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Perfomance Evaluation of a Modified I.A.R. Multicrop Thresher

Muna N.H. Muhammed, U.S., El-Okene, A.M. and Isiaka, M.

Abstract— A modified Institute for Agricultural Research (IAR) multicrop thresher was evaluated for threshing performance in Agricultural Engineering Department, Ahmadu Bello University, Zaria. Unthreshed soybean crop (samsoy-2 soybean variety) and unthreshed millet crop (SOSAT C88 Millet variety) were used for the experiments. The machine was subjected to three experimental treatments and three replications were made for each threshed sample. A two days interval was given between threshing to allow the crop to dry naturally to different moisture content level. Maximum Feed rate, Threshing efficiency, Cleaning efficiency, Scatter loss, Grain damage and Throughput capacity of 14 kg/min, 99.98 %, 99.71 %, 12.18 %, 0.62 %, and 520.6 kg/hr respectively were attained with millet and 12 kg/min, 100 %, 97.26 %, 7.25 %, 6 %, and 205 kg/hr respectively were attained with Soybean. Mean Threshing efficiency, Cleaning efficiency, Scatter loss, Grain damage and Throughput capacity of 98.53 %, 94.61 %, 9.67 %, 0.20 %, and 324.11 kg/hr respectively were attained with millet and 99.27 %, 86.19 %, 3.97 %, 0.60 %, and 118.43 kg/hr respectively were attained with Soybean. Graphs of D. M. R. Relationships indicate that throughput capacity is directly proportional to speed and feed rate but inversely proportional to moisture contents; threshing efficiency is directly proportional to speed but inversely proportional to feed rate and moisture contents; cleaning efficiency is directly proportional to speed but inversely proportional to feed rate and moisture content; scattered grain loss is directly proportional to speed but inversely proportional to feed rate and moisture content; grain damage is directly proportional to speed and moisture content above 13.5 % wet basis but inversely proportional to feed rate.

Index Terms— Determination, Evaluation, Multicrop, Performance, Relationships, Thresher, Threshing.

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1 Introduction

Performance evaluation of Institute for Agricultural Research (IAR) multicrop thresher involved determination of the following parameters: throughput capacity (kg/hr), threshing efficiency (%), cleaning efficiency (%), scattered grain loss (%), damaged grain (%) and their relationships with three experimental treatments: cylinder speed, feed rate and crop moisture content.

1.1 Objectives of the Study

The aim of the study was to evaluate the threshing performance of IAR multicrop thresher.
The specific objectives are:

1 to evaluate the performance of the multi-crop thresher with Samsoy-2 Soybean variety and SOSAT C88 Millet variety as the test materials.
2 to determine the throughput capacity, threshing efficiency, cleaning efficiency, scattered grain loss and damaged grain of the multi-crop thresher.
3 to determine the relationships between cylinder speed, feed rate and crop moisture content on throughput capacity, threshing efficiency, cleaning efficiency, scattered grain loss and damaged grain.

2 DESCRIPTION OF THE MODIFIED IAR MULTICROP THRESHER

The modified Institute for Agricultural Research (IAR) multicrop thresher is a machine designed to thresh many different types of grain crops such as Soybean, Millet, Maize, Sorghum, Sunflower, Rice and Wheat. The thresher can be powered by electric motor, diesel/ petrol engines as well as tractor power take off (PTO) shaft. It was design such that the direction of flow for grains after threshing was vertical by a combination of impact by the bitters and gravitational force acting on it while the direction of flow for chaffs and un-threshed material was lateral by a combination of impact by the bitters and suction generated by the chaff throwers positioned at the end of the threshing cylinder.

The machine consists of the following components: A structural frame; top cover with feed hopper, step-shaped threshing cylinder; perforated concave sieve plate with horizontal knife edge flat bars; centrifugal blower, shaker mechanism, power transmission unit and bottom tray with flat sieve plate to collect grainThe machine was constructed from gauge 16 and 18 mild steel metal sheets. The threshing unit is located directly below the feed hopper and consists of the step-shaped threshing cylinder with bitters and chaff thrower. A perforated concave sieve plate with horizontal cutting knives was placed below the threshing cylinder for primary separation of grains from chaff. Clearance between the free end of the beaters and concave sieve plate was maintained at 20 mm for soybean threshing and 10 mm for millet threshing. The blower unit is located below the concave sieve plate and consists of a four blade centrifugal fan that blow's off the lighter chaff and dust from the grain as it flows down a conveyor on to a sieve plate on the grain collector. The shaker tray at the bottom of the machine is connected to a shaker mechanism to further separates grains and chaff of similar weight as the shaker oscillates. The clean grain was then collected at the bottom tray and conveyed through the grain outlet. All power transmission took place at one end and it consists of pulleys, V-belts and a 7Hp (5.22 kW) diesel engine mounted on a structural frame. Two 14 inch tires were fixed at the base of the frame for easy mobility. plate 1 illustrates the rear view of the modified IAR multicrop thresher.

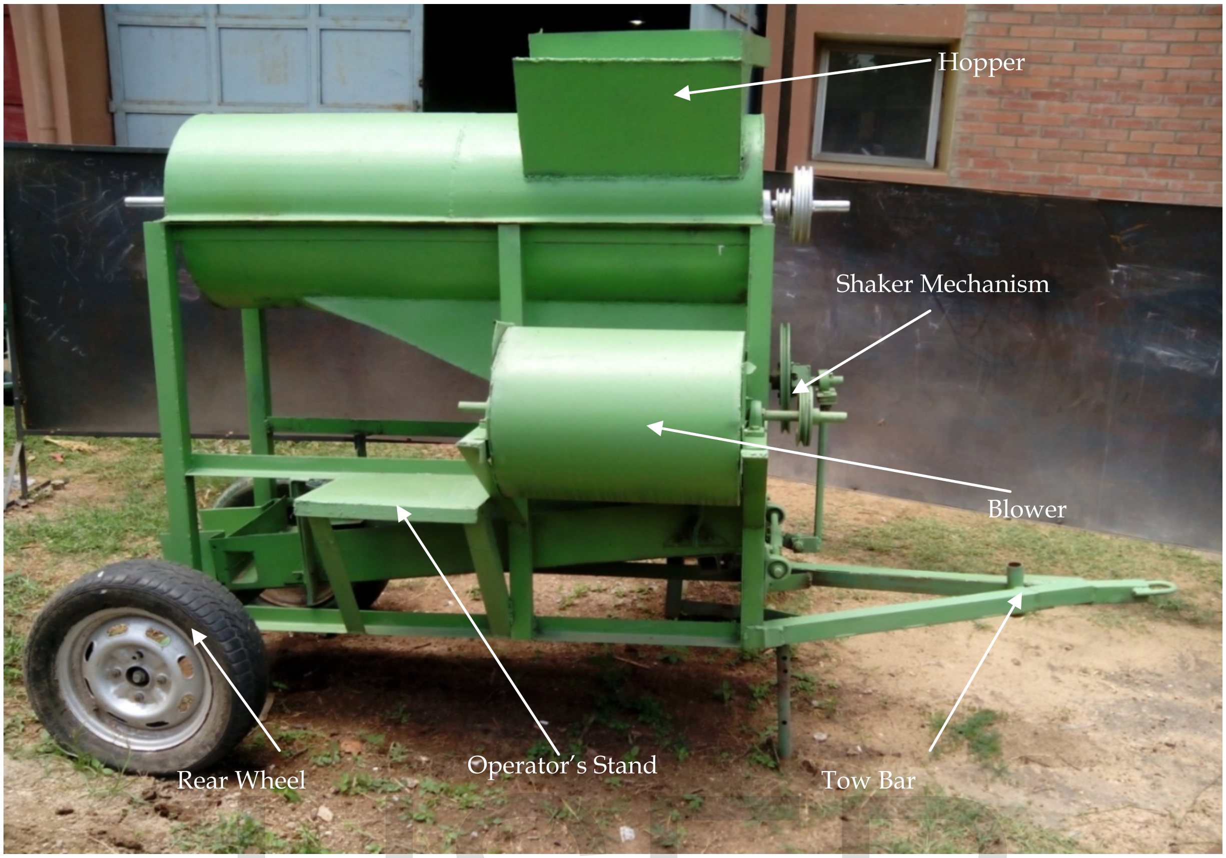

Plate 1: Rear view of the modified IAR multicrop thresher illustrating the Hopper, Shaker mechanism, Blower, Tow bar, Operator's Stand, and Rear wheels

3 MATERIALS AND METHODS

3.1 Test materials

The test materials were: unthreshed soybean crop (samsoy-2 soybean variety) and unthreshed millet crop (SOSAT C88 Millet variety).

3.2 Test apparatus

The test apparatus were: mettler balance (model pn 1210), 7Hp (5.22 kW) 4-stroke water cooler diesel engine, diesel, digital tachometer (tz5000 model), digital stop watch, digital scale (with 0.01g sensitivity) and oven.

3.3 Performance Evaluation

The machine was evaluated in the Department of Agricultural Engineering, Ahmadu Bello University, Zaria. It involved determination of the following parameter and their relationships with cylinder speed, feed rate and crop moisture content:

1. throughput capacity (kg/hr)
2. threshing efficiency (%)
3. cleaning efficiency (%)
4. scattered grain loss (%)
5. damaged grain (%)

3.3.1 Determination of crop moisture content

The crop moisture content on wet basis (in the range 10 - 16 %) was determined by oven-dry method according to ASAE Standard (1983) thus:

$$M_{wb} = [(W_w - W_d)/W_w]x100 \quad (1)$$

Where,

W_w = weight of wet samples before drying (g)
W_d = weight of sample after drying (g)
M_{wb}= moisture content on wet basis (%)

3.3.2 Determination of throughput capacity

The throughput capacity of the machine was evaluated according to Mohammed (2009):

$$C = Q_T / t \quad (2)$$

Where,

C = throughput capacity (Output) (kg/hr).
Q_T = weight of whole grain collected in unit time (kg).
t = threshing time (hr)

3.3.3 Determination of threshing efficiency

The threshing efficiency of the machine was evaluated according to Mohammed (2009):

$$\eta_T = [100 - (U_M / T_M)]x100 \quad (3)$$

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Where,

η_T = threshing efficiency (%)

U_M = weight of unthreshed material in unit time (kg)

T_M = weight of total material input in unit time (kg)

3.3.4 Determination of cleaning efficiency

The cleaning efficiency of the machine was evaluated according to Mohammed (2009):

$$\eta_C = (B/D)x100 \quad (4)$$

Where,

η_C = cleaning efficiency (%)

B = weight of whole clean grain in unit time at grain outlet (kg)

D = weight of whole material collected in unit time at the grain outlet (kg)

3.3.5 Determination of scattered grain loss

The scattered grain loss of the machine was evaluated according to Mohammed (2009):

$$S_g = (E/T_G)x100 \quad (5)$$

Where,

S_g =scattered grain loss (%)

E = weight of scattered grain collected in unit time (kg)

T_G = total grain input per unit time by weight (kg)

3.3.6 Determination of damage grain

The damage grain of the machine was evaluated according to Mohammed (2009):

$$Dg = (G/100)x100 \quad (6)$$

Where,

D_g = damage grain (%)

G = weight of visually damaged grain isolated in 100 grams of threshed sample (g)

3.4 Data Collection

As the materials were harvested from farm the initial moisture content wet bases was determined to be 18.2 %. This moisture content was considered not good for threshing as most of the materials pass out un-threshed when fed into the machine. So the material was closely monitored daily until its moisture content reaches 15.8 % wet basis where threshing was possible. The moisture content was varied as the crop dried naturally. The materials to be threshed were first weighed according to feed rate and then sun dried for two hours to warm them. Samples were randomly selected from each and taken to the laboratory for moisture content determination. Three replications were made for each threshed sample and a two days interval was given between threshing to allow the crop to dry naturally to different moisture content. During threshing, sacks were placed at both chaff outlets. One was placed at the top chaff outlet to collect chaffs, unthreshed materials and grain losses. Another was placed at the blower outlet to collect chaffs and grain losses. Also one was placed at the grain outlet to collect threshed grains, broken grains and chaff. The contents of the sacks were emptied, winnowed manually and weighed to obtain the weights of clean grains, unthreshed materials, chaffs, broken grains and grain losses. 3000 kg of soybean crop and 3750 kg of millet were used for the experiments. Plate 2 and 3 illustrates soybean and millet experimental materials respectively sun dried prior to threshing.

Plate 2: Illustration of soybean experimental materials sun dried for few hours to warm them prior to threshing.

Plate 3: Illustration of millet experimental materials sun dried for few hours to warm them prior to threshing.

3.5 Experimental Treatments

For both crops the multicrop thresher was subjected to three experimental treatments. Thus the following treatments were considered for millet threshing:

1. Moisture content (M) at 5 levels: M1 = 10.6 %, M2 = 11.9 %, M3 = 13.2 %, M4 = 14.3 % and M5 = 15.8 %.
2. Cylinder speed (S) at 5 levels: S1 = 550 rpm (12.1 m/s), S2 = 650 rpm (14.3 m/s), S3 = 750 rpm (16.5 m/s), S4 = 850 rpm (18.7 m/s) and S5 = 909 rpm (20 m/s).

3. Feed rate (F) at 5 levels: F1 = 6 kg/min, F2 = 8 kg/min, F3 = 10 kg/min, F4 = 12 kg/min and F5 = 14 kg/min

   Thus the following treatments were considered for soybean threshing:

1. Moisture content (M) at 5 levels: M1 = 10.8 %, M2 = 12.2 %, M3 = 13.5 %, M4 = 14.6 % and M5 = 15.4 %.
2. Cylinder speed (S) at 5 levels: S1 = 550 rpm (12.1 m/s), S2 = 650 rpm (14.3 m/s), S3 = 750 rpm (16.5 m/s), S4 = 850 rpm (18.7 m/s) and S5 = 909 rpm (20 m/s).
3. Feed rate (F) at 5 levels: F1 = 4 kg/min, F2 = 6 kg/min, F3 = 8 kg/min, F4 = 10 kg/min and F5 = 12 kg/min

3.6 Experimental Design and Data Analysis

A randomized complete block design (RCBD) was used. The experimental unit was grouped into 5 blocks and treatments were assigned randomly within a block. SAS Statistical package was used to analyze the data. The difference between the means and variables was compared using ANOVA and Duncan's multiple range tests.

4 RESULTS AND DISCUSSION

4.1 Throughput Capacity

Throughput capacity evaluates the quantity of clean grain collected at the grain outlet of the multicrop thresher for the total quantity of crop fed per hour. It ranges from 166.6 kg/hr to 520.6 kg/hr for millet and from 42 kg/hr to 205 kg/hr for soybean when threshing was done at different levels of cylinder speed, feed rate and moisture content. The analysis of variance (ANOVA) of throughput for millet and soybean are shown on tables 1 and 2 respectively. The ANOVA indicates that the differences between the means were highly significant. The graphs of Duncan's Multiple Range (DMR) relationship indicates that throughput increases with increase in speed and feed rate, Fig. 1 (a and b), Fig. 2 (a and b) respectively; throughput decreases with increase in moisture content, Fig. 3(a and b). These results were similar to those of Osueke (2013).

4.2 Threshing Efficiency

Threshing efficiency evaluates the percentage of grains detached from the crop fed by the beaters of the multicrop thresher. It ranges from 94.02 % to 99.98 % for millet and from 95.6 % to 100 % for soybean when threshing was done at different levels of cylinder speed, feed rate and moisture content. The ANOVA of threshing efficiency for millet and soybean are shown on tables 3 and 4 respectively. The ANOVA indicates that the differences between the means were highly significant. The graphs of Duncan's Multiple Range relationship indicates that threshing efficiency increases with increase in speed, Fig. 4 (a and b); threshing efficiency decreases with increase feed rate and moisture content, Fig. 5 (a and b), Fig. 6 (a and b) respectively. These results were similar to those of Osueke (2013).

4.3 Cleaning Efficiency

Cleaning efficiency evaluates the percentage of clean grain collected at the grain outlet. It indicates the effectiveness of the sieves, the blower and the shaker to separate grains from chaffs as they flow to the bottom of the thresher. It ranges from 84.27 % to 99.71 % for millet and from 72.34 % to 97.26 % for soybean when threshing was done at different levels of cylinder speed, feed rate and moisture content. The ANOVA of cleaning efficiency for millet and soybean are shown on tables 5 and 6 respectively. The ANOVA indicates that the differences between the means were highly significant. The graphs of Duncan's Multiple Range relationship indicates that cleaning efficiency increases with increase in speed, Fig. 7 (a and b); cleaning efficiency decreases with increase feed rate and moisture content, Fig. 8 (a and b), Fig. 9 (a and b) respectively. These results were similar to those of Osueke (2013).

4.4 Scattered Grain Loss

Scattered grain loss (S_g) includes: threshed grains sucked out with chaffs at the top chaff outlet, plus threshed grains falling out of the hopper, plus threshed grains blown away with chaffs by the blower, plus threshed grains falling from the shaker during threshing and cleaning. It ranges from 5.77 % to 12.18 % for millet and from 1.54 % to 7.25 % for soybean when threshing was done at different levels of cylinder speed, feed rate and moisture content. The ANOVA of scattered grain loss for millet and soybean are shown on tables 7 and 8 respectively. The ANOVA indicates that the differences between the means were highly significant. The graphs of Duncan's Multiple Range relationship indicates that grain loss increases with increase in speed Fig. 10 (a and b); grain loss decreases with increase feed rate and moisture content, Fig. 11 (a and b), Fig. 12 (a and b) respectively.

4.5 Grain Damage

Grain damage evaluates all the broken grains present within the clean grains collected at the throughput. It was as a result of direct impact between the beaters of the threshing cylinder and the crop fed. It ranges from 0.001 % to 0.62 % for millet and from 0.001 % to 6 % for soybean when threshing was done at different levels of cylinder speed, feed rate and moisture content. The ANOVA of grain damage for millet and soybean are shown on tables 9 and 10 respectively. The ANOVA indicates that the differences between the means were highly significant. The graphs of Duncan's Multiple Range relationship indicates that grain damage increases with increase in speed, Fig. 13 (a and b); grain damage decreases with increase feed rate, Fig. 14 (a and b); grain damage decreases greatly as moisture content decreases from 15.8 % to 13.5 %, then increases gently as moisture content decrease further from 13.5 % to 10.6 %, for both millet and soybean alike, Fig. 15 (a and b), These results were similar to those of Osueke (2013).

TABLE 1

ANOVA OF THROUGHPUT FOR SOSAT C88 MILLET VARIETY

Source	Degree of Freedom	Sum of Squares	Mean Squares	F Value
Replication	2	1.47		
Moisture (M)	4	32850.78	8212.70	10056.3 **
Speed (S)	4	3197133.97	799283.49	978706 **
Feed rate (F)	4	16764.92	4191.23	5132.07 **
M × S	16	2274.61	142.16	174.08 **
M × F	16	1465.07	91.57	112.12 **
F × S	16	25563.07	1597.69	1956.34 **
M × S × F	64	3763.91	58.81	72.01 **
Error	248	202.54	0.82	
Total	374	3280020.32		

** = Highly significant
R-Square = 0.999, Coeff. Var = 0.279, Root MSE = 0.904,
Mean Throughput= 324.11 kg/hr

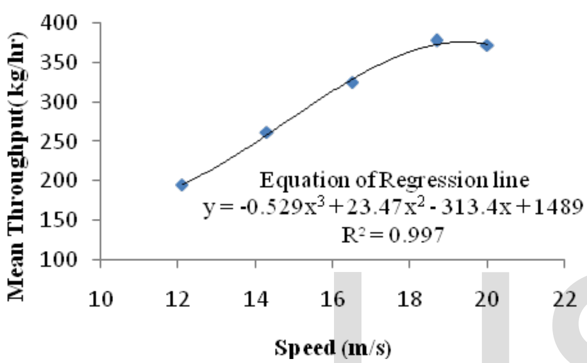

Fig. 1a: Graph of D. M. R. Relationship between Speed and Mean Throughput at Constant Feed Rate and Moisture Content for millet

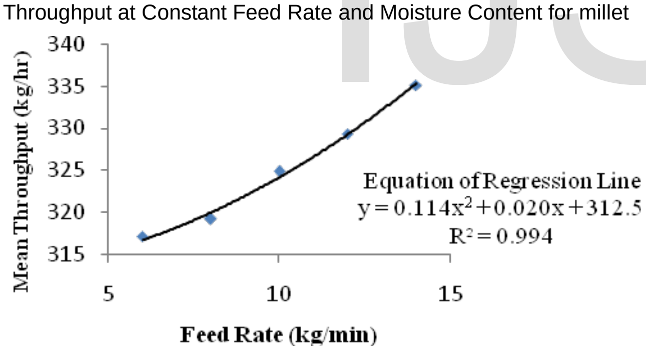

Fig. 2a: Graph of D. M. R. Relationship between Feed Rate and Mean Throughput at Constant Speed and Moisture Content for millet

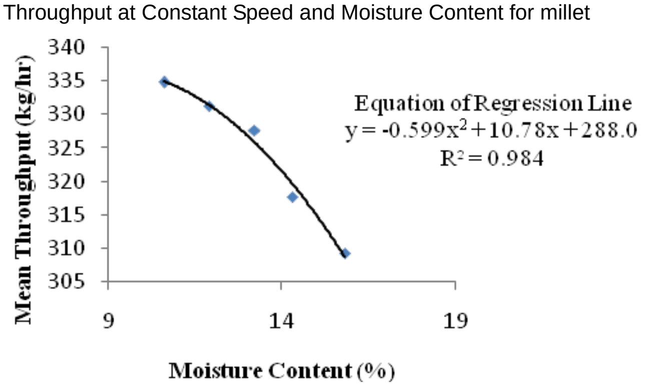

Fig. 3a: Graph of D. M. R. Relationship between Moisture Content and Mean Throughput at Constant Feed Rate and Speed for millet

TABLE 2
ANOVA OF THROUGHPUT FOR SAMSOY-2 SOYBEAN VARIETY

Source	Degree of Freedom	Sum of Squares	Mean Squares	F Value
Replication	2	0.00		
Moisture (M)	4	56413.90	14103.47	5.01E15 **
Speed (S)	4	19863.50	4965.88	1.76E15 **
Feed rate (F)	4	699203.80	174800.95	6.21E16 **
M × S	16	5490.67	343.17	1.22E14 **
M × F	16	7819.58	488.72	1.74E14 **
F × S	16	6960.51	435.03	1.54E14 **
M × S × F	64	4495.19	70.24	0.49E13 **
Error	248	0.00	0.00	
Total	374	800247.13		

** = Highly significant
R-Square = 1, Coeff. Var = 1.42E-6, Root MSE = 1.68E-6,
Mean Throughput= 118.43 kg/hr

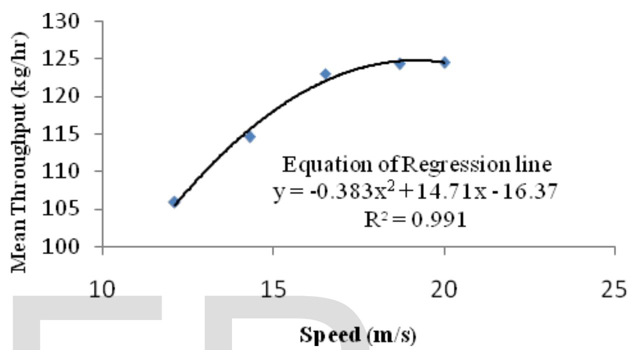

Fig. 1b: Graph of D. M. R. Relationship between Speed and Mean Throughput at Constant Feed Rate and Moisture Content for soybean

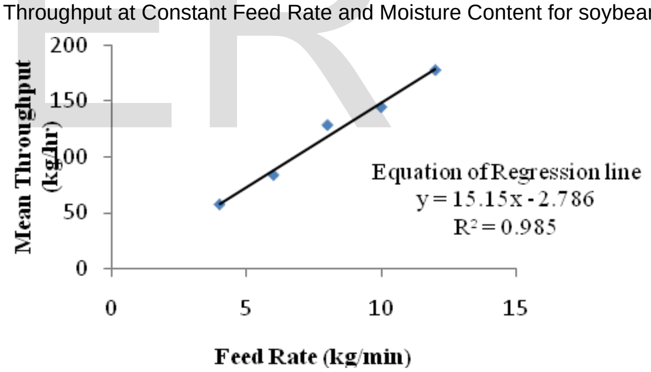

Fig. 2b: Graph of D. M. R. Relationship between Feed Rate and Mean Throughput at Constant Speed and Moisture Content for soybean

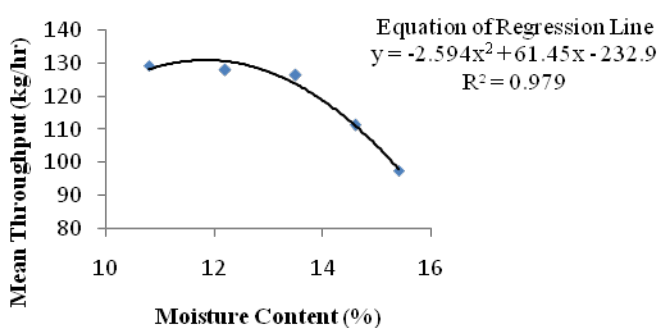

Fig 3b: Graph of D. M. R. Relationship between Moisture Content and Mean Throughput at Constant Feed Rate and Speed for soybean

TABLE 3
ANOVA OF THRESHING EFFICIENCY FOR SOSAT C88 MILLET VARIETY

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Source	Degree of Freedom	Sum of Squares	Mean Squares	F Value
Replication	2	0.003		
Moisture (M)	4	812.649	203.162	46041.8**
Speed (S)	4	7.271	1.818	411.93**
Feed rate (F)	4	16.259	4.065	921.19**
M × S	16	2.793	0.175	39.56**
M × F	16	8.705	0.544	123.30**
F × S	16	3.761	0.235	53.27**
M × S × F	64	6.600	0.103	23.37**
Error	248	1.094	0.004	
Total	374	859.136		

** = highly significant

R-Square = 0.999, Coeff. Var = 0.067, Root MSE = 0.066, Mean Threshing Efficiency = 98.53%

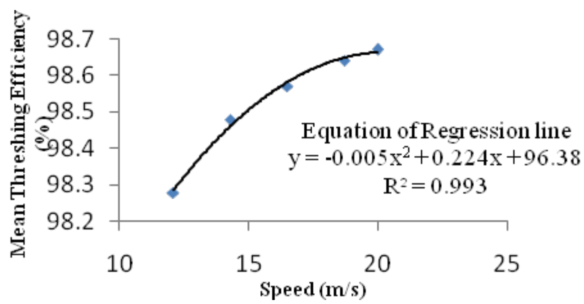

Fig. 4 a: Graph of D. M. R. Relationship between Speed and Mean Threshing Efficiency at Constant Feed Rate and Moisture Content for millet

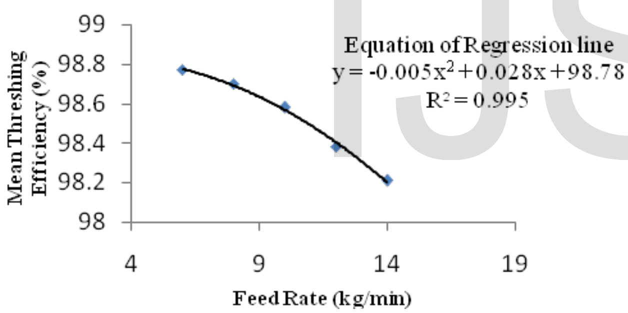

Fig. 5 a: Graph of D. M. R. Relationship between Feed Rateand Mean Threshing Efficiency at Constant Speed and Moisture Content for millet

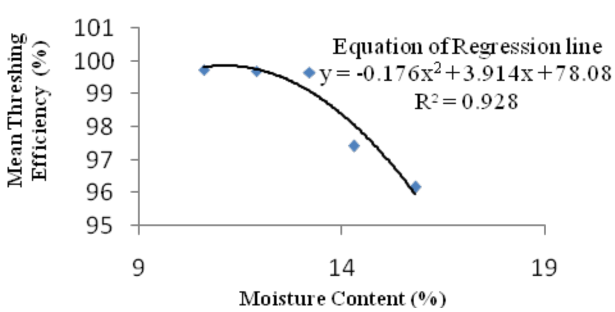

Fig. 6 a: Graph of D. M. R. Relationship between Moisture Content and Mean Threshing Efficiency at Constant Feed Rate and Speed for millet

TABLE 4

ANOVA OF THRESHING EFFICIENCY FOR SAMSOY-2 SOYBEAN VARIETY

Source	Degree of Freedom	Sum of Squares	Mean Squares	F Value
Replication	2	0.00		
Moisture(M)	4	329.45	82.363	Infinity**
Speed (S)	4	5.13	1.283	Infinity**
Feed rate (F)	4	4.68	1.171	Infinity**
M × S	16	7.84	0.490	Infinity**
M × F	16	7.03	0.440	Infinity**
F × S	16	0.03	0.002	Infinity**
M × S × F	64	0.12	0.002	Infinity**
Error	248	0.00	0.000	
Total	374	354.29		

** = highly significant

R-Square = 1, Coeff. Var = 0, Root MSE = 0,
Mean Threshing Efficiency = 99.27 %

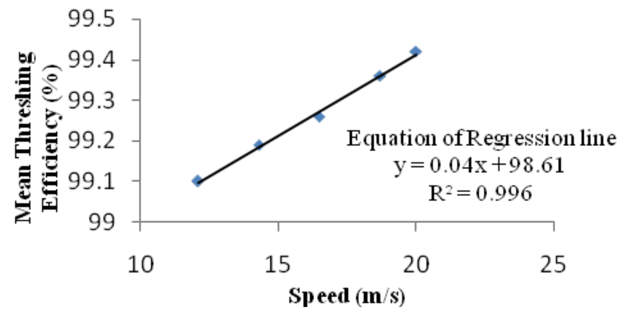

Fig. 4 b: Graph of D. M. R. Relationship between Speed and Mean Threshing Efficiency at Constant Feed Rate and Moisture Content for soybean

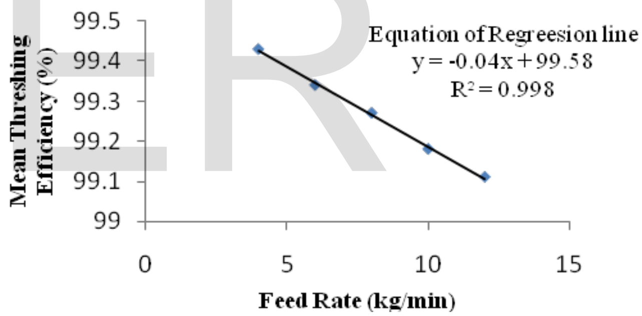

Fig. 5 b: Graph of D. M. R. Relationship between Feed Rate and Mean Threshing Efficiency at Constant Speed and Moisture Content for soybean

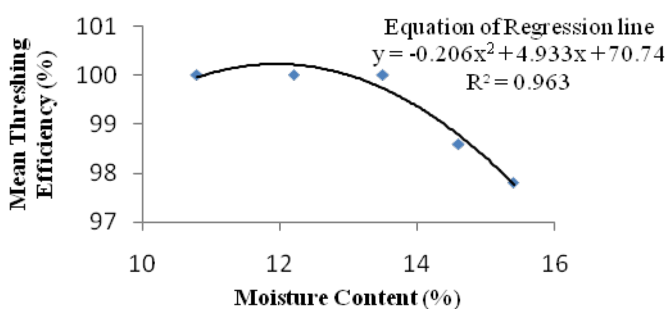

Fig. 6 b: Graph of D. M. R. Relationship between Moisture Content and Mean Threshing Efficiency at Constant Feed Rate and Speed for soybean

TABLE 5

ANOVA OF CLEANING EFFICIENCY FOR SOSAT C88 MILLET VARIETY

Source	Degree of Freedom	Sum of Squares	Mean Squares	F Value
Replication	2	0.01		
Moisture (M)	4	4850.31	1212.58	55341.7**
Speed (S)	4	112.61	28.15	1284.85**
Feed rate (F)	4	192.62	48.16	2197.83**
M × S	16	97.67	6.10	278.60 **
M × F	16	74.05	4.63	211.23 **
F × S	16	44.49	2.78	126.90 **
M × S × F	64	92.03	1.44	65.63 **
Error	248	5.43	5.43	
Total	374	5469.23	5469.23	

** = highly significant
R-Square = 0.999, Coeff.Var = 0.16, Root MSE = 0.15,
Mean Cleaning Efficiency = 94.61 %

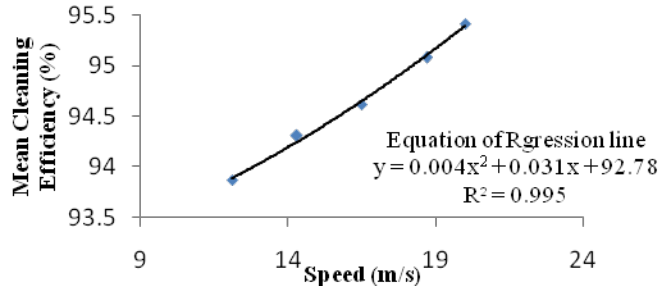

Fig. 7 a: Graph of D. M. R. Relationship between Speed and Mean Cleaning Efficiency at Constant Feed Rate and Moisture Content for millet

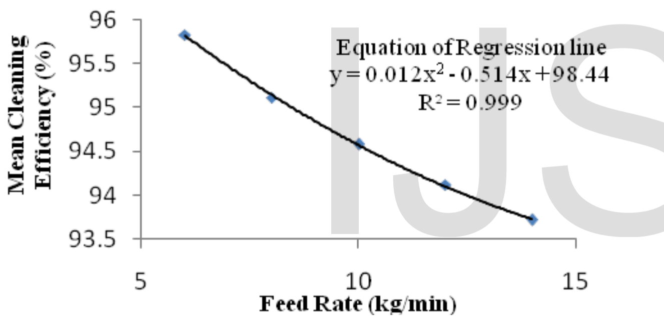

Fig. 8 a: Graph of D. M. R. Relationship between Feed Rate and Mean Cleaning Efficiency at Constant Speed and Moisture Content for millet

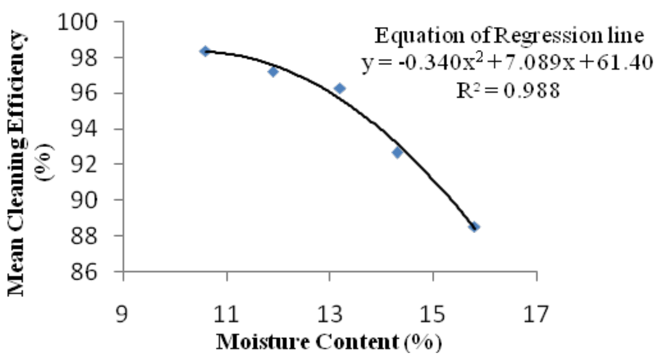

Fig. 9 a: Graph of D. M. R. Relationship between Moisture Content and Mean Cleaning Efficiency at Constant Feed Rate and Speed for millet

TABLE 6
ANOVA OF CLEANING EFFICIENCY FOR SAMSOY-2 SOYBEAN VARIETY

Source	Degree of Freedom	Sum of Squares	Mean Squares	F Value
Replication	2	0.00		
Moisture (M)	4	22614.16	5653.54	Infty**
Speed (S)	4	3273.21	818.30	Infty**
Feed rate (F)	4	1847.22	461.81	Infty**
M × S	16	2235.87	139.74	Infty**
M × F	16	557.34	34.83	Infty**
F × S	16	876.44	54.78	Infty**
M × S × F	64	1497.11	23.39	Infty**
Error	248	0.00	0.00	
Total	374	32901.35		

** = highly significant
R-Square =1, Coeff. Var = 0, Root MSE = 0, Mean Cleaning Efficiency = 86.19 %

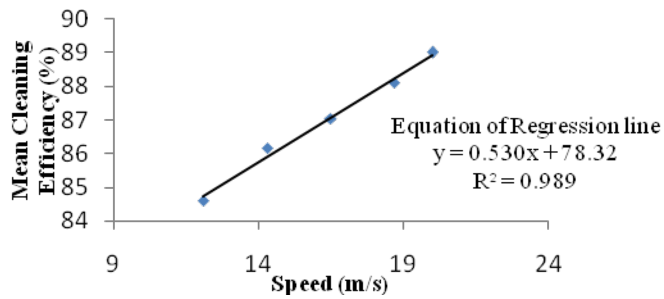

Fig. 7 b: Graph of D. M. R. Relationship between Speed and Mean Cleaning Efficiency at Constant Feed Rate and Moisture Content for soybean

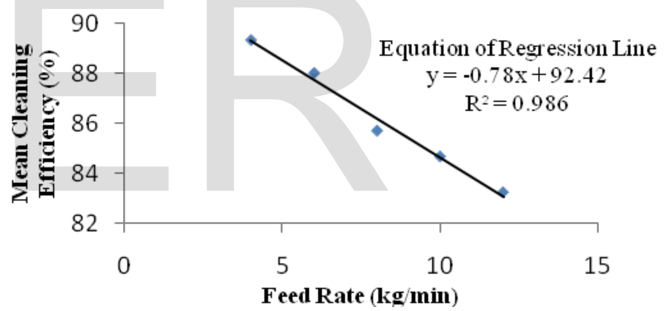

Fig. 8 b: Graph of D. M. R. Relationship between Feed Rate and Mean Cleaning Efficiency at Constant Speed and Moisture Content for soybean

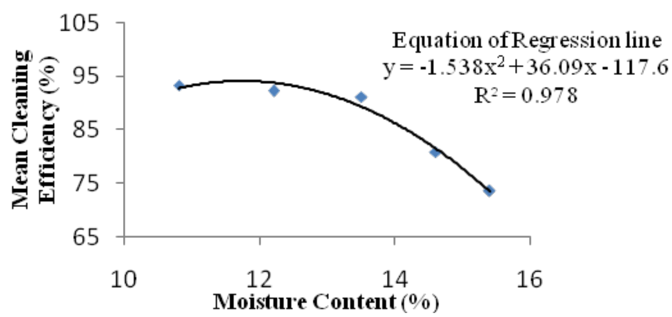

Fig. 9 b: Graph of D. M. R. Relationship between Moisture Content and Mean Cleaning Efficiency at Constant Feed Rate and Speed for soybean

TABLE 7
ANOVA OF SCATTERED GRAIN LOSS FOR SOSAT C88 MILLET VARIETY

Source	Degree of Freedom	Sum of Squares	Mean Squares	F Value
Replication	2	0.00		
Moisture (M)	4	1239.92	309.98	1.453E7**
Speed (S)	4	17.92	4.48	209943**
Feed rate (F)	4	42.85	10.71	502106**
M × S	16	0.74	0.05	2159.33 **
M × F	16	2.23	0.14	6539.99 **
F × S	16	0.69	0.04	2010.32 **
M × S × F	64	3.13	0.05	2288.87 **
Error	248	0.01	0.00	
Total	374	1307.47		

** = highly significant
R-Square = 0.999, Coeff. Var = 0.048, Root MSE = 0.005,
Mean Grain Loss = 9.67 %

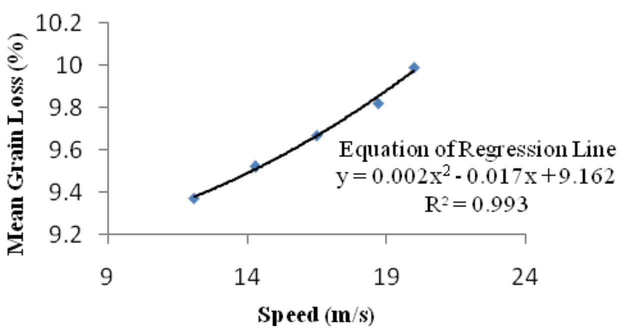

Fig. 10 a: Graph of D. M. R. Relationship between Speed and Mean Scattered Grain Loss at Constant Feed Rate and Moisture Content for millet

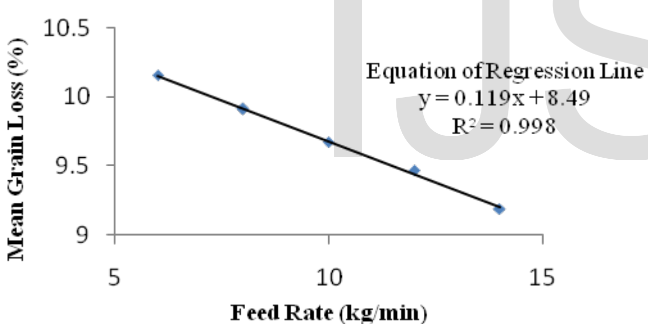

Fig. 11 a: Graph of D. M. R. Relationship between Feed Rate and Mean Scattered Grain Loss at Constant Speed and Moisture Content for millet

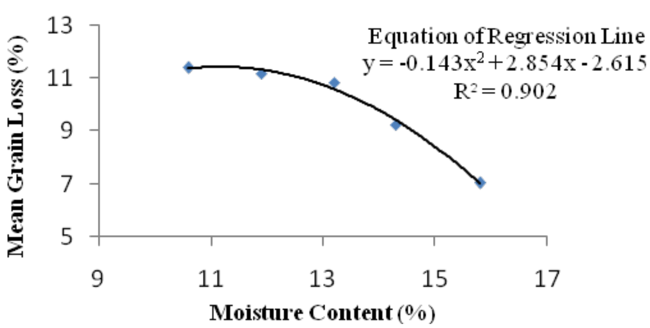

Fig. 12 a: Graph of D. M. R. Relationship between Moisture Content and Mean Scattered Grain Loss at Constant Feed Rate and Speed for millet

TABLE 8
ANOVA OF SCATTERED GRAIN LOSS FOR SAMSOY-2 SOYBEAN VARIETY

Source	Degree of Freedom	Sum of Squares	Mean Squares	F Value
Replication	2	0.00		
Moisture (M)	4	641.10	160.27	2068243**
Speed (S)	4	85.82	21.45	276857**
Feed rate (F)	4	47.12	11.78	152000**
M × S	16	2.66	0.17	2141.42 **
M × F	16	2.24	0.14	1807.92 **
F × S	16	1.39	0.09	1124.97 **
M × S × F	64	1.25	0.02	252.39 **
Error	248	0.02	0.00	
Total	374	781.59		

** = highly significant
R-Square = 0.999, Coeff. Var = 0.221, Root MSE = 0.009,
Mean Grain Loss = 3.976 %

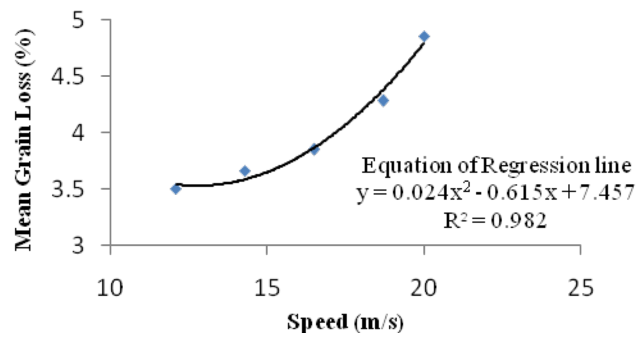

Fig. 10 b: Graph of D. M. R. Relationship between Speed and Mean Scattered Grain Loss at Constant Feed Rate and Moisture Content for soybean

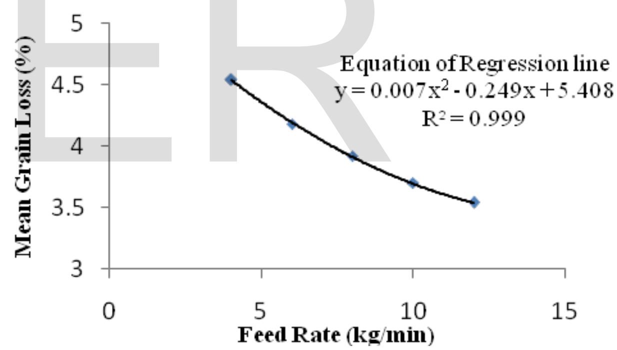

Fig. 11 b: Graph of D. M. R. Relationship between Feed Rate and Mean Scattered Grain Loss at Constant Speed and Moisture Content for soybean

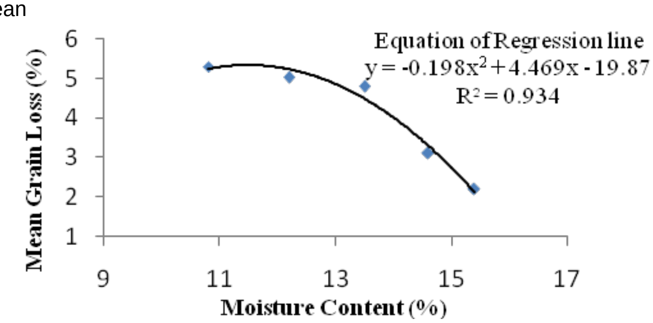

Fig. 12 b: Graph of D. M. R. Relationship between Moisture Content and Mean Scattered Grain Loss at Constant Feed Rate and Speed for soybean

TABLE 9
ANOVA OF GRAIN DAMAGE FOR SOSAT C88 MILLET VARIETY

Source	Degree of Freedom	Sum of Squares	Mean Squares	F Value
Replication	2	0.00		
Moisture (M)	4	15.77	3.941	Infty**
Speed (S)	4	0.22	0.054	Infty**
Feed rate (F)	4	0.26	0.064	Infty**
M × S	16	0.07	0.004	Infty**
M × F	16	0.06	0.004	Infty**
F × S	16	0.03	0.002	Infty**
M × S × F	64	0.02	0.001	Infty**
Error	248	0.00	0.00	
Total	374	16.42		

** = highly significant
R-Square =1, Coeff. Var = 0, Root MSE = 0,
Mean Grain Damage = 0.2 %

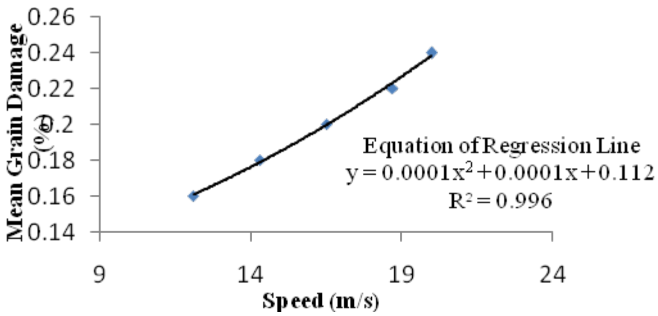

Fig. 13 a: Graph of D. M. R. Relationship between Speed and Mean Grain Damage at Constant Feed Rate and Moisture Content for millet

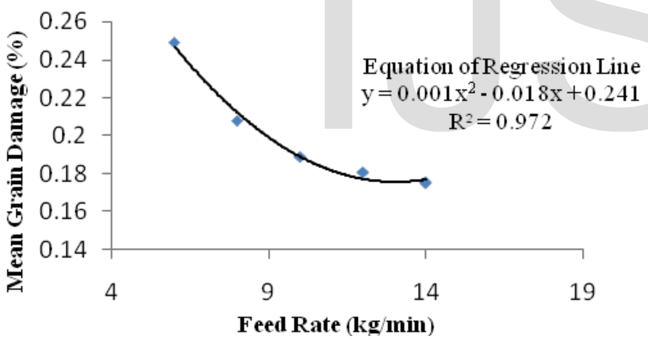

Fig. 14 a: Graph of D. M. R. Relationship between Feed Rate and Mean Grain Damage at Constant Speed and Moisture Content for millet

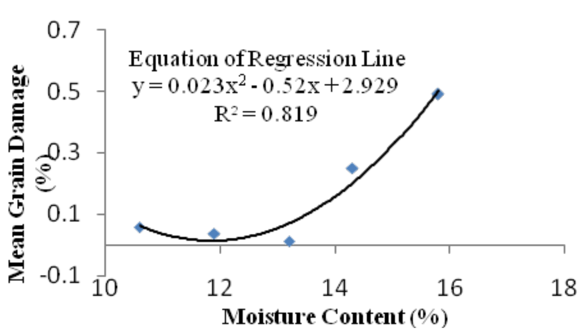

Fig. 15 a: Graph of D. M. R. Relationship between Moisture Content and Mean Grain Damage at Constant Feed Rate and Speed for millet

TABLE 10

ANOVA OF GRAIN DAMAGE FOR SAMSOY-2 SOYBEAN VARIETY

Source	Degree of Freedom	Sum of Squares	Mean Squares	F Value
Replication	2	0.00		
Moisture (M)	4	107.62	26.91	5.87E16**
Speed (S)	4	143.70	35.92	7.84E16 **
Feed rate (F)	4	8.98	2.25	4.90E15 **
M × S	16	129.83	8.11	1.77E16 **
M × F	16	2.21	0.14	3.01E14 **
F × S	16	5.61	0.35	7.65E14 **
M × S × F	64	1.35	0.02	4.59E13 **
Error	248	0.00	0.00	
Total	374	399.30		

** = highly significant
R-Square =1, Coeff. Var = 3.55, Root MSE = 2.14E-8,
Mean Grain Damage = 0.6 %

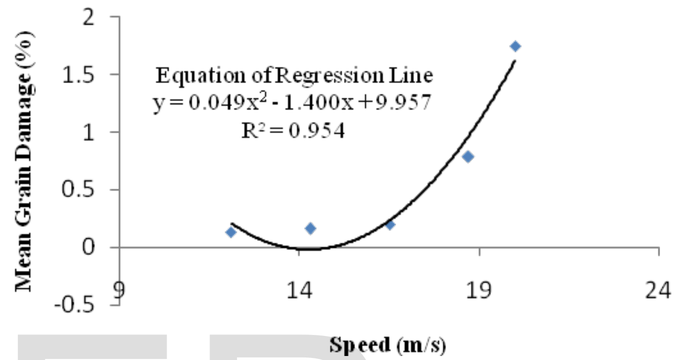

Fig. 13 b: Graph of D. M. R. Relationship between Speed and Mean Grain Damage at Constant Feed Rate and Moisture Content for soybean

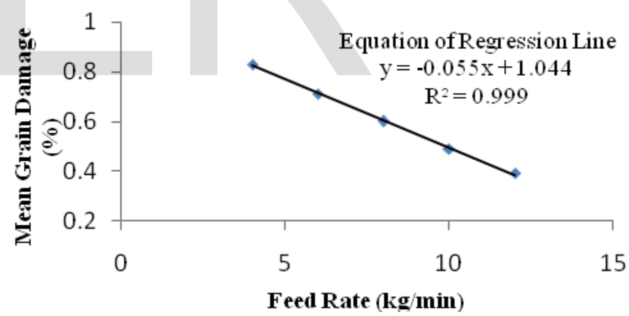

Fig. 14 b: Graph of D. M. R. Relationship between Feed Rate and Mean Grain Damage at Constant Speed and Moisture Content for soybean

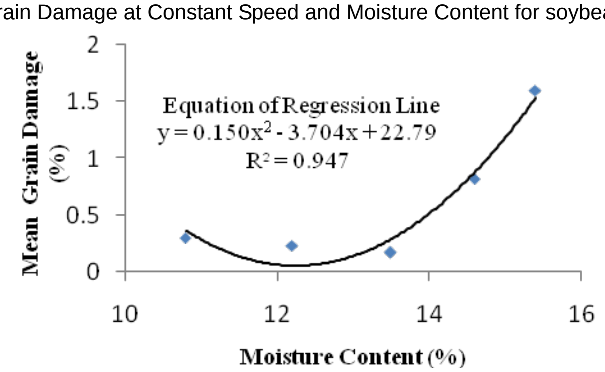

Fig. 15 b: Graph of D. M. R. Relationship between Moisture Content and Mean Grain Damage at Constant Feed Rate and Speed for soybean

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5 CONCLUSION

A Maximum Feed rate, Threshing efficiency, Cleaning efficiency, Scatter loss, Grain damage and Throughput capacity of 14 kg/min, 99.98 %, 99.71 %, 12.18 %, 0.62 %, and 520.6 kg/hr respectively were attained with SOSAT C88 Millet variety and 12 kg/min, 100 %, 97.26 %, 7.25 %, 6 %, and 205 kg/hr respectively were attained with Samsoy-2 Soybean variety.

A Mean Threshing efficiency, Cleaning efficiency, Scatter loss, Grain damage and Throughput capacity of 98.53 %, 94.61 %, 9.67 %, 0.20 %, and 324.11 kg/hr respectively were attained with SOSAT C88 Millet variety and 99.27 %, 86.19 %, 3.97 %, 0.60 %, and 118.43 kg/hr respectively were attained with Samsoy-2 Soybean variety.

Graphs of D. M. R. Relationships indicate that throughput capacity is directly proportional to speed and feed rate but inversely proportional to moisture contents; threshing efficiency is directly proportional to speed but inversely proportional to feed rate and moisture contents; cleaning efficiency is directly proportional to speed but inversely proportional to feed rate and moisture content; scattered grain loss is directly proportional to speed but inversely proportional to feed rate and moisture content; grain damage is directly proportional to speed and moisture content above 13.5 % wet basis but inversely proportional to feed rate.

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