FIELD EVALUATION OF A WHEAT STRAW CHOPPER

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ABSTRACT:- Wheat straw chopper is a resource conservation technology that makes chaff from combine-harvested wheat straw and saves the environment from smoke pollution, if straw is burnt in the field. Field performance of this technology has not been evaluated yet, although this technology has been adopted in Pakistan for many years. The objective of this study was to evaluate the performance of an improved version of wheat straw chopper in combine-harvested wheat fields of southern Punjab and to determine the economics of this machine. Five test plots ranging from 0.39 to 0.61 ha were selected to determine the performance of this machine. Results revealed that a 75 hp tractor was suitable for operating this machine. Average operating speed of chopper was 2.7 km h^{-1}. Average effective field capacity of chopper was 0.40 ha h^{-1} and field efficiency was 67.9%. Amount of chaff recovered was 2404 kg ha^{-1} and chaff recovery from straw was 61.1%. The operating cost of chopper setup was Rs. 5,262 ha^{-1}. Total worth of recovered chaff was Rs. 24042 ha^{-1} (@ Rs. 10 kg^{-1}). Net gain in terms of recovered wheat straw was Rs. 18780 ha^{-1}. The break even point (use) of this machine for harvesting own fields and rental fields was 77 h (31 ha) and 266 h (105.5 ha), respectively. Wheat straw chopper is a profitable technology that is getting momentum in combine-harvested wheat fields of the country, which saves chaff for cattle feed and increases the benefit of the farmer.

Key Words: Wheat Straw Chopper; Straw Management; Field Testing; Agronomic Characters; Economics; Break-Even Point; Pakistan.

INTRODUCTION

Wheat is a staple food of the people of Pakistan. Wheat was cultivated on 8.7 mha during 2013. Wheat crop contributes 10.1% to the value added in agriculture and 2.2% to Gross Domestic Product (GoP, 2013a).Wheat is cultivated in different cropping systems, such as cotton-wheat, rice-wheat, sugarcane-wheat, maize-wheat and fallow-wheat. Of these cropping systems, cotton-wheat and rice-wheat systems contribute about 60% of the total wheat area in the country (Farooq et al., 2007). In Pakistan, wheat harvesting starts from the early March in the South and continues till the end of July in the Northern parts of the country. Harvesting of wheat crop is carried out when the crop reaches maturity and the grain contains 14-20% moisture content (Pioneer, 2013).

In conventional wheat harvesting methods, wheat crop is first cut manually or with a reaper windrower. After harvesting, a stationary wheat

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thresher is used to separate grains from chaff, locally called as *bhoosa*. Wheat chaff is a common cattle-feed and is mainly used during green fodder shortage period. However, timely folding-up the wheat crop is not possible using conventional method of wheat harvesting, which takes about one month to harvest 30 ha using 10 labourers. Due to early monsoon rains, not only a significant amount of grains and chaff may be lost producing overall low yield, but delays sowing of next crop too.

For timely harvesting of wheat crop, combine harvesters are gaining a great acceptance in Pakistan now-a-days and replacing conventional wheat harvesting and threshing methods (Zafar et al., 2002). Currently, more than 5000 combine harvesters are being used in the country for harvesting wheat and rice crops (GoP, 2013b). These combine harvesters only collect grains and leave anchored high stubbles and combine-ejected loose straw in the field (Zafar et al., 2002; Gill et al., 2012). Due to non-availability of a proper technology, about 75% of combine-harvested stubbles and loose straw go as waste besides causing environmental pollution due to straw burning in the field prior to tillage for subsequent sowings (Mangaraj and Kulkarni, 2011).This phenomenon raises three major issues: environmental pollution associated with fire hazards, burning of rich soil organic matter and loss of valuable commodity the wheat chaff.

Wheat straw should be conserved for making chaff, which is a common cattle-feed. Furthermore, burning of wheat straw shrinks the farmer's profit and burns soil organic matter and other nutrients. Wheat straw can be used effectively using a baler or a wheat straw chopper (Thakur et al. 2000). The combine harvesters can produce grains many times faster than the conventional threshers, but the management of uncut and loose straw is a big problem for farmers. Therefore, farmers were demanding a technology that could harvest the combine harvested wheat stubbles and loose straw and chop them as *bhoosa* for feeding their cattle and selling it in the local market.

Agricultural and Biological Engineering Institute (ABEI), National Agricultural Research Centre, Islamabad, identified and acquired a tractor operated wheat straw chopper-cum-blower from India in 2002 through Rice Wheat Consortium and demonstrated this technology in the Punjab province (Zafar et al., 2002). It harvests the anchored wheat stubbles and picks up the combine-ejected loose straw from the field, chops it into *bhoosa* and blows it into a trolley hooked at its rear (Zafar et al., 2002). This Institute provided technical assistance to local manufactures for indigenisation of this technology. Currently, more than 15 agricultural machinery manufacturers are making this machine in Lahore, Daska, Hafizabad, Gujranwala and Faisalabad districts. Now, a large number of locally developed wheat straw choppers are in operation in the rice-wheat and cotton-wheat cropping systems of the Punjab (Rehman et al., 2011).

The machine performs cutting, picking, threshing and blowing operations in a single action. In the early versions of this machine, a number of problems associated with its gear box, cutter bar, crank shaft and safety mechanism were encountered during field operation. Different modifications were incorporated in the machine to improve its performance. The improved versions of wheat straw chopper are now more reliable and have better field performance.

Although, the wheat straw chopper has been adopted in Pakistan for many years, yet field performance of this technology has not been thoroughly evaluated and reported in any scientific paper for future reference. The objective of this study was to evaluate the performance of an improved version of wheat straw chopper in combine-harvested wheat fields of Southern Punjab and to determine the economics of this machine.

MATERIALS AND METHOD

Study Sites and Test Plots

Two test sites were selected in Multan, first site at a farmer's field near Adda Bund Bosan, whereas the second site was selected in the research fields of Bahauddin Zakariya University (BZU), Multan. On these sites, wheat crop was harvested with combine harvesters. Total straw harvesting area using wheat straw chopper was 18 ha (45 acres): 12 ha (30 acres) at first site and 6 ha (15 acres) at second site. The soil texture of the first site was sandy and the second site was loamy. The fields of first site consisted of big boundaries at 10-15 m distance within the field. The fields of second site have normal small boundaries 30 m apart. Five tests were conducted for evaluating the performance of the machine (three tests at first site and two tests at second site). The area of test plots ranged from 0.39 to 0.61 ha. All test plots were rectangular in shape. Appropriate field patterns were selected for eliminating the non-productive time or keeping it to its minimum. In most cases, the circuitous pattern with rounded corners was used.

Wheat Straw Chopper

An improved version of wheat straw chopper was procured at ABEI from a private manufacturer. It was a trailed machine towed behind a tractor during transportation and powered by a tractor PTO during field operation. The chopper travels on two wheels having rubber tyres (Table 1). The wheat straw chopper performs four major operations: (1) loose straw pickup; (2) anchored straw harvesting; (3) straw threshing and (4) chaff blowing. The power for machine operation is supplied through tractor

Table 1. Field evaluation of a wheat straw chopper

Machine parameters	Specifications *
Length (mm)	3910
Width (mm)	2670
Height (mm)	2380
Threshing drum type	Cutter type
Fan type	Suction cum blower
Tractor power (hp)	65 or higher
Width of cut (mm)	2330
Cutter bar type	Reciprocating sickle bar
Cutter bar length (mm)	2380 mm
Number of cutters on cutter bar	33
Threshing drum diameter (mm)	500
Concave type	9 x 9 mm square bar
Concave opening (mm)	12
Trolley wheel distance (mm)	2260

** Local agricultural machinery lacks standardisation. The specifications of wheat straw choppers fabricated by different agricultural machinery manufacturers may differ.*

PTO by using a universal shaft. This power is supplied to the pick-up reel, cutter-bar, threshing drum, blowing fans, oscillating sieves and feeding auger. The power to pick-up reel, cutter bar, threshing drum, lowing fans and oscillating sieves is provided through v-belts, whereas the feeding auger is driven through a chain and sprockets. The cutter bar reciprocates with the help of a cam and connecting rod assembly (Figure 1). The reel having suspended fingers on its periphery rotates during forward motion of the machine and picks up loose straw and throws it on the feeding table. The cutter bar reciprocates side-wise and harvests anchored straw left by the combine harvester. The cutter bar has replaceable double-edged serrated triangular cutters. The picked and cut straw is accumulated on the feeding table by the reel and cutter bar. Feeding auger congregates this straw in the middle and a conveyor feeds the straw into the threshing unit, which comprises a threshing drum and concave both having serrated knives for threshing and chopping the straw. The concave consist of square bars spaced at 12 mm that are welded in a semi-circular shape. With the rotation of drum, the straw is chopped into fine pieces by knife action, which falls down through concave openings on the oscillating sieve. Any uncut and scattered wheat kernels are also cut and picked up by the chopper. These kernels are threshed and the grains are separated by the sieve and collected into a tray provided underneath. Two blowers throw back the chopped straw through the duct into a mesh-covered trolley.

Field Operation of Wheat Straw Chopper

This study was conducted in April-May, 2014. Chopper was attached with a 75 hp tractor (MF-375). A trolley having a wire-mesh canopy was hitched behind the straw chopper for chaff collection. The machine was operated at two field speeds: 3.4 km h^{-1} using second low gear of tractor with average throttle (1800 engine rpm) and 1.6 km h^{-1} using first low gear with average throttle (1800 rpm). The throttle position was

Figure 1. Improved wheat straw chopper in operation in the field at first site

changed to decrease or increase the ground speed depending upon the straw load in the field. The machine was also operated at about 5 km h^{-1} using third low gear of tractor, but the straw load was not manageable at this field speed and as such this speed was not included as one of the test parameters.

Data Collection

Data were collected on machine; crop and machine performance aspects. Following parameters were measured under these aspects.

Machine Aspects

Parameters related to the machine aspects, such as ease of operation, adjustment, maintenance, safety, ease of transportation, local repair and the frequency of defect / breakdown were measured. These parameters can greatly affect the performance. All these parameters were qualitative, which were measured in qualitative terms, such as good, acceptable and poor or easy, manage-able and difficult.

Crop Aspects

Crop related parameters included: moisture content of straw, height of wheat stubbles, number of tillers per hill, diameter of wheat straw, row spacing and variety of wheat crop. Moisture content was the most important parameter for harvesting wheat straw. The straw was harvested when the moisture of straw was about18% or less (Pioneer, 2013), so that proper threshing could be ensured. Moisture content was measured qualitatively by expert feel method by twisting and breaking the straw with hands. Ten spots were randomly selected from each test field before straw harvesting. Averages were then calculated of these parameters.

Machine Performance Aspects

Forward Travelling Speed

Two pegs were inserted in the field at 30 m distance. Travelling time of the machine was measured from initial peg to the final peg. The process was repeated thrice and took its average.

Theoretical and Effective Cutting Width

Theoretical cutting width was measured before operation and confirmed from the manufacturer's specifications. Effective cutting width of the machine was measured in the field for five consecutive runs (rows) and five readings were taken from each run. Average of these measurements was calculated for getting effective cutting width.

Cutting Height

It was a compromise between the wastage of chaff and the safety of the machine. Too high cut could waste a considerable amount of chaff, whereas too low cutting height could damage the cutter bar of the machine due to stones or clogging in the field boundaries. The machine was operated at the lowest safe cutting height of 3-5 cm above ground level.

Theoretical Field Capacity

It is the machine performance in terms of work done in ideal conditions assuming no time is lost in turning, refuelling, adjustment, machine trouble, etc. and utilisation of 100% width of the machine without any overlapping. Theoretical field capacity was determined using Equation 1 (RNAM, 1995; Field and Solie, 2007):

$$TFC = \frac{S \times W}{10}$$

where,

TFC = Theoretical field capacity (ha h^{-1}),
S = Forward speed (km h^{-1})
W = Theoretical working width (m)

Effective Field Capacity

It is the amount of performance that had actually occurred in the field and is measured by dividing the actual area covered by total time consumed in productive operations, turning and machine adjustment. Refuelling or machine trouble time was not added in this time. Effective field capacity was determined using Equation 2 (RNAM, 1995):

$$EFC = \frac{A}{T_P + T_L}$$

where,

EFC = Effective field capacity (ha h^{-1}),
A = Total area actually covered by the machine (ha),
T_P = Productive time of the machine (h)
T_L = Non-productive time or time lost (h) consumed in turning and machine adjustment.

Field Efficiency

It is the ability of machine to perform work in the field, which was determined from the ratio of effective field capacity and theoretical field capacity as shown in Equation 3 (Field and Solie, 2007):

$$\eta = \frac{EFC}{TFC} \times 100$$

where,

η = Efficiency of the machine (%).

Fuel Consumption

The fuel tank of the tractor was completely filled before and after the test. Amount of refuelling in litres after the test was the quantity of fuel consumption.

Labour Requirement

The man-hours required for operating the chopper during the test were calculated. The man-hours required for unloading the chaff trolley were also noted during the test.

Cost of Operation of Wheat Straw Chopper

It was calculated based on the chopper price, trolley price and a 75 hp tractor price. Generally, operating cost is the combination of ownership costs (fixed costs) and operating costs (variable costs) (Field and Solie, 2007). The fixed costs includes depreciation, interest on average investment, insurance, tax and shelter; whereas the variable cost includes fuel, oil, repair and maintenance, consumables and required labour for the machine. Cost of operation of wheat straw chopper was determined according to the procedure (RNAM, 1995).

Amount of Chaff Recovery

The amount of chaff recovered from each test was measured. Based on the test data, the amount of chaff recovered from one hectare was determined.

RESULTS AND DISCUSSION

Machine Aspects

Ease of handling/operation indicates how machine behaves while operation, turning and crossing boundaries in heavy crop or in sandy and moist soils, With easier machine handling operation, the work will be done more efficiently. The machine was operated with a 75 hp tractor as earlier experience had shown that a smaller tractor could not handle and operate this machine in the field. The handling of machine train in the field was not so easy, but was manageable. Turning of this machine train needed more space than the normal tractor ope-rated machines due to hooked trolley at the rear of the tractor. While crossing field boundaries, lifting the chopper too high can break the universal shaft (Table 2). On the other hand, the cutter bar may break if not lifted up while crossing field boundaries. An experienced driver can operate this machine without any fatigue.

Adjustment and maintenance of machine was easy. Adjustment of belts, greasing the bearings and setting the height of cut was done easily by the operator; however, frequent adjustment of machine during operation decreased its performance. During field operation, the machine develops lot of vibrations (due to lack of precision manufacturing techniques); therefore, nuts and bolts needed frequent checking before and during field operation. All nuts and bolts were regularly inspected and tightened, if necessary while changing the chaff trolley.

Table 2. Results of machine related parameters

Machine aspects or parameters	Good/ Easy	Average / Manageable	Poor/ difficult
Ease of handling/ operation		✓	
Adjustment/operation	✓		
Maintenance	✓		
Safety	✓		
Ease of transportation		✓	
Local repair (major)			✓
Defects and breakdown		✓	

Operator's safety has much concern during machine operation. The operator had no risk of safety because the fast moving parts of the machine were enclosed in main casing. Similarly, transportation of this machine was also easy with the help of a 75 hp tractor.

Minor repair works can be easily performed in the field by the tractor operator or a mechanic. However, for major repair of the machine, such as universal shaft, cutter bar, gear box and threshing drum, the machine is required to be taken to an agricultural machinery workshop. This means that its repair is difficult and all repair works cannot be performed at general repair workshops available in that locality. Similarly, average amount of breakdowns were observed during field operation. The farmer prefers the machine which offers minimum breakdowns in the field while operation, which mainly depends on the skill of the operator. If proper care is not taken, the operator may break machine while turning and crossing the field boundaries.

Crop Aspects

These parameters were also responsible for the performance of the machine and overall chaff recovery from the test fields. From the crop related parameters, the moisture content of the straw was very important. At high moisture content, the performance of wheat straw chopper was reduced. Harvesting the straw of higher moisture content clogged the threshing machine frequently and brought breakage in the machine (Table 3). Fuel consumption was increased and reduced the efficiency of the machine significantly. The tractor used its maximum power for threshing the wet straw in the mornings. The moisture content ranged from 14% to 18 % of all test fields.

Table 3. Results of crop related parameters

Crop parameters	Test 1	Test 2	Test 3	Test 4	Test 5
Crop variety	Punjab 2011	Punjab 2011	Punjab 2011	Sehar	Sehar
Row spacing (mm)	18.7	18.3	19.1	18.5	17.5
Straw moisture content (%)	15-18	14-16	14-16	12-14	14-16
Height of wheat plant (mm)	920	930	905	890	895
Height of wheat stubbles (mm)	340	330	360	350	320
Number of tillers per hill	4.2	4.5	4.3	3.9	4.1
Diameter of wheat straw (mm)	4.3	4.2	4.3	4.1	4.3

Machine Performance Aspects

Forward Travelling Speed

Travelling speed directly affected the performance of the wheat straw chopper. The machine was operated at 1.6 km h^{-1} (first low gear) and 3.4 km h^{-1} (second low gear) successfully. Chopper was also operated at about 5 km h^{-1} (third low gear) field speed, but at this speed, the machine worked successfully in only low straw load and in heavy straw load, this speed was not practical. Low speed was used in heavy straw load and in sandy soil where less traction force was available for tractor due to extra slippage (Table 4). This is suggested that the chopper should not be used in only one field speed, but the speed should be switched over between the above two field speeds according to straw load. The chopper should always be operated transverse to the windrows of combine-ejected straw. If chopper is used along the rows, heavy combine-ejected straw will reduce the performance of machine and there are chances of machine breakage or

Table 4. Machine performance parameters

Test No	Area of test field (ha)	Travel speed (km h^{-1})	Effective cutting width (m)	Cutting height (mm)	Theoretical field capacity (ha h^{-1})	Effective field capacity (ha h^{-1})	Field efficiency (%)	Fuel consumption (l h^{-1})	Fuel consumption (l ha^{-1})
1	0.48	3.4	2.20	30	0.79	0.45	57.1	6.0	13.3
2	0.39	3.4	2.00	40	0.79	0.43	54.0	6.0	14.0
3	0.61	1.6	2.00	35	0.37	0.29	79.2	5.0	17.2
4	0.40	1.6	2.10	30	0.37	0.30	82.5	5.0	16.7
5	0.40	3.4	2.20	40	0.79	0.53	66.8	6.0	11.3
Average	0.46	2.7	2.10	35	0.62	0.40	67.9	5.6	14.5

clogging. Forward speed should be controlled or reduced accordingly for feeding big heaps of combine ejected straw.

Theoretical and Effective Cutting Width

The theoretical cutting width of this wheat straw chopper was 2.33 m before starting field tests and was confirmed from the manufacturer's specifications. The effective cutting width ranged from 2.00 m to 2.20 m in different tests. The average effective cutting width of the machine was 2.10 m (Table 4). The difference between theoretical and effective cutting width was due to overlapping of the cutting swath in the consecutive runs. The amount of overlap was kept minimum for increasing field efficiency.

Cutting Height

The height of cut was controlled by adjustable skids provided on both sides of the header unit. The test fields were free of stones and therefore, the height of cut was kept at minimum possible level, which ranged from 30-40 mm above the ground (Table 4). However, in stony field, a cutting height of 70-80 mm would be safe to avoid machine breakage.

Theoretical Field Capacity

The theoretical field capacity was 0.79 ha h^{-1} on the field speed of 3.4 km h^{-1} and was 0.37 ha h^{-1} on field speed of 1.6 km h^{-1} (Table 4). Theoretical field capacity is the working capacity of chopper in ideal condition, when there is no time loss in turning, adjustment, unloading and with zero overlap. This is never possible in the field conditions. The average theoretical field capacity in all field tests was 0.62 ha h^{-1}.

Effective Field Capacity

This is always less than the theoretical field capacity in all field tests (Table 4). The effective field capacity of the chopper ranged from 0.29 to 0.53 ha h^{-1}. The effective field capacity was lower at 1.6 km h^{-1} and higher at 3.4 km h^{-1} field speed. It was directly linked with operating speed and unproductive time 'T_L' in the field. If the unproductive time is minimum, the effective field capacity of the chopper or any other machine will be the maximum. Secondly, the effective field capacity was also directly linked with the utilisation of the full width of the machine. If the overlap swath is zero or minimum, the effective field capacity will be the maximum and may be close to the theoretical field capacity (Field and Solie, 2007). The average effective fie-ld capacity in all tests was 0.40 ha h^{-1}.

Field Efficiency

The field efficiency of chopper ranged from 54.0% to 82.5% in different field tests. The average efficiency of the machine in all tests was 67.9% (Table 4). The field efficiency of this version of machine has been improved from the previous versions, which had the maximum field efficiency of 60% (Zafar et al., 2002). This means that the amount of fatigue in this improved version of the chopper available in the market has been reduced and therefore, the amount of unproductive time has also been reduced considerably. That is why, the use of wheat straw choppers in the combine harvested wheat fields is now getting momentum among farming community.

Fuel Consumption

It depends on the gear and field speed used, crop load and moisture content of the straw. At heavy crop loads, the tractor used more power and therefore, consumed more fuel (diesel) the higher moisture content of the straw, higher fuel consum-ption. The average fuel consumption of the tractor at 1.6 km h^{-1} field speed was about 17 l ha^{-1} (5 l h^{-1}), whereas the average fuel consumption at 3.4 km h^{-1} was about13 l ha^{-1} (6 l h^{-1}). The average fuel consumption in all field tests was calculated as 14.5 l ha^{-1} (5.6 l h^{-1}) (Table 4). In this study, the chopper was operated at normal throttle at 400-450 PTO rpm. If tractor is operated at full PTO speed (540 rpm), the consumption of fuel will be increased. Furthermore, working at full speed, the tractor can heat up and may need to stop after an hour or so. Besides higher fuel consumption and hazard of engine heating, to operate the tractor at 540 PTO rpm, the tractor engine will have to be run at 2000 rpm which will result in field speed of 2.3 km h^{-1} at first low gear, which will be higher than the test speed of 1.6 km h^{-1}. All these aspects will ultimately reduce the efficiency of work. This machine can be easily operated with a 75 hp tractor with about 400 rpm of tractor PTO. At this speed, the tractor does not heat up frequently. This is also good for the safety of the tractor, otherwise frequent wear and tear or breakdowns can further reduce the working efficiency of the machine.

Labour Requirement

One driver was needed for driving tractor, chopper and trolley. Two more persons were engaged for unloading the chaff trolley at a chaff collection point. One of them was also responsible to transport chaff-filled trolley from field to the chaff collection point. For operating the tractor and machines, 2.5 man-hours were needed for harvesting one hectare. For unloading and trans-portation of chaff trolleys, 4.9 man-hours were needed for the chaff of one hectare. The total labour input required to harvest one hectare of loose and anchored wheat straw was 7.4 man-hours.

Cost of Operation of Wheat Straw Chopper

Cost analysis of wheat straw chopper was calculated using the fixed and variable costs of the chopper, tractor and trolley based on the full life (10 years) of these machines. Different assumptions like machine life, annual use and fuel and labour prices were also made to calculate the fixed and variable costs of tractor and chopper machine (RNAM, 2005; Field and Solie, 2007). The average cost of operation of wheat straw chopper with tractor and trolley was calculated as Rs. 5262 ha^{-1} or Rs. 1990 h^{-1} (Table 5).

It was assumed that tractor and trolley would be used for other purposes also throughout the year, but the wheat straw chopper was used for about one month only in wheat harvesting season. The full life of the tractor and trolley was kept as 10 years. Therefore, for calculating the break even point, the annual use of wheat straw chopper was varied from 10 h to 300 h, whereas the annual use of tractor and trolley was 1200 h and 240 h, respectively. The fixed and variable costs of all machines were calculated based on their annual usage. The economics of

Table 5. Cost of operation and chaff recovery analysis

Test No.	Test area (ha)	Cost of operation (Rs.ha^{-1})	Cost of operation (Rs.h^{-1})	Grain yield (kg ha^{-1})	Amount of grains from test field (kg)	Actual chaff recovered from test field (kg)	Chaff recovered (kg ha^{-1})	Chaff recovery (%)	Price of chaff Rs.10kg^{-1} (Rs.ha^{-1})	Saving (Rs.ha^{-1})
1	0.48	4424	1988	3853	1841	1089	2279	59.2	22790	18368
2	0.39	4629	1968	4150	1613	1004	2583	62.2	25830	21201
3	0.61	6864	2001	3952	2400	1445	2380	60.2	23800	16936
4	0.40	6636	2015	3754	1520	931	2300	61.3	23000	16364
5	0.40	3756	1977	3952	1600	1004	2479	62.7	24790	21034
Average	0.46	5262	1990	3932	1795	1095	2404	61.1	24042	18780

the operation of wheat straw chopper was studied on the basis of annual use both in terms of hours and the area covered in hectares (Figure 2). The cost of operation decreased gradually with the increase in annual use (Figure 2a). The breakeven point in terms of price of wheat chaff recovered (recovered grain price was not included in this analysis) reached at 77 h for ownership basis and 266 h for rental use. Similarly, the cost of operation decreased gradually with the increase in annual use (Figure 2b). The breakeven point in terms of price of wheat chaff recovered reached at 31 ha for ownership basis and 105.5 ha for rental use. The rental price of wheat straw chopper during test season was Rs. 9386 ha^{-1} (Rs. 3800 acre^{-1}). The rental entrepreneur recovers the chaff from the whole field regardless the straw load.

Amount of Chaff Recovery

This is a common rule in wheat growing areas that a stationary thresher produces the same amount of *bhoosa* as that of wheat grains from an acre with little variation due to varietal trait. For instance, if a farmer gets 4000 kg (100 md) wheat grains from one hectare, the amount of chaff will also be 4000 kg. Using a wheat straw chopper, the average chaff recovery of all tests was 61.1% of that the amount of grains (Table 5). This result of chaff recovery is consistent

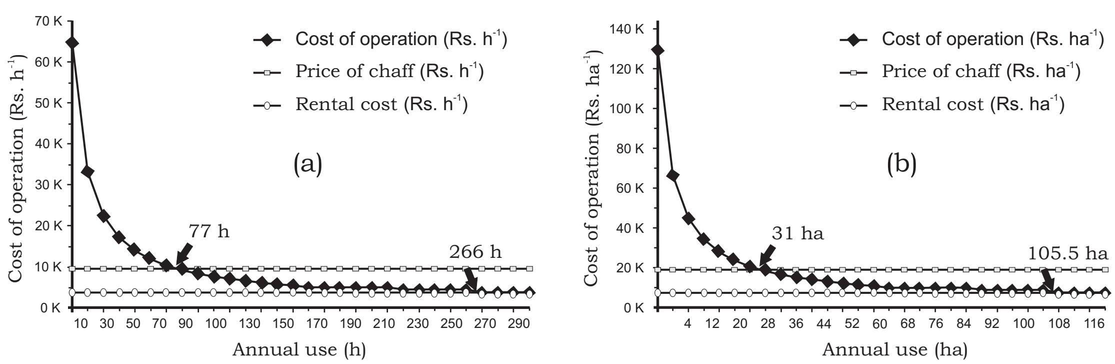

Figure 2. Beak-even point of wheat straw chopper based on the annual use in (a) hours and (b) hectare

with the preliminary study by Zafar et al. (2002). Therefore, the average amount of chaff recovered was 2404 kg ha^{-1}, whereas the average amount of grains harvested during the tests was 3932 kg ha^{-1}. The remaining amount of chaff from 1:1 grain chaff ratio was unrecoverable. This amount may vary depending on the variety of wheat crop as mentioned earlier. The first reason of low chaff recovery using wheat straw chopper is that the combine harvester cuts the wheat straw from the middle and tramples it while threshing to make it a bit fine. This fine straw is spread around the field and cannot be picked up by the wheat straw chopper. Therefore, straw is lost due to combine operation. Secondly, the farmer is mostly concerned to harvest the portions of the field having heavy straw load, so many patches of field are left uncut, which reduces the overall low chaff recovery. Thirdly the wheat straw near boundaries, remains uncut that is also the reason of low chaff recovery. The unrecoverable straw includes uncut straw near headlands, uncut straw near boundaries, lodged straw due to combine operation and threshed straw by the combine lying on the ground surface that cannot be cut by the cutter. Finally, some amount of chaff is also lost from the mesh canopy of trolley due to high pressure of the blower or due to broken mesh from different places. All these losses roughly assumed as 15 % of the total recovered chaff by the straw chopper. The canopy of the trolley should be repaired to increase chaff recovery.

Price of the chaff produced by wheat straw chopper was Rs. 10 kg^{-1} according to local market price. Total price of chaff was Rs. 24042 ha^{-1}. The net saving of the farmer was Rs. 18,780 ha^{-1}. (Table 5), which is a reasonable amount. Using the wheat straw chopper, the chaff is recovered for cattle feeding, soil organic matter is saved from burning and environmental pollution is reduced.

Comparison of Costs of Different Methods

The operating cost of wheat straw chopper was compared with other methods, such as manual cutting and threshing and reaper cutting and threshing. The operating costs of manual cutting, reaping, threshing and combine harvesting were calculated from the rental prices of these methods available in that area. The wheat straw chopper was owned in this comparison. Total cost of manual cutting and threshing; reaper cutting and threshing and combine cutting and straw chopping was Rs. 16163 ha^{-1}, Rs. 14619 ha^{-1} and Rs. 10202 ha^{-1}, respectively (Table 6). This revealed that the cost of combine cutting was the minimum of three methods. Chaff recovery ratio was almost 1:1 grain to chaff in manual and reaper cutting, but for wheat straw chopper the ratio was 1:0.61 grain to chaff. But, the chaff made by thresher was sold as Rs. 7.5 kg^{-1}, whereas the chaff made by wheat straw chopper was sold by Rs. 10 kg^{-1} because this chaff was very clean without any dust and fine particles. Net benefit for manual, reaper and chopper methods was Rs. 136202 ha^{-1}, Rs. 137746 ha^{-1} and Rs. 136663 ha^{-1}, respectively. The difference in net benefit of these methods is not so significant, but the folding-up work is significantly expedited in combine

Table 6. Comparison of cost of different wheat harvesting methods

Operation	Manual cutting and threshing*	Reaper cutting and threshing*	Combine cutting and wheat straw chopping
Cutting/harvesting cost (Rs. ha^{-1})	10263	8719	4940
Threshing/chopping cost (Rs. ha^{-1})	5900	5900	5262
Total cost of cutting/ harvesting & threshing/ chopping cost (Rs. ha^{-1})	16163	14619	10202
Grain price (3,932 kg ha^{-1}) (Rs. ha^{-1})	122875	122875	122875
Amount of chaff produced (kg ha^{-1})	3932	3932	2399
Chaff price (Rs. 7.5 kg^{-1} and Rs. 1 kg^{-1})(Rs. ha^{-1})	29490	29490	23990
Total price of grain and chaff (Rs. ha^{-1})	152365	152365	146865
Net benefit (Rs. ha^{-1})	136202	137746	136663

** These results are based on 10 interviews of farmers for getting rental prices of different operations of wheat cutting.*

harvesting followed by wheat straw chopper. Therefore, this method should be preferred for saving precious time for sowing subsequent crops and saving the wheat crop from the wastage of early monsoon rains. The improved version of chopper offers minimum fatigue in operation. Wheat straw chopper is a profitable technology that is getting momentum in combine-harvested wheat fields of the country, which saves chaff for cattle feed and increases the benefit of the farmer. The cost of this machine needs to be reduced to make it affordable to all farmers

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AUTHORSHIP AND CONTRIBUTION DECLARATION

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1.	Dr. Hafiz Sultan Mahmood	Conceived the idea, Data collection, Data analysis, Results and Discussion, Introduction, Overall management of the article
2.	Dr. Tanveer Ahmad	Conclusion, Technical input at every step
3.	Mr. Zulfiqar Ali	Data analysis, Wrote abstract, Methodology
4.	Dr. Munir Ahmad	Wrote abstract, Methodology, Conclusion
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