Determination of the Effects of Some Operating Parameters on the Performance of an *Acha* Harvesting Machine

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ABSTRACT

Acha (*Digitaria exilis*) harvesting is still being done by manual traditional methods because harvesters for the crop are non-existent. This method is expensive and time consuming, yet the demand for the crop is on the increase. It is difficult to adapt regular combines to *acha* harvesting due to its unique grain characteristics as well as the current small sizes of *acha* field. The objective of this study was to evaluate the performance of a locally developed *acha* harvester. The machine consists of a header, transport mechanism and collection tank. A 3^3 factorial experimental design was used to collect data for evaluation of the performance the machine. Factors varied were operating speed (V) (1, 3, and 5 km/h); knife cutting speed (S) (300, 400, and 500 rpm) and reel index (I) (1.0, 1.25, and 1.5). Quantity measured was the amount of grain retrieved from each plot of the field. This was used to determine the material capacity (C_{mat}) of the harvester. Analysis of variance (ANOVA) was used to determine the effect of each of the parameters as well as their interactions. Results obtained showed that increasing machine forward speed, knife cutting speed and reel index had a reducing effect on the material capacity of the machine. Operating speed and reel index had a significant effect at $p \leq 0.01$, while knife speed effect was only significant at $p \leq 0.05$. The interaction of reel index and operating speed, as well as the interaction of all three factors were very low, significant only at $p \leq 0.05$. The study concluded that the three parameters, operating speed, knife cutting speed and reel index were critical to the performance of the *acha* harvesting machine and recommended that further studies be done to determine their optimum values.

Keywords: Material Capacity, Operating Speed, Knife Speed, Reel Index

1.0 INTRODUCTION

The performance of an agricultural machine is dependent on the purpose for which it is designed. A milling machine for instance, will be evaluated by its throughput capacity, which in turn, as inferred from Olaoye and Babatunde (2001), depends on the efficiency of the milling machine. The rate at which a tillage implement effectively covers a field, referred to as its effective field capacity (Tanam and Babatunde, 1995, Veerangouda *et al*, 2010, Olowojola *et al*, 2011) is a sufficient performance index for a the implement. Performance of a harvesting machine is measured by either the quantity of crop it is able to gather from the field, referred to as its material capacity, or the level of loss incurred in the harvesting process (Junsiri and Chinsuwan, 2009, Abdi and Jalali, 2013). A harvester with high material capacity is considered good or efficient. Tanam (2021) described a harvester with low level losses in similar manner.

Several factors are known to influence the performance of a harvesting machine. They include, but not limited to forward speed of operation (Olowojola *et al*, 2011, Jalali and Abdi, 2014, Hummel and Nave, 1979, cited by Junsiri and Chinsuwan, 2009), knife approach angle (Chattopadhyay and Pandey, 1999), knife cutting speed (Tanam, 2021), reel index (Chunsuwan *et al*, 2004, Junsiri and Chinsuwan 2009, Jalali and Abdi, 2014), knife – reel clearance (Quick, 1999, Jalali and Abdi, 2014), reel position ahead of cutter bar, crop density (Yore *et al*, 2002), crop moisture content (Chinsuwan *et al.*, 1997, Sangwijit and Chinsuwan, 2010), crop maturity, crop height (Olowojola *et al*, 2011), timeliness of operation, threshing and cleaning efficiency (Veerangouda *et al*, 2010), service life of cutter bar (Klenin *et al*, 1985) and stem length (Siebenmorgrn *et al*, 1994). Tanam and Olaoye (2022) identified three of these factors (operating speed, knife cutting speed and reel index) as most critical in the performance of a cutter bar type harvester. Improper adjustment of these factors leads to considerable losses (Junsiri and Chinsuwan, 2009) and hence low material capacity of the harvester. Tanam (2021) developed the first *acha* harvesting machine. The purpose of this study was to evaluate effects of the operating speed, knife speed and reel index on the performance the *acha* harvesting machine.

2.0 MATERIALS AND METHODS

A motorized *acha* harvesting machine consisting of a cutter bar, a reel, a conveyor and a collection tank developed by Tanam (2021) was considered. Three parameters of the machine considered critical to its performance, namely, operating speed (V), knife speed (S) and reel index (I) were considered. A 3^3 factorial experimental design described by Davies (1956) was used to collect data to study the effect of these factors as well as their interaction. Three levels of each parameter were investigated in two replicates. Value for V were 1, 3 and 5 km/h, S had values of 300 (0.500), 400 (0.0667) and 500 (0.833) rpm (m/s) while those for I were 1.0, 1.25 and 1.5. Quantity measured was the amount of grain harvested (Y) per treatment. Table 1 is the layout of the experiment. Subscripts 0, 1, and 2 represent low, intermediate, and high levels of each parameter

Table 1: Factor Level Combinations for a 3^3 Factorial Experiment

Treatments		
$V_0S_0I_0$	$V_0S_0I_1$	$V_0S_0I_2$
$V_0S_1I_0$	$V_0S_1I_1$	$V_0S_1I_2$
$V_0S_2I_0$	$V_0S_2I_1$	$V_0S_2I_2$
$V_1S_0I_0$	$V_1S_0I_1$	$V_1S_0I_2$
$V_1S_1I_0$	$V_1S_1I_1$	$V_1S_1I_2$
$V_1S_2I_0$	$V_1S_2I_1$	$V_1S_2I_2$
$V_2S_0I_0$	$V_2S_0I_1$	$V_2S_0I_2$
$V_2S_1I_0$	$V_2S_1I_1$	$V_2S_1I_2$
$V_2S_2I_0$	$V_2S_2I_1$	$V_2S_2I_2$

The field used for this work is located in Zawan District (latitude 9º 45′″ 17” North and longitude 8º 52′ 29″ East) of Jos-South Local Government Area of Plateau State. The field was prepared in accordance with the recommendations of the *Acha* Station of the National Cereal Research Institute (NCRI), located in Riyom, Riyom Local Government Area of Plateau State. The field was divided into twenty-seven blocks of two plots each, with each plot measuring 5m x 1.2m. Two adjacent plots were used as replication for the same treatment. Planting was done by manual broadcast method at the rate of 20 kg/ha. Materials collected from each run were threshed manually and weighed.

Analysis of variance (ANOVA) was performed on the data using the “Systematic Method for the analysis of a 3^n Factorial Design” described by Davis (1956) as an extension of the Yate’s algorithm. Effect of each factor and their interactions were tested at two levels of confidence interval, 5% and 1%. F-test was used to determine the significance of each factor on the treatment at both the 5% and 1% significance levels. Factors with the highest F-Statistic and lowest p-values, provided the p-value ≈ 0, were considered important and significant to the performance of the harvester.

3.0 RESULTS AND DISCUSSIONS

Table 2 is the ANOVA derived from the analysis of data collected.

Table 2: Analysis of Variance (ANOVA) for Material Capacity

Source of variation	SS	Df	MS	F
Main effects				
Linear V	1044.26	1	1044.259	88.174
Quadratic V	310.51	1	310.510	26.218
Sum for V	1354.77	2	677.385	57.196++
Linear S	13.37	1	13.374	1.129
Quadratic S	77.74	1	77.745	6.564
Sum for S	91.12	2	45.559	3.847+
Linear I	340.54	1	340.538	28.754
Quadratic I	206.44	1	206.438	17.431
Sum for I	546.98	2	273.488	23.092++
Two-factor Interaction				
Linear V x Linear S	24.77	1	24.766	2.091
Quadratic V x Linear S	97.13	1	97.134	8.202
Linear V x Quadratic S	0.02	1	0.021	0.002
Quadratic V x Quadratic S	7.47	1	7.466	0.630
Sum for V x S	129.39	4	32.347	2.731+
Linear V x Linear I	74.14	1	74.138	6.260
Quadratic V x Linear I	11.74	1	11.739	0.991
Linear V x Quadratic I	13.63	1	13.629	1.151
Quadratic V x Quadratic I	31.32	1	31.318	2.644
Sum for V x I	130.82	4	32.706	2.762+
Linear S x Linear I	17.81	1	17.814	1.504
Quadratic S x Linear I	15.73	1	15.726	1.328
Linear S x Quadratic I	0.94	1	0.936	0.079
Quadratic S x Quadratic I	1.55	1	1.548	0.131
Sum for S x I	36.02	4	9.006	0.760
Three-factor interaction				
Linear V x Linear S x Linear I	37.43	1	37.430	3.160
Quadratic V x Linear S x Linear I	182.74	1	182.738	15.430
Linear V x Quadratic S x Linear I	37.07	1	37.069	3.130
Quadratic V x Quadratic S x Linear I	0.17	1	0.168	0.014
Linear V x Linear S x Quadratic I	1.87	1	1.871	0.158
Quadratic V x Linear S x Quadratic I	0.06	1	0.064	0.005
Linear V x Quadratic S x Quadratic I	47.45	1	47.451	4.007
Quadratic V x Quadratic S x Quadratic I	1.38	1	1.381	0.117
Sum for V x S x I	308.17	8	38.522	3.253+
Sum of Square (Effects)	2,597.27			
Error Sum of Square	319.77	27	11.843	
Total Sum of Square	2,917.04	53		

+ Significant at 5% confidence level

++ Significant at 1% confidence level

From the analysis, Crude Sum of Square was 188,372.42, Correction for mean was 185,455.38 and Corrected Total Sum of Square was 2,917.04. Error sum of square, SSE was obtained as

SSE = 2,917.04 - 2,597.27= 319.77.

At 5% confidence level, critical value from the F - distribution table was ${}_{0.05}F_{2,27} = 3.354$ while at 1% critical value, ${}_{0.01}F_{2,27} = 5.488$. For the Two - factor interactions at 5%, ${}_{0.05}F_{4,27} = 2.728$ while at 1%, critical value was ${}_{0.01}F_{4,27} = 4.106$. For all three factor interaction at 5%, critical value was ${}_{0.05}F_{8,27} = 2.305$ while at 1%, critical value was ${}_{0.01}F_{8,27} = 3.256$

3.1 Effect of Operating Speed on Harvester Material Capacity at Constant Knife Speed

Table 2 shows that the effect of the machine operating speed was highly significant at 1% critical level, especially at low-speed levels. There was an increase in material capacity as operating speed was increased from 1 km/h to 3 km/h. A further increase to 5 km/h resulted to a drop in performance. Figures 1 - 3 are graphical representation of this phenomenon.

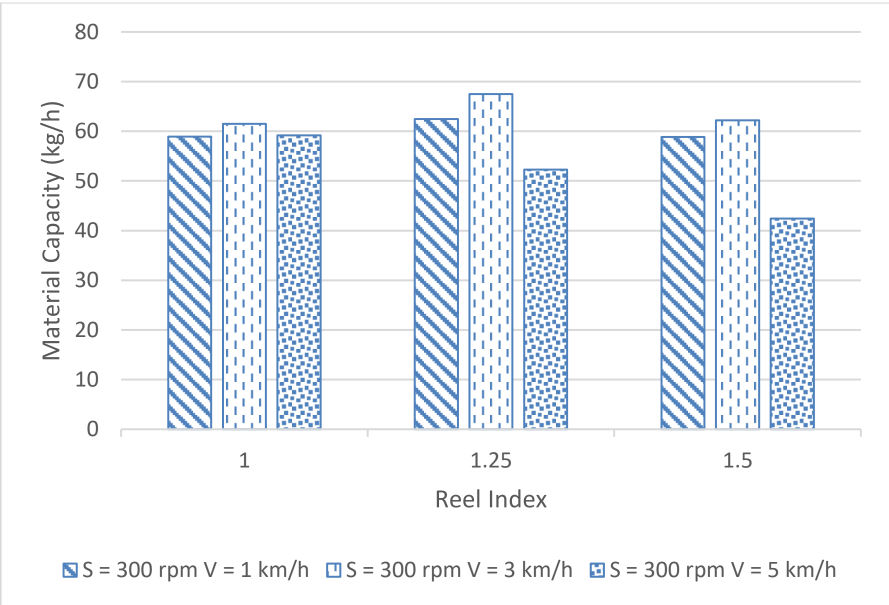

Figure 1: Effect of Operating Speed on Material Capacity Constant Knife Speed of 300 rpm

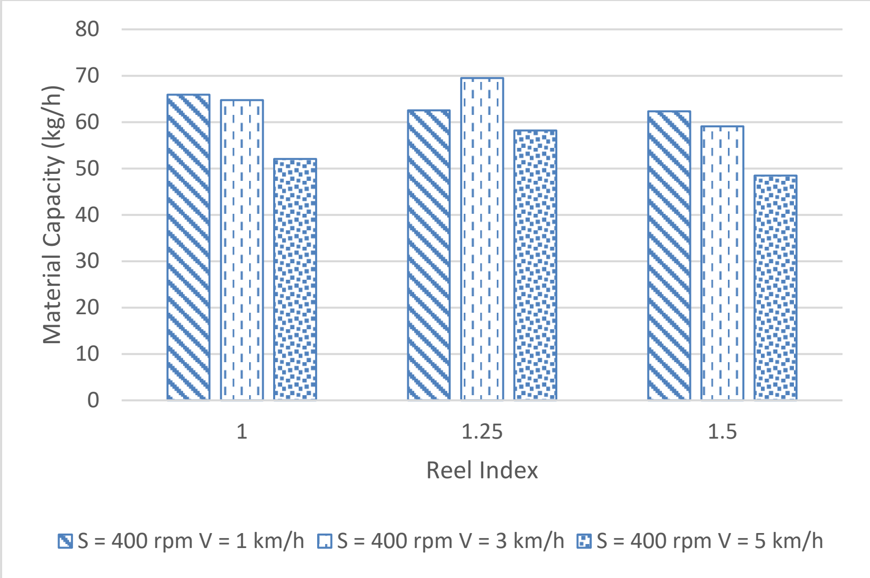

Figure 2: Effect of Operating Speed on Material Capacity at Constant Knife Speed of 400 rpm

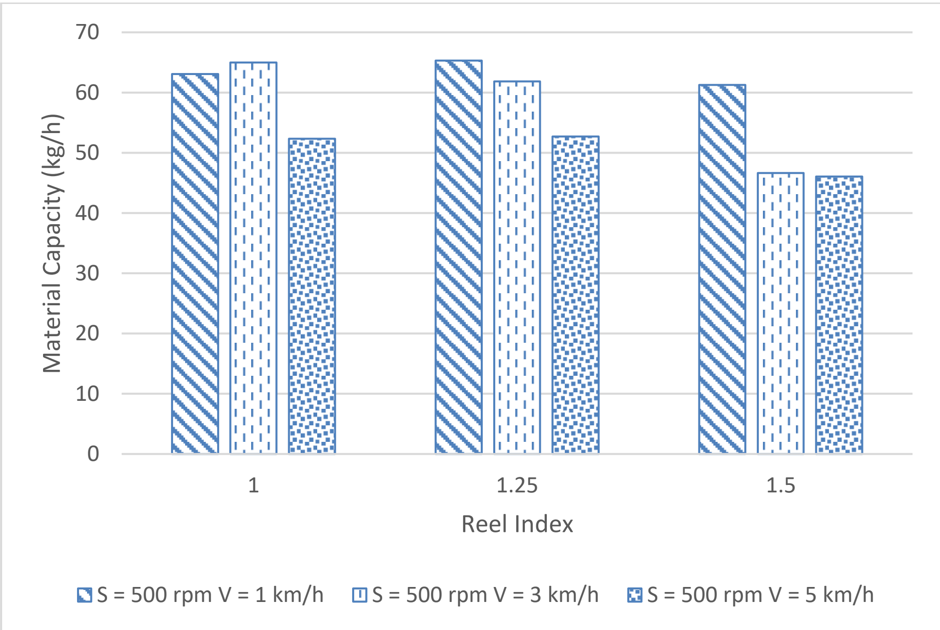

Figure 3: Effect of Operating Speed on Material Capacity at Constant Knife Speed of 500 rpm

This trend agrees with finding of several researchers. For instance, Lamp *et al* (1961) discovered that grain losses were higher at high speeds when harvesting soybeans. Ojomo *et al* (2010) observed a similar pattern while harvesting cowpea. While harvesting wheat, Qarna-uz-Zaman *et al* (1992) observed that grain losses increased with increase in harvester ground speed, and Sangwijit and Chinsuwan (2010) observed the same trend in the harvest of Khaw Dok Mali rice variety. This can be explained by the fact that at high speeds, the harvester cutting tool rides over the crop without cutting except if there is no corresponding increase in knife speed.

3.2 Effect of Knife Speed on the Harvester Material Capacity at Constant Operating Speed

The effect of knife speed (S) was low, showing a slight significance at 5 % confidence level. At a given operating speed and reel index, no clear difference in capacity of machine was observed except at low operating speed were increasing knife speed increased harvester capacity. At knife speed of 300 rpm (0.500 m/s), harvester capacity was low due to difficulty in cutting (Junsiri and Chinsuwan, 2009). There was increase in material capacity when knife speed was increased to 400 rpm (0.667 m/s). This is in agreement with the findings of Olowojola *et al* (2011). A further increase of knife speed to 500 rpm (0.833 m/s) caused a decreased in material capacity. This is shown in figures 4 - 6. The explanation for this is that as knife speed is increased to higher levels, it results in violent vibration causing severe impacts on the crop so that grains dropped to the ground before the stem is cut. Sangwijit and Chinsuwan (2010) observed the same trend while harvesting Dok Mali 105 rice variety. This shows that manipulating knife speed alone does not necessarily improve the performance of the harvester.

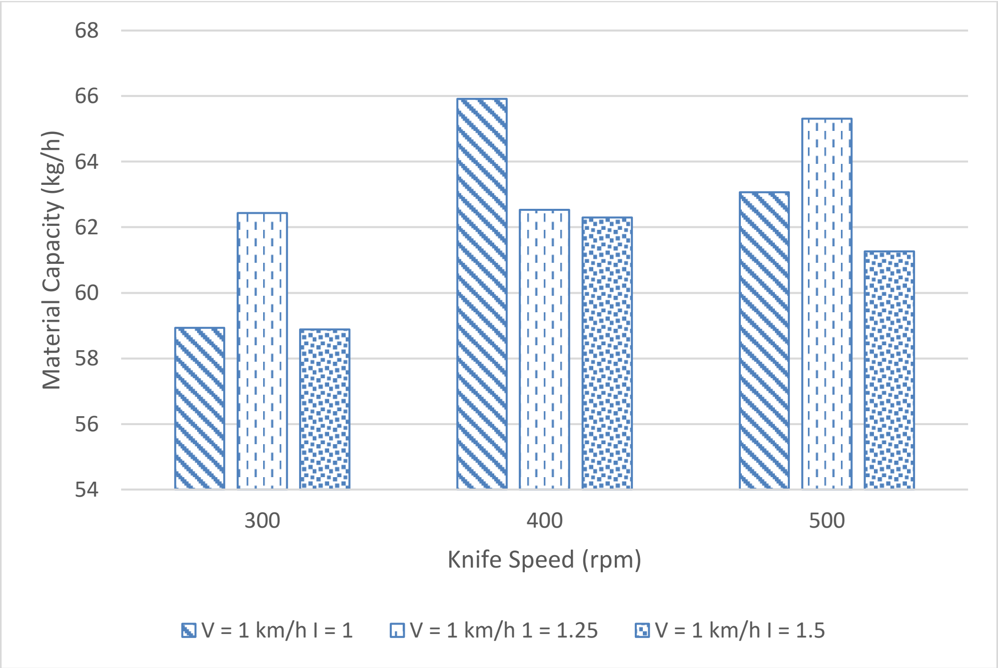

Figure 4: Effect of Knife Speed on Material Capacity at Constant Operating Speed of 1 km/h

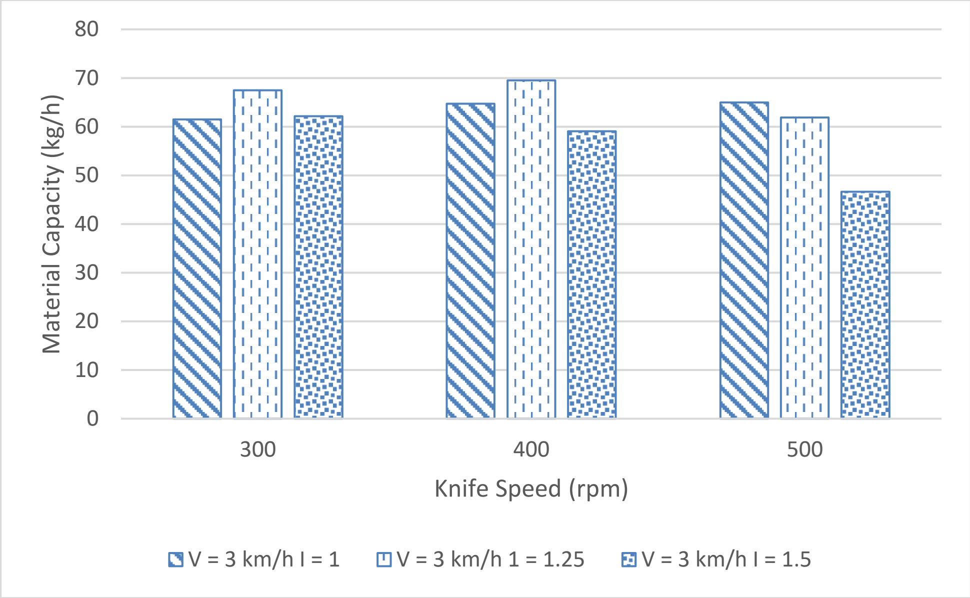

Figure 5: Effect of Knife Speed on Material Capacity at Constant Operating Speed of 3 km/h

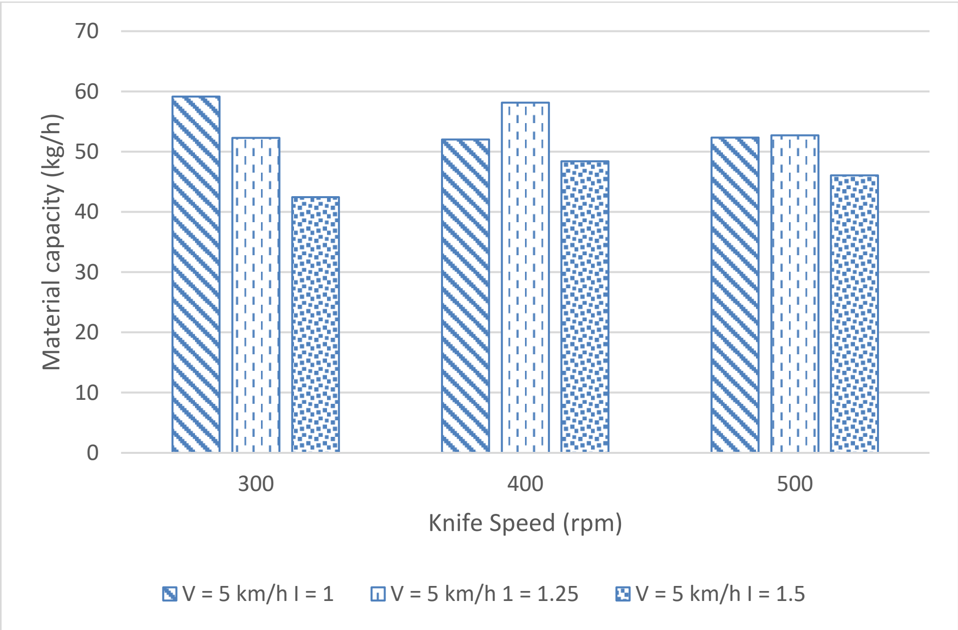

Figure 6: Effect of Knife Speed on Material Capacity at Constant Operating Speed of 5 km/h

3.3 Effect of Reel Index on the Harvester Capacity at Constant Knife Speed

The ANOVA shows that the effect of reel index was highly significant at 1 % confidence level. Best performance was observed when reel index was 1.25. At a reel index of 1.0, material capacity was observed to be low, except when operating at a forward speed of 5 km/h and knife speed of

300 rpm (0.500 m/s). The reason is the reel was not able to sweep cut material onto the conveyor thereby resulting in clogging and the machine moves past the cutting region. Chinsuwan *et al* (2004) had similar observation with combine harvester. When reel index was increased from 1.25 to 1.50, a drop in performance was observed. These results are shown graphical This is due to the fact that the reel beat violently on the uncut crop causing it to lose its grains before cutting takes place. The same was observed by Abdi and Jalali (2013) and Jalali and Abdi (2014). This shows that provided operating speed is low, increasing reel index increased the quantity of material retrieved, except when increased to 1.5. Figures 7 – 9 show these graphically.

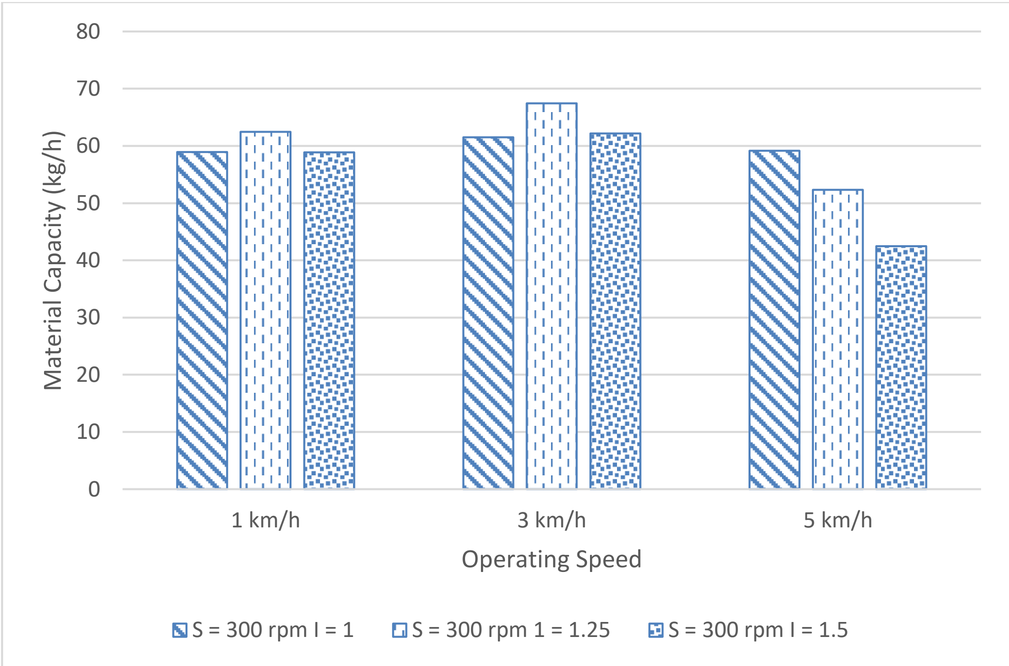

Figure 7: Effect of Reel Index on Material Capacity at Constant Knife Speed of 300 rpm

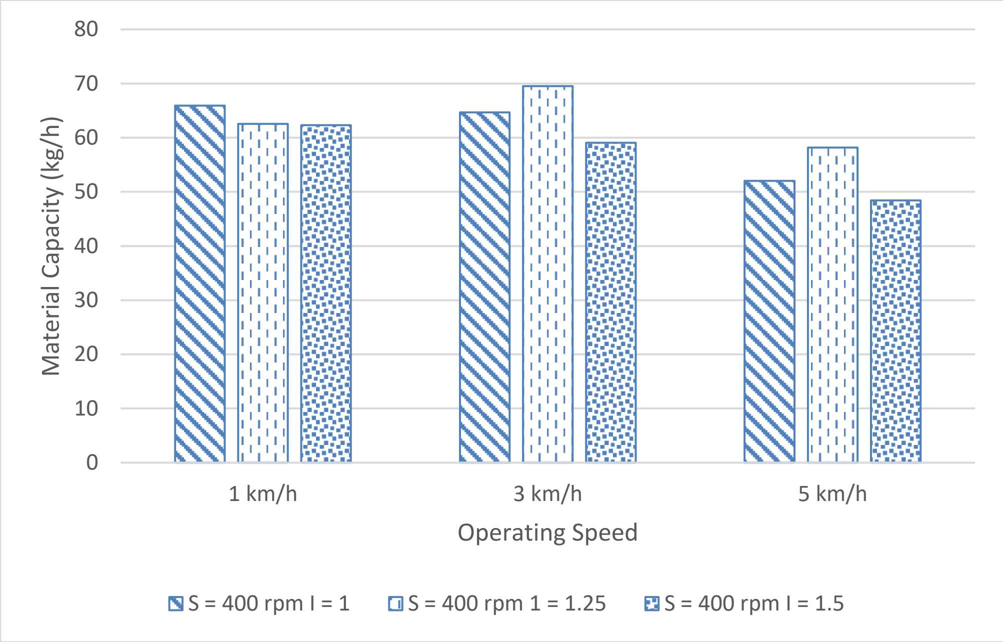

Figure 8: Effect of Reel Index on Material Capacity at Constant Knife Speed of 400 rpm

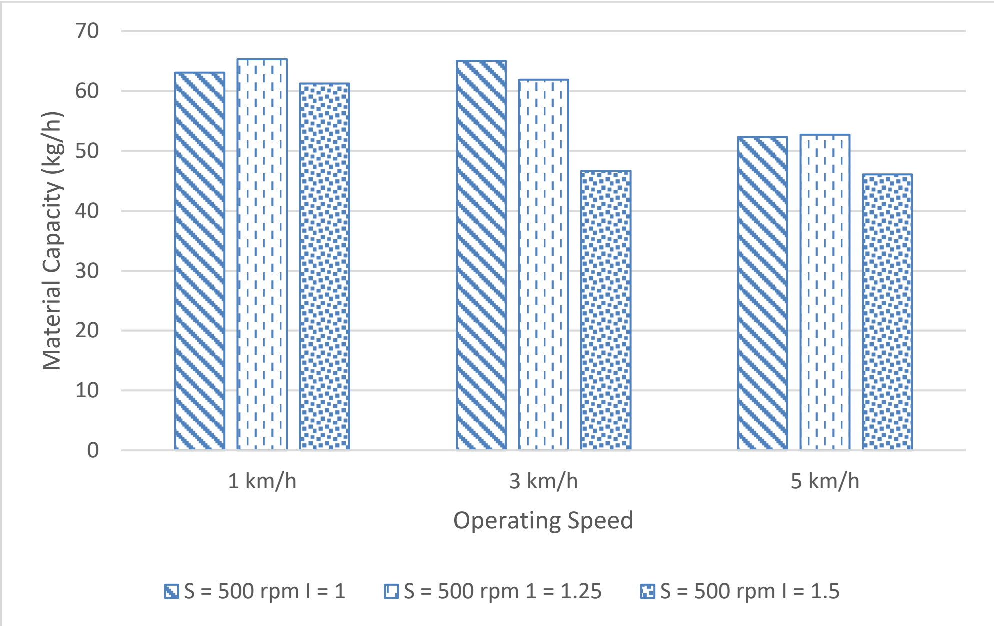

Figure 9: Effect of Reel Index on Material Capacity at Constant Knife Speed of 500 rpm

3.4 Effect of the Interactions between Machine Parameters on Material Capacity

Although operating speed had the greatest influence on the harvester performance, its setting must be done in conjunction with other parameters. The observed high significant effect of operating speed (V) was sharply brought low by its interaction with the knife speed (S), so low that it showed only a very low significance at 5 % confidence level. It was observed that each time cutting speed was high, performance is enhanced only with increase in operating speed. This shows that machine operating speed must be appropriate for any increase in knife speed.

The effect of the interaction between V and I was only slightly significant. Performance of the harvesting machine was low when operating speed and reel index were at their high levels. This is in conformity with the observation of Jalali and Abdi (2014). Abdi and Jalali (2013) agrees that the adjustment of reel speed should be between 1.5 and 1.25 of operating speed. The interaction between S and I were very low, showing no significant effect, not even at 5 % confidence level.

The three-factor interaction of all the factors was low, showing significance only at 5 % confidence level. Barring rounding errors, it could be significant at 1 % confidence level since its F-value is approximately equal to the critical value. The implication is that no single factor can independently be varied to improve performance. Lamp *et al* (1961) agree that grain losses are higher at high operating speed because of the action of the reel and the effects of knife speed. Best performance of the harvesting machine was observed when machine operating forward speed was 3 km/h, knife speed was 400 rpm and reel index was 1.25.

4.0 CONCLUSION

Although operating speed is the single most critical factor in the performance of the *acha* harvesting machine, its adjustment must be done with due consideration of knife cutting speed and reel index.

Increasing the values of forward speed, knife speed and reel index reduced the material capacity of the machine. The effects of operating speed and reel index were significant at $p \leq 0.01$, while knife speed effect was significant at $p \leq 0.05$. The interaction between operating speed and the reel index, as well as the interaction between all the three factors were very low, significant at $p \leq 0.05$.

Best performance of the machine was observed with operating speed, knife speed and reel index set at 3 km/h, 400 rpm (0.667 m/s) and 1.25 respectively.

This study therefore recommends that optimum levels obtained from the study should be used as basis for adjustment of a combine harvester for harvesting *acha* when *acha* fields become larger. It is further recommended that other factors outside the scope of this study be subjected to further studies to determine their effects on the performance of the *acha* harvesting machine.

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