorial treatment combinations of two levels of rotor heights (R) of 270mm and 220mm (the height of the lowest part of the rotor above the ground based on rice variety height), five forward speeds (U) 3km/hr, 4km/hr, 5km/hr, 6km/hr and 7km/hr and five rotor speeds (V) of 10.50m/s, 13.00m/s, 15.70m/s, 18.00m/s, and 21.00m/s. This was to cover wider speed range than what has been tested on tractor mounted header in Nigeria by Elegbeleye et al (2003) before now. The nose height was fixed at 100mm below plant height with fixed hood clearance. A parameter was varied while others were fixed at a time. These three factorial experiments gave 150 combinations (RxUxV) with three replications i.e.150 plots was required. Plot size was 0.3m by 10m. The following variables were measured throughout each run:

- Header loss (grain lost on the stubble, lodge and shatter)
- MOG/ grain ratio of the material collected.
- Percentage of grain threshed in the material collected.

Four field men were involved in carrying out the field experiments which includes harvester operator that guides harvester through each run, the time keeper took note and recorded time taken for each run and measured amount of fuel consumed per run from a calibrated cylinder. On the header loss, a man picked the unstripped grains that were left on the stubble (standing crop), grains left on lodged crop, and shattered grains that fell within the 0.10m^2 quadrat. A technician assisted the team to change the pulleys and belts to obtain right speeds and heights variation. The speed combinations were checked to confirm the accuracy before each run for the forward speed, rotor speed and auger speed. Also rotor height was confirmed before each run commences. The performance of the machine was also tested by clearing rows for the machine when crop obstruction was observed on the spot planted rice field to test on row planted field.

2.5 Parameters Computed

The following are the parameters computed in this study:

Moisture content was determined by equation (1),

$$MC_{wet\ basis} = \frac{W_{initial} - W_{final}}{W_{initial}} \times 100 \quad \text{-.(1).} \quad \text{(ASAE Year Book, 1979)}$$

- Shattering losses, S_l (loss caused by the header due to vibration and it impact on the crop during harvesting, kg).

- Cracked grain loss, S_c (cracked grains during harvesting, kg).
  Lodging loss, L_g (grains left behind on lodged plants, kg).
- Stubble loss, S_t (grains left on stubbles by the header, Kg)

Each of the loss was expressed as percentage of the total yield (TY) in each plot (Ichikawa, 1981):

$TY = C_t + S_l + S_c + L_g + S_t$ (kg) --(2)

C_t = mass of total grain and MOG harvested (kg)

$$S_l = \frac{\text{mass of shattered grains}}{TY} \times 100\ (\%) \quad \text{--(3)}$$

$$S_c = \frac{\text{mass of cracked grains(mech. damage)}}{TY} \times 100(\%) \quad \text{-------(4)}$$

$$L_g = \frac{\text{mass of grains left on lodged crops}}{TY} \times 100(\%) \quad \text{-------(5)}$$

$$S_t = \frac{\text{mass of grains left on stubble (standing crop)}}{TY} \times 100(\%) \quad \dots\ (6)$$

$$\text{Crop purity} = \frac{\text{mass of grain harvested}}{\text{mass of grain plus MOG harvested}} \times 100\% \quad \text{..... (7)}$$

$$\text{Total crop losses } T_{tl} = \frac{S_L + S_c + L_g + S_t}{TY} \times 100\ (\%) \quad \text{-----(8)}$$

$$\text{Fuel consumption rate} = \frac{\text{fuel consumed per plot (litres)} \times 10^4}{\text{plot area } (m^2)} \text{(litres/ha)} \quad \text{---------(9)}$$

The whole time (total) was categorized into productive and non productive time. Effective field efficiency was determined by measuring all the time elements involved while harvesting. Productive time was the actual time used for harvesting the grains while non productive time was made up of turning time, repair and adjustment time and other time losses during harvesting as shown below:

$$\text{Harvester field efficiency} = \frac{\text{Productive time}}{\text{Total time taken}} \times 100(\%) \quad \text{--(10)}$$ (Kalsirilp and Singh, 2001)

The harvester efficiency was calculated by expressing the mass of grain harvested (stripped) and conveyed through the box to the total yield as shown below.

$$\eta = \frac{C_{tg}}{TY} x100(\%) \text{...... (11)}$$ ------ (Kalsirisilp and Singh, 2001)

Where C_{tg} = total grain stripped and collected, kg

The grain purity was calculated as below:

$$\text{Grain purity} = \frac{\text{Clean grain}}{\text{Total material stripped}} \times 100\% \quad \text{--- --(12)}$$ (Kalsirisilp and Singh, 2001)

2.6 Data Analysis

Data collected from the experiments were analyzed using analysis of variance (ANOVA) technique. Determination of contributing factors like forward speed, rotor speed, and rotor height influencing the parameters like machine harvesting field efficiency and grain losses were considered using multiple regressions. The performance of the stripper rotor was evaluated using Duncan Multiple Range Test (DMRT) to determine critical factors affecting the harvester's performance which were statistically and graphically determined.

3 Results and discussion

3.1 Results of field experiment

The crop moisture content at the period of carrying out the experiment varied from 21.00% to 15.60% on wet basis with the average of 18.30% within the seven days of the experiment as shown in Table 1. The soil moisture content was averagely 11.00%, the height of crops harvested varied from 55cm to 90cm with the average of 72.50cm because the seed materials planted was found not pure but the stalk heads were relatively stripped. The machine experienced less obstruction when operated on row crop harvesting than on spot planted rice field.

Table 1: Machine Design Crop Related Physical Properties (Measured)

Physical properties	**Number of samples measured**	**Average values**	**SD[a]**
Plant to plant spacing, cm	50	25.00	4.24
Crop height at maturity, cm	20	72.50	8.94
Pre harvest loss, kg/ha	10	40.00	3.79
Crop yield, kg/ha	10	1,300.00	15.81
Angle of repose of paddy rice, degrees	10	25.00	0.70
Soil moisture content, percent	5	11.00	0.67
Geometric mean diameter grain, mm	50	4.14	0.28
Volume of grain, m^3	50	$0.36x10^{-7}$	0.15
Bulk density of paddy rice, kg/m^3	10	839.00	9.49
Grains moisture content at harvest, percent	10	18.30	2.85
Maximum ground slope, degrees	10	3.00 (5.20%)	0.25
Number of tillers per hill, number	20	10.00	2.13
Diameter of straw below panicle, mm	50	1.20	0.06

(a) SD= Standard deviation

Table 2: Summary of Analysis of Variance for Data Generated in the 2x5x5 Factorial Experiment

Source of variation	Degree of freedom	Computed F – Values[1]									
		Shattered loss	Stubble loss	Lodging loss	Total loss	Time spent	Fuel consumed	Field capacity	Grain purity	Field efficiency	Harvester efficiency
Replication	2	1.05	13.02**	1.11	3.03	10.60**	20.39**	22.30**	3.28	3.72	4.54
Treatment	49	1.43	1.41	0.84	0.98	2.77	2.04	2.38	1.17	1.60	0.09
Rotor height, R	1	8.23*	0.10	0.66	0.46	0.39	0.38	0.74	4.20	1.01	0.01
Forward speed, U	4	0.38	1.49	0.81	0.42	11.88**	2.56	4.08*	1.07	4.41*	0.38
Stripper rotor speed, V	4	1.98	0.49	2.36	1.66	0.23	0.27	0.56	1.61	0.33	1.16
R∗U	4	0.69	1.57	0.07	0.05	0.38	0.50	0.49	1.27	0.26	0.41
R∗V	4	0.70	0.47	0.85	0.56	1.42	1.40	2.27	0.95	0.44	0.16
U∗V	16	1.70	1.26	0.80	1.19	2.12	1.44	1.51	0.93	1.98	1.16

R*U*V	16	1.28	0.60	0.69	0.86	1.87	1.32	1.38	0.91	1.25	0.63
Error	98										
Total	149										

** Significant at 1% level (highly significant)

* Significant at 5% level (significant)

Table 3: Duncan Multiple Range Test Result of the Mean Separation

	Time spent(s)	**Other Times (s)**	**Fuel (ml)**	**Total Stripped (g)**	**Clean Grain (g)**	**Unthreshed Grain (g)**	**MOG (chaff)(g)**	**Shattered loss (g)**
R								
1	14.41^{a}	10.80	8.32^{a}	3026.6	279.33^{a}	6.08^{a}	17.26^{a}	20.73^{a}
2	14.15	a	8.47^{a}	7^{a}	256.80^{a}	4.13^{a}	16.36^{a}	25.07^{a}
U								
1	14.80	11.07	8.54^{ab}	312.07^{a}	288.61^{a}	5.85^{a}	17.61^{a}	22.22^{a}
2	b	a	8.00^{b}	289.93^{a}	266.05^{a}	5.69^{a}	18.19^{a}	22.20^{a}
3	13.27	11.00	9.09^{a}	b	b	4.20^{a}	17.03^{a}	23.06^{a}
4	c	a	8.01^{b}	290.64^{a}	269.41^{a}	5.36^{a}	14.73^{a}	24.66^{a}
5	16.50	11.03	8.36^{ab}	b	b	4.42^{a}	16.49^{a}	22.38^{a}
SE	a	a	0.28	252.59^{b}	232.59^{b}	0.68	1.44	1.69
±	12.17	12.10		269.56^{a}	248.65^{a}			
	c	a		b	b			
	14.76	16.67		13.5	12.73			
	c	a						
	0.48	0.70						
V								
1	14.06	11.33	8.36^{a}	283.50^{a}	260.54^{a}	5.03^{ab}	17.93^{a}	22.47^{ab}
2	a	a	8.65^{a}	b	b	4.07^{b}	17.53^{a}	24.89^{a}
3	14.40	11.80	8.32^{a}	285.43^{a}	263.83^{a}	3.91^{b}	17.52^{a}	23.81^{ab}
4	a	a	8.27^{a}	b	b	6.17^{a}	15.80^{a}	18.96^{b}
5	14.50	10.70	8.39^{a}	315.54^{a}	294.11^{a}	6.36^{a}	15.26^{a}	24.38^{a}
SE	a	a	0.28	255.81^{b}	233.84^{b}	0.68	1.44	1.69
±	14.07	11.00		277.10^{a}	255.48^{a}			
	a	a		b	b			
	14.43	11.00		13.5	12.74			
	a	a						
	0.48	0.70						
Interaction								
R*	NS	NS	NS	NS	NS	NS	NS	NS
U	0.68	1.0	0.40	19.09	18.03	0.96	2.04	2.39
SE	NS	NS	NS	NS	NS	NS	NS	NS
±	0.68	1.0	0.40	19.09	18.03	0.96	2.04	2.39
R*	*	NS	NS	NS	NS	NS	NS	NS
V	1.07	1.58	0.63	30.18	28.51	1.52	3.23	3.78
SE	*	NS	NS	NS	NS	NS	NS	NS
±	1.51	2.23	0.89	42.68	40.32	2.15	4.56	5.35
U*	**Stubble**	**Lodging**	**Total loss(g)**	**Total yield**	**Field Capaci**	**Field efficien**	**Grain**	**Harvester**

R								
1	19.04	11.84	51.62a	337.03	0.045a	57.39a	89.76a	79.58a
2	a	a	53.60a	a	0.044a	a	89.71a	76.40a
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
U								
1	19.24a	9.77a	51.23a	345.69	0.0043a	57.94a	90.06a	80.43a
2	b	12.71	53.48a	a	b	b	89.19a	77.60a
3	18.58c	a	52.36a	325.22	0.047a	55.29a	90.33a	b
4	b	11.52	55.73a	a	0.040b	c	89.43a	79.17a
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
V								
1	20.12	9.92b	49.96a	315.52	0.045a	56.11a	89.30a	78.27a
2	a	12.29a	56.34a	ab	0.043a	55.69a	90.21a	77.61a
3	19.16	b	52.52a	324.24	0.046a	57.79a	90.89a	79.80a
4	a	9.63b	47.0a	ab	0.045a	56.34a	88.82a	78.28a
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Interacti								
R*U	NS	NS	NS	NS	NS	NS	NS	NS
SE ±	2.27	1.69	4.63	19.62	0.027	2.29	1.02	1.75
R*V	NS	NS	NS	NS	NS	NS	NS	NS
SE ±	2.27	1.69	4.63	19.62	0.027	2.29	1.02	1.75
U*V	NS	NS	NS	NS	NS	*	NS	NS
SE ±	3.6	2.67	7.32	31.02	0.036	3.58	1.59	2.49
R*U*V	NS	NS	NS	NS	NS	NS	NS	NS

∗ - significant at 5% level, ∗∗- Highly significant at 1% level, N.S – Not significant.
Means with different letters are significantly different in the groupings (i.e. a, ab, b).

4 Discussion

4.1 Result of Analysis of Variance and Duncan Multiple Range Test of Mean Groupings

The replication was highly significant for stubble loss, time spent, fuel consumed and field capacity, see Table 2. That is, the blocking was considered effective in reducing the experimental error since F (replication) was significant (Gomez and Gomez, 1976). Also rotor height was significant for shatter loss. Forward speed was significant for field capacity, field efficiency and highly significant for time spent. The effect of variation on crop heights between 55cm to 90cm with average of 72.50cm as shown in Table 1 and ground gradient (non uniform ground slope) was responsible for these significance effects. Tyre rolling resistance and wheel slip that occurred when it ran over crop stalks on the spot planted rice field, also contributed to these effects which were greatly minimized when tried on row crop field as observed.

Result of the analysis of variance presented in Table 2 and Duncan groupings in Table 3 did not show that the stripper rotor speed have high significant effect on the total loss. The trend with which the total loss increased with the rotor speed is as shown in Figure 3. The minimum total loss occurred at R_1 (270mm) rotor height setting and rotor speed was 14.56m/s, while it occurred at R_2 (220mm) rotor height setting and rotor speed was 17.52m/s before it both increased again.

Figure 4 shows how the total loss increases both linearly and polynomially as the harvester's forward speed increased. This was as a result of combined effects of machines behaviour under varied crop feeding rate of stripping unit and rotor height in relation to crop height.

Table 4: Rice Stripper Optimum Settings of Critical Operating Parameters

S/No	Parameters	At rotor height 270mm	At rotor height 220mm
1	Harvester forward speed	3km/h	4km/h
2	Stripper rotor speed	17.55m/s	14.67m/s
3	Harvester nose height above ground	530mm	480mm
4	Field capacity	0.078ha/h	0.075ha/h
5	Fuel consumption rate	27.60 litre/ha	26.60 litre/ha
6	Harvester efficiency	81%	77%
7	Grain purity	90.20%	87.50%
8	Threshed grains, percent of total stripped	97.50%	92.70%

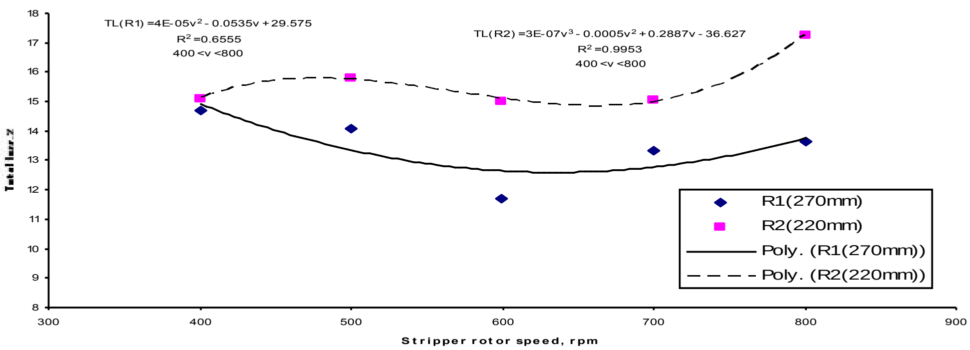

Fig. 3: Effect of Stripper Rotor Speed on Total Loss at Two Levels of Rotor Heights

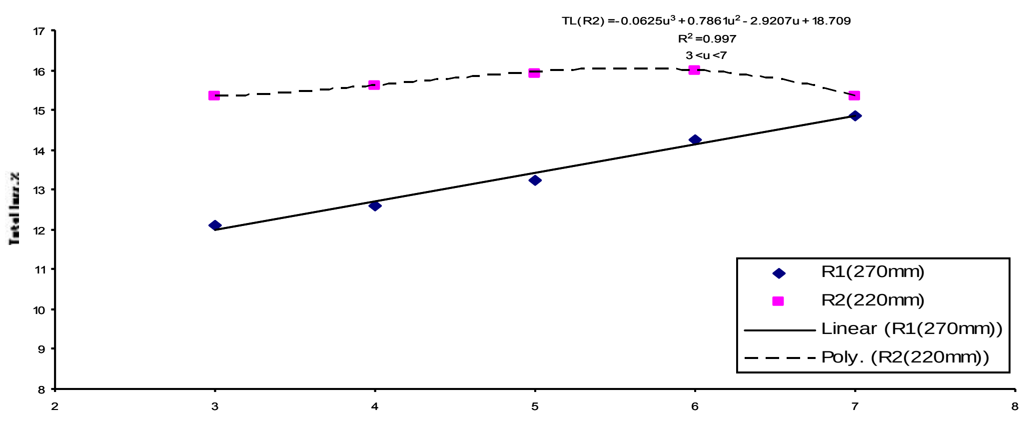

Fig. 4: Effect of Harvester's Forward Speed on Total Loss at Two Levels of Rotor Heights

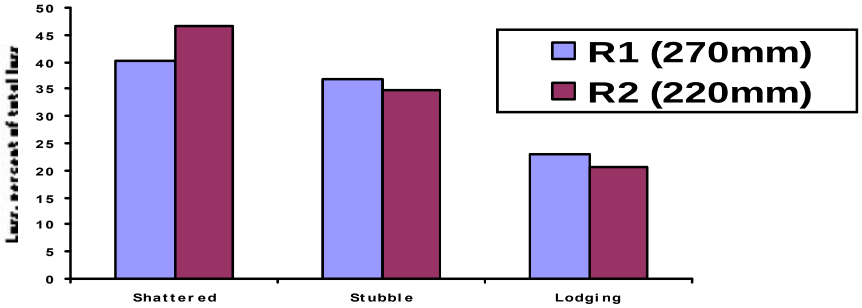

Fig. 5: Contribution of the Various Sources of Loss to the Total Loss in a 2x5x5 Factorial Experiments

Bar chart in Figure 5 shows the contributions of the various sources of loss. Figure 5 shows that the shattering loss contributed the highest of 40.20 percent to the total loss 13.44% at a rotor height R_1(270mm) while the shattered loss also had the highest contribution of 46.60 percent of the total loss 16.87% for rotor height R_2 (220mm).Duncan grouping had shown that there was no significant difference in the means of shattering stubble and lodging losses at two rotor heights.

The minimum total loss as shown in figures 3 and 4 was obtained at rotor height 270mm and estimated values of stripper rotor speed were 17.47m/s and 3.00km/h harvester forward speed corresponding to ($R_1U_1V_4$). At rotor height 220mm the estimated values of stripper rotor speed 14.56m/s and 4.20km/h harvester forward speed corresponding to ($R_2U_2V_3$).

Kalsirisilp and Singh (2001) tested this same similar rice stripping machine in Thailand and got the shattering loss to be 5.30%, stubble loss as 4.00% and 5.60% lodging loss of the total yield. Klinner et al (1987) got overall losses that ranged between minimum of 4.30% and as high as 10.70% of the total yield on his machine tested in England on some cereal crops (not rice). Although the stripper header compared well in terms of operation performance with existing ones but it required further improvement.

The stripper optimum settings result of the critical operating parameters is as shown in Table 4. The best machine settings was at 270mm rotor height, stripper rotor speed 17.55m/s and forward speed 3.00km/h which gave the field capacity of 0.078ha/h, harvester efficiency was 81.00%, grain pusrity was 90.20% and 97.50% stripped grains was threshed. The best settings at the rotor height of 220mm gave the forward speed to be 4.00km/h and rotor speed was 14.67m/s while the field capacity was 0.075ha/h, harvesting efficiency was 77.00%, grain purity was 87.50% and threshed grains was 92.70% of the total grains stripped.

5 Conclusion

The developed 30cm width self propelled pedestrian controlled prototype stripper header was tested, it maneuvered easily on small parcel field. From this study, the best machine settings for optimum critical operating parameters was at 270mm rotor height, stripper rotor speed 17.55m/s and forward speed of 3km/h, the field capacity was at 0.078ha/h, harvester efficiency was 81.00% , grain purity was 90.20% and grain threshed was 97.50% of the total grains stripped. Similarly, at machine 220mm rotor height, 4.00km/h forward speed, and 14.67m/s rotor speed settings, the machine optimum field capacity was 0.075ha/h, harvester efficiency was 77.00%, grain purity was 87.50%, and the threshed grains was 92.70% of the total grains stripped. The performance of small capacity stripper harvester on row planted crop field was better in overcoming tyre rolling resistance problem than on spot planted rice field.

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