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Performance of pneumatic loader for loose straw handling on a farm yard

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Abstract
Indian agricultural bears heavy labour and cost in the straw handling process after harvest. During peak harvesting season, unavailability of labourers and need of timeliness of operation, burning of straw in field have been a conventional practice. Mechanization in this field has been low but loading/ unloading of loose straw is a tedious work. These operations can be performed efficiently using a tractor operated pneumatic loader and with less effort. Present study was aimed at optimizing the working of pneumatic loader at varying suction, delivery length and power take-off (PTO) speeds for wheat, soybean and pigeon pea straws. The optimized suction and delivery lengths for all the three straws were obtained as 2 and 10 m, respectively. The PTO speeds of 302, 366, and 373 rpm were identified as optimum for wheat, soybean, and pigeon pea straws, respectively. The operational cost of the machine with tractor was calculated as Rs. 228 for loading one tonne straw which resulted in heavy savings.

Keywords: Capacity, Loose straw, Pigeon pea, Pneumatic blower, Soybean, Wheat

Introduction

Straw is an agricultural by-product or residue derived from dry stalks of cereal plants after removal of grain and chaff. It constitutes half the yield of cereal crops such as wheat and rice. It is used as fodder or for livestock bedding, fuel, basket making and other commercial uses. Indian agriculture produces 253.3 million tonnes of crop residues every year, whereas, the requirement is of about 415.8 million tonnes. Consequently, there is a paucity of almost 40% which becomes one of the major constraints in development of livestock sector. The availability of green fodder in country is 142.8 million tonnes whereas requirement is of about 221.6 million tonnes with a deficit of almost 36% (Kumar *et al.*, 2015). A large portion of these crop residues i.e. about 90-140 million tonnes is annually burnt on-farm, primarily to clear the fields in order to ensure timely sowing of the next crop; as delayed sowing could decrease the crop yield (Pathak *et al.*, 2010).

In-field straw burning is generally practiced when a farmer does not require it for any other purpose like fodder, fuel, soil mulch, manure or thatching for rural homes (Singh *et al.*, 2020). Burning of crop residues causes certain negative impacts such as environmental pollution, global warming, elimination of beneficial insects, negative nutrient balance, decrease in soil organic content and increase in soil compaction (Jain *et al.*, 2014; Dixit *et al.*, 2015; Bhatt *et al.*, 2016; Liu *et al.*, 2020). The disposal and management of crop residues in the field after harvesting of wheat, paddy, soybean and chickpea is one of the major issues encountered by Indian farmers (Cardoen *et al.*, 2015; Singh *et al.*, 2018). Conventionally, straw in the field is heaped after harvesting and threshing. Heaped straw is then loaded for transportation. Loading and unloading of loose straw becomes a tedious and labour intensive operation. Transportation is inconvenient and costly due to the lower bulk density and loose biomass of straw (Fosnacht and Fosnacht, 2016). A large amount of straw dust particles are suspended in the air during manual handling. This causes poisoning, allergy in the respiratory tract and inflammation of the eyes, lungs, and skin (Matthews and Knight, 1971; Witney, 1988). The dust concentration in breathing zone during manual harvesting and threshing of wheat crop has been reported as 11.89, 4.67 and 3.20 mg/m^3 for inhalable, thoracic and respirable dust, respectively (Pandirwar *et al.*, 2014). Another drawback with transportation is the cost involved which falls around 36% of the production cost (Wright, 2010). Thus to improve handling as well as to reduce transportation and loading cost of these operations, technological and economical interventions were needed.

In the current scenario, level of mechanization is confined to land preparation, intercultural operations, harvesting, threshing equipment and urea treatment (Singh, 2015; Das *et al*., 2017). Despite a number of useful agricultural machinery that has been developed in India, the adoption levels have not been encouraging. Usage of modern machinery for straw handling is almost non-existent. Loose straw is compressed by straw baler but fine straw is still handled manually. Consequently, straw must be loaded and unloaded with a machinery of corresponding capacity and required lift elevation. In this particular study, performance of a pneumatic straw loader was evaluated which could perform loading and unloading operations efficiently as compared to manual handling. The objective of the present study was to optimize the operating parameters of straw loader for illustrating its potential to operate with higher capacity and lower fuel consumption. Additionally, the study also aimed at calculating the cost economics of the straw loader in comparison to manual handling.

Materials and Methods

Tractor operated pneumatic straw loader: Experiments were carried out at ICAR-Central Institute of Agricultural Engineering, Bhopal, India. The pneumatic straw loader is a trailed type machine which is operated by tractor power take-off (PTO) (Fig 1). It comprises of main frame, power transmission unit, pneumatic blower, suction pipe, delivery pipe and transport wheels. The overall dimensions of the straw loader were 2560×1005×310 mm. The blower was made of eight mild steel blades of 160×250×5 mm dimensions which were attached to the hub at 45° angle from each other. The power from PTO shaft to blower was transmitted through a belt and pulley arrangement. The transmission ratio between the blower and PTO shaft was 5.5. Suction and delivery pipes were made of PVC plastic having length of 2 to 5 m and 10 to 30 m, respectively.

Physical properties of straw: Three types of straw *i.e*. wheat, soybean, and pigeon pea were used for this study. The straws were obtained from the excperimental farm of ICAR-Central Institute of Agricultural Engineering, Bhopal, India. Initial moisture content of the straws was measured using ASABE standard S358.3 (ASABE, 2012) Three samples each weighing 50 g, were placed in an oven set at 105°C for 24 h. The samples were cooled in desiccators, reweighed and the moisture content of the straw was then calculated. Physical properties i.e. geometric mean diameter (GMD), bulk density and terminal velocity of the straw were determined. The size of the straw in terms of GMD was measured. Straw sample of 150 g was placed in a stack of sieves arranged from the largest to the smallest opening. The sieve sizes of 5.0, 4.0, 3.0, 2.0, 1.0, 0.5 and 0.25 mm were used. The set of sieves was placed on the sieve shaker (Entek instruments Private Limited, India). The duration of sieving was 10 min. After sieving, the material retained on each sieve was collected and weighed. Sieve analysis was repeated three times for each straw sample. The GMD of the straw was calculated according to ASAE standard S319.3 (ASAE, 2001). Bulk density of straw was determined according to the Lam *et al.* (2007). Terminal velocity of straw was measured using a hollow transparent plastic cylinder having 50 mm diameter and 70 mm length. Lower end of cylinder was connected to the electric blower (GBL 620, Bosch limited, India). A sample of 30 g straw was poured into the cylinder. Air

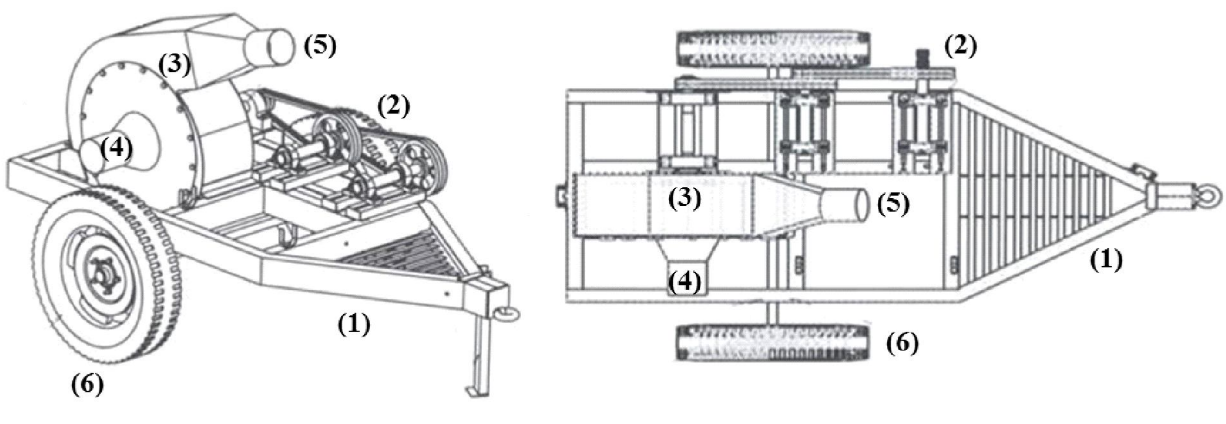

Fig 1. Schematic diagram of pneumatic straw loader. (1) main frame, (2) power transmission unit, (3) pneumatic blower, (4) suction pipe, (5) delivery pipe and (6) transport wheels

flow rate was adjusted to suspend the straw in the air for 30 s. Air velocity was measured using a vane anemometer (AVM-03, Prova, India). The air velocity at suspension was calculated as terminal velocity (Khoshtaghaza and Mehdizadeh, 2006).

Experimental procedure: The experiments were conducted during the month of November, 2017 for soybean straw and in April, 2018 for wheat and pigeon pea straw. Three independent parameters i.e. suction length, delivery length, PTO speed and two dependent parameters *i.e*. capacity and fuel consumption were considered for the field study (Table 1). The experiments were designed as per face-centred central composite design (FCCCD) and were subjected to response surface methodology (RSM). The machine was operated on the concrete surface of threshing yard. Each run was performed for 15 minutes and data was collected. A total 20 runs were carried out with three replicates. A tractor (3630, New Holland, India) was used to operate the straw loader. The PTO speed was measured with non-contact type tachometer (CA1727, AEMC Instruments, USA) and air flow rate was measured by using vane anemometer (AVM-03, Prova, India) during operation. The straw was collected in plastic bags during each run performed and the time was noted using a stop watch (23011, Supelco, India). Collected straw was weighed using an electronic weighing balance (1620C, Adair Dutt, India) and capacity of the straw loader was calculated (weight of collected straw divided by the time required in collection). Fuel consumption for each run was measured using fuel flow meter (CONTOIL® VZD4, Aqua metro, Germany). One fuel flow meter was attached to the fuel inlet line and another was to the return line of the tractor. Difference of this two was recorded as the fuel consumption during experiment.

Optimization: The performance parameters of straw loader *i.e*. suction length; delivery length and PTO speed were optimized using RSM. Second order polynomial regression models were developed for the capacity and fuel consumption in terms of the coded value of the independent parameters. Optimum parameters were calculated for maximum capacity of straw loader at minimum fuel consumption using design expert software (Version 7.1.6. Stat-Ease, Inc., MN, USA). The adequacy of the models was tested using F-value, P-value and coefficient of determination (R^2).The second order polynomial model is given as:

$$Y_i = \beta_o + \Sigma\beta_i X_i + \Sigma\beta_{ii} X_i^2 + \beta_{i\hat{j}} X_i X_{\hat{j}} \qquad (1)$$

Where, Y_i is the predicted response (i.e. capacity, fuel consumption), X_i, and X_j are input variables (i.e. suction length, delivery length, PTO speed); β_0 is the offset term; β_i is the linear coefficient; β_{ii} the i^{th} quadratic coefficient and β_{i5} is the 5^{th} interaction coefficient (Myers *et al*., 2002).

The validation of optimized parameters was done by operating pneumatic loader at optimum conditions of suction length, delivery length and PTO speed for wheat, soybean and pigeon pea straws. The capacity and fuel consumption were measured according to the aforementioned procedure. The experiments were replicated five times.

Cost economics: The total cost of operation of straw loader was determined based on fixed cost and variable cost following the test code IS: 1964-1979 (Indian Standard, 1979). Fixed cost that occurs regardless of machine use includes depreciation, interest on investment, insurance, taxes and housing. Variable cost which varies directly with the amount of machine use that includes the repair and maintenance cost, fuel cost, cost of lubricants and labour cost. The breakeven point (BEP) was calculated in terms of the fixed cost, variable cost and custom hiring charges using following formula:

BEP (h/year) = (Fixed cost per year)/(custom hiring charges per h – variable cost per h)

Table 1. Experimental parameters for the perfomance of the straw loader

Parameters		**Level 1**	**Level 2**	**Level 3**
Actual	**Coded**	**(-1)**	**(0)**	**(+1)**
Independent parameter	X_1	2	3.5	5
Suction length, m	X_2	10	20	30
Delivery length, m	X_3	250	350	450
PTO speed, rpm				
Dependent parameter				
Capacity (C), kg/h				
Fuel-consumption (F), l/h				

Annual profit to the entrepreneur/farmer due to the use of pneumatic straw loader was calculated by deducting annual expenditure from annual income. The cost of operation of pneumatic loader was compared with manual operation of straw loading. The cost involved in the manual operation was calculated by considering man-hour required for loading of one tonne straw.

Results and Discussion

Physical properties of straw: Physical property of different types of straw was recorded (Table 2). Moisture contents of different straws were in the range of 11.1 to 11.8%. The GMD of wheat, soybean and pigeon pea straws were 1.47, 2.88 and 3.10 mm, respectively. Size and shape of pigeon pea and soybean straw were irregular as compared to wheat straw. This might be the reason that they occupied more pore space as compared to wheat straw. Thus the bulk density of pigeon pea (92 kg/m^3) and soybean (101 kg/m^3) straw were found to be lower as compared to wheat straw which had a bulk density of 108 kg/m^3. The observation recorded was found to be in agreement with the results of bulk density of wheat straw reported by Lam *et al.* (2007). Terminal velocity of wheat straw was recorded as 0.83 m/s which were found to be lower than that of soybean (1.41 m/s) and pigeon pea (1.28 m/s) straws. This low terminal velocity was probably due to the smaller particle size of wheat straw. Similar results were reported for what straw earlier (Khoshtaghaza and Mehdizadeh, 2006).

Effect of different parameters on capacity of straw loader: The analysis of variance (ANOVA) showed significant effect (P<0.05) of suction length, delivery length and PTO speed on the capacity of the pneumatic loader for wheat straw (Table 3). The interaction effect of suction length with delivery length was also found to be significant. The coefficients of second order polynomial regression model were also estimated (Table 4). Using the values of significant coefficients in the equation, the model for capacity of wheat straw in coded terms (C_W) was recognised as follows:

$$C_W = 19.61-2.65\,X_1-2.44\,X_2+1.08\,X_3+0.59\,X_1X_2-0.36\,X_1X_3-0.93\,X_2^2 \qquad (2)$$

Table 2. Physical properties of different types of straw

Property of straw	Wheat	Soybean	Pigeon pea
Moisture content (db), %	11.1±0.36	11.8±0.67	11.5±0.55
Geometric mean diameter, mm	1.47	2.88	3.10
Bulk density, kg/m^3	108	101	92
Terminal velocity, m/s	0.83	1.41	1.28

Table 3. ANOVA for the quadratic model of capacity and fuel consumption

Responce	Type of straw	Source	SS	DF	MS	F-value	P-value	R^2
	Wheat	Model	150.82	9	16.76	41.96**	0.0001	0.97
		Residual	3.99	10	0.40			
		Cor. total	154.81	19				
Capacity	Soybean	Model	203.60	9	22.62	57.60**	0.0001	0.98
		Residual	3.93	10	0.39			
		Cor. total	207.53	19				
	Pigeon pea	Model	181.00	9	20.11	45.65**	0.0001	0.97
		Residual	4.41	10	0.44			
		Cor. total	185.41	19				
	Wheat	Model	3.57	9	0.40	15.10**	0.0001	0.93
		Residual	0.26	10	0.026			
		Cor. total	3.83	19				
Fuel consumption	Soybean	Model	2.91	9	0.32	11.49**	0.0003	0.91
		Residual	0.28	10	0.028			
		Cor. total	3.19	19				
	Pigeon pea	Model	4.04	9	0.45	6.54**	0.0035	0.85
		Residual	0.69	10	0.069			
		Cor. total	4.73	19				

SS = Sum of squares, Df = Degree of freedom, MS = Means square, R^2 = Coefficient of determination, **(P<0.01)

The statistical significance of equation 2 was evaluated via ANOVA. The F-value of 41.96 indicated that the model was highly significant ($P<0.01$). For the fitted model, the coefficient of determination was recorded 0.97, which indicated the goodness of the model. The capacity of straw loader for wheat straw ranged from 1.42 to 2.54 t/h. The response surface plot showed the effect of varying suction and delivery length with constant PTO speed of 350 rpm on capacity of straw loader (Fig 2). The capacity of pneumtic loader was observed to be decreasing with increase in suction and delivery lengths of pipe. This might be due to increase in frictional pressure with increase in suction length. Similar results were reoported by Woodcock and Mason (2012), where frictional pressure loss was found to increase and air flow rate decrease with increase in loading distance.

Similarly, it was observed that the suction length, delivery length and PTO speed significantly influenced the capacity of the straw loader for soybean and pigeon pea straws (Table 3). The interaction effect of suction length with delivery length and PTO speed were also found to be significant (Table 4). The models for capacity of soybean (C_S) and pigeon pea straw (C_p) in coded terms were as follows:

$$C_S = 12.50-3.66\,X_1-1.57\,X_2+1.78\,X_3+0.66\,X_1X_2-0.66\,X_1X_3-0.91\,X_1^2 \quad (3)$$

$$C_P = 15.48-3.27\,X_1-1.60\,X_2+1.85\,X_3+0.94\,X_1X_2-0.56\,X_1X_3-1.06\,X_1^2+0.34X_3^2 \quad (4)$$

Minimum and maximum capacities for soybean straw were 0.61 and 1.63 t/h, respectively. While, it was 0.98 and 2.21 t/h, respectively for pigeon pea straw. Similar trends of decrease in capacity with increase in suction and delivery lengths of pipeswere observed for soybean and pigeon pea straws (Fig 3-4). While increase in capcacity with PTO speed was found similar to as in wheat straw.

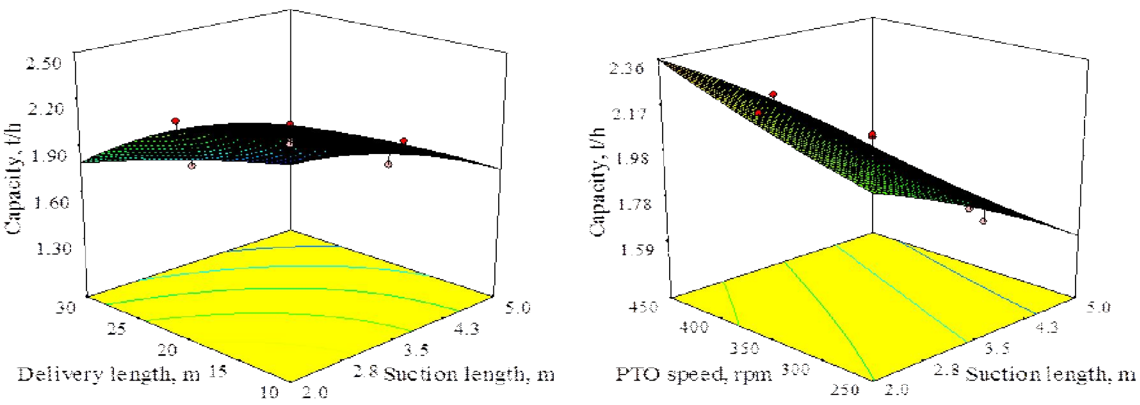

Fig 2. Effect of suction length, delivery length and PTO speed on capacity of straw loader for wheat straw

Table 4. Estimated coefficients of second order polynomial regression model

Coefficient	Capacity (t/h)			Fuel consumption (l/h)		
	Wheat	Soybean	Pigeon pea	Wheat	Soybean	Pigeon pea
β_0	19.61**	12.50**	15.48**	3.74**	3.87*	3.85*
β_1	-2.65**	-3.66**	-3.27**	-0.29**	-0.29*	-0.31*
β_2	-2.44**	-1.57**	-1.60**	NS	NS	NS
β_3	1.08**	1.78**	1.85**	0.47**	0.41**	0.52**
$\beta_1\,\beta_2$	0.59*	0.66*	0.94*	NS	NS	NS
$\beta_2\,\beta_3$	NS	NS	NS	NS	NS	NS
$\beta_1\,\beta_3$	NS	-0.66*	-0.56*	NS	NS	NS
$\beta_1\text{-}^2$	NS	-0.91*	-1.06*	0.23*	NS	NS
β_2^2	-0.93*	NS	NS	NS	NS	NS
β_3^3	NS	NS	0.34*	NS	NS	NS

*(P<0.05); **(P<0.01); NS: Not significant

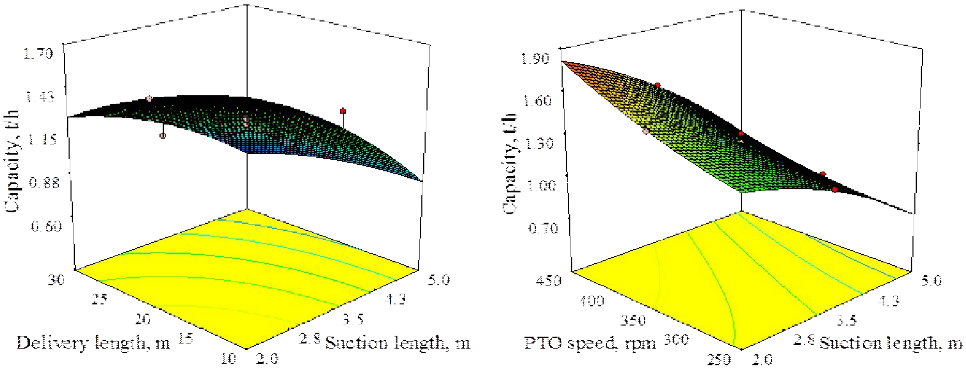

Fig 3. Effect of suction length, delivery length and PTO speed on capacity of straw loader for soybean straw

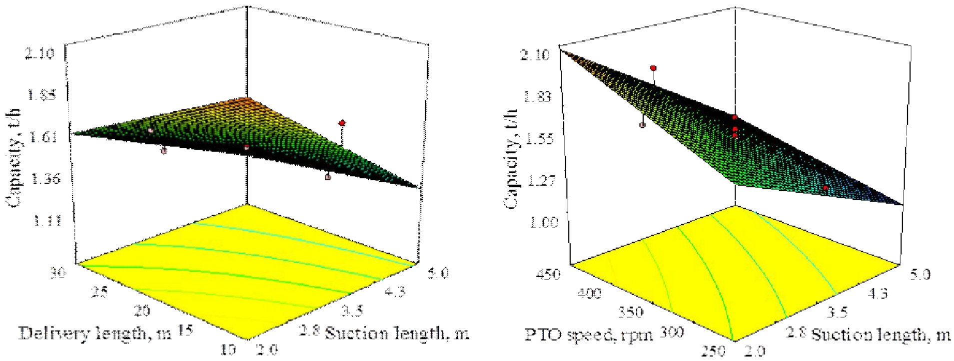

Fig 4. Effect of suction length, delivery length and PTO speed on capacity of straw loader for pigeon pea straw

The capacity of pneumatic loader was found higher for wheat straw followed by pigeon pea and soybean straw. Higher capacity might be due to the smaller size and lower terminal velocity for wheat straw. Results of the study showed that the terminal velocity was inversely correlated with the capacity of straw loader. Lower terminal velocity was observed for wheat straw as compared to pigeon pea and soybean straws (Table 2). Similar effects of size, terminal velocity and density of straw on flow rate were reported earlier (Gorial and O'callaghan, 1990; Khoshtaghaza and Mehdizadeh, 2006).

Effect of different parameters on fuel consumption of straw loader: The ANOVA showed that the fuel consumption was significantly influenced by suction length and PTO speed (Table 3). However, delivery length showed no significant effect ($P<0.05$) on fuel consumption. No significant difference was found in fuel consumption due to the interaction effect of different variables considered under performance of straw loader. After eliminating non-significant coefficients, the model of fuel consumption for wheat straw in coded terms (F_W) was equated to be as follows:

$$F_W = 3.74-0.29\,X_1+0.47\,X_3+0.23\,X_1^2 \qquad (5)$$

The model was found significant ($P<0.01$) with coefficient of determination of 0.93. Maximum fuel consumption of 5 l/h for loading of wheat straw was recorded at suction length, delivery length and PTO speed of 2 m, 30 m and 450 rpm, respetively. Whereas it was recorded to be minimum (3.1 l/h) at 5 m suction length, 10 m delivery length and 250 rpm PTO speed. From response surface plot it was found that fuel consumption reduced with increase in suction length. However, it increased with increasing delivery length at constant PTO speed of 350 rpm (Fig 5a). It might be due to decrease in straw carrying capacity and load with increase in suction length. Suuml *et al.* (2010) reported that the fuel consumption of PTO driven machines increased with incresing load. However, increase in delivery length might create back pressure on the blower which could result in higher fuel consumption. Power requirement of machine and pressure drop were found to increase with increase in blower revolution. Whereas material conveying capacity was found to decrease with the increase in pipe diameter and length which was in confirmation with the study performed by Kilickan and Guner (2010).

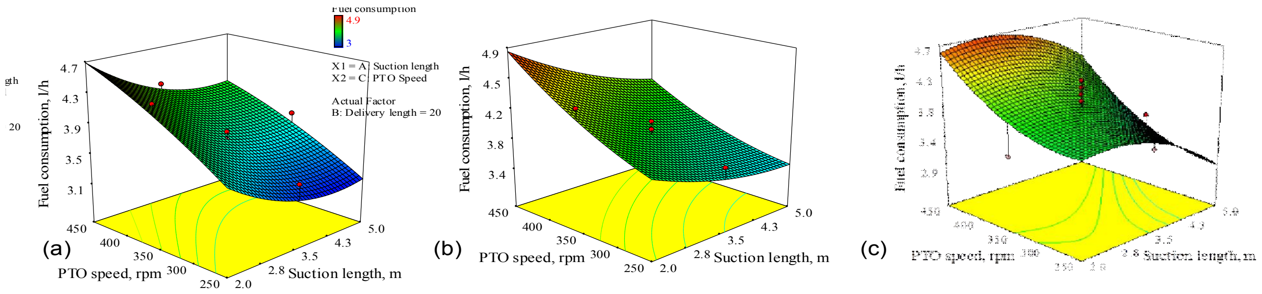

Fig 5. Effect of suction and PTO speed on fuel consumption of straw loader for (a) wheat straw, (b) soybean straw and (c) pigeon pea straw

The suction length and PTO speed significantly influenced the fuel consumption of straw loader with respect to soybean straw, whereas delivery length had no significant effect (Table 3). Interactions effect of variables were not found to be significant as well (Table 4). The model of fuel consumption for soybean straw in coded terms (F_S) after eliminating non-significant variables was equated to be as follows:

$$F_S = 3.87 - 0.29\, X_1 + 0.41\, X_3 \qquad (6)$$

The coefficient of determination for developed model was 0.91. The trend for reduced fuel consumption with increasing suction length and decreasing PTO speed was similar to that in wheat straw (Fig 5b). Maximum and minimum fuel consumption for soybean was found to be 4.9 and 3.0 l/h, respectively. Similarly the model was singifcant for pigeon pea straw. The coefficient of determination was 0.85. The numerical depiction of fuel consumption for pigeon pea in coded terms (F_P) with different variables was as follows:

$$F_{P-} = 3.85 - 0.31\, X_1 + 0.52\, X_3 \qquad (7)$$

The relation between fuel consumption and different variables for loading of pigeon pea straw was also found to be similar to that of wheat and soybean straw (Fig 5c). Maximum and minimum fuel consumption were recored as 4.8 and 3.0 l/h, respectively.

Optimization and validation: The pneumatic loader was operated at different combinations of suction length, delivery length and PTO speed. RSM was used to determine the optimum operating parameters for the pneumatic loader (Table 5). The optimum variables were selected from the sets of experimental values for maximum capacity and minimum fuel consumption. Equal weightage was given to capacity and fuel consumption during optimization. The optimized parameters for wheat straw were 2 m suction length, 10 m delivery length and 302 rpm of PTO speed. The corresponding predicted values of capacity and fuel consumption were 2.33 t/h and 4 l/h, respectively. Similarly the optimized parameters for soybean straw were 2 m suction length, 10 m delivery length and 366 rpm of PTO and predicted values of capacity and fuel consumption were 1.72 t/h and 4.33 l/h, respectively. The optimum values of suction length, delivery length and PTO speed for pigeon pea straw were 2 m, 10 m and 377 rpm, and predicted values of capacity and fuel consumption were 2.07 t/h and 3.97 l/h, respectively.

The experimental values for loading capacity of wheat straw and fuel consumption were 2.30 t/h and 4.18 l/h against the predicted values of 2.33 t/h and 4 l/h, respectively (Table 5). The experimental values were at par with optimized values. Similarly the experimental values for capacity of soybean straw and pigeon pea were 1.69 and 2.03 t/h against predicted values of 1.72 and 2.07 t/h, respectively. The fuel consumption for soybean and pigeon pea straws were 4.42 and 4.10 l/h against the predicted values 4.33 and 3.97 l/h, respectively.

Cost economics of straw loader: The cost analysis of straw loader and manual operation was performed (Table 6). The results showed that the fixed and variable costs of pneumatic straw loader were Rs. 122.20 and Rs. 333.10 per hour, respectively which gave the total cost of operation as Rs. 455.30 per hour. The BEP of pneumatic straw loader was calculated as Rs. 83.3 h per year for an operation of 250 hours per year with custom hiring charges of Rs. 700 per hour. Profit to entrepreneur/farmer after subtracting the annual expenditure from annual income was calculated to be Rs. 61,175 per year. The man-hours required per tonne of straw loading by pneumatic loader and manual handlings were 1.5 and 10, respectively. The operating cost of straw loader (Rs. 228 per tonne) was less as compared to manual operation (Rs. 400 per tonne). The percentage saving in cost and labour time were found to be 43 and 85%, respectively in pneumatic straw loader against the manual operation.

Table 5. Predicted values of the responses at optimum conditions

Parameters	Goal	Optimum/Predicted values			Experimental values		
		Wheat	Soybean	Pigeon pea	Wheat	Soybean	Pigeon pea
Suction length, m	In range	2	2	2	-	-	-
Delivery length, m	In range	10	10	10	-	-	-
PTO speed, rpm	In range	302	366	373	-	-	-
Capacity, t/h	Maximum	2.33	1.72	2.07	2.30	1.69	2.03
Fuel consumption, l/h	Minimum	4.00	4.33	3.97	4.18	4.42	4.10

Table 6. Cost economics of operation of pneumatic straw loader

Parameters	Tractor	Straw loader
(A) Fixed cost		
i. Initial cost of tractor, Rs.	450000	35000
ii. Salvage value @ 10% of initial cost, Rs.	45000	3500
iii. Service life, years	15	10
iv. Depreciation{(i-ii)/iii}, Rs./year	27000	3150
v. Annual uses, h/year	800	250
vi. Interest on investement @ 16% per annum, Rs./year	39600	3080
vii. Capacity of machine, t/h	-	2
viii. Insurance, taxes and housing@ 2% of initial cost per annum, Rs./year	9000	700
ix. Total fixed cost (iv+vi+viii), Rs./year	75600	6930
x. Fixed cost of operation, Rs./h	94.5	27.7
xi. Total fixed cost of operation, Rs./h	122.2	
(B) Variable cost		
i. Repair and maintenance cost, Rs./h	28.1	7.0
ii. Fuel required, l/h	4	-
iii. Fuel cost @ Rs.70/l, Rs./h	140	-
iv. Cost of lubricants @ 20% of fuel cost, Rs./h	28	-
v. Labour required with machine @ 8 h/day, No.	1	2
vi. Labour cost (Rs./h) @ Rs. 50 per h for skilled and Rs. 40 per h for unskilled labour	50	80
vii. Variable cost (i+iii+iv+vi), Rs./h	246.1	87.0
viii. Total variable cost, Rs./h	333.1	
(C) Cost of operation		
i. Total cost of operation (Fixed cost + Variable cost), Rs./h	455.3	
ii. Capacity of straw loader, t/h	2	
iii. Cost of operation, Rs./t	228	
(D) Labour cost in manual loading/unloading		
i. Labour required, man-h/t	10	
ii. Cost of operation @ Rs. 40 per h for unskilled labour, Rs./t	400	
(E) Break even analysis		
i. Custom hiring rate, Rs./h (assumption)	700	
ii. Break-even point, h/year	83.3	
iii. Annual Expenditure, Rs.	113825	
iv. Annual Income, Rs.	175000	
v. Profit to entrepreneur/farmer, Rs./year	61175	
(F) Saving in operation due to machine		
i. Saving in cost, %	43	
ii. Saving in labour, %	85	

Conclusion

In this study, pneumatic conveying system was used for wheat, soybean and pigeon pea straws. Size, shape and density of biomass affect their flow ability, thus performance of the loader was evaluated and optimized through response surface methodology to achieve maximum capacity at minimum fuel consumption. It was found that suction and delivery lengths significantly influenced the capacity and fuel consumption but the PTO speed was most vulnerable to variation in capacity and fuel consumption. Performance for wheat straw was found to be best followed by pigeon pea and soybean straw. Use of straw loader in above study showed a saving of cost and labour by 43 and 85%, respectively as compared to manual loading. Thus the study showed the potential of this machine to complete the mechanization chain for straw handling from farm to storage house.

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