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## Performance evaluation of braked wheel in puddled soil condition

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**Abstract**

The ground wheel in seed drills and planters works as a braked wheel. The braked wheel experiences negative slip (i.e. skid). Excessive value of skid will result in alteration of spacing between hills. Skid increases with the increase in braking torque resulting in large variations in hill to hill spacing. Hence, the relationship between braking torque and skid is important for the designing of seed drills and planters. The relationships between pull, torque and slip characterizes the behavior of the braked wheel. An experiment was carried out to determine skid at different lug height (15, 20, 25 and 30 mm), different axle load (98.1, 147.15 and 196.2 N) and different torque and it was found that there was a little effect of axle load on skid. Expected value of skid at different values of lug height and braking torque was calculated from the regression equation. This was used for determining lug height when torque requirement and permissible level of skid were known. It was found that skid increases with decrease in lug height almost for all values of braking torque. At 15 mm minimum lug height, skid increased with braking torque rapidly. The variation in torque with skid was comparatively less at maximum lug height of 30 mm. The increase in braking torque was not constant with respect to the increase in skid value. The maximum skid was 32.4 percent at the maximum braking torque of 17.14 N-m, minimum lug height of 15 mm and additional axle load of 20 Kg.

**Keywords:** Lug height, pull, torque, skid, axle load and braked wheel

**Introduction**

Agriculture plays a vital role in India's economy. 54.6% of the population is engaged in agriculture and allied activities and it contributes 17% to the country's Gross Value added (Census 2011) [1]. Rice production in India is an important part of the national economy. It is grown widely across the nation in more than 20 states and in an area of over 433 lakh hectares. India is one of the world's largest producers of rice and brown rice next to China, accounting for 20% of all world rice production. The overall production of rice is 104.32 million tonnes in 2015-16 according to Annual Report, 2017 (Department of Agriculture, Cooperation and Farmers Welfares, Government of India) [2].

Puddling leads to soil compaction, increases the bulk density and soil penetration resistance in sub-soils which ultimately decreases their permeability and reduces the water losses (Verma and Dewangan, 2006) [3]. The ground wheel in seed drill, planter or transplanter works as a braked wheel. Metering device requires torque which is provided by the ground wheel (Sahoo and Srivastava, 2000) [4]. A braked wheel experiences skid which is known as negative slip. Excessive value of skid will alter spacing between hills. When braking torque increases skid also increases, due to skid hill to hill spacing will vary. In puddled soil condition (moisture content 47.8%), the optimum lug spacing of 30° which meant 12-lug in a wheel transmit highest drawbar power at 30° lug angle (Gee-Clough *et al*, 1981) [5]. The relationship between braking torque and skid is important for design of the power transmission. The relationships between pull, torque and slip of the braked wheel will be useful for designers of seed drills, planters and transplanter.

Many research works have been carried out for performance evaluation of braked wheel in dry land condition but no one properly emphasize on the performance evaluation of braked wheel in wet land condition while skidding is major problem in wet land condition i.e., puddled soil condition. Hence, performance evaluation of braked wheel was taken up in puddled soil conditions with following objectives:

## Objectives

1. To determine the skidding at different braking torque values of a rigid wheel in puddled soil conditions.
2. To determine the torque available for the rigid wheel at different lug heights and different axle loads.

## Material and methods

### Description of study area

The test set-ups were fabricated in the workshop of Agricultural and Food Engineering Department, IIT Kharagpur. During the entire project work various steps were adopted as:

- (1) Design and development of lugged wheel.
- (2) Development of braking device.
- (3) Development of test setup.
- (4) Preparation of field (puddling of soil)
- (5) Procedure for Testing of lugged wheel for analysis of effect of different parameter.
- (6) Analysis of experimental data.

### Development of test lugged wheel

The materials taken for making rigid wheel is MS mild steel sheet of 5mm thickness for lug and wheel rim and MS mild

steel thin walled pipe for spokes. For hub a MS mild steel rod is taken and after drilling and proper machining it is used as hub of given dimensions.

S.N.	Particulars	Parameters	Value
1	Wheel rim		
		Rim outer diameter	600 mm
		Rim width	50 mm
		Rim thickness	5 mm
2	Hub		
		Hub outer diameter	35 mm
		Hub inner diameter	25 mm
		Hub thickness	5 mm
		Hub width	50 mm
3	Lug		
		Lug width	50 mm
		Lug height	15, 20, 25 and 30 mm
		Lug thickness	5 mm
		Number of lugs	12
		Lug angle	30°
4	Spoke		
		Spoke(rod) length	277.5 mm
		Spokes outer dia	19 mm
		Spokes thickness	2 mm
		Number of spokes	3



Fig 1: Fabricated wheel lug



Fig 2: Fabricated wheel

### Development of braking system

Brake drum of the brake dynamometer was made of mild steel. Brake shoe of the brake dynamometer was made of wood and screwed to the tie bars. To adjust rim pressure, nut

and bolt is loosen and tighten, operated through compression springs on the tie bars (Paul *et al*, 1996) [6]. A load cell was attached to the lower end of the load bar to measure axle torque and skid at different axle torque.



Fig 3: Brake attached to the test wheel



Fig 4: Tension link load cell with digital recorder



### Fabrication of handle assembly

Handle assembly was made of mild steel flat sheet, hollow pipe and square bar. A pocket load cell was fitted in between the handle assembly for measuring pull. Fabricated handle assembly is shown in the figure given below.



**Fig 5:** Pocket load cell attached with handle assembly for pull measurement

### Development of Test Setup

The main objective of this test is to determine an optimum lug size of rigid braked wheel for given field condition. Test wheel has been developed as explained above. The lug height will be varied between 15, 20, 25 and 30 mm. The test setup consisted of:

- i) Test wheel
- ii) Wheel shaft
- iii) Brake
- iv) Support wheels, two in number,
- v) Handle, handle bracket and spring
- vi) Frames, and
- vii) Dead weights



**Fig 6:** Fabricated test set-up

### Design of experiment

The lugged wheel was installed in a test setup and the test setup was pulled by a man in puddled soil condition. The performance of lugged wheel used as ground wheel in seed drills and planters was evaluated at 4 different lug heights (15, 20, 25 and 30), three different braking torque and three different loading condition (98.1 N, 147.15 N and 196.2 N). The magnitude of pull is measured by a pocket load cell fitted in between handle assembly and the braking torque is measured by a digital scale installed at the arm of brake drum. The lugged wheel setup was tested in the Experimental Farm of Agricultural and Food Engineering Department, IIT Kharagpur. The experiment was conducted with three replications and pull, torque and skid were measured. According to first objective "To determine the skidding at different braking torque values of a rigid wheel in puddled

soil conditions." different variables and parameters were taken which is given below:

- a) Independent variables – Braking torque
- b) Dependent variables – Skid, and
- c) Constant/controlled parameter – weight and pull

According to second objective "To determine the torque available for the rigid wheel at different lug heights and different axle loads." different variables and parameters were taken which is given below:

- a) Independent variables – Lug height, Axle load and Braking torque
- b) Dependent variables – Skid, and
- c) Constant/controlled parameter – nothing.

### Test Procedure

The experiments were conducted in the Experimental Farm of Agricultural and Food Engineering Department. For conducting the test following steps were adopted

- i) Experimental field of 10×10 meter<sup>2</sup> area was selected for the test.
- ii) Experimental field was prepared by ploughing with a mould board plough followed by one pass of cultivator, two passes of disc harrow and one pass of leveler. After then puddling has been done for the experiment.
- iii) Lugs of different height were fitted on the test wheel during the test,
- iv) The value of torque, pull, forward speed and skid were recorded simultaneously at different lug heights.

For measuring skid the method used was distance travelled method. The theoretical distance was calculated from the rim diameter without lug. For actual distance I have pulled the trolley and measured the distance along with number of revolution of testing wheel.

$$\text{Slip}\% = \frac{d_t - d_a}{d_t} \times 100$$

Where,

$d_t$  = Theoretical distance travelled for a given number of revolution

$d_a$  = Actual distance travelled for a given number of revolution

Pull has been measured by noting down the reading in digital scale of the pocket load cell.

P = Pull, kg

For braking torque the distance from the centre of the wheel to the lever end was multiplied by the force (kg) read from the scale.

Equation for the calculation of braking torque:

$$T = 9.81 M \times r$$

Where, M is load shown by digital scale (kg), r is Distance from centre of flywheel to hanger, T is Torque applied, N-m

### Results and Discussion

#### Experimental results

Test set-up was weighed on the electronic weighing machine. The dead weight of whole test set-up was 42.5 kg and dead weight of front axle was 22.5 kg. After that test set-up was brought to the field for doing experiment. It was pulled by a man and readings for torque, pull and skid were taken simultaneously. Additional load of 10, 15 and 20 Kg were given on the front axle for different lug height and different value of torque and pull and skid were measured. The mean responses obtained during experiments are given below.

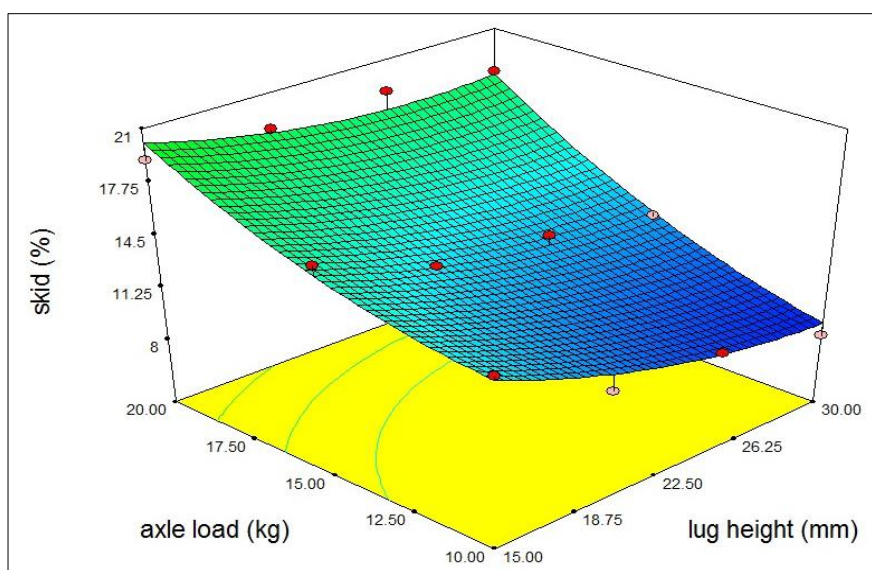
**Table 1:** Mean of the responses obtained according to the experimental design are given below (Length of torque arm = 0.29 m):

S. No.	Lug Height (mm)	Axle Load (Kg)	Torque (N-m)	Pull (N)	Skid (%)
1.	15	10	14.99	266.832	24.40
2.	15	10	9.8	206.8929	18.72
3.	15	10	4.89	141.264	14.35
4.	15	15	16.29	296.1639	27.70
5.	15	15	9.88	219.9402	22.13
6.	15	15	5.11	159.2163	16.61
7.	15	20	17.14	334.521	32.4
8.	15	20	9.76	247.5063	23.10
9.	15	20	5.02	186.1938	19.16
10.	20	10	15.01	273.6009	23.20
11.	20	10	10.52	211.4055	15.59
12.	20	10	6.21	150.4854	10.44
13.	20	15	16.01	314.9991	26.10
14.	20	15	9.92	221.0193	16.68
15.	20	15	5.21	151.4664	13.98
16.	20	20	15.5	315.6858	29.92
17.	20	20	8.95	256.2372	22.23
18.	20	20	5.19	188.0577	18.82
19.	25	10	14.53	261.0441	20.02
20.	25	10	9.75	217.1934	15.50
21.	25	10	5.2	131.5521	9.92
22.	25	15	15.19	315.0972	24.45
23.	25	15	9.62	217.0953	15.21
24.	25	15	4.84	171.7731	13.38
25.	25	20	14.97	334.7172	28.85
26.	25	20	9.88	240.9336	23.25
27.	25	20	4.92	184.6242	19.02
28.	30	10	14.82	259.1802	20.50
29.	30	10	10.15	214.6428	14.82
30.	30	10	4.71	143.1279	10.21
31.	30	15	15.22	312.8409	24.40
32.	30	15	9.89	318.6288	14.71
33.	30	15	5.02	176.58	12.21
34.	30	20	14.79	330.4008	29.01
35.	30	20	9.79	232.9875	22.10
36.	30	20	4.68	178.4439	18.28

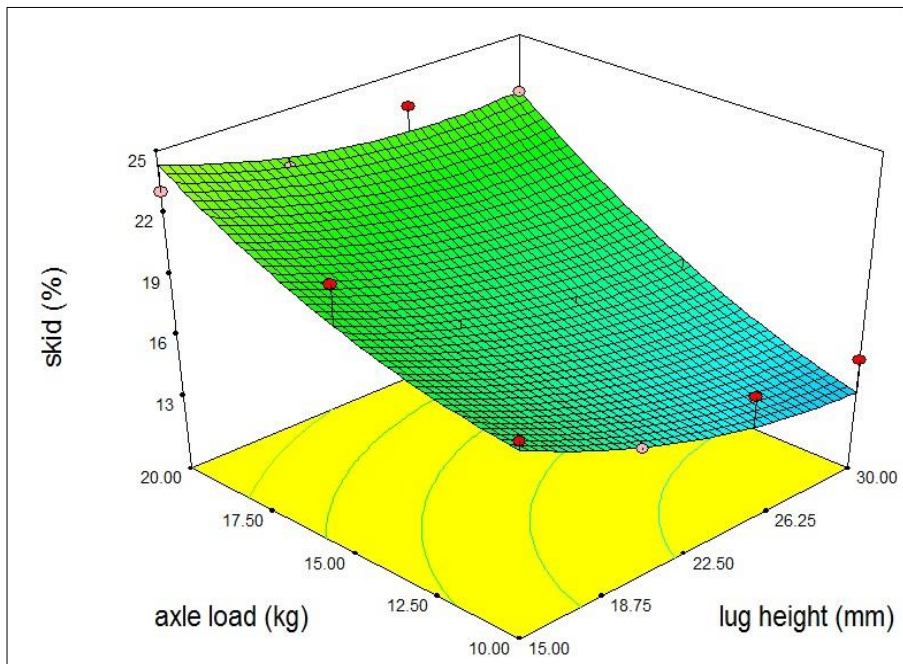
### Response surface analysis of skid at different values of lug height, axle load and torque

The values of skid at different lug height, torque and axle load were measured. A response surface model showing the

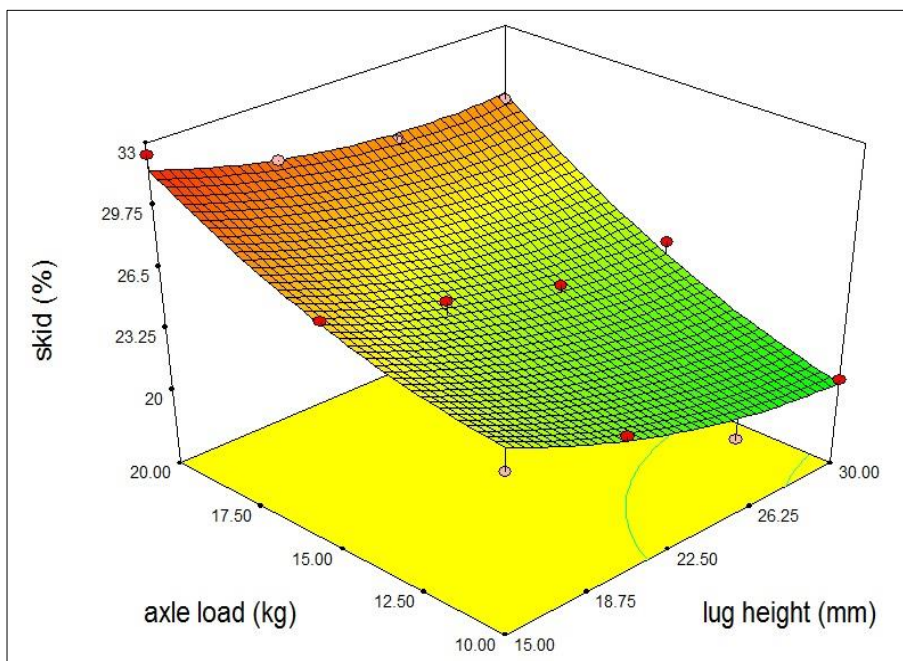
interaction between axle load and lug height corresponding to skid at different axle torque was developed and shown in Fig. 7.



(a)



(b)



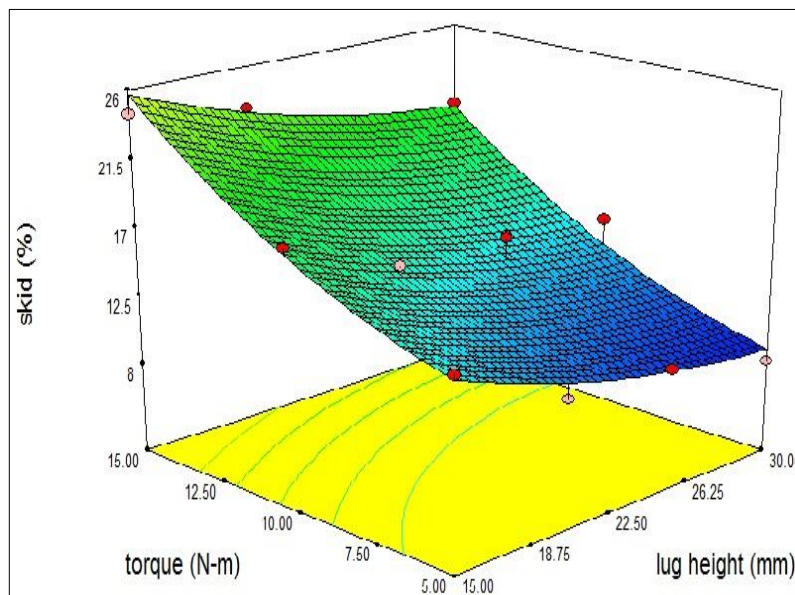
(c)

**Fig 7:** Response surface plot of skid, axle load and lug height at (a) Torque = 5 N-m (b) Torque = 10 N-m and (c) Torque = 15 N-m.

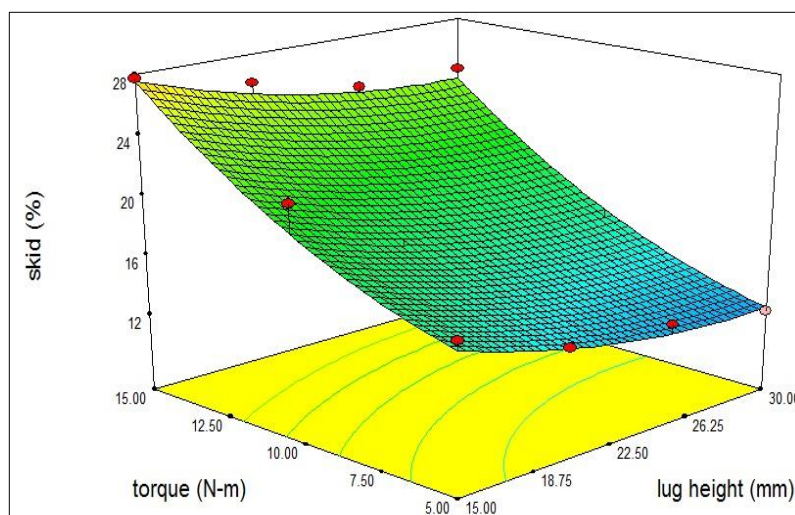
The values of skid at different lug height, torque and axle load were measured. A response surface model showing the interaction between braking torque and lug height

corresponding to skid at different axle load was developed. This is shown in Fig.-8.

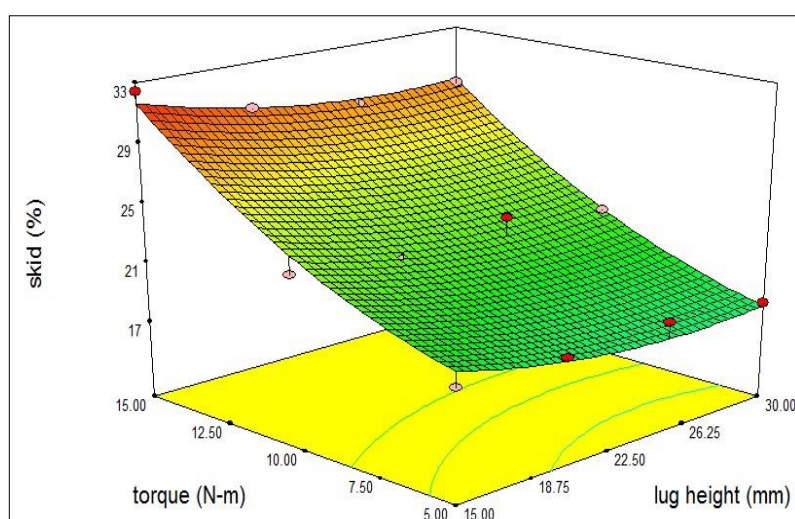




(a)



(b)



(c)

**Fig 8:** Response surface plot of skid, torque and lug height at (a) Axle load = 10 Kg (b) Axle load = 15 Kg and (c) Axle load = 20 Kg.

At minimum value of braking torque if lug height was increased, skid decreased and after that skid started to increase with braking torque at constant lug height. At 15 mm minimum lug height, skid increased with braking torque

rapidly. At the maximum lug height of 30 mm variation in torque with skid was less as shown in Fig.-8. At 30 and 25 mm lug height, the corresponding braking torque increased with comparatively less variation in skid. The increase in

braking torque was not constant with respect to the increase in skid value. The maximum skid was 33.4 percent at the highest braking torque and 15 mm lug height.

A regression analysis was carried out with the value of skid at different lug height, axle torque and axle load. ANOVA is presented in Table-2.

**Table 2:** ANOVA table for variation of skid of braked wheel at different values of lug height (A), axle load (B) and braking torque (C).

Source	Sum of Squares	df	Mean Square	F value	p-value Prob > F	
Model	1229.86	9	136.65	116.18	< 0.0001	significant
A-lug height (mm)	67.65	1	67.65	57.52	< 0.0001	
B-axle load (kg)	341.03	1	341.03	289.94	< 0.0001	
C-torque (N-m)	777.14	1	777.14	660.72	< 0.0001	
AB	7.48	1	7.48	6.36	0.0182	
AC	0.052	1	0.052	0.044	0.8356	
BC	5.625E-003	1	5.625E-003	4.782E-003	0.9454	
A2	7.34	1	7.34	6.24	0.0192	
B2	9.89	1	9.89	8.41	0.0075	
C2	19.27	1	19.27	16.38	0.0004	
Residual	30.58	26	1.18			
Cor Total	1260.44	35				

The Model F-value of 116.18 implies the model is significant. There is only a 0.01% chance that a "Model F-Value" this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case A, B, C, AB, A2, B2, C2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant.

A regression model was developed relating skid (s) with lug height (A), axle load (B) and axle torque (C) is shown in equation 1. The terms (A, B, C, A×B, A<sup>2</sup>, B<sup>2</sup> and C<sup>2</sup>) that were found significant in Table-2 were considered for developing the regression model. The "Pred R-Squared" of 0.9550 is in reasonable agreement with the "Adj R-Squared" of 0.9673 depicting that the relationship is acceptable. Based on the

ANOVA shown in Table-2 an empirical relationship was developed using significant terms. The empirical relationship obtained is given below.

$$\text{Skid} = 31.80275 - 1.34062 \times A - 1.02233 \times B - 0.054983 \times C + 0.019967 \times A \cdot B + 0.018056 \times A^2 + 0.044483 \times B^2 + 0.06208 \times C^2 \quad (1)$$

Expected value of skid at a different lug height and braking torque calculated for an additional axle load of 15 Kg from equation 1 and are tabulated in Table-3. It can be seen that skid increases with decreasing lug height almost for all values of braking torque. This table can be useful to select lug height for a given braking torque with in an expectable level of skid.

**Table 3:** Skid at different lug height, different braking torque and axle load of 15 Kg (Calculated from equation 1).

S. No.	Braking Torque (N-m)	Lug height (mm)	Skid (%)
1	2	15	15.07
2	2	20	13.02
3	2	25	11.87
4	2	30	11.62
5	4	15	15.71
6	4	20	13.66
7	4	25	12.51
8	4	30	12.26
9	6	15	16.84
10	6	20	14.79
11	6	25	13.64
12	6	30	13.39
13	8	15	18.65
14	8	20	16.42
15	8	25	15.27
16	8	30	15.02

#### Example for using Table-3

Suppose a planter requires 7 N-m torque and skid should be limited to 14 percent. Now examine serial numbers 12 to 16,

where 6 N-m and 8 N-m torque are given. Look at skid values, serial No.12 has skid = 13.39 % and serial No. 16 has skid = 15.02 %.

**Table 4:** Sample calculation of lug height and skid at given braking torque

Serial No.	Braking torque (N-m)	Lug height (mm)	Skid (%)
12	6	30	13.39
13	8	15	18.65
15	8	25	15.27
16	8	30	15.02

Let us look at lug height 30mm. Skid at 7 N-m torque will be  $\frac{1}{2}(13.39 + 15.02) = 14.2\%$ . This is very close to 14 %. Hence lug height = 30 mm is sufficient.

According to second objective 'To determine the torque available for the rigid wheel at different lug heights and different axle loads' torque is calculated at different lug

heights, different axle loads and different skid of 10 %, 15% and 20%. The values of available torque are tabulated below:

**Table 5:** Available torque at 10%, 15% and 20% skid for different lug height and axle loads

S. No.	Lug height (mm)	Axle load (Kg)	Torque at 10 % skid (N-m)	Torque at 15 % skid (N-m)	Torque at 20 % skid (N-m)
1	15	10	-	5.73	10.73
2	15	15	-	3.22	8.26
3	15	20	-	-	6.27
4	20	10	-	9.62	13.03
5	20	15	-	7.14	11.27
6	20	20	-	-	6.53
7	25	10	5.09	9.69	14.29
8	25	15	-	7.66	11.80
9	25	20	-	-	6.15
10	30	10	6.18	10.30	14.41
11	30	15	-	8.45	12.23
12	30	20	-	-	6.89

To design a planter or seed drill it is very important to keep skid as minimum as possible because higher skid can alter hill to hill spacing but at the same time we need a higher torque so that maximum power can be transmitted to the metering unit. The table-5 will help to design the planter which will operate in puddled soil condition. For example we require higher available torque at minimum skid thus we can choose serial no. 10 where 6.18 N-m torque is available at 10 % skid and 10.30 N-m torque is available at 15 % skid. Therefore if our allowable skid is 10 % then we should choose 30 mm lug and 10 Kg additional load on axle to obtain available torque of 6.18 N-m and if our permissible skid is 15 % then we should choose the same to obtain 10.3 N-m available torque.

### Summary and conclusions

Field experiment was carried out in puddled soil condition to study the torque, pull and skid characteristics of ground wheel, used in transplanters. An experiment was carried out to determine skid at different lug height, axle load and torque and a regression model was developed. Based on the analysis the following conclusions were drawn.

### Conclusions

Regression model was developed relating skid with lug height, axle load and torque. The quadratic polynomial equation related skid as a function of lug height axle load and torque. The regression equation describes the relation satisfactorily with a correlation coefficient ( $R^2 = 0.95$ ). Skid increased with decreasing lug height almost for all values of braking torque. A table was prepared to calculate skid at different lug heights and braking torques. This table can be useful to select lug height for a given braking torque with in an acceptable level of skid. At minimum value of braking torque if lug height was increased, skid decreased and after that skid started to increase with braking torque at constant lug height. At 15 mm minimum lug height, skid increased with braking torque rapidly. At the maximum lug height of 30 mm variation in torque with skid was comparatively less. The increase in braking torque was not constant with respect to the increase in skid value. The maximum skid was 32.4 percent at the maximum braking torque of 17.14 N-m, minimum lug height of 15 mm and additional axle load of 20 Kg. To design a planter or seed drill it is very important to keep skid as minimum as possible because higher skid can alter hill to hill spacing but at the same time we need a higher torque so that maximum power can be transmitted to the metering unit. The

table-5 will help to design the planter which will operate in puddled soil condition. We require higher available torque at minimum skid thus we can choose 6.18 and 10.30 N-m torque which is available at 10 % and 15 % skid respectively at 30 mm lug height and 10 kg additional load on the axle. That means if our allowable skid is 10 % then we should choose 30 mm lug and 10 Kg additional load on axle to obtain available torque of 6.18 N-m and if our permissible skid is 15 % then we should choose the same to obtain 10.3 N-m available torque. Dead load at the axle of the test wheel was 22.5 Kg.

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