Evaluation of Reliability of Prototype Tractor–Mounted Cocoyam *(Xanthosoma spp.)* Harvester

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ABSTRACT

An elevator digger type harvester for cocoyam *(Xanthosoma spp.)* was designed and fabricated at the Federal University of Technology, Akure, Nigeria using locally available materials. The harvester prototype is tractor–mounted and powered from the tractor power–take–off shaft (P.T.O). Field tests were conducted to evaluate the effect of different levels of operational parameters on the reliability of the implement. The operational parameters were forward speed (v), rake angle (α) and web speed (n). The harvester was operated at the forward speeds of 2, 4 and 6 km/h, rake angles of 15°, 20° and 25° and web speeds of 540 and 1000 rpm. These combinations were tested on a factorial basis employing a split - split plot design with three replications. The indices of reliability of the implement investigated were material failure to machine parts, clogging and machine adjustment. Cocoyam cormels were harvested from 10 m long rows of crops on clay loam soil with a spacing of 0.8 m x 0.6 m according to each treatment. The soil moisture content during field experimentation was 9.46 ± 1.02%, and bulk density was 1.18 ± 0.22 g/cm^3. The field tests revealed that machine performance was limited by delays due to clogging and machine adjustments and a high percentage of tuber damage (55%). The analysis of variance performed on the descriptive statistics for machine performance variables obtained showed that the results are significant for only machine adjustments at $P < 0.01$.

Keywords: Reliability, Breakdown, Clogging, Material failure, Failure rate, Mean time before failure, Nigeria

1. INTRODUCTION

Cocoyam constitutes a major part of food consumed in Nigeria, and also in the tropical regions of the world. The edible corms are roasted, cooked or pounded into paste for food (Phillips, 1977). The tender leaves and petioles are also eaten either as vegetables or meat supplements. Among its advantages over related tuber crops like yams and cassava is the simpler external morphology and husbandry practices; absence of a woody stem, not requiring stakes for mechanical support and vegetative propagation from crop parts that are not of considerable economic importance. In spite of the huge economic importance, production has been limited by the lack of appropriate farm power to remove the tedium associated with the manual harvesting methods. This has presented a challenge to developers of root and tuber crop harvesters.

The duration and frequency of damage to such new machine prototype during operations often serve as an indication of machine reliability. Machine failure rate is also an interesting tool to machine developers. According to ASABE Standards (2008) the failure rate (No of failures/unit of cumulative time) and the inverse figure which is the mean time before failure (MTBF) are the two easily determined reliability figures of merit. In addition it is often desirable to know which parts of a machine are most prone to breakdown during performance evaluation, so that adequate remedial measures can be taken and for further research and development.

The objective of this paper is to evaluate the reliability of a prototype tractor driven cocoyam harvester designed and fabricated using locally available materials.

2. METHODOLOGY

Following the preliminary and detailed design analysis of the harvester, the various components were fabricated at the engineering workshop using locally sourced materials. The whole machine was later assembled, tested in the laboratory and the performance was found satisfactory. A cocoyam farm was subsequently established at the research farm of the Federal University of Technology, Akure, Nigeria for field evaluation of the machine prototype. The experimental plot has a dimension of 14 m x 10 m, area of 140 m^2 and has a total of 300 stands of cocoyam extrapolated to a plant population of 20,833 plants per hectare. The experimental plot was ploughed, harrowed and ridged. Cocoyam cormels were planted at the onset of the rains in May, 2007.

2.1 Description of the Machine.

This implement is designed to work as the second stage of a three stage harvesting operation for cocoyam. The implement (Fig 1) is semi-mounted and attached to the tractor 3–point linkage while the cleaning system is powered from the tractor PTO (45kW).

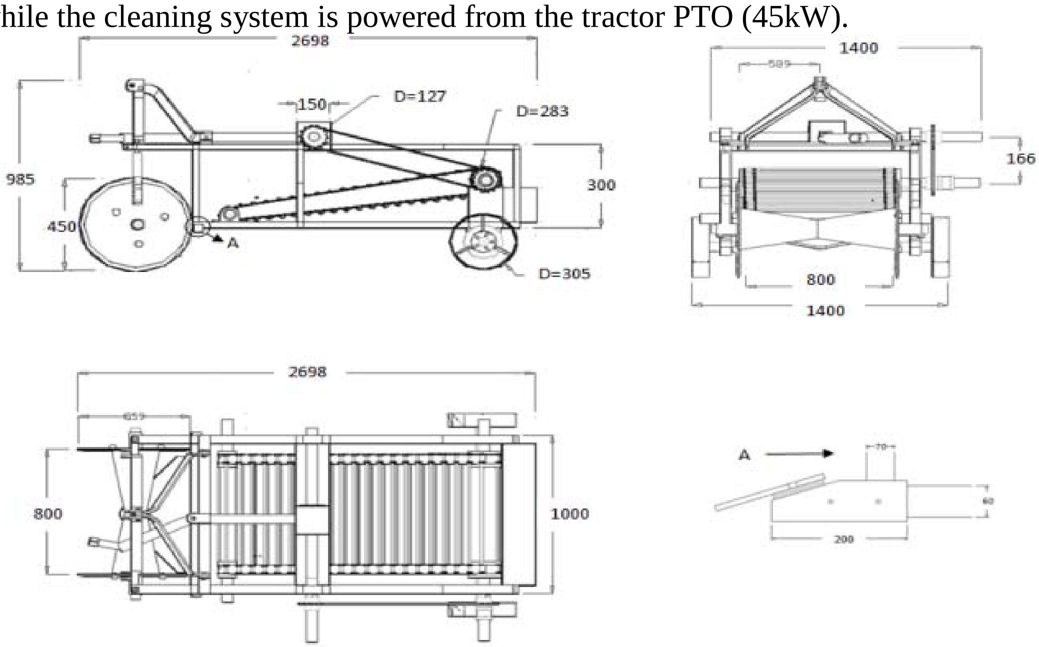
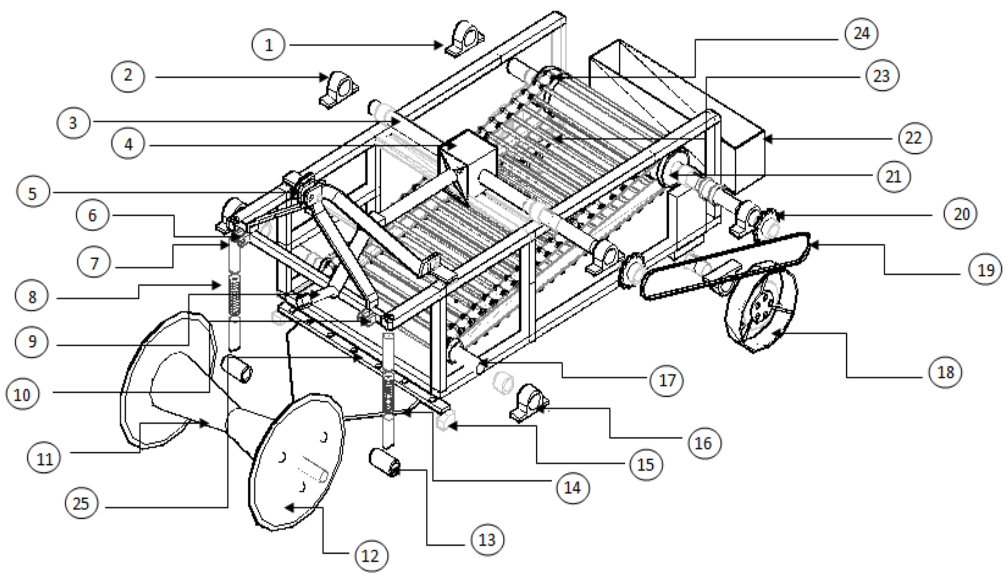


Figure 1: Orthographic drawings of the machine

The first stage is to combine a topping operation with winnowing. This stage is to remove the vegetative mass of the crop including the weeds growing on the field to prevent the clogging on the elevator digger. The major components of this machine are; the blade, ridge roller, variable angle bevel gear, and a cleaning web fabricated from flat leather belt slatted with steel rods (Fig. 2).



LEGEND

No	Name	No	Name
1	Bearing Ø 47mm	14	Blade
2	Bearing Ø 35mm	15	Blade shoe
3	Gear shaft Ø 30mm	16	Bearing
4	Gear box	17	Front roller shaft
5	Upper hitch point	18	Implement wheel
6	Lower hitch point (Left)	19	Chain
7	Compression spring housing	20	Sprocket (wheel)
8	Compression spring coils	21	Rear roller
9	P.T.O shaft coupling	22	Hopper
10	Lower hitch point (Right)	23	Rod Link
11	Ridge roller	24	Conveyor belt
12	Furrow discs	25	Blade holder
13	Bearing		

Figure 2: Model of the harvester in isometric view

2.2 Experimental Variables and Operational Parameters

The performance of the prototype harvester was evaluated under different operational conditions. The tests were to determine the machine output for the major indices of reliability that constitute the evaluation parameters, such as:

i. material failure
ii. clogging, and
iii. frequency of machine adjustments .

Three operational parameters varied during the field tests were: a) Forward speed (v) b) Rake angle (α) and PTO speed (n). The forward speeds of V_1, V_2 and V_3 in km/h used during the tests were monitored on the tractor speedometer on the instrument panel. The three levels of rake angle (α), α_1 , α_2 , α_3 were varied through a device attached to the frame while the two levels of web speed 1000 rpm (n_1), 540 rpm (n_2) were chosen directly from the tractor PTO gear system. Other soil and crop conditions were assumed constant.

2.3 Experimental Design

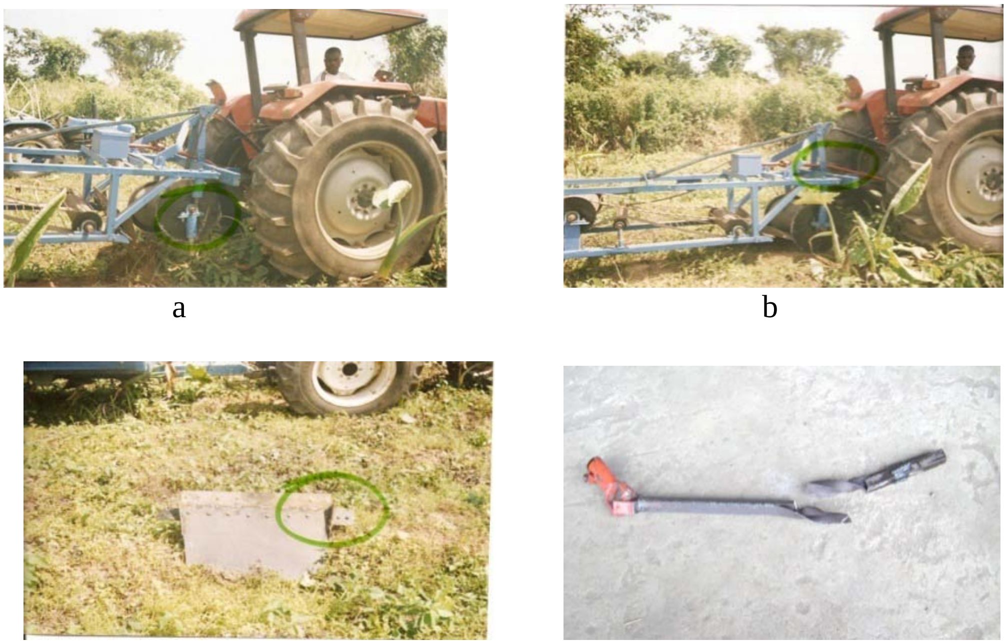
The experimental layout consists of eighteen treatments of a split plot design in a 3 x 2 x 3 (α, n and v) factorial design. This gives a total of 54 sets of data for all the parameters tested in the three replicates.

2.4 Measurement of Test Criteria

The times spent on breakdowns and delays described by the evaluation parameters were recorded in addition to the frequency of the failures and ranked. A time-motion study was used to evaluate lost time during the field operations. During the field test, the machine performance was severely limited by repeated failures on major components of the machine typical of machines during the first field tests (Maw *et al*., 2002). Some of the parts affected by these failures are shown in Figure 3 and they include:

i. broken universal shaft coupling;
ii. shearing of blade holder from the rake angle device;
iii. broken blade holder;
iv. running out of the chain from sprocket at high web speed;
v. separation of the spring from the ridge roller;
vi. misalignment of the tractor lower links i.e. damage to the stabilizer links

Data collected were analyzed to determine the effects of three experimental variables (web speed, forward speed and rake angle) on indices of reliability that include: material failure and time loss as a result of machine adjustments and breakdown. Data obtained were also analysed to evaluate significant differences within treatments. A multiple regression model was fitted for each of the response variables (machine performance indicators) using the experimental variables as independent variables.



a b

c. d.

Figure 3: Pictures of damage to machine while in operation; a-spring; b-blade holder; c-Universal shaft coupling; d-universal shaft.

3. RESULTS AND DISCUSSION

The data obtained from the field tests were analysed for the desired indicators of machine performance using the experimental variables as shown in Table 2. From the descriptive statistics in Table 1, delays due to machine adjustments are highest at T3 (609 s) and lowest with T15 (22 s) both at the highest test speed. The result shows that clogging of the machine system (CLOG) constitutes the most lost time that occurred, equivalent to an average of 5335 s (50.16%) of the total time lost during operations. This was followed by machine adjustments (MAJ) on the test implement (22.84%) and material failure and damages to machine members (BD) (27.00%). An average of 172 min. was lost as a result of these factors during the tests.

Furthermore, adjustment of test implements was timed on a point to point basis. For adjustments, the following results were obtained and ranked in order of duration of occurrence during testing, transmission 1485 s, universal shaft 802 s, frame and hitch points 340 s, conveyor 213 s and blade 32 s. The same statistic was applied to the time lost due to material failure and the following results were recorded, universal shaft 1250 s, blade 591 s, frame and linkages 386 s and conveyor 202 s. Table 2 shows further analysis of failures and adjustments to the machine during field experimentation.

Table 1: Descriptive statistics of treatments and machine performance variables (secs)

Treatment	**CLOG**	**MAJ**	**BD**
1	553 ± 174	152 ± 88	170 ±170
2	407 ± 407	114 ± 59	151 ± 151
3	137 ± 73	609 ±252	205 ± 205
4	302 ± 181	92 ± 44	102 ± 102
5	199 ±105	149 ±53	184 ± 101
6	129 ± 62	370 ± 210	108 ±108
7	528 ± 199	104 ± 55	242 ± 242
8	583 ± 369	287 ± 178	152 ± 152
9	365 ± 279	437 ± 278	106 ± 106
10	499 ± 253	35 ± 19	160 ±160
11	438 ± 60	87 + 82	108 ± 108
12	106 ± 53	60 ± 13	128 ± 128
13	342 ± 99	59 ± 59	104 ± 104
14	106 ± 53	27 ± 27	68 ± 68
15	54 ±31	22 ± 22	160 ± 160
16	222 ± 85	61 ± 61	0 ± 0
17	42 ± 22	61 ± 61	154 ±154
18	316 ± 268	140 ± 74	120 ± 120
Avg.	296 ± 44	159 ± 31	134 ± 28

Legend: CLOG- Clogging; MAJ-Machine adjustments; BD-Breakdown

From the data presented, the failure rate of the machine prototype was determined to be 2.74 failures/hr and the mean time before failure is 0.445 hrs

Table 2: Analysis of breakdowns

Nature of failure and adjustments	***Duration of occurrence (s)***			***Mean (s)***	***Rank***	***%***
	R_1	R_2	R_3			
Clogging/surcharge	5127	6636	4241	5335	1	50.16
Adjustment on implement						
a) Blade	63		32	32		
b) Conveyor	303	237	98	213		
c) Frame/Linkages	388	508	124	340		
d) Transmission	1722	1665	1068	1485		
e) Universal shaft	686	983	738	802		
Total	3162	3393	2060	2872	3	27.00
Material failure						
a) Blade	913	859		591		
b) Conveyor	147	307	152	202		
c) Frame/Linkages	766		393	386		
d) Transmission						
e) Universal shaft	1120	1902	727	1250		
Total	2946	3068	1272	2428	2	22.83

3.1 Effect of Forward Speed on Evaluation Parameters.

The times spent on clearing clogging as a result of weeds, lodgment of cormels and other dirt's as well as machine adjustments and breakdown are illustrated in Figure 4: The machine prototype recorded the highest time of machine adjustment (233 s) while moving at 6 km/h. It also recorded the lowest time (184 s) with respect to clogging at this speed. Conversely, at 2 km/h the test result show that CL was highest (445 s) and machine adjustments was lowest. Times spent on BD show that only minor differences exists between the three range of forward speeds, although the maximum value was obtained at 2 km/h followed by 138 s at 6km/h. The results with respect to the three response variables are not significant at $P < 0.05$ level. The reduction of clogging at higher speeds might be due to more rapid acceleration of soil and other particles as noticed by Kepner *et al*. (1978), the results in respect of BD seem not to be in agreement with previous works which indicated that at higher than optimum speeds, vibrations of component parts of machine is increased and therefore BD are more likely to occur (Sharma et al, 1986).

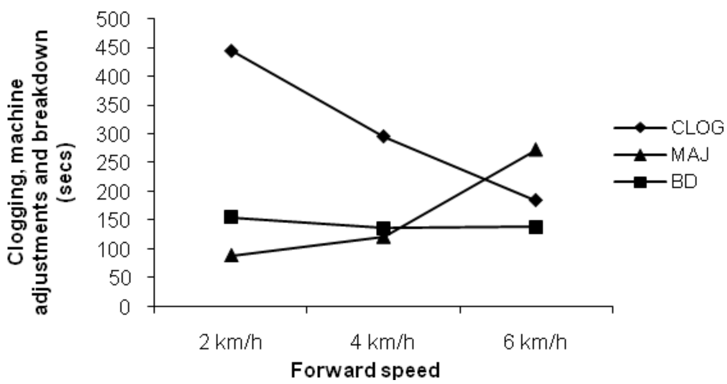


Figure 4: Effect of forward speed on clogging, machine adjustments and breakdown.

3.2 Effect of Rake Angle on Evaluation Parameters.

Figure 5 illustrate the result of machine performance indicators; clogging, machine adjustments and breakdown when compared at the three rake angles. The result indicated that clogging of the machine is highest for the three machine performance variables. This is probably due to weed infestation of the plots. This is followed by MAJ at 15° and 20°. The 25° rake angle has the least times spent on CLOG (180 s), BD (101 s) and MAJ (61 s).

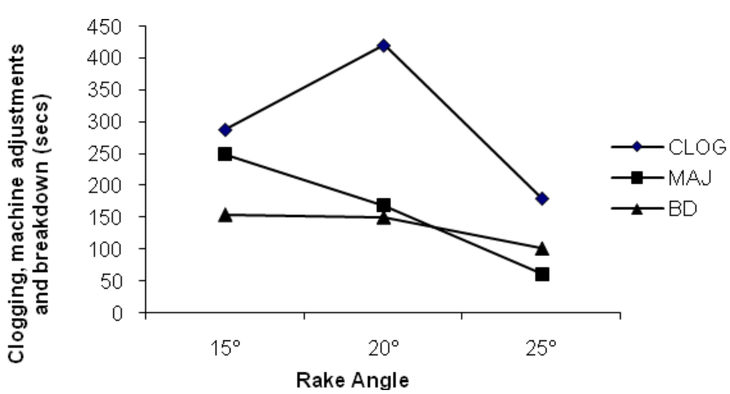


Figure 5: Effect of rake angle on clogging, machine adjustments and breakdown.

While the result in respect of CL might be attributed to a more complete cut of decayed vegetation that might cause blockage at the higher rake angle, the reason for the lower rates of BD and MAJ at this level might not be obvious yet. According to Ademosun and Agbetoye (1995) higher rake angles leads to increase in the amount of soil lifted and draught requirements. Such excess load might be expected to increase the incidence of machine breakdown and adjustments contrary to the current result.

3.3 Effects of Web Speed on Evaluation Parameters

Figure 6 shows that there are more time delays due to adjustments on the machine prototype at 1000 rpm PTO speed. Maximum values are 609 s for n_1 and 370 s for n_2. This indicates that at higher web speeds, more vibration of moving parts will predispose machine to more frequent adjustments. A plot of the effects of PTO speed on delays as a result of clogging in Figure 7 shows that apart from the pair of observation on T9, the values of n_1 are consistently higher than that of n_2 which indicated that clogging on machine parts is reduced when the PTO speed is operated at the lower level.

In Figure 8 the two values of PTO speed were compared with respect to delays arising from machine breakdown. The results indicate that the 1000 rpm PTO speed (n_1) recorded slightly higher times than the 540 rpm PTO speed (n_2) although values vary within the treatments. Breakdown times for n_1 range from 68 to 242 s while for n_2 it ranges between 0 to 184 s. The slight increase of BD at higher PTO speeds as a consequence of increased vibration and wear of the conveyor at this speed is consistent with the findings in Shippen *et al.* (1980).

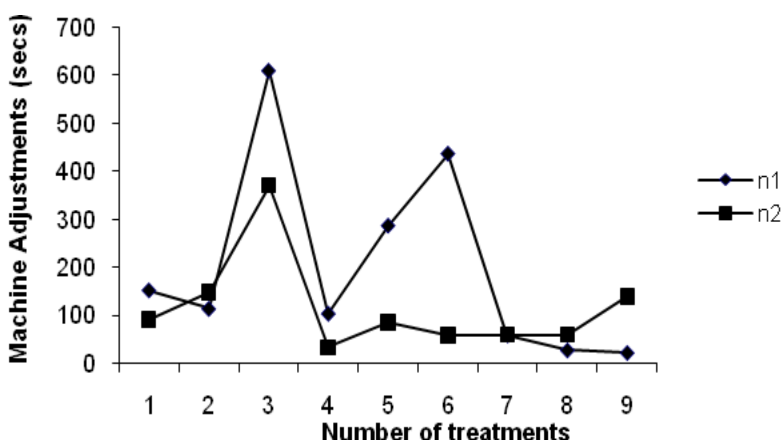


Figure 6: Effects of PTO speed on machine adjustments

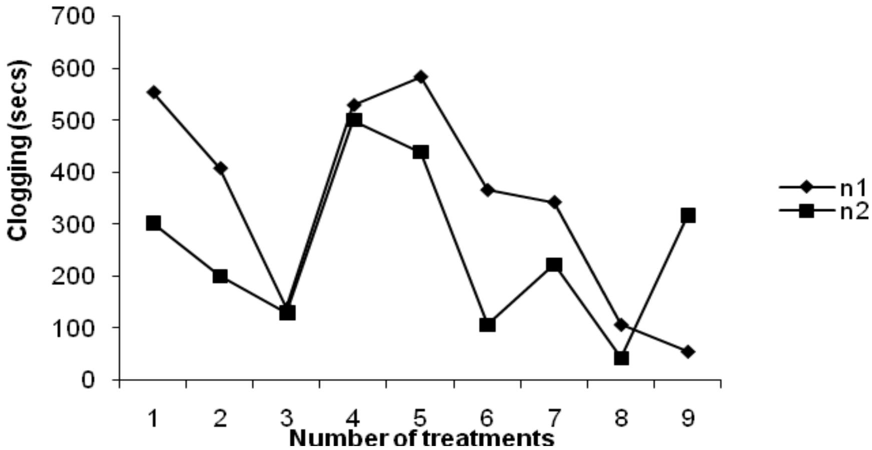


Figure 7: Effects of PTO speed on clogging

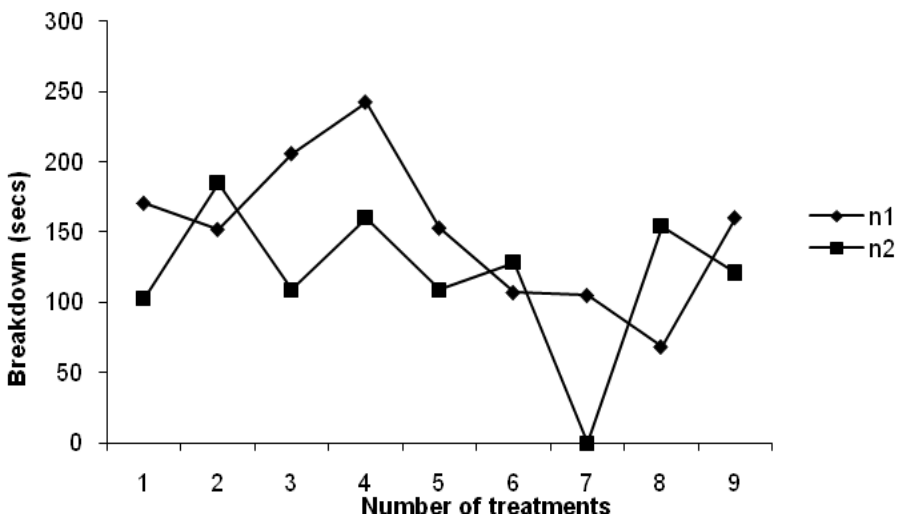


Figure 8: Effects of PTO speed on machine breakdown

The analysis of variance performed on the results presented in the descriptive statistics showed that the results are significant for only two of the response variables. Machine performance variables are significant at $P< 0.01$ for MAJ. This result is contrary to some previous studies such as Misener et al. (1984) and Sharma *et al.* (1986) where the effects of treatments on implement performance related to machine reliability especially clogging were directly affected by the selected operational parameters. The non-expression of these treatments might be due to the several stops made for repairs, adjustments and data collection during field tests, the skill of the tractor operator or other environmental factors.

Follow up tests were performed using multiple comparisons to evaluate the significance of specific treatments means on the indices of machine performance under consideration. A summary of this result indicate that only 15 % are significant for MAJ at the 5% level.

CONCLUSION

A semi mounted, power – take – off (P.T.O.) driven cocoyam harvester was designed and fabricated from locally available materials. The performance of the harvester was evaluated in the laboratory and with field tests. The tests have shown that the designed prototype cocoyam harvester satisfied most of the general and functional requirements of a machine in this category. It is simple in design and mobile as a semi mounted implement. Power and labour use is low and parts are locally available. However, in addition to high tuber damage, frequent breakdown and delays recorded during the field tests, described by the failure rate of 2.74 failures/hr and the mean time before failure of 0.445 hrs among others, represented practical limitation during the field test and they prevented the full expression of treatments. However, according to Maw *et al*. (2002) such cases are common on machines during the first field test and often result in an increased understanding of the harvester prototype.

REFERENCES

Ademosun, O. C. and Agbetoye L. A. S. (1995). Performance evaluation of digging blades for harvesting cocoyam. *Journal of Institution of Engineers, India.* 15: 64 – 66.

ASABE (2008). Test and Reliability Guidelines, ASABE Standards, ASAE. EP. 456 1986 (R2006) pp. 321

Kepner, R. A.; Bainer, R. and Bagger, E. L. (1978). Principles of Farm Machinery. 3rd Edition. Avi publishing Coy. West port, Connecticut. Pp. 117 – 134.

Maw, B. W.; Purvis, A. C.; Mullnix, B. G. (2002). Enhancing the performance of the CPES sweet onion harvester. *Transactions of American Society Agricultural Engineers* 18(1):23-28.

Misener, G.C., Mcleod, C.D. and Macmillan, L . P. (1984). Evaluation of prototype potato harvester. *Transactions of American Society Agricultural Engineers.* July edition. P.24.

Philips, T.A. (1977). Cocoyam. An Agricultural Notebook. Longman group, London. Pp. 17-18.

Sharma A.P; Verma, S. R and Bomsal, A.S. (1986). Design, development and field evaluation of an oscillatory potato digger. *Agric. mech. In Asia, Africa and Latin America 17 (3): 60.*

Shippen, J. M ; Ellin C.R. and Clover C. H.(1980). Basic farm machinery. 3rd Edition, Pergamon Press, Oxford.Pp. 235-249.