Performance Evaluation of Tractor Drawn Round Straw Baler for Paddy

THESIS

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CERTIFICATE- I

*This is to certified that the thesis entitled "Performance Evaluation of Tractor Drawn Round Straw Baler for Paddy" submitted in partial fulfilment of the requirement for the degree of **MASTER OF TECHNOLOGY** In Agricultural Engineering in **FARM MACHINERY AND POWER ENGINEERING** of Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur is a record of the bonafied research work carried out by **MISS KUMUDINI VERMA** under my guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee and the Director of Instruction.*

No part of the thesis has been submitted for any other degree or diploma (Certificate awarded etc.) or has been published/published part has been fully acknowledged. All the assistance and help received during the course of the investigation has been acknowledged by her.

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This is to certified that the thesis entitled "***Performance Evaluation of Tractor Drawn Round Straw Baler for Paddy***" submitted by **MISS KUMUDINI VERMA** to the Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur in partial fulfilment of the requirement for the degree of **MASTER OF TECHNOLOGY** In Agricultural Engineering in the Department of **FARM MACHINERY AND POWER ENGINEERING** has been, after evaluation, approved by the External Examiner and by the Student's Advisory Committee after an oral examination on the same.

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LIST OF ABBRIVIATIONS

Abbreviation/ Symbol	**Stand for**
@	To address
˚C	Degree Celsius
Anon	Anonymous
BIS	Bureau of Indian Standard
BPH	Bullock paired hour
C	Energy coefficient
CAE	College of Agricultural Engineering
CH	Chemical
CH_4	Methane
cm	Centimetre
cm^2	Centimetre
CO	Carbon mono oxide
CO_2	Carbon dioxide
DE	Direct energy
EC	Electricity consumption
et. al.	And others
FC	Fuel consumption
Fig.	Figure
FYM	Farm yard manure
GHG	Green house gas
h	Hour
HLH	Human labour hour

IE	Indirect energy
JNKVV	Jawaharlal Nehru Krishi Vishwa Vidyalaya
kg	Kilogram
Kg/ha	Kilogram/hectare
Km/h	Kilometre/hour
l/h	Litre/hour
LCA	Low cost analysis
m	Meter
MC	Moisture content
MJ	Mega joule
mm	Millimetre
MT	Million tonnes
N_2O	Nitrous oxide
OA	Operation area
RME	Residue management equipment
RNAM	Regional Network for Agricultural Managment
S. No.	Serial number
SO_2	Sulphur dioxide
t	Time
TE	Total energy
V	Volume
WM	Weight coefficient

INTRODUCTION

1.1 Introduction

Rice (*Oriza sativa*) is a staple food crop of world's population, and every day million of Indians find comfort in it. With high carbohydrate content, it is known to provide instant energy and is a staple that is consumed by the majority of India's population. India is not only a leading consumer of rice crop but also the second largest producer in the world (106.5 million tonnes), lagging behind only China (144 million tonnes) according to the annual report (2015-16) of United States Department of Agriculture. Paddy is one of the major cereal crops of Madhya Pradesh covering an area of 17.04 million hectares during the year 2017-18 with a production of 33.45 million tonnes with a yield of 1963 kg/ha (Directorate of Economics and Statistics, MoA&FE).

Govt. of India has estimated that about 500 Mt of crop residues are generated every year (GoI, 2016). However, a large portion of the residues, about 140 Mt, is burned in the field primarily to clear the field from straw and stubble after the harvest of the preceding crop. Farmers in northwest India dispose of a large part of rice straw by burning in situ. There is a large variability in crop residues generation and their use depending on the cropping intensity, productivity and crops grown in different states of India. Residue generation is highest in Uttar Pradesh (60 Mt) followed by Punjab (51 Mt) and Maharashtra (46 Mt). Madhya Pradesh contributes about 33.18 Mt (NPMCR, 2014).

Farmers usually burn their straw yield at the end of the rice harvesting season for the fields are prepared for the next crop. Burning rice straw may increase the soil surface layer temperature, causing a sharp drop in winter crop seedling emergence. The frequent straw burning may cause subsoil hardpan, which makes the drainage difficult, restricts seedlings emergence (Agricultural Magazine, 1999).

Burning of agricultural wastage like rice, wheat straw has put the ecosystem and agriculture in danger. Every 4 tons of rice & wheat straw grain produces about 6 tons of straw & each tonne of straw on burning releases 3 kg particulate matter, 60 kg CO, 1460 kg Co_2, 199 kg ash & 2 kg of So_2 (Gadi *et al.*, 2003). To minimize the effects of these burn by using straw baler machine and use these straw marital as fodder for dairy farming, soil mulching, bio manure making, paper industries, biomass generation, thatching for rural homes, craft arts, fuel for domestic and industrial uses by making briquettes, etc.

Straw potentially has a high nutrient value potential and could be more economically beneficial. It is a great loss if this agricultural residue is wasted. Agricultural by products developments are also capable of driving the development of agro-based industry potentially, towards greater economic competitiveness. In an economic sector that demands highly competitive products, an increasing biotechnology development, the potential of straw development could be envisioned to drive the country towards creating a stronger industrial chain. Moreover, it is a new strategy in the further development of the agricultural sector, which can also create additional opportunities for rural economic development in generating farmers income.

Making the utilization viability some times questionable the unbaled nature of the straw is the main contributor to the higher landed price. The situation is further deteriorated due to loss of straw in transit by wind blowing and road jerks ranging between 2 to 5% of total straw loaded. There is a solution to collect the straws in baled form. For the purpose, baling equipment is required to bale the straws.

After combine harvesting, the straw is left on the earth in swaths. The straw should be removed as quickly as possible so, that the treatment of the soil preparation can begin thereby establishing next year's crop. A baler is a machine used to compress straw into bales for easy transport and storage.

Performance of baler was affected by the following factors: 1) The condition of field surface, 2) The condition of the hay, 3) The size and uniformity of the windrows, 4) The capacity of the picking up and feed mechanisms, 5) The forward speed of the baler and 6) The amount of power available (Kepner et al., 1978).

Therefore, agricultural practices need to manage the crop residual on the harvested field without hazard to the soil, environment, soil fertility, and another factor. The crop residue must be removed from the field by using baler machines either self propelled or tractor drawn. This project is under taken to evaluate the tractor-drawn round baler for paddy crop with following objectives:

1.2 Objectives

1. Performance evaluation of tractor-drawn round straw baler for harvested paddy at different speeds and moisture content.
2. Cost economic of tractor-drawn round straw baler & comparative study with manual collection method.

REVIEW OF LITERATURE

This chapter briefly reviews the results carried out by various researchers of India and foreign in the field of residue management. The reviewed literature reveals various problems faced during straw management practices and also highlights recent developments in straw management machinery. In agriculture, timeliness in farm operations, especially the harvesting the crop is of crucial importance. The studies show that the alternative to burning is more profitable. The available literature has been reviewed under the following headings:

2.1 Problems occurred due to straw left in the field after harvesting

2.2 Adverse effect of burning of straw

2.3 Properties of straw

2.4 Performance evaluation of baling technologies

2.5 Management of crop residue for better economic use

2.1 Problems occurred due to straw left in the field after harvesting

Dobie *et al.* (1973) studied systems for handling and utilizing rice straw and observed that bailing can be (and commonly) applied to improve the characteristics of agricultural residues for transportation and storage. Packed loose straws to bales of different sizes and shapes, small square bales, round large square, and compact bales, can improve the low density attributed to straw. The bulk density of rice straw is around 75 kg/m^3 for loose straw and 100-180 kg/m^3 in packed baled form as an energy feedstock. The baled straw has relatively low moisture content and can be stored for a long period without significant dry matter loss and deterioration in fuel quality.

Schraeder *et al.* (1987) developed a rear mounted straw chopper for a combine. This receives the straw from straw walkers of the combine and discharges chopped straw rearward. The chopper slide over a pair of longitudinally oriented, spaced apart guide rails so that chopper can be adjusted from operating position to a forward inoperative position in which straw bypassed the chopper.

Bansal (2002) conducted a study on different technologies for the sowing of wheat under paddy residue conditions. The direct drilling of wheat using a no-till drill, no-till drill with disc coulter and strip drill in plots having loose straw removed, loose straw spread and loose straw spread after chopping. The suitable technology for direct drilling of wheat was strip-till followed by no-till drill under loose straw spread conditions. However, choking of furrow openers was observed in all seeding machines in case of loose straw spread on the soil surface.

Pannu *et al.* (2002) developed paddy straw spreader which was attached to tractor operated combine harvester. The combine harvester cut paddy crop from a width of 3.6 m and throw the straw in 1 m wide windrow which needs to be uniformly distributed. The spreader had four blades 30 cm long each were mounted on the horizontal shaft had diameter 115 cm and was operated at 300-400 rpm. The labor required to spread straw manually in the field is 5 man-h/ha. It provides a uniform feed rate to any subsequent operation (chopper/ tillage operation).

Shukla *et al.* (2002) reported that direct drilling in combine harvested paddy fields was not possible due to loose straw and chaff coming from the combine. The accumulation of straw in seed drill's furrow opener, traction problem in ground wheel due to the presence of loose straw and non-uniform depth of seed placement due to the frequent lifting of implement under heavy trash conditions were the main problems faced during direct drilling of wheat in combine harvested paddy fields.

Mangaraj and Kulkarni (2005) studied on wheat straw retrieval from combine harvested field for use as cattle feed: An economic approach and they reported that the loose straw and stubbles left on the field was estimated to be 581 g/ sq.m and recovered wheat grain amounting to 22 kg/ha. These amounted to a revenue generation of Rs. 2408 from wheat straw (bhusa) and grain recovered. The tractor energy use was 591 MJ/ha and the operation cost was Rs. 755/ha at effective field capacity and field efficiency of 0.34 ha/h and 67.4%, respectively. The net income was estimated to be Rs. 1653/ha. Therefore, instead of burning of straw in the field, retrieval of straw by mechanized harvesting after grain combining is a better option. The chopped straw may be used for use as cattle feed.

Veerangouda *et al.* (2010) conducted the performance evaluation of tractor operated combine harvester as per RNAM and BIS test codes in farmers' fields and found that the average value of effective field capacity of the machine was 0.64 to 0.81 ha/h with field efficiency of 67.02 to 76.83 per cent. The harvesting losses were in the range of 2.88 to 3.60 per cent for paddy harvesting. The cost of operation was lesser for tractor operated combine harvester as compared to a manual method by 57.65 to 65.55 per cent.

Hegazy and Dhaliwal (2011) reported that main operational problem in direct drilling of paddy straw residue is the accumulation and wrapping of loose straw within/on the tines and frame of zero-till drill and traction problems of the ground wheel. They developed and evaluated residue management equipment (RME) which cut and remove paddy straw away from furrow openers of the zero-till drill. Zero-till drill with RME increased the fuel consumption and time, but the amount of residue clogged decreased and the grain yield was increased as compared to zero- till drill without RME.

Misra *et al.* (2013) estimated wheat straw availability and variation in straw quality they reported that a significant variation ($P<0.001$) in straw to grain ratios was observed among wheat cultivars grown in different states. In 2010-11, 112 million tons of wheat straw is expected to be available in the country and in the year 2020 this quantity will increase up to 120 million tonnes, registering a growth of 6 per cent. Significant variations ($P<0.01$) in all the quality attributes were observed among the wheat cultivars. The dry matter digestibility of straw from different wheat cultivars ranged from 35.0 to 52.3 per cent. It was concluded that straw grain ratios were variable and variability in nutritional parameters among varieties need to be exploited by plant breeders, particularly in areas where straw is an important component of ruminant feed.

2.2 Adverse effect of burning of straw

Graham et al. (1986) reported that the direct drilling of wheat in presence straw residue over soil surface results in lower yield and the highest yield was reported where straw was burnt. Choking of furrow openers resulted in patchy seed distribution. Mechanical problems during drilling were the main reason for yield reduction. Incorporation of straw reduced the detrimental effects of straw on yield but yield still remained lower than after burning. The public concern over the problems associated with straw burning such as smoke, ash deposition and damage to property and trees meant that alternative methods of straw disposal must be investigated.

Andreae and Merlet (2001) studied on the emission of trace gases and aerosols from biomass burning and found that burning one tone of rice straw in the 25 field causes the emission of greenhouse gases such as methane (CH_4), which is produced at a rate of 1.2–2.2 g per kg dry straw and 0.03–0.07 kg of N_2O.

Gadi et al. (2003) studied on the emission of SO_2 and NO_x from bio-fuels in India and found that one tonne of rice straw on burning releases about 3 kg particulate matter, 60 kg CO, 1460 kg CO_2, 199 kg ash and 2 kg SO_2. Besides other light hydrocarbons, volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs) including polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), SO_X and NO_X are also emitted. These gases are of major concern for their global impact and may lead to an increase in the levels of aerosols, acid deposition, increase in tropospheric ozone and depletion of the stratospheric ozone layer.

Gadde *et al.* (2009a) studied on rice straw as a renewable energy source in India, Thailand, and the Philippines investigated that rice straw availability as a source of power generation and green house gas emission due to its current uses and also green house gas saving potential if the straw is utilized for power generation. India, Thailand, and the Philippines produced

97.19, 21.86, and 10.68 Mt of rice straw residue per annum, respectively. In India, 23% of rice straw residue produced remains as surplus or unused. Punjab, Haryana and Uttar Pradesh are the three major rice straw producing states in India. About 48% and 95% of rice straw residue are open-field burnt in Thailand and the Philippines, respectively. The GHG emissions due to open-field burning of rice straw in India, Thailand, and the Philippines are 0.05%, 0.18%, and 0.56% respectively. The GHG emissions mitigation potential from rice straw based power would be 0.75%, 1.81%, and 4.31% in India, Thailand, and the Philippines respectively, compared to the total country GHG emissions.

Gadde *et al.* (2009b) studied on air pollutant emissions from rice straw open-field burning in India, Thailand, and the Philippines and they estimated the quantity of rice straw subject to open-field burning in these countries, congregated pollutant-specific emission factors for rice straw burning and quantified the resulting air pollutant emissions. Their results showed a substantial reduction in uncertainty compared to general methods in which emission factors for crop residues, in general, are used.

Mussoline *et al.* (2013) revealed that the removal of rice straw from rice fields can reduce greenhouse gas emission significantly as rice fields are regarded as a major source of methane emission. Through anaerobic digestion process, methane yields from rice straw range from 92 to 280 l/kg of volatile solids. Operating conditions such as pH (6.5-8.0), temperature (35-40°C) and nutrients (C:N ratio of 25–35) are important for optimum digestion of rice straw. Furthermore, pre-treatment (i.e., fungi, acid, and alkali solutions) and microbial engineering can increase biogas production. increase biogas production. It is evident that agricultural residues including rice straw are a prospective source of renewable energy generation. However, spatial tools and technique are required to assess the spatiotemporal availability and distribution of agricultural residue biomass.

Jain (2014) studied on the emission of air pollutants from crop residue burning in India and found that the burning of crop residue contributes towards the emission of greenhouse gases and air pollutant thereby treat to the human health. According to IPCC the amount of residue generated in 2008-09 was 620 Mt out of which ~15.9% residue was burnt on the farm. Rice straw contributed 40% of the total residue burnt followed by wheat straw (22%) and sugarcane trash (20%). The burning of crop residues emitted 8.57 Mt of CO, 141.15 Mt of CO_2, 0.037 Mt of SO_X, 0.23 Mt of NO_X, 0.12 Mt of NH_3 and 1.46 Mt NMVOC, 0.65 Mt of NMHC, 1.21 Mt of particulate matter for the year 2008–09. The variability of 21.46% in annual emission of air pollutants was observed from 1995 to 2009.

2.3 Properties of straw

Morad (1996) found that the power requirement increased with an increase of both the baler feeding rate and forward speed of baler along with the window. They also added that most of this power is used in driving the plunger.

Ayhan and Ayse (1998) studied that waste paper and wheat straw or their mixtures can be compressed to a relative density greater than unity, and stabilized at that density without binder material. The effects of the briquetting pressure on the density, moisture content and bending and compressive strengths of the briquettes were determined at six different pressures of 300, 400, 500, 600, 700 and 800 MPa. The optimum moisture contents and compressive strengths were found to be 18.0 % and 38.2 MPa for waste paper, 22.0 % and 22.4 MPa for wheat straw, and 18.0% and 32.0 MPa for a 20.0 % by weight of waste paper and straw mixture respectively.

Cook *et al.* (2000) conducted the study of straw management and crop rotation alternative to burning straw. He found that using machinery, reduction in straw height helps in the decomposition of straw.

Lam *et al.* (2008) suggested that the bulk density was a major physical property in designing the logistic system for biomass handling. They investigated the effects of true particle lengths ranging from 6 to 50 mm and moisture contents ranging from 8 % to 60 % wet basis on the bulk density of wheat straw and switchgrass. The bulk density of both loose fill and packed fill biomass samples was examined. The calculated wet and dry bulk density ranged from 24 to 111kg/m^3 for straw and from 49 to 266kg/m^3 for switchgrass. The corresponding tapped bulk density ranged from 34 to 130 kg/m^3 for straw and 68 to 323 kg/m^3 for switchgrass.

Bamgboye and Bolufawi (2009) conducted an experiment to find physical characteristics of briquettes of Guinea corn residue for densification. The moisture content of corn residue collected from the field was found to be 9.08 % (db) and mean a moisture content of the relaxed briquettes was 7.15 %. The briquettes were produced by a hydraulic press and cylindrical die at pressures of 7.7, 8.5, 9.5 and 10.5 MPa. The bulk density of the unprocessed material was 46.03 kg/m^3 and the mean relaxed briquettes bulk density was 208.15 kg/m3. The maximum bulk density of the briquettes ranged from 789 to 1372 kg/m^3.

Kargbo *et al.* (2010) studied property analysis and pretreatment of rice straw for energy use in grain drying. The two fundamental properties analyzed are calorific (heating) and density values. The bulk density of rice straw varied from 20-40 kg/m^3 for loose filled and 40-80 kg/m^3 for chopped straw.

Singh *et al.* (2011) reported that the effect of moisture content on the size of chopping was found to be non-significant. Per cent size of cut (up to 4 cm) of paddy straw increased with increase in chopper speed and decreased with an increase in forward speed. Fuel consumption (l/h) increased with increase in chopping speed as well as with an increase in forward speed. Fuel consumption was found to be low at lower moisture content.

Theerarattananoon *et al.* (2011) studied the physical properties of pellets made from sorghum stalk, corn stover, wheat straw, and big bluestem. An increase in moisture level resulted in a decrease in bulk density and true density of the pellets. The effect of moisture content on the durability of the pellets made from corn stover, wheat straw, and big bluestem showed a similar trend, the maximum durability value was 96.8% at the equilibrium moisture content (EMC) range of 9% (d.b.) to 14 % (d.b.) for corn stover and wheat straw, and 9% (d.b.) to 11 % (d.b.) for big blue stem.

2.4 Types and performance evaluation of various baling technologies

Sandhya et al. (2007) studied Performance evaluation of field balers and found that the performance of combine harvesting + stubble shaver is greater than that of combine harvested field condition and also got the baler efficiency was 74.6% storage capacity for paddy straw to be 0.15 ton/m^3 and 0.054 ton/m^3 for wheat straw. The total cost of the operating straw baler in the stubble-shaved field came out to be Rs. 2276.00/ha and total cost of transportation of bales by tractor trailers were Rs. 4400.00/ha. therefore, the total cost of bailing in stubble shaved field including transportation of bales was Rs. 6676.00/ha and total income from sales of straw @Rs 600/ton come out Rs 5865/ha, which is lesser than the total cost of operation of Rs. 6676/ha. Thus, the cost of transportation is a major contributor to the total cost of using straw baler as a possible method of paddy straw management. Figure 2.3 shows the schematic diagram of the rectangular baler and below the values of field performance for paddy and wheat crop after harvesting with combine and combine + stubble shaver baler is given in table 2.2.

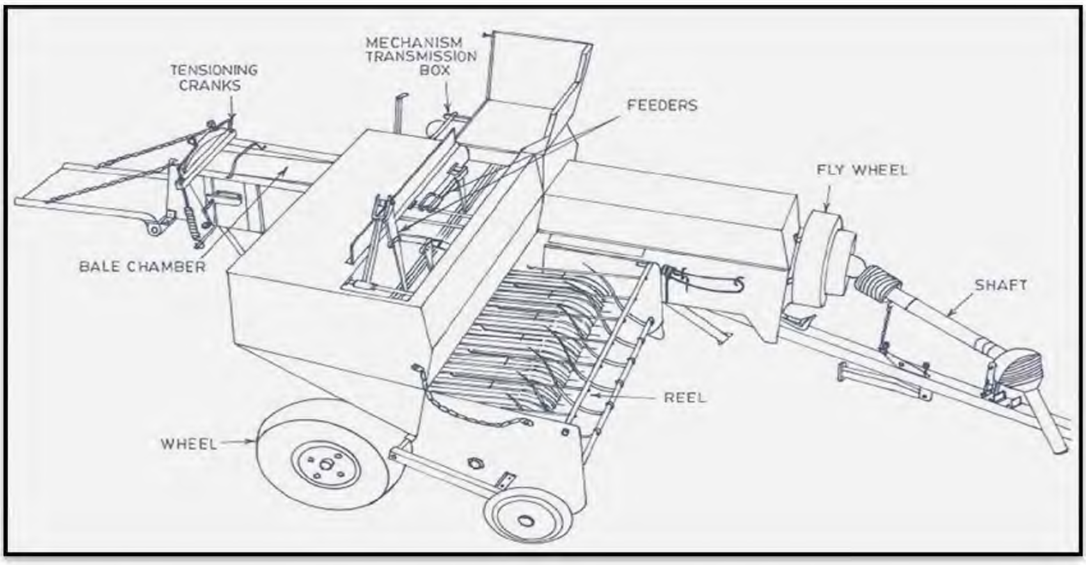
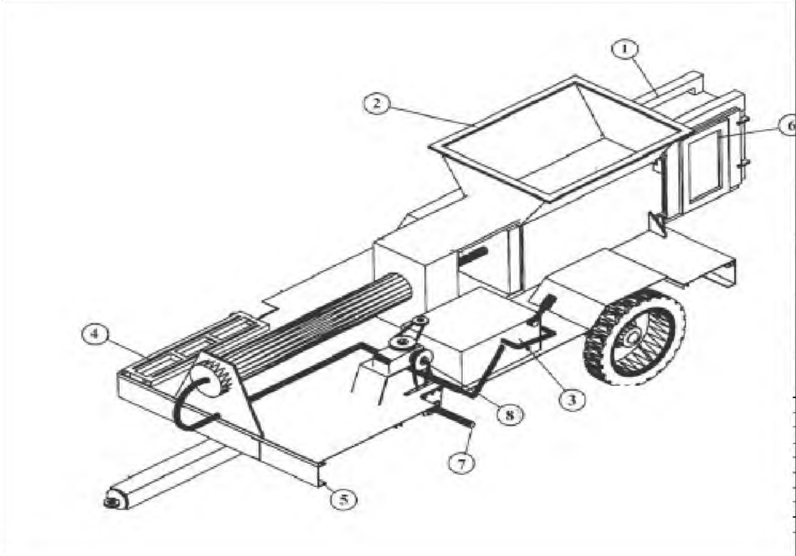


Fig. 2.3 Schematic view of the rectangular straw baler

Table 2.2 Field performance of the baler

S.N.	Parameter	Field condition			
		Combine-harvested		Combine harvesting + Stubble shaver	
		Paddy	Wheat	Paddy	Wheat
1.	Area of field, ha	0.4	0.084	0.4	0.084
2.	No. Of stubbles, m^2	25	27	25	27
3.	Height of stubbles, cm	45-48	39-43	3-7	3-7
4.	Operating width, cm	130	140.25	130	140.25
5.	Forward speed, km/h	2.13	1.20	2.39	1.49
6.	Fuel consumption, l/h	5.50	5.25	5.35	5.15
7.	Field capacity, ha/h	0.26	0.12	0.36	0.27
8.	Size of bales, cm	89 x 47x 36	96 x 47 x 36	89 x 47x 36	96 x 47x 40
9.	Number of bales formed/ha	82	73	170	143
10.	Weight of one bale, kg	23.0	9.70	23.0	9.70

Yasin (2012) developed a mobile straw baler operated by the power take-off unit during the year to make bale in the field. It can be operated by a 36.75 kW (50 hp) tractor, or a 14.7 kW (20 hp) diesel engine or a 14 kW electric motor. It has the capacity to make a bale of 34.6 kg with an overall dimension of 391 x 457.13 x 635 mm. It requires 4.3 minutes and 17 men-minutes to prepare one bale. The baler can be used for other crop residues such as cotton sticks, corn stover, and sugarcane chuff. The baler has an output of 20, 16, 18 and 16 bales per hour for bhoosa, cotton sticks, corn stovers, and sugarcane chuff, respectively. The capital cost of the baler is Rs. 0.35 million with an operating cost of Rs. 17, 10 and 38 when operated with the diesel engine, electric motor, and tractor, respectively. Figure 2.4 shows the schematic view of the mobile straw baler.



Details of parts	
1.	Bale chamber
2.	Feeding hopper
3.	Plunger pump
4.	Engine base frame
5.	Main frame
6.	Chamber gate
7.	PTO shaft
8.	Gear box

Fig. 2.4 Sketch of the mobile straw baler

Manjunatha *et al.* (2015) reviewed the role of balers in agricultural crop residue management- A review and found that there are several technologies in India for managing crop residues. However, there are a few constraints, which limit the large-scale adoption of these technologies. One major handicap in using large amounts of straw is the high cost and labour requirement crop residues are of great economic values as livestock feed, fuel, and industrial raw material and in conservation agriculture for which it is a pre-requisite.for its collection and transportation. Figure 2.1 and 2.2 show the rectangular and round straw baler respectively.

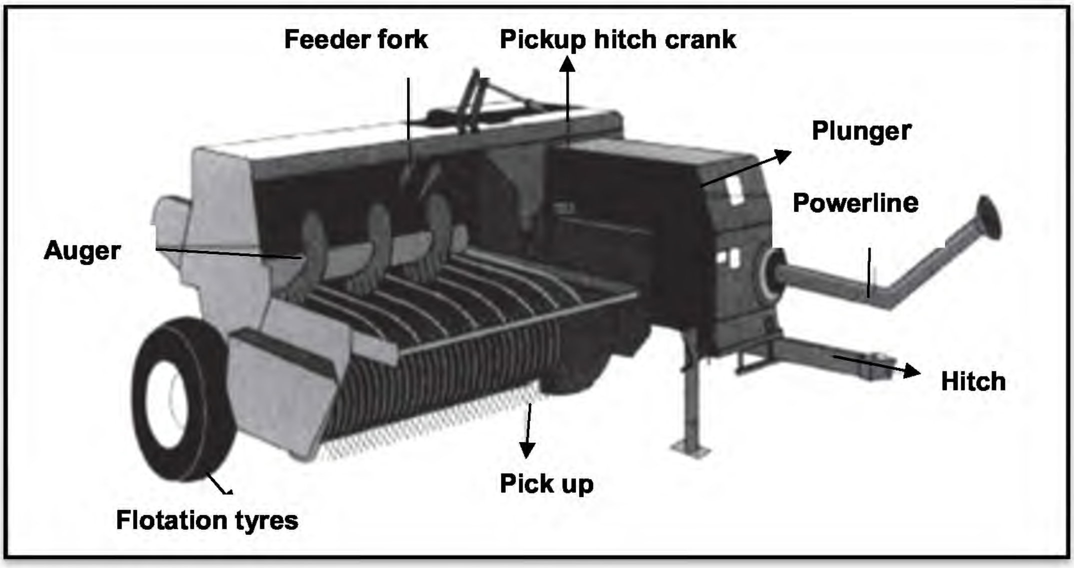


Fig. 2.1 A view of the rectangular baler

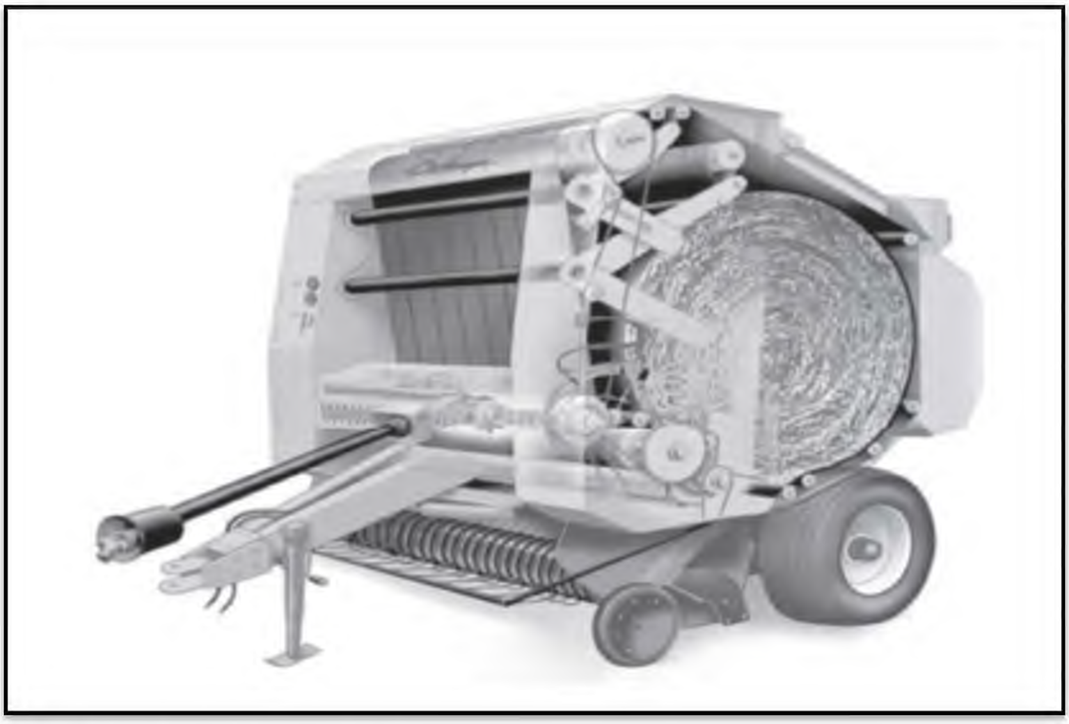


Fig. 2.2 A view of round baler

Table 2.1 Depicted the generation and surplus of crop residues in various states of India @ Manjunatha *et al.* (2015).

Table 2.1 Generation and surplus of crop residues in various states of India

States	Residue generation (Mt/yr)	Residue surplus (MNRE,2009)	Residue burned (IPCC coeff.)	Residue burned (Pathak et al. 2010)
Andhra Pradesh	43.89	6.96	5.73	2.73
Arunachal pradesh	0.4	0.07	0.06	0.04
Assam	11. 43	2.34	1.42	0.73
Bihar	25.29	5.08	3.77	3.19
Chhattisgarh	11.25	2.12	1.84	0.83
Goa	0.57	0.14	0.08	0.04
Gujrat	28.73	8.9	6.69	3.81
Haryana	27.83	11.22	5.45	9.06

Himachal pradesh	2.85	1.03	0.20	0.41
J & K	1.59	0.28	0.35	0.89
Jharkhand	3.61	0.89	1.11	1.10
Karnataka	33.94	8.98	2.85	5.66
Kerala	9.74	5.07	0.40	0.22
M.P	33.18	10.22	3.46	1.91
Maharastra	46.45	14.67	6.27	7.41
Manipur	0.9	0.11	0.14	0.07
Meghalaya	0.51	0.09	0.10	0.05
Mizoram	0.06	0.01	0.01	0.01
Nagaland	0.49	0.09	0.11	0.08
Odisa	20.07	3.68	2.57	1.34
Punjab	50.75	**24.83**	8.94	19.62
Rajasthan	29.32	8.52	3.58	1.78
Sikkim	0.15	0.02	0.01	0.01
Tamil Nadu	19.93	7.05	3.55	4.08
Tripura	0.04	0.02	0.22	0.11
Uttarakhand	2.86	0.63	**13.34**	**21.92**
Uttar Pradesh	**59.97**	13.53	0.58	0.78
West Bengal	35.93	4.29	10.82	4.96
India	**501.76**	**140.84**	**83.66**	**92.81**

*Maximum value in each column is bolded for better evaluation

Senthilkumar et al. (2016) studied the performance evaluation of round type rice straw balers and reported that the field capacity was recorded as 0.11 ha/h at the forward speed of 1.7 to 1.8 km/h and 0.27 ha/h at the forward speed of 1.8 to 2 km/h for Baler I and Baler II respectively. The average fuel consumption was 2.3 l/h, but in the case of the baler II was 2.25 l/h. The cost of baler II (Rs.4472/ha) was lesser than that of baler I (Rs. 6556/ha). The highest baling efficiency of 96% was recorded for baler II and the lowest baling efficiency of 85% was recorded for Baler I. Overall, the performance of baler II was better than baler I.

2.5 Management of crop residue for better economic use

Chakravarthy *et al.* (1981) reported that paddy straw substrate along with 4 grams of nitrogen; phosphorus and potassium fertilizers favoured an optimal yield of Calocybe indica P. & C.

Chattopadhyay and Pandey (1999) found the impact cutting energy required by the knife of a flail harvesting machine on a single stem of forage sorghum. Specific cutting energy of the machine didn't change significantly with forward speed. The cutting energy contributed less than 10% of total energy consumption. The total specific energy requirement increased by 3-4 folds as the cutting speed was increased from 20 to 60 m/s and reduced to 70- 75% when the knife rake angle was increased from 20° to 60°. The effect of the knife bevel angle on the total specific energy requirement was found to be non-significant.

Thakur *et al.* (2000) observed that the combine harvested rice-wheat fields are generally left with long loose straw and stubbles in the field which creates several operational problems in land preparation for the next crop. Nearly 75% of the rice-wheat straw goes as waste besides causing environmental pollution due to straw burning in the field prior to tillage for subsequent showings. Lack of suitable straw management practices for incorporation or retrieval of straws from combine harvested rice-wheat fields is the primary reason for straw burning. Retrieval of straw from combine harvested rice-wheat fields was thus a challenge. Retrieved straw is useful as animal feed and for many industrial uses. The retrieval of straw can be done either by use of a straw baler or a straw harvester.

Matusumura *et al.* (2005) studied on the amount, availability, and potential use of rice straw (agricultural residue) biomass as an energy resource in Japan reported that rice straw and rice husk are the two main agricultural residues in Japan. Rice residue could provide 0.47% of Japan's total electricity demand. At present, the cost of electricity production from rice straw is double than the current cost of electricity. Nevertheless, with the improvement in conversion technology and introducing cost incentives, rice residue based power generation could be an attractive option in Japan and

GHG emission reduction achieved through this process can be counted under the Kyoto Protocol. Considering the importance of sound technology for biomass energy generation.

Zeng *et al.* (2007) studied on the utilization of straw in biomass energy in China and reviewed that direct combustion, biogas, straw gasification, and straw briquetting, including improved stove, biogas, straw gasification and straw briquette in China. The authors observed that enhancing combustion efficiency of the improved stove, developing comprehensive biogas eco-agricultural technology, popularising straw gasification systems for central gas supply, developing straw direct combustion and briquetting equipment are the key technologies of large scale and efficient utilization of straw in biomass energy in the future in China.

Ahlawat *et al.* (2008) evaluated the yields of Pleurotus platypus and Sajor-caju which was grown on both hot and cold water in Imphla and pre-treated with different agricultural and forest residues. Both the species gave maximum yield on hot water pre-treated substrate followed by cold water treated paddy straw, saw dust and pine needles.

Kargbo *et al.* (2009) in their study entitled "Pre-treatment for energy use of rice straw" found that, as long as the process of straw collection is correlated to transportation, the situation in transportation system not so far from the situation of collection in most of developing countries, mostly they depend on using two-wheel tractor, animal, and small & medium trucks. Transport of baled straw can be up to 50% cheaper than the transportation of loosed material and about1% cheaper than that of wood chips (Caldwell, 1988). However, this method requires a good transport system to carry the baled rice straws from the field to the power plant or storage. It is also dependent on weather and soil conditions of the field. This technique can be carried out efficiently in many developing countries with simple transport devices like bullock cart where trucks and trailers are not available.

Ganea (2013) observed that rice straw compression tools are different from rice straw balers in construction and use; normally they are manually operated tools to form a square or rectangular bales or straw blocks. These blocks aroused in building eco-friendly and energy-efficient houses. Straw bale houses are extremely sustainable and earthquake-resistant structures and make alternatives for some regions.

Silalertruksa and Gheewala (2013) conducted a study on a comparative LCA of rice straw utilization" and found that comparative LCA of four rice straw utilization pathways viz. (i) direct combustion for electricity, (ii) biochemical conversion to bio-ethanol and biogas, (iii) thermo-chemical conversion to bio-DME, and (iv) incorporation into the soil as fertilizer. It is found that per tonne of dry rice straw basis, the bio-ethanol pathway results in the highest environmental benefit with regard to the reduction in global warming and resource depletion potential. Rice straw electricity and fertilizer also could provide several environmental benefits. The major environmental benefit of rice straw utilization comes from avoiding the harmful impacts of in situ burning of rice straw in the field.

Rosmiza *et al.* (2014) observed that rice straw in Malaysia is presently disposed of mostly by open burning. This results in the release of various pollutants affecting the environment, weather, and local communities. there are several potential uses for rice straw which can still be explored and developed to benefit Malaysia's rural economy. This research found that most farmers knew only some of the potential uses of the straw, namely as a source of animal feed, compost, vermin-compost, nursery mats for seed germination, and paper making. Farmers acquired most of this information from other farmers who had realized the potentials through involvement in straw development projects. This point to the fact that more farmers could be motivated to get directly involved in the future development of straw projects presently conducted by agricultural agencies. Better information and extension services relating to commercial straw development and management could help further these economic as well as the environmental causes of straw development

Shafiea *et al.* (2014) conducted a study on LCA study of rice straw based power generation in Malaysia" they found rice straw based power generation can save GHG emissions of about 1.79 kg CO_2-eq/kWh and 1.05

kg CO_2-eq/kWh compared to coal-based and natural gas-based power generation, respectively. Rice straw based power plants not only could solve the problem of removing rice straw from fields without open burning but also could reduce GHG emissions.

MATERIAL AND METHODS

This chapter deals with the procedures adopted to study the effect of different operational parameters on the performance of paddy straw baler. The field experiments for the evaluation of the machine were carried out at University Farm, College of Agricultural Engineering, JNKVV, Jabalpur. The experiments were conducted during the year 2018. The range of variables for the study was based on the literature reviewed and test reports. An experiment was planned to compare the performance evaluation of tractor-drawn round straw baler with a manual collection of paddy straw. The material and methods used for the study have been discussed under the following sub-heads:

3.1 Site selection
3.2 Climatic condition
3.3 A brief description of the machine
3.4 Independent variables
3.5 Dependent variables
3.6 Experimental layout and evaluation procedure

3.1 Site selection

The experiment was conducted in the field of Jawaharlal Nehru Krishi Vishwa Vidyalaya Jabalpur Madhya Pradesh. The university is located at 23˚ 13’ 15.32” N and 79˚ 57’ 50.80” E and 390 m. Above MSL Soil type was clay loam which constitutes with sand 29.10%, silt 20.15% and clay 50.75%.

3.2 Climate condition

Paddy is a Kharif crop generally sown in the month of July and harvested during October. The average normal annual rainfall is about 1353.8 mm which occurs 80% during the monsoon period. The remaining months are usually dry, except for light occasional showers. The average annual normal minimum temperature, maximum temperature, evaporation, relative humidity (morning - evening) is about 18.5 ℃, 31.4 ℃, 3.9 mm and 77.8% - 42.4% respectively. The climate data during the research period is given in Table 4.1

3.3 Brief Description of Baler machine

Smith et al. (2002) described baler as a mechanical machine operated by a tractor power take-off or an engine incorporated within the baler. It physically picked up the straw and placed it into a compression chamber. The straw in the compression chamber was compressed by a hydraulic ram. The hydraulic pressure applied to a bale straw varied from 136 to 170 kg/cm^2. Plate 3.1 & table 3.1 shows the view and specification of tractor-drawn round straw baler.

Plate 3.1 View of the tractor-drawn round straw baler

Table 3.1 Technical Specification of round baler

S.No.	Model	SRB – 60
1.	**Dimensions & weights** {overall length x width x height (mm)}	2350 x 1780 x 1515
1.1	Ground clearance (axle height) (mm)	337
2.	**Tyre size**	
2.1	Axle tyre size	5.2-14, 6 ply
2.2	Pick-up tyre size	4-8, 6 ply
3.	**Tractor requirement**	
3.1	Horsepower (hp/kw) & pto speed (rpm)	25/19 (minimum) & 540
3.2	Hitching system	Draw bar hitch
4.	**Bale chamber**	
4.1	Type	Chain driven pressure rollers rotating on sealed bearing at ends
4.2	No. of roller	19
4.3	Roller dia. X length (mm)	93 x 622
4.4	Bale chamber dia x width (mm)	595 x 633
5.	**Bale size**	
5.1	Bale dia x width (mm)	600 x 635
5.2	Working capacity (bales/hr)	50*
5.3	Bale weight (kg)	17 to 22**
5.4	Baler weight	700kg
6.	**Pick up system**	
6.1	Pick up type	Fully floating, cylindrical drum with spring tines
6.2	Tine bar	4
6.3	No. of tines	40
7.	**Binding (twine) system**	
7.1	Binding activation	Manual
7.2	Twine recommended	Sisal or polypropylene

Source: Shaktimanagro.com

Table 3.2 Overall dimension of the round straw baler

S.N.	Particulate	Dimension (mm)
1	Length	2350
2	Width	1780
3	Height	1515
4	Total Mass (kg)	700

3.4 Machine parameter

The machine parameters were included a unit of gathering, compacting and baling of the straw (like pick up unit, feeder unit, aluminium rollers, electric buzzer, binding unit, hydraulic valve, bale counter). Machine parameters can be terms as a feature of baler machine for this equipment.

3.4.1 Pick up unit

4 feet wide pick up to pick any combine harvested filed windrow in one pass. This baler employs fully floated, cylindrical drum type unit with spring tines. There are 4 tine bars in each of 40 tines. The pickup is centrally positioned in front of the baler to evenly feed the performing chamber. The low profile design means the crop doesn't have to be lifted as high, minimizing crop disturbance, again saving leaves. Plate 3.2 shows the view of the pickup unit.

Plate 3.2 View of pick up unit of the tractor-drawn round straw baler

3.4.2 Floating wind guard

The floating wind guard holds the crop down on the pickup wrappers to ensure positive feeding in all crop conditions. The wind guard is especially useful in light crops and windy conditions. The floating wind guard increases productivity by allowing the operator to work in most crop and wind conditions.

3.4.3 Feeder unit

Feeder unit equipped for uniform loading of straw from pickup to bailing chamber. It pushes straw from the pickup unit to the bale chamber in a uniform manner.

3.4.4 Bale chamber

The crop is moved feeder through pickup to directly into the pre-forming chamber. The crop continues in a straight line, assuring the leaves will be distributed evenly throughout the bale. There the hay is pre-compressed into a slice before it enters the bale chamber. Here straw id wrapped onto itself by 19 aluminum roller. Plate 3.3 shows the view of the bale chamber.

Plate 3.3 View of bale chamber & aluminium roller of the tractor-drawn round straw baler

3.4.5 Aluminium roller

This type of roller is fixed type in nature, means they rotate in their own axis independently. These rollers are made up of the durable aluminium roller with angled ribs which are made by pressure die casting. It is light in weight and having less slippage & better compaction with smooth bale surface. Plate 3.3 shows the view of aluminium rollers.

3.4.6 Electric buzzer

Electric buzzer and light indicator to indicate bale completion. The operator no need to look back to know the completion of baling. Plate 3.4 shows the view of the electric buzzer.

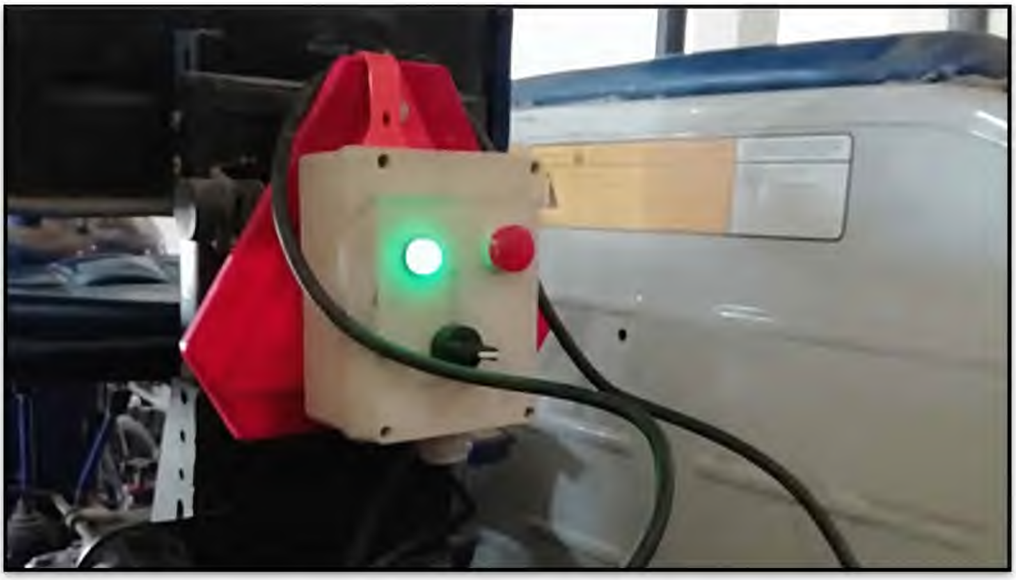


Plate 3.4 View of electric buzzer of the tractor-drawn round straw baler

3.4.7 Binding unit

Binding unit to wrap the bale using twine. The binding activation is manually operated and twine recommended is sisal or polypropylene. Plate 3.5 shows the view of the binding unit.

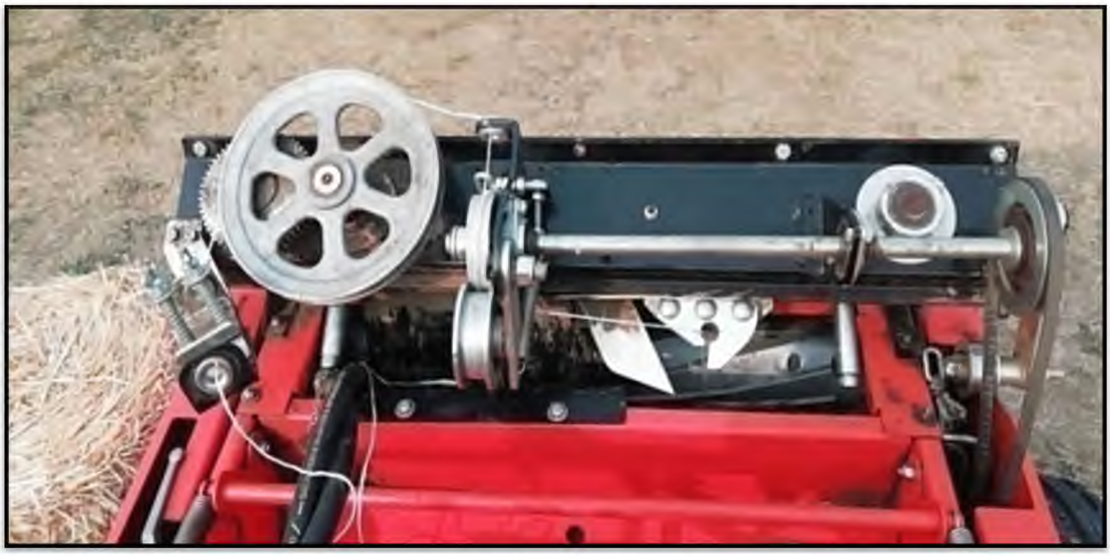


Plate 3.5 View of a binding unit of the tractor-drawn round straw baler

3.4.8 Hydraulic valve

Hydraulic control valves are mounted to open the door of the bale chamber and to maintain pickup height. Plate 3.6 shows the view of a hydraulic valve.

Plate 3.6 View of hydraulic valves in the tractor-drawn round straw baler

3.4.9 Floating tire

Flotation tires are used to reduce ground compaction in the field. Less soil compaction promotes faster regrowth of hay crops, maximizing crop performance. Plate 3.7 shows the view of a floating tire.

Plate 3.7 View of the floating tire of the tractor-drawn round straw baler

3.4.10 Bale counter

Bale counter is a device which makes easy to count the no of bale produced by baler till date. It shows the numerical value of bale produced so we do not need to count no of bale produced. Plate 3.8 shows the view of the bale counter.

Plate 3.8 View of bale counter unit in the tractor-drawn round straw baler

3.5 Performence evalution of tractor drawn round straw baler

Performance evaluation of the tractor-drawn round straw baler in combine harvested paddy field shown in Plate no 3.9 was evaluated with variety Kranti. Figure no 3.1 shows the total field was evaluated with two levels of average range of straw moisture (i.e. 29-31% and 19-21%) and three levels of operating speed (i.e. 1.8 km/h, 2.4 km/h, 3 km/h). The field was divided into three blocks and each block was divided into four main plots where four replications were allocated. After this, each main plots further divided into three sub-plots of size 900 m^2 (90 m × 10 m). The machine was operated at the required speed, whereas, the clearence of the machine from the ground was kept fixed at the desired cut height. A graduated plastic cylinder was attached to the tractor for measuring the fuel consumption and a stopwatch was used for measuring the time. The pressure required to make a tight bale from crop residue. Plate no 3.10 (a) & (b) shows the setting pressure for baler.

A tractor of 55 hp was used for operating the machine during the experiment. The measurement of fuel consumption (l/h), the cylindrical plastic box has a capacity of 2.8 l and with the least count of 50ml. In each treatment the time of operation, area covered and the fuel consumed (l) was recorded. Whereas, for manual collection method of straw, that is control method was also conducted in the field with only 29-31% available moisture content of straw. Plate no 3.11 shows the performance evaluation of tractor-drawn round straw baler.

Plate 3.9 View of testing field

(a) (b)

Plate 3.10 (a) & (b) Setting of pressure for the baler

Plate 3.11 View of testing and performance evaluation of round straw baler

With two levels of straw moisture and three levels of operating speed with four replications, the total number of plots was 28. The details of the experiment are given below

Table 3.3 Independent & dependent variables

Independent variable	Level	Values
Moisture content of straw (MC, %)	2	Second day after combine harvesting (29-31, M_1)
		After 15 days of combine harvesting (19-21, M_2)
Forward speed of baler (S, km/h)	3	1.8 (S_1)
		2.4 (S_2)
		3.0 (S_3)

Dependent variable	
Theoretical field capacity (ha/h)	
Actual field capacity (ha/h)	
Field efficiency (%)	
Straw parameter	Stubble height (cm), Bulk density of loose straw (kg/cubic meter)
Bale parameter	Size of bale (Diameter * height), Density of bale (kg/m³), Weight of bale (kg)
Cost of operation (Rs/ha)	
Energy requirement (MJ/ha)	

The following treatment was selected for the experiment:-

T_1 - M_1S_1 (At moisture content 19-21% & tractor speed 1.8 km/h)

T_2 - M_1S_2 (At moisture content 19-21% & tractor speed 2.4 km/h)

T_3 - M_1S_3 (At moisture content 19-21% & tractor speed 3.0 km/h)

T_4 - M_2S_1 (At moisture content 29-31% & tractor speed 1.8 km/h)

T_5 - M_2S_2 (At moisture content 29-31% & tractor speed 2.4 km/h)

T_6 - M_2S_3 (At moisture content 29-31% & tractor speed 3.0 km/h)

T_7 - Manual collection method

The figure 3.1 shows the layout of the experiment.

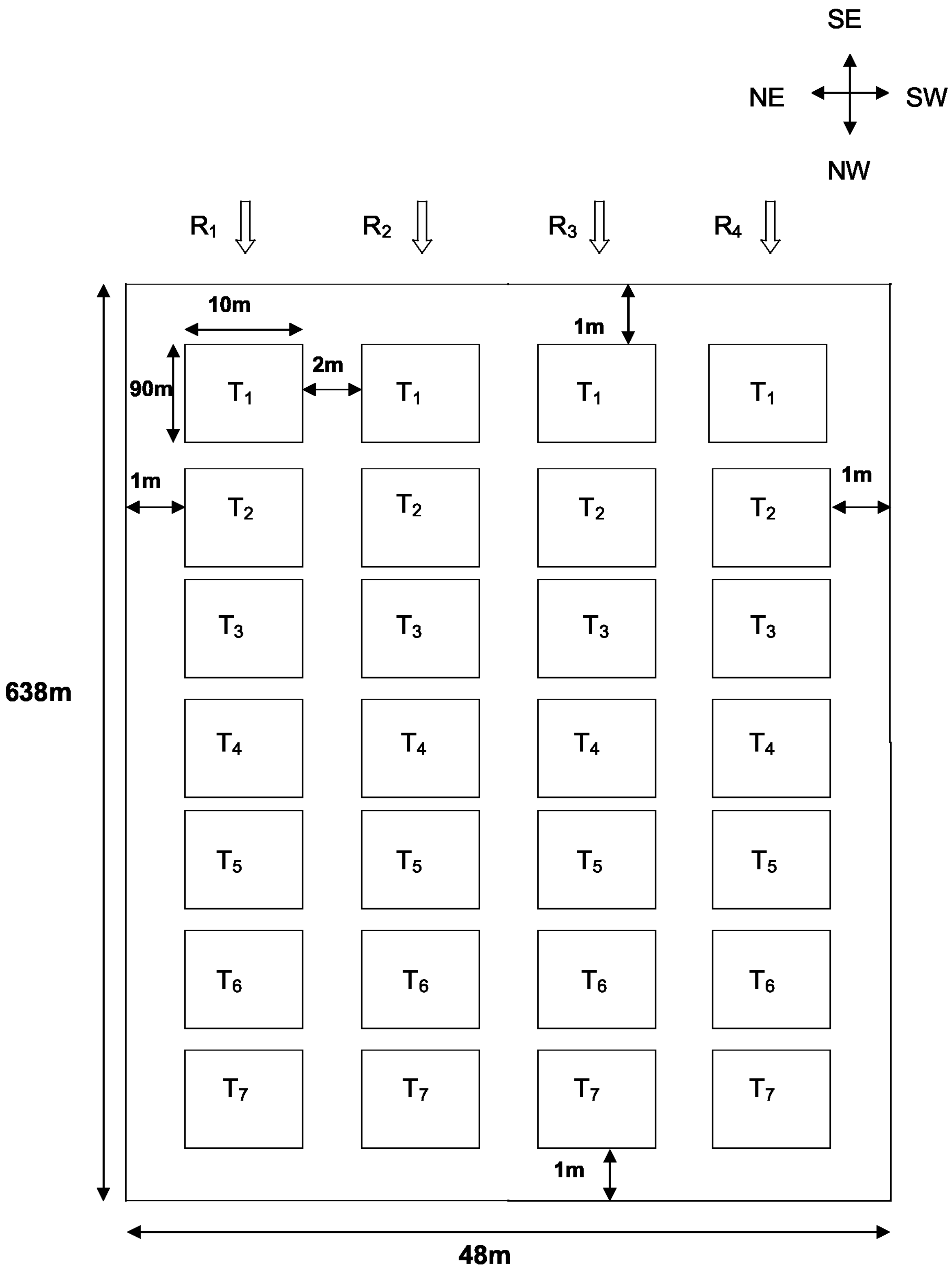


Fig. 3.1 Experimental Field layout

Design used: 2x3 factorial randomized block diagram (RBD)

3.6 Straw parameter

The straw parameter was measured i.e. bulk density of loose straw, stubble height, straw mass and straw length.

3.6.1 Avalability of loose straw per unit area

The weight of loose straw per unit area at a different location in various treatments were measured. The loose straw was collected manually within the area of 1x1 meter with the help of m.s. rod frame.

3.6.2 Stubble height

Stubble height was recorded from randomly selected locations in each treatment with a measuring scale from the soil surface to the tip of the plant and their average was taken. Plate 3.12 shows the view of measurement of stubble height.

Plate 3.12 View of measurement of stubble height in the field of paddy

3.6.3 Straw mass

The initial straw mass of the paddy crop was calculated using a square frame of area 1x1 meter placed randomly in the field where the operation was performed. Seven samples were taken from each replication and then the average value of straw population was calculated from the marked area of 1 m^2. Appendix A shows the data of stubble height, crop height, and plant population at different speed and moisture content.

3.6.4 Straw recovery

The straw was collected using a square frame of area 1x1 meter square placed randomly in the field where the operation was performed before and after the operation with the implement. The reading was taken from five different locations and the average value (kg/ha) was taken for the calculation. Plate 3.13 (a) & (b) shows the view of straw recovery.

(a) **(b)**

Plate 3.13 (a) A view of the field after running the baler &(b) View of the field before running the baler

3.7 Test procedure

Before the testing operation with baler machine, the adjustment was made in three-point linkage and power take shaft as per the following codes-

As per IS 4931:1995, Indian standard code for Agricultural tractors - Rear-mounted power take-off type 1, 2 and 3- for adjustment of PTO shaft for the clearance zones around them and protection of the power take-off on agricultural tractors.

As per IS 4468 (part 1):1997 Indian standard code for Agricultural wheeled tractors- rear mounted three –point linkage for the dimensions and requirements of the three-point linkage for the attachment of implements to the rear of agricultural wheeled tractors. The machine ground clearance was adjusted at 30 cm.

3.7.1 Laboratory tests

3.7.1.1 Specification checking

The specification of the machine was checked.

3.7.1.2 Visual observation

The machine was subjected to thorough inspection with particular attention to bearings, drives and other moving parts, the correctness of various adjustments, tightness of bolts and nuts, etc. design of the device and operating speed, mechanisms of pick up the device, bailing, knotting unit and discharging device as well as other adjustable mechanisms.

3.7.1.3 Crop parameter testing in the laboratory

3.7.1.3.1 Bulk density of loose paddy straw

The bulk density of paddy straw was determined by the standard method by putting a known weight of respective sample into an empty graduated jar (1000ml) and the volume occupied by the sample was noted (Mohsenin, 1980). The procedure was repeated for M_1% and M_2% of straw moisture content. Each time, the test was replicated five times and the average value was taken as bulk density. Bulk density was calculated as given equation 3.1 & Plate 3.14 (a) & (b) shows the view of the determination of bulk density of straw in the laboratory.

$$\rho = \frac{W_2 - W_1}{V} \qquad \text{................(3.1)}$$

Where,

ρ = Bulk density of paddy straw (kg/m³);

W_1 = Weight of empty jar (kg);

W_2 = Weight of jar + paddy straw (kg); and

V = Volume of the jar (m³).

(a) **(b)**

Plate 3.14 (a) & (b) view of the determination of bulk density of loose straw

3.7.1.3.2 Moisture content of paddy straw

Moisture content was determined using an oven drying method. A petri dish was weighed using a digital balance. The sample was placed in the dish and sample were weighed. The dish and sample were then placed in an air-forced drying oven and kept at 105°C until a constant weight was achieved (Syed and Kumar, 2015). The dish containing the dried sample was cooled to the room temperature in desiccators and then weighed. The moisture content was calculated on a wet basis as follows eq. 3.2 and plate 3.15 (a) & (b) shows the view of measurement of moisture content of straw.

$$MC = \frac{W_w - W_d}{W_w} \times 100 \qquad ....(3.2)$$

Where,

MC = Moisture content in per cent (wet basis in %);

W_w = Wet weight of the sample and dish (g); and

W_d = Dry weight of the sample and dish (g).

(a) (b)

Plate 3.15 (a) and (b) view of the determination of moisture content of straw

3.7.2 Field tests

3.7.2.1 Field condition and observations

The machine was operated under the different field condition for the paddy crop. The test was carried out at second day and 15 days after combine harvesting (i.e. at different moisture content) and at a different forward speed of tractor (i.e. S_1, S_2 and S_3). The area of each plot was 0.09 ha. The total plot area for the experiment was 3.07 ha.

3.7.2.2 Field operation and collection of data

The machine was operated 20 min before recording the data. The machine was operated at a uniform speed and in such a manner as to use its full width of pickup unit. In each field, the test was carried out at the selected forward speed and no change in forward speed is allowed during the test run.

3.7.2.3 Labour requirement

The number of workers and man-hour required for baling operation for one hectare were recorded. Plate no 3.16 (a) & (b) shows the manual collection method of straw.


Plate 3.16 (a) & (b) View of field operation by T_7 (Manual collection of straw)

3.7.2.4 Theoretical field capacity

The theoretical field capacity (ha/h) was also calculated as per equation 3.3.

$$\text{Theoretical field capacity (ha/h)} = \frac{\text{Width of equipment (m)} \times \text{Speed of operation } \left(\frac{\text{km}}{\text{h}}\right)}{10}$$

........................(3.3)

3.7.2.5 Actual field capacity

The actual field capacity (ha/h) was also calculated as per equation 3.4

$$\text{Actual field capacity (ha/h)} = \frac{\text{Width of field coverage(m)} \times \text{Lenth of field coverage(m)}}{\text{Time for covering total area (h)} \times 10000}$$

.......................(3.4)

3.7.2.6 Field efficiency

The field efficiency (%) is the ratio of actual field capacity (ha/h) to the theoretical field capacity (ha/h). Field efficiency is calculated as per eq. 3.5

$$\text{Field efficiency (\%)} = \frac{\text{Actual field capacity} \left(\frac{\text{ha}}{\text{h}}\right)}{\text{Theoretical field capacity } \left(\frac{\text{ha}}{\text{h}}\right)} \times 100$$

................(3.5)

3.7.2.7 Straw recovery

Straw recovery refers to the amount of straw pickup by baler and the amount of straw left behind the baler was weighted and calculated in the percentage as per equation 3.7.

$$\text{Straw recovery (\%)} = \frac{W_s - w_s}{W_s} \times 100 \qquad \text{..........................(3.7)}$$

W_s = Weight of straw collected from 1m^2 area before run of baler (kg);

w_s = Weight of straw collected from 1 m^2 area after run of baler (kg).

3.7.2.8 Fuel consumption

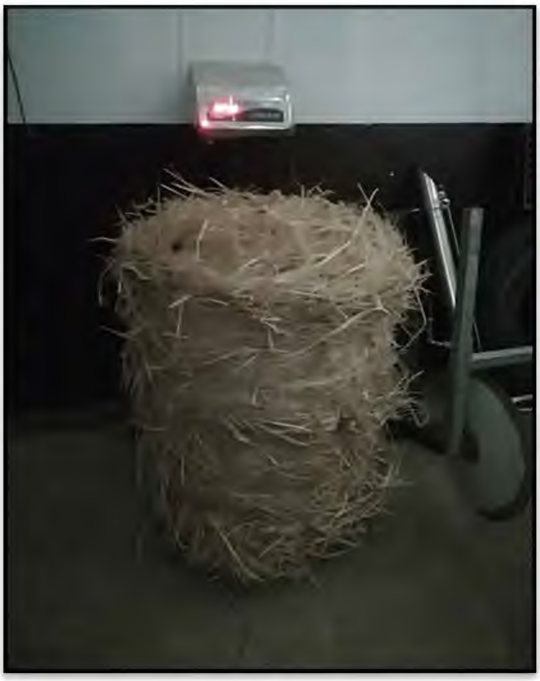
For the measurement of fuel consumption (l/ha) the intake and overflow fuel line is connected to a graduated plastic cylinder from bottom and top. The cylindrical plastic box has a capacity of 2.8 l and having the marking in 50 ml apart. In each treatment the time of operation, area covered and the fuel consumed (l) was observed and fuel consumption was estimated as given below.

$$\text{Fuel consumption (l/ha)} = \frac{\text{Fuel consumption (l)}}{\text{Area covered (ha)}} \qquad \text{......................(3.6)}$$

3.8 Bale yield parameter

3.8.1 Weight of the bale

The weight of a bale was measured by a digital weighing machine from different plots. Plate 3.17 (a) & (b) shows the view of weighing of the bale.



(a)

(b)

Plate 3.17 (a) View of weighing of bale & (b) view of measurement of the size of the bale

3.8.2 Size of the bale

Diameter and height of bale were measured through measuring tape and selection of bale done randomly. Plate 3.17 (b) shows the view of measurement of the size of the bale.

3.9 Energy requirement

In each treatment, the energy consumed in the form of direct energy, Indirect energy, renewable energy, non-renewable energy, commercial energy, and non-commercial energy was estimated taking into account all the inputs like machines, human labour, diesel, etc.

The estimation of energy was done as explained below. The energy equivalent used in the study is shown in appendix M.

3.9.1 Energy from direct sources

$$DE = HLH \times 1.96 + BPH \times 14.07 + FC \times 56.31 + EC \times 11.9 \quad \text{.......................(3.7)}$$

Where,

DE = Direct Energy (MJ);

HLH = Human Labour Hour used (h/ha);

BPH = Bullock Paired Hour used (h/ha);

FC = Fuel Consumption (l/ha); and

EC = Electricity Consumption (kWh/ha).

3.9.2 Energy from indirect sources

$$IE = C \times WM \times OA + FYM \times 0.3(MJ/kg) + S \times 14.7\ (MJ/kg) + CH \times 120\ (MJ/kg) \times Fertilizer\ (N \times 60.0 \times P \times 11.1 \times K \times 6.7) \quad \text{.........................(3.8)}$$

Where

IE = Indirect Energy input from machinery (MJ,);

C = Energy Coefficient (MJ/kg);

WM = Weight coefficient (MJ/kg);

OA = Operation Area (ha);

FYM = Farm Yard Manure (kg/ha);

S = Seed (kg/ha);

CH = Chemicals (l/ha)p;

N = Nitrogen (kg,);

P = Phosphorous (kg); and

K = Potash (kg).

3.9.3 Total energy

$$TE = DE + IE \quad \text{........................(3.9)}$$

Where,

TE = Total Energy (MJ)

3.10 Cost of operation

The cost of operation under each treatment was estimated as per IS: 9164-1979.

The cost of using farm machinery consists of expenses for ownership, operation, and overhead charges. It may also include a margin for profit. Ownership costs are independent of use and are often called as fixed costs. Costs for operation vary directly with use and were referred to as a variable cost.

3.10.1 Fixed costs

3.10.1.1 Depreciation

This cost reflects the reduction in the value of a machine with use (wear) and time (obsolescence). While actual depreciation would depend on the sale price of the machine after its use, on the basis of different computational methods deprecation can be estimated by the straight-line method as given below:-

$$D = \frac{P - S}{L} \qquad \text{.....................(3.10)}$$

Where

D = Depreciation cost, average per year in Rs;

P = Purchase price of the machine in Rs;

S = Salvage value of the machine in Rs; and

L = Useful life of the machine in years.

The depreciation cost per hour can be estimated by dividing D by the number of hours the machine is expected to be utilized in a year. Salvage value if the machines may be taken as 5 per cent of the purchase price.

3.10.1.2 Interest

An annual charge of interest was calculated taking 12 per cent of purchase price. The average purchase price was calculated using the formula given below.

$$I = \frac{P+S}{2} \qquad \text{.....................} (3.11)$$

Where,

I = Intrest ,Rs;

P = Purchase price of the machine in Rs; and

S = Salvage value of the machine in Rs.

3.10.1.3 Insurance and taxes

Insurance and taxes were estimated taking 2 per cent of purchase price of the machine into consideration.

3.10.1.4 Housing

It was calculated on the basis of 1.5 per cent of the purchase price of the machine.

3.10.2 Variable cost

3.10.2.1 Fuel cost

The actual fuel consumption in each treatment was observed and estimation was done accordingly.

3.10.2.2 Lubrication cost

The cost of engine oils and lubricants was estimated as 3% of fuel consumption cost.

3.10.2.3 Repair and maintenance cost

The IS: 9164-1979 indicates that the percentage of the accumulated repair cost of 63.4 for the usable life of 10 years.

3.10.2.4 Labour charges

The cost of labour was estimated taking the prevailing rate of Rs 46/h @369/day as per JNKVV, Jabalpur.

3.11 Economic analysis

3.11.1 Break-even Point Analysis

The level at which the investment operation would neither incur a loss nor produce a profit is called the break-even point (BEP). Essentially then, the BEP is the level at which costs equal benefits.

$$Fc + Vc(X) = B(X) \qquad \text{.................(3.12)}$$

Where,

Fc= Annual cost in rupees per year;

Vc = Variable cost in rupees per hour;

X = Break-even point in hour and;

B = Benefits (Income from thresher rental in Rs/h).

3.11.2 Payback period

Payback period is length of time required to get back the total investment recover. The payback period of the project is estimated by

$$PBP = I/E \qquad \text{.............(3.13)}$$

Where,

PBP = Payback period in years;

I = Investment in rupees;

E = Annual net cash revenue in rupees.

RESULTS AND DISCUSSION

This chapter deals with the results of the experiment described in MATERIAL & METHODS in order to fulfil the objectives for which this project was undertaken.

The data were collected at three different speeds i.e. 1.8 km/h, 2.4 km/h and 3.0 km/h and at two moisture content i.e. 30% and 19.5% (wb) during the field evaluation trails. The data collected were analyzed to determine fuel consumption (l/h), effective field capacity (ha/h), field efficiency (%), straw recovery (%), time required (h), energy requirement (MJ/ha), and cost of operation (Rs/h & Rs/ha) was calculated for baling machine and compared with conventional one for all the treatments. The results of the study have been discussed under following heads:

- Performance evaluation of tractor drawn round type straw baler for harvested paddy straw at different speeds and moisture content.
- To compare the cost economics, time & energy consumption between round straw baler and manual collection of straw.

4.1 Climatic condition at the time of baling operation

The climatic conditions at the time of baling operation are presented in table 4.1 the baling operation was done during the month of November and December for different moisture content of straw available in the field. The straw baling was done between 11 am to 2 pm. The temperature, vapour pressure, relative humidity, and wind velocity was in the range (maximum-minimum) of 32.5˚C-6.0˚C, 12.9-11.8 mm, 85-35 %, 1.9 km/h respectively on 16/11/18 and 26.5˚C-10˚C, 10.9-8.2 mm, 88-34 %, 1.7 km/h respectively on 3/12/18.

Table 4.1 Climatic condition at the time of baling operation

S. N.	Particular	N_1 (16/11/18)	N_2 (3/12/18)
1.	Temperature (˚C)	32.5- 6	26.5- 10
2.	Pressure (mm)	12.9-11.8	10.9-8.2
3.	Relative humidity (%)	85- 35	88- 34
4.	Wind velocity (km/h)	1.9	1.7

4.2 Crop parameters

Table 4.2 reveals about the loose straw parameters like bulk density of loose straw, stubble height, plant population, and moisture content of straw.

The average stubble height, number of plant/m^2 were observed to be 29.6 cm and 15 -17 for Kranti variety of paddy crop during experiments i.e. both the moisture content of straw 31% and 19% respectively. The average bulk density of straw for M_1 and M_2 was found to be 39.143 kg/m^3 and 27.796 kg/m^3. Whereas, the average straw grain ratio for Kranti variety of paddy ranges from 1.985 to 2.013 for other verity it may be change. This straw grain ratio may not affected the perfomence of machine.

The data of crop height, stubble height, and plant population were given in appendix A.

Data revealed that the bulk density of straw is directly proportional to straw moisture content. The similar opinion was represented by other researchers such as Sandhya et al. (2007) and Senthilkumar et al. (2016). Appendix C and D shows the data of the moisture content and bulk density of straw for a different treatment respectively.

Table 4.2 Crop parameters

S.No.	Particulate	treatment					
		T_1	T_2	T_3	T_4	T_5	T_6
1.	Variety of crop	Paddy (Kranti)			Paddy (Kranti)		
2.	Date of baling operation	16/11/18			03/12/18		
3.	Average stubble height (cm)	29.6			29.6		
4.	Average straw MC (%)	31%			19.5%		
5.	Average bulk density of loose straw (kg/m^3)	39.143			27.796		
6.	Average plant population	17			17		
7.	Average length of straw	50.53			50.53		

4.2.1 Moisture content of straw (%)

Fig 4.1 shows the average moisture content of paddy straw for both the day of baling operation for Kranti variety. The average moisture content was taken as M_1 that was 30.82% on the second day after harvesting and M_2 that was 19.5 % at 15 days after harvesting. Appendix C shows the data & moisture content of straw (%) at the time of baling with different speed of operation of baler i.e. 1.8, 2.4 and 3.0 km/h respectively.

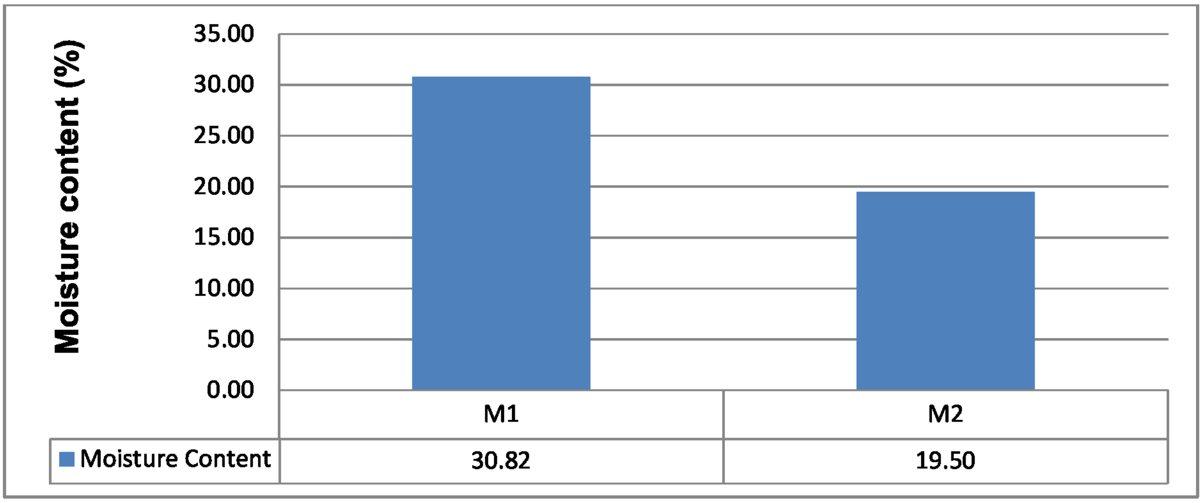


Fig.4.1 Moisture content of straw at different day after harvesting

4.3 Machine Parameters

4.3.1 Theoretical field capacity

The theoretical field capacity was calculated by taking rate of field coverage that would be obtained if the machine were performing its function 100% of the time at the rated forward speed and always covered 100% of its rated width.

So, that the revealed that theoretical field capacity was 0.612, 0.816, and 1.02 ha/h when speed of operation was 1.8, 2.4, and 3.0 km/h respectively.

4.3.2 Actual field capacity

For calculating actual field capacity, the time is taken for actual work and that lost for other activities such as refilling of twine bundles, adjustment of machine and time spend for machine troubles were taken into consideration. The length and width of the plot were measured and the area covered in that time was calculated. By calculating the area covered per hour, the actual field capacity was calculated.

Table 4.3 revealed that the actual field capacity of different treatments i.e. T_1, T_2, T_3, T_4, T_5, T_6, and T_7 was found to be 0.467, 0.515, 0.530, 0.547, 0.583, 0.669 and 0.0281 ha/h respectively.

It is evident from figure 4.2, the lowest actual field capacity (i.e. 0.0281 ha/h) was obtained in treatment T_7 because of human limitation and drudgery. The highest actual field capacity (i.e. 0.669 ha/h) was obtained with treatment T_6. It was highest in comparison of all selected treatments because of lower moisture content (i.e. 19-21%) and higher speed (i.e. 3.0 km/h). The actual field capacity of T_6 was found to be 30.19, 23.01, 20.77, 18.23, 12.85, and 95.79% more as compared to T_1, T_2, T_3, T_4, T_5, and T_7 respectively. Appendix F shows the data on actual field capacity.

Table 4.3 Actual field capacity (ha/h) of different treatments

Treatments	Actual field capacity (ha/h)
T_1	0.467
T_2	0.515
T_3	0.530
T_4	0.547
T_5	0.583
T_6	0.669
T_7	0.0281

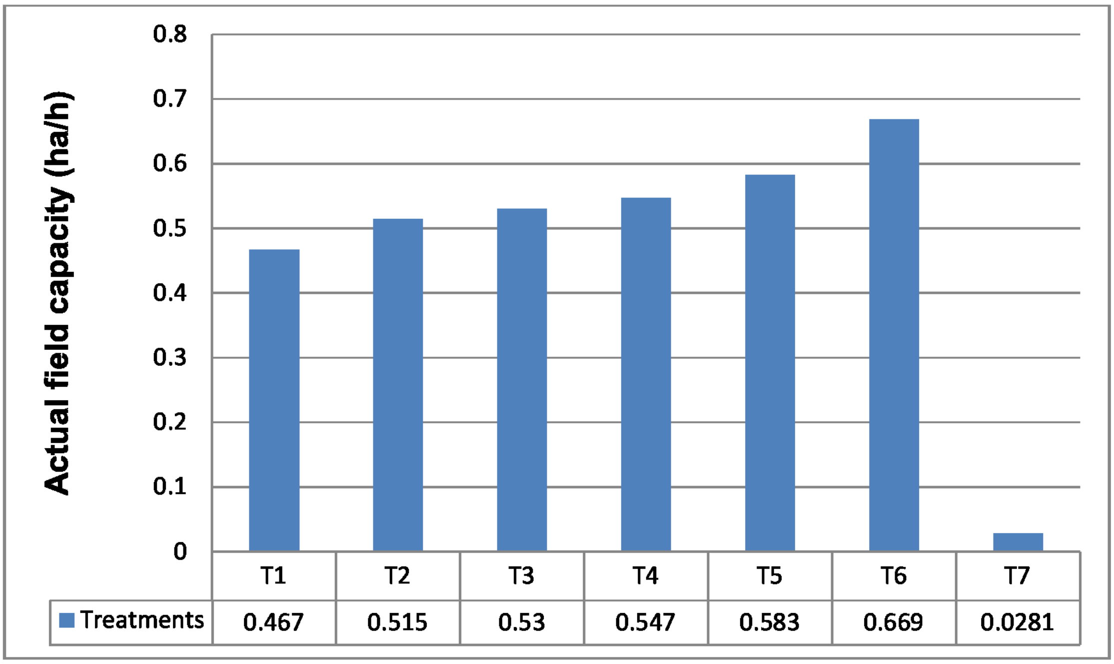


Fig. 4.2 Actual field capacity (ha/h) of different treatments

4.3.3 Field efficiency (%)

Field efficiency was taken as the ratio of actual field capacity and theoretical field capacity.

Table 4.4 revealed that field efficiency of different treatments i.e. T_1, T_2, T_3, T_4, T_5, T_6, and T_7 was found to be 76.30, 63.11, 51.96, 89.37, 71.44, 68.53 and 83.63% respectively.

It is evident from figure 4.3, the lowest field efficiency (i.e. 51.96%) was obtained in treatment T_3 because of higher moisture content (i.e. 29-31%) and higher speed of operation (i.e. 3.0 km/h). The highest field efficiency (i.e. 89.37%) was obtained in treatment T_4. It was highest in comparison of all selected treatments because of lower moisture content (i.e. 19-21%) and lower speed (i.e. 1.8 km/h). The field efficiency of T_4 was found to be 14.62, 29.38, 41.85, 20.06, and 23.31% more as compared to T_1, T_2, T_3, T_5, and T_6 respectively. Appendix G shows the data of field efficiency.

Table 4.4 Field efficiency (%) of different treatments

Treatments	Field efficiency (%)
T_1	76.3
T_2	63.11
T_3	51.96
T_4	89.37
T_5	71.44
T_6	68.52

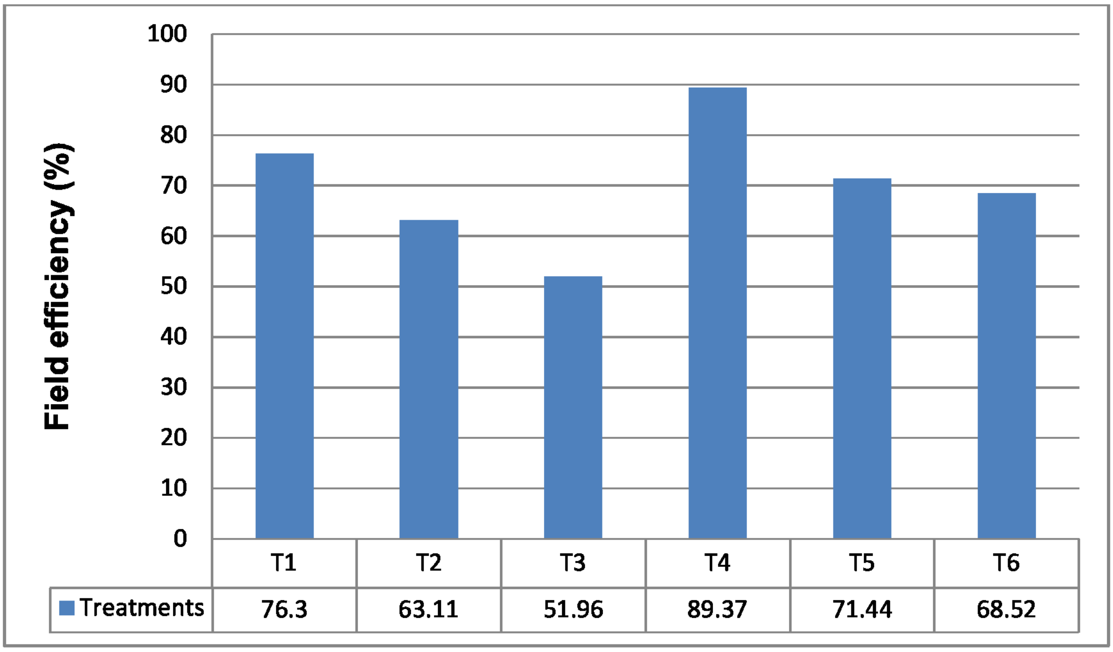


Fig. 4.3 Field efficiency (%) of different treatments

4.3.4 Straw recovery

Straw recovery was calculated by using the formula that is the ratio of the weight of straw collected before baling operation from the marked area and weight of straw collected after the baling operating from the same area.

Table 4.5 revealed that straw recovery of different treatments i.e. T_1, T_2, T_3, T_4, T_5, T_6, and T_7 was found to be 92.409, 92.103, 92.344, 93.674, 93.752, 94.423, and 96.083% respectively.

It is evident from the figure 4.4, the lowest straw recovery (i.e. 92.409%) was obtained in treatment T_1 because of higher moisture content (i.e. 29-31%) of straw and low speed of tractor (i.e. 1.8 km/h). The highest straw recovery (i.e. 96.083%) was obtained in treatment T_7. It was highest in comparison of all selected treatments because of the precision skill of human. The straw recovery of T_7 was found to be 3.82, 4.14, 3.89, 2.50, 2.42, and 1.72 % more as compared to T_1, T_2, T_3, T_4, T_5, and T_6 respectively. Appendix H shows the data for straw recovery.

Table 4.5 Straw recoveries (%) for different treatments

Treatments	Initial weight of straw per m^2 of area before baling	Final weight of straw per m^2 of area after baling	Average Straw recovery (%)
T_1	1031	78	92.409
T_2	996	79	92.103
T_3	1111	85	92.344
T_4	943	60	93.674
T_5	1021	64	93.752
T_6	1054	59	94.423
T_7	1005	39	96.083

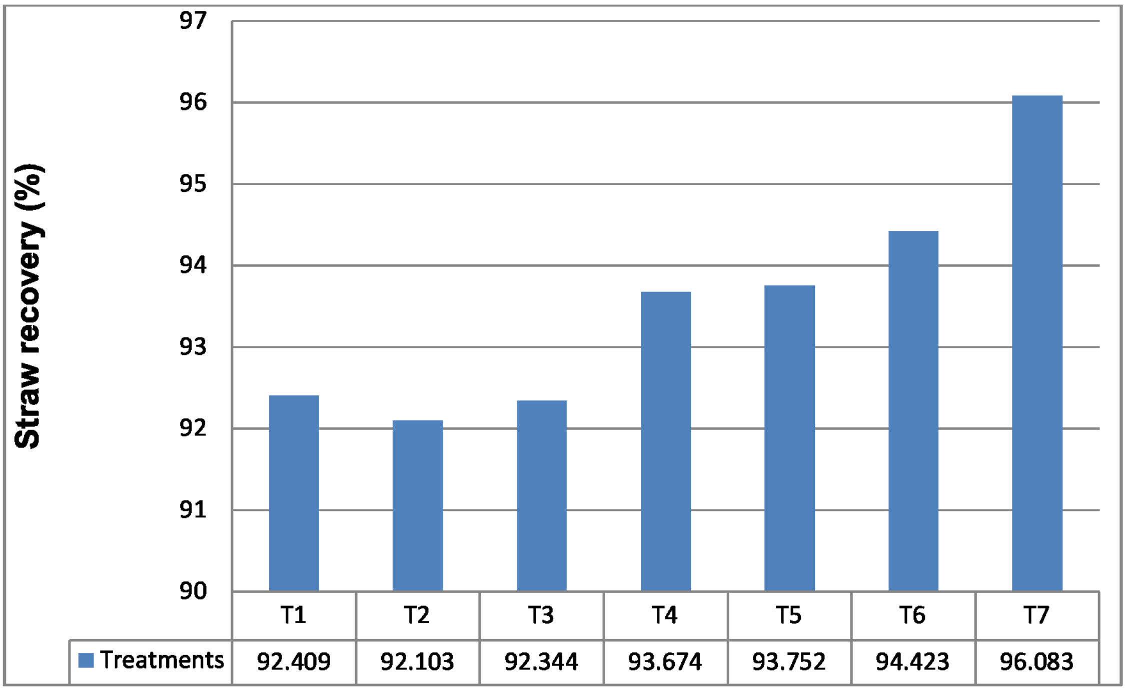


Fig. 4.4 Straw recoveries of different treatments

4.3.5 Fuel consumption

Table 4.6 revealed the fuel consumption of different treatments i.e. T_1, T_2, T_3, T_4, T_5, T_6, and T_7 respectively.

It is evident from the figure 4.5, the lowest fuel consumption (i.e. 3.122 l/h) was obtained in treatment T_6 because of lower moisture content of straw (i.e.19-21%) and highest speed of tractor (i.e. 3.0km/h), except T_7 because of the manual collection method. The highest fuel consumption (i.e. 4.167 l/h) was obtained in T_1 was highest in comparison of all selected treatments because of higher moisture content (i.e.29-31%) and lowest speed (i.e. 1.8 km/h). The fuel consumption of T_6 was found to be 33.47, 19.21, 7.30, 25.14, and 8.74 % less as compared to T_1, T_2, T_3, T_4, and T_5 respectively. Appendix I shows the data on fuel consumption.

At lower speed coverage per hour is lesser than higher speed, which is mainly responsible for more fuel consumption which can be seen in table 4.6. Where $T_1 > T_2 > T_3$ for M_1 (29-31%), and $T_4 > T_5 > T_6$ for M_2 (19-21%).

Table 4.6 Fuel consumption (l/h) for all the treatments

Treatments	Fuel consumption (l/h)	Fuel consumption (l/ha)
T_1	4.167	8.921
T_2	3.722	7.224
T_3	3.350	6.318
T_4	3.907	7.141
T_5	3.395	5.822
T_6	3.122	4.664
T_7	-	-

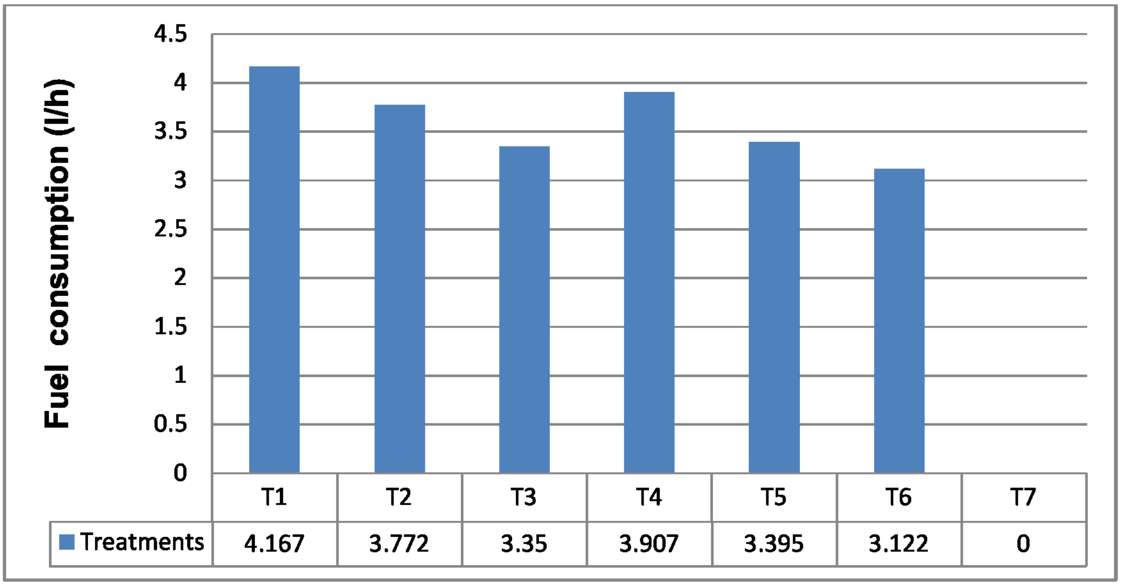


Fig. 4.5 Fuel consumption (l/h)

It is evident from the figure 4.6, the lowest fuel consumption (i.e. 4.664 l/ha) was obtained in treatment T_6 because of low moisture content (i.e. 19-21%) of straw and high speed of tractor (i.e. 3.0 km/h), except T_7 because of the manual collection method. The highest fuel consumption (i.e. 8.921 l/ha) was obtained with T_1 was highest in comparison of all selected treatments because of higher moisture content (i.e. 29-31%) and lower speed (1.8 km/h). The fuel consumption of T_6 was found to be 91.27, 54.88, 35.46, 53.10, and 24.82% less as compared to T_1, T_2, T_3, T_4, and T_5 respectively.

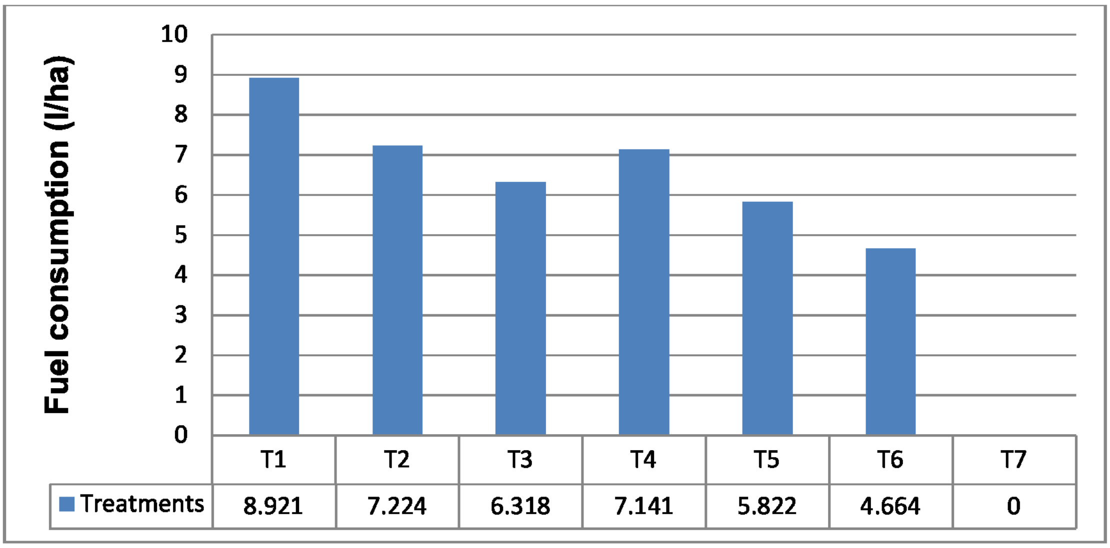


Fig. 4.6 Fuel consumption (l/ha)

4.3.6 Labour requirement (man-h/ha)

The labour requirement and other machine parameter under different treatments T_1, T_2, T_3, T_4, T_5,T_6 and T_7 shown in Table 4.7 and it is evident from Fig 4.7 that the labour requirements were 2.64, 2.44, 2.38, 2.32, 2.21, 1.99, and 23.7 h/ha for all the treatments respectively except T_7 because of manual collection method and It includes one skilled driver for baling operation. The difference was mainly due to the difference in moisture content and speed of operation. The same opinion was given by researchers such as Sandhya et al. (2007).

In case of T_7, it is the manual collection method of straw it requires highest labour time which is 88.86, 89.70, 89.95, 90.21, 90.67 and 91.60% more compare to T_1, T_2, T_3, T_4, T_5, and T_6 respectively.

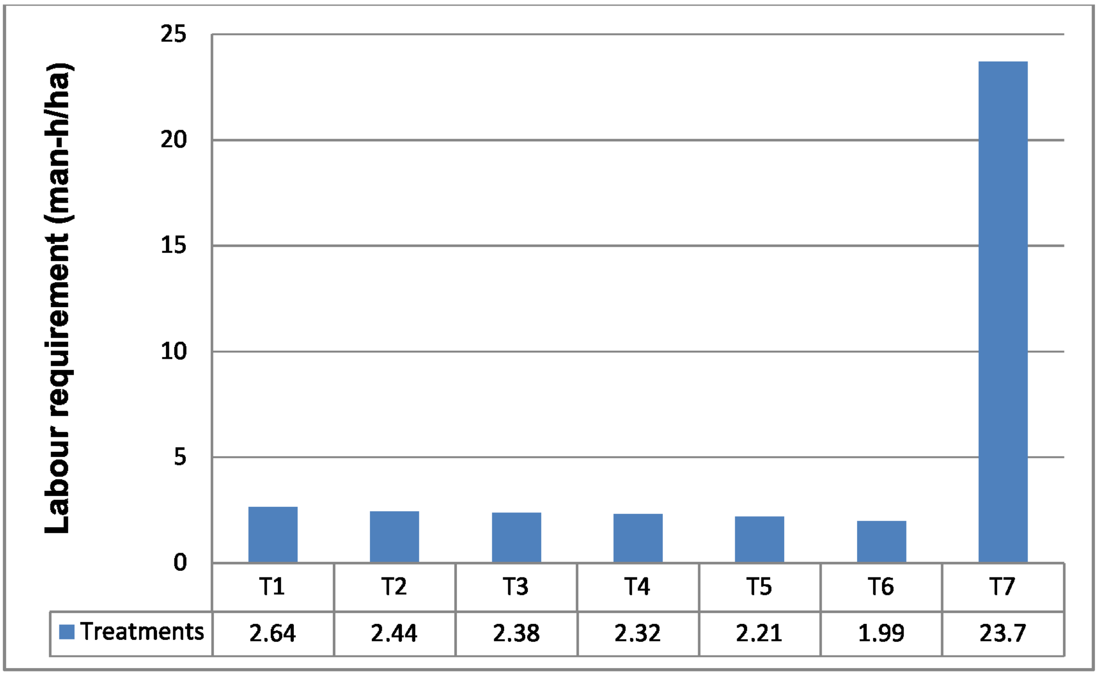


Fig.4.7 Labour requirement for different treatments

Table 4.7 Machine parameters for different treatments

S.No.	Particular	Treatments						
		T_1	T_2	T_3	T_4	T_5	T_6	T_7
1.	Average speed (km/h)	1.8	2.4	3.0	1.8	2.4	3.0	-
2.	Actual field capacity (ha/h)	0.467	0.515	0.530	0.547	0.583	0.669	0.0281
3.	Field efficiency (%)	76.30	63.11	51.96	89.96	71.44	68.52	-
4.	Straw recovery (%)	92.40	92.10	92.34	93.67	93.75	94.42	95.20
5.	Fuel consumption (l/h)	4.167	3.722	3.350	3.907	3.395	3.122	-
6.	Fuel consumption (l/ha)	8.921	7.224	6.318	7.141	5.822	4.664	-
7.	Time required (h/ha)	2.141	1.941	1.886	1.828	1.715	1.494	23.7
8.	Labour requirement (man-h/ha)*	2.64	2.44	2.38	2.32	2.21	1.99	23.7

* It includes 0.5 hour as a time to attach the baler to tractor

4.4 Bale parameters

The parameters included were size of bale, volume of bale, weight of bale, density of bale, no of bale formed per hour no of bale formed per hectare. It includes a weight of straw collected per hour and compared to manual collecting method. Table 4.8 shows the bale yield parameters. Appendix J shows the data of bale parameters.

Table 4.8 Bale parameters

Treatment	Parameter								
	Dia (cm)	Height (cm)	Weight (kg)	Volume (m^3)	Density (kg/m^3)	No of bale		Bale output	
						Per hour	Per hectare	(kg/h)	(kg/ha)
T_1	62	62	22.76	0.178	127.77	38	81	864.88	1846.56
T_2	64	65	23.14	0.178	130.01	40	78	910.40	1804.92
T_3	63	63	23.53	0.178	132.21	41	76	933.16	1788.28
T_4	64	65	13.91	0.178	78.174	44	80	637.28	1112.80
T_5	65	63	14.21	0.178	79.83	45	77	651.76	1094.17
T_6	64	64	15.32	0.178	86.101	46	68	666.25	1041.76
T_7	-	-	9.35	-	-	-	-	140.3*	-

* T_7 It is the weight of loose straw not bales weight.

4.4.1 Weight of bale

It is evident from the table 4.8 that the heaviest bale formed in T_3 due to higher moisture content and lightest bale formed in T_4 due to lowest moisture content and lower speed of tractor except for T_7* because of the manual collection method. Fig 4.10 shows the weight of bale in different treatments. Appendix J shows the data of the weight of the bale.

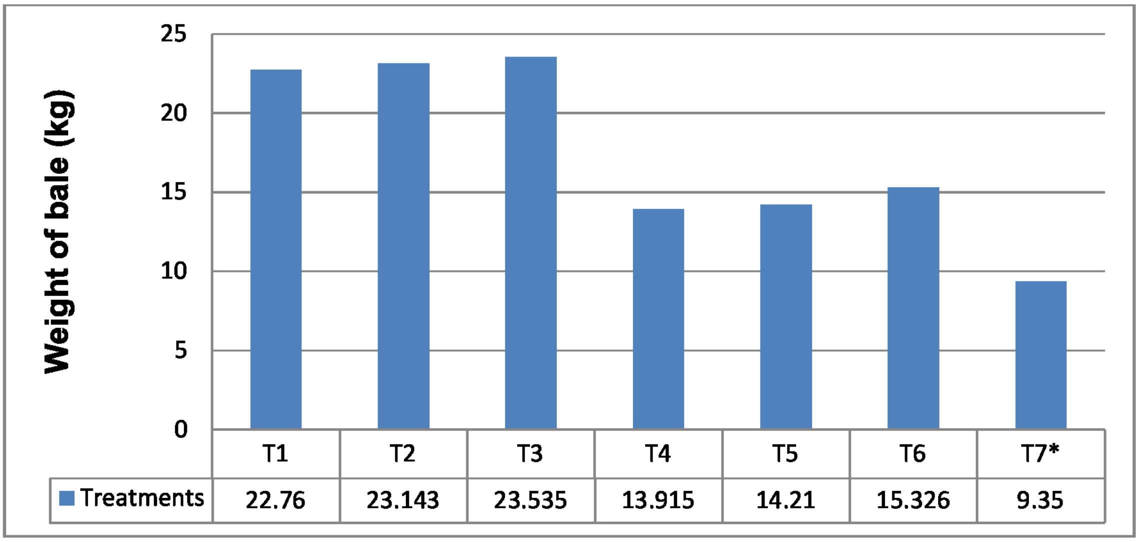


Fig. 4.8 Weight of bale for different treatments

4.4.2 Density of bale

It is evident from the table 4.8 that the density of bale formed in T_3 was greater (i.e. 132.21 kg/m^3) due to higher moisture content (i.e. 29-31%) and highest speed (i.e. 3.0 km/h). The bale formed in T_4 had the lowest density (i.e. 78.174 kg/m^3) due to lowest moisture content (i.e. 19-21%) and lower speed (i.e. 1.8 km/h) of tractor. Fig 4.9 shows the density of bale in different treatments. Appendix J shows the data of the density of bales.

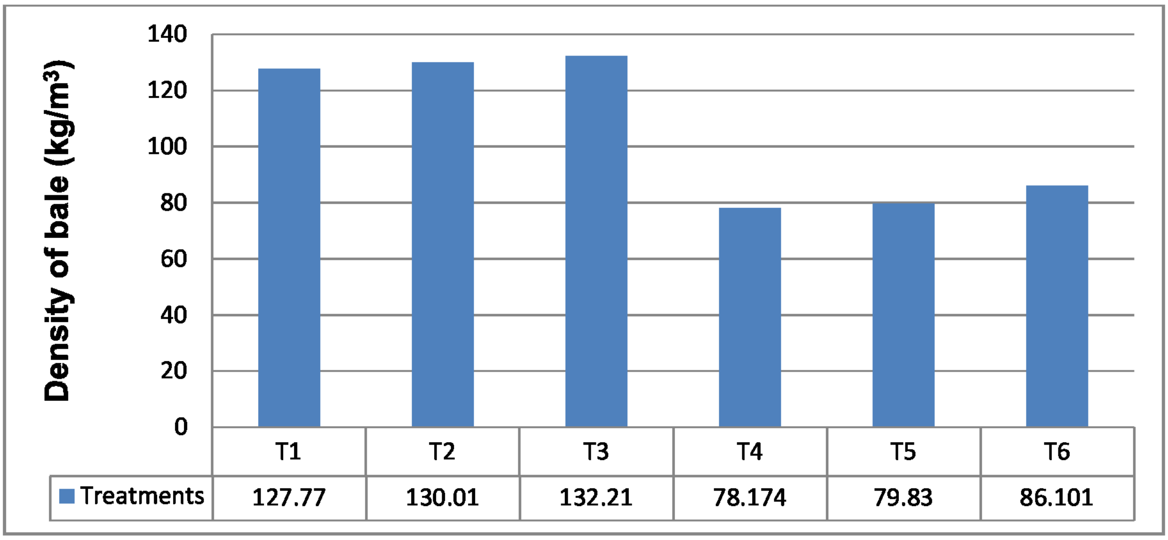


Fig 4.9 Density of bale for different treatments

4.5.3 Bale output

It is evident from the table 4.8 that the average number of bales formed per hour is highest in T_6 (i.e. 46) and lowest in T_1 (i.e. 38) due moisture content and speed of the tractor. On a weight basis the maximum weight in T_3 that was 933.16 kg/h and minimum weight in T_4 that was 637.28 kg/h. Fig 4.10 and 4.11 shows the number of bale formed per hour and mass of straw baled per hour and hectare. Appendix K shows the data of bale output.

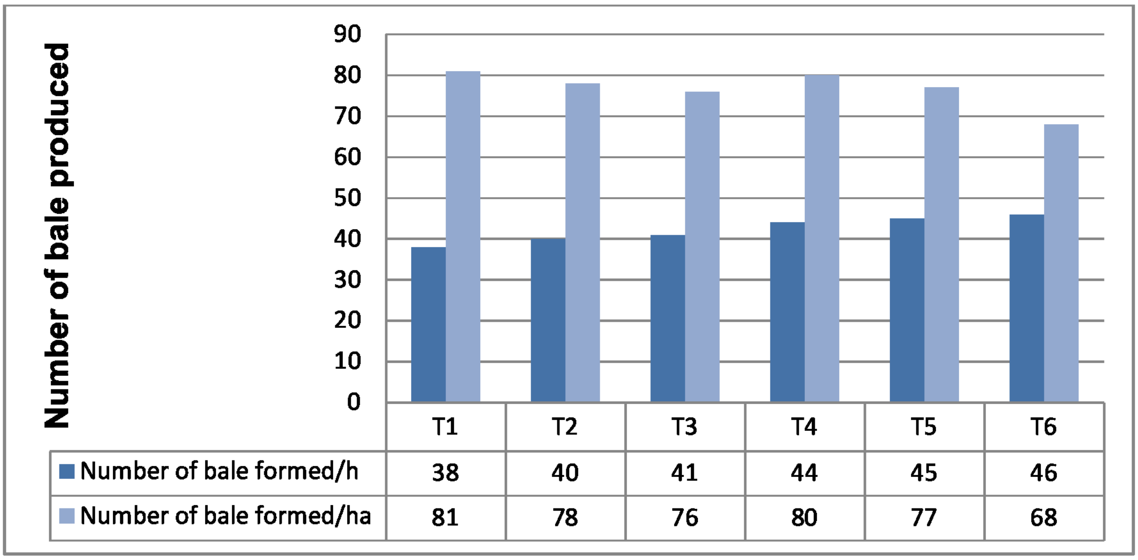


Fig. 4.10 Number of bale formed per hour for different treatments

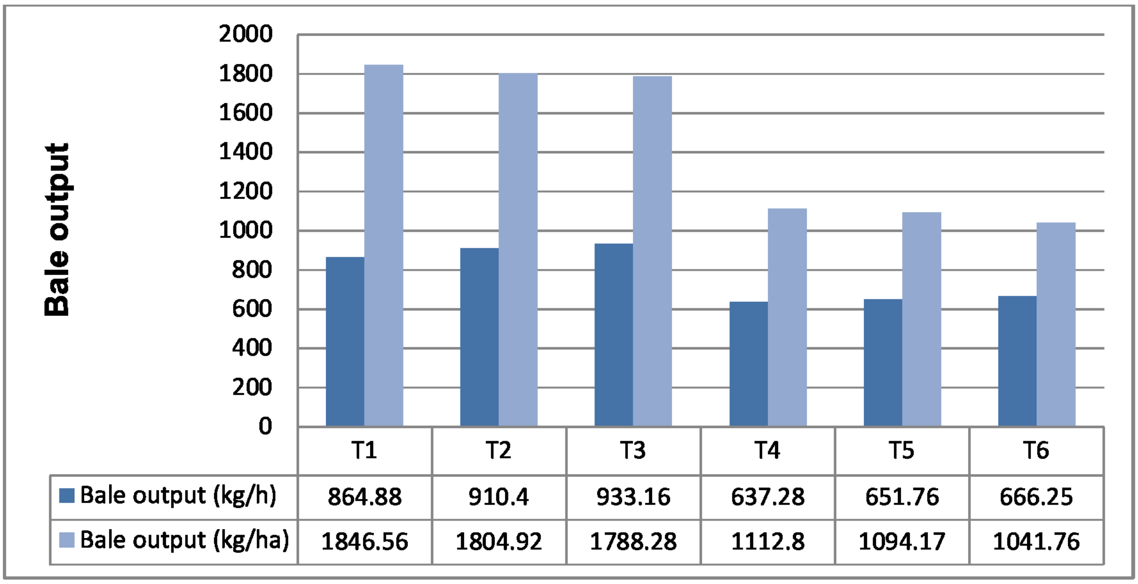


Fig 4.11 Bale output for different treatments

4.4.4 Percentage saving in space

It is evident from table 4.8 that the minimum volumetric space (i.e. 132 kg /0.178 m^3) contains by bale in T_3 due to higher moisture content (i.e. 29-31%) and higher speed of tractor (3.0 km/h) and maximum volumetric space contain by straw bundle due to T_7 (i.e. 9.35 kg of straw/ unit space) due to human limitation.

It is evident from fig 4.12 that highest percentage saving in space was found in T_3 due to a lower moisture content of straw (i.e. 19-21%) and compact bale due to the highest speed of tractor (i.e. 3.0 km/h). If we take percentage saving in space with respect to T_3 (It saves maximum space in all treatment) as 100 per cent from fig 4.12 shows that percentage space of T_3 was found 3.35, 1.66, 40.87, 39.61, and 34.87 and 69.74% more from T_1, T_2, T_4, T_5, T_6, and T_7 respectively.

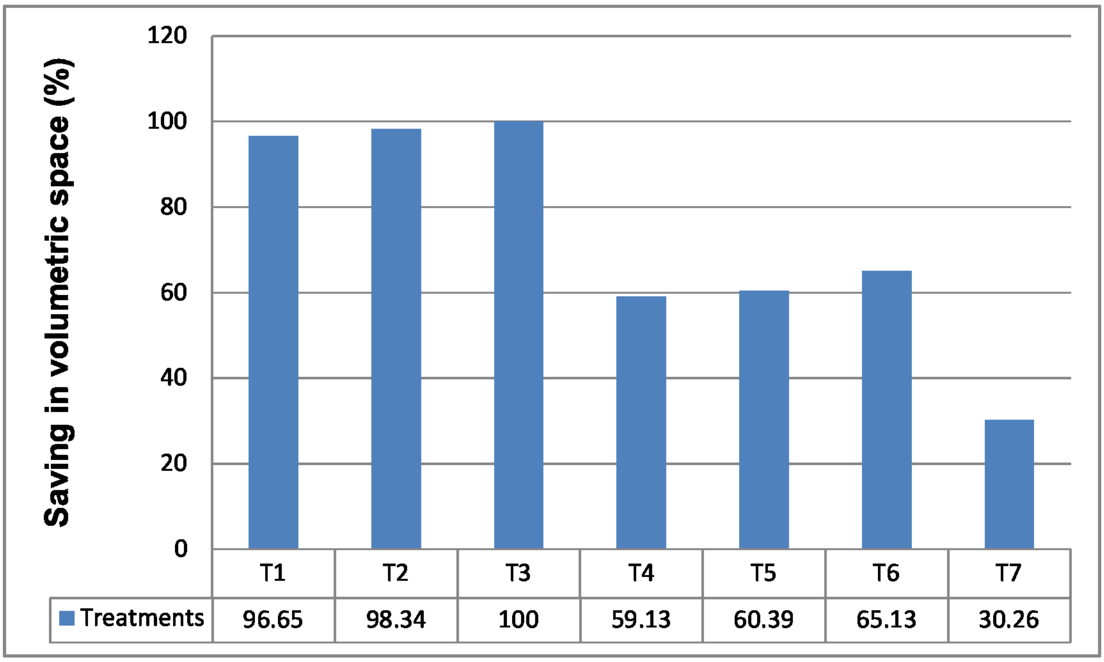


Fig. 4.12 Percentage saving in volumetric space for different treatments

4.4.5 Baler performance

Overall results of tractor drawn round straw baler can be depicted from table 4.9.

Table 4.9 Baler performance

Treatment	Parameters					
	Actual field capacity (ha/h)	Field Efficiency (%)	Straw recovery (%)	Fuel consumption (l/h)	No of Bale per hour	Bale output (kg/h)
T_1	0.467	76.30	92.712	4.1	38	864.88
T_2	0.515	63.11	91.999	3.63	40	910.40
T_3	0.530	51.96	92.507	3.31	41	933.16
T_4	0.547	89.37	93.894	3.88	44	637.28
T_5	0.583	71.44	93.930	3.46	45	651.76
T_6	0.669	68.52	94.373	3.11	46	666.25

4.5 Energy requirement

Appendix M shows the energy required for different treatments. Fig 4.14 shows the energy consumption under treatment T_1, T_2, T_3, T_4, T_5, $T_{6,}$ and T_7. It is evident from the fig 4.13 that the energy consumed by man in case of treatment T_1, T_2, T_3, T_4, T_5, $T_{6,}$ and T_7 were 3.100, 3.504, 3.196, 3.360, 2.938, 2.477, and 69.678 MJ/ha respectively. Table 4.10 shows the total energy consumed by different treatments and fig 4.14 shows the total energy consumed (MJ/ha) by different treatments.

Table 4.10 Energy requirement for different treatments

Treatment	Energy consumed by a human (MJ/ha)	Direct energy (energy consumed by diesel) (MJ/ha)	Indirect energy (energy consumed by machinery) (MJ/ha)	Total energy consumed (MJ/ha)
T_1	4.196	502.155	25.62	**531.971**
T_2	3.804	406.48	23.23	**433.514**
T_3	3.696	345.63	22.57	**371.896**
T_4	3.582	402.10	21.88	**427.562**
T_5	3.360	327.83	20.52	**351.71**
T_6	2.928	262.62	17.88	**283.428**
T_7	46.452	-	-	**46.452**

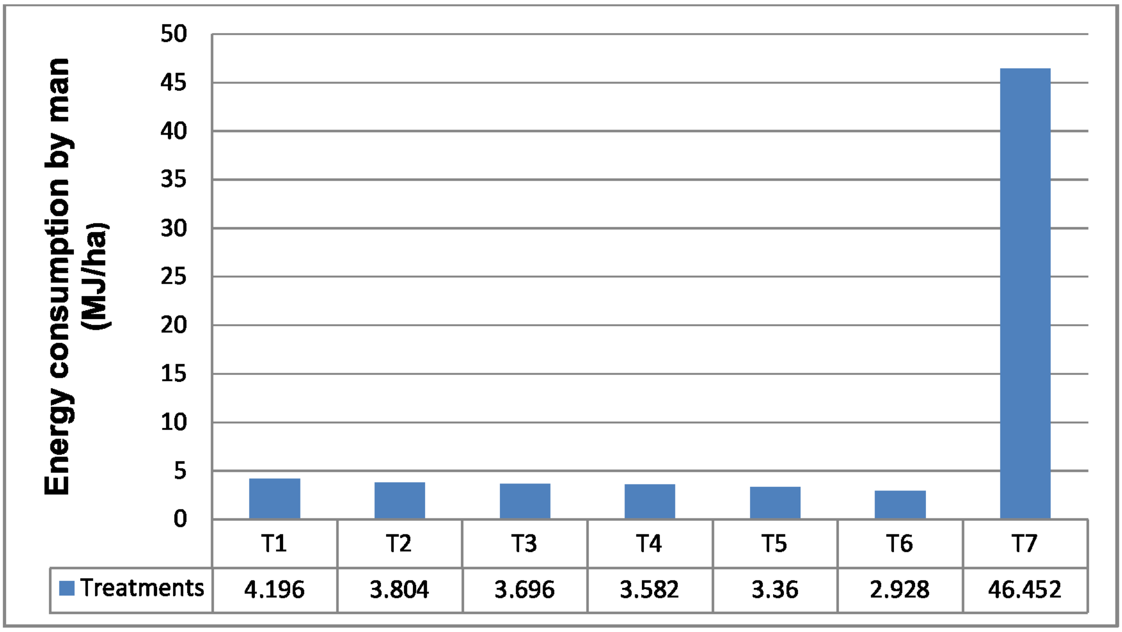


Fig. 4.13 Energy consumption by man for different treatments

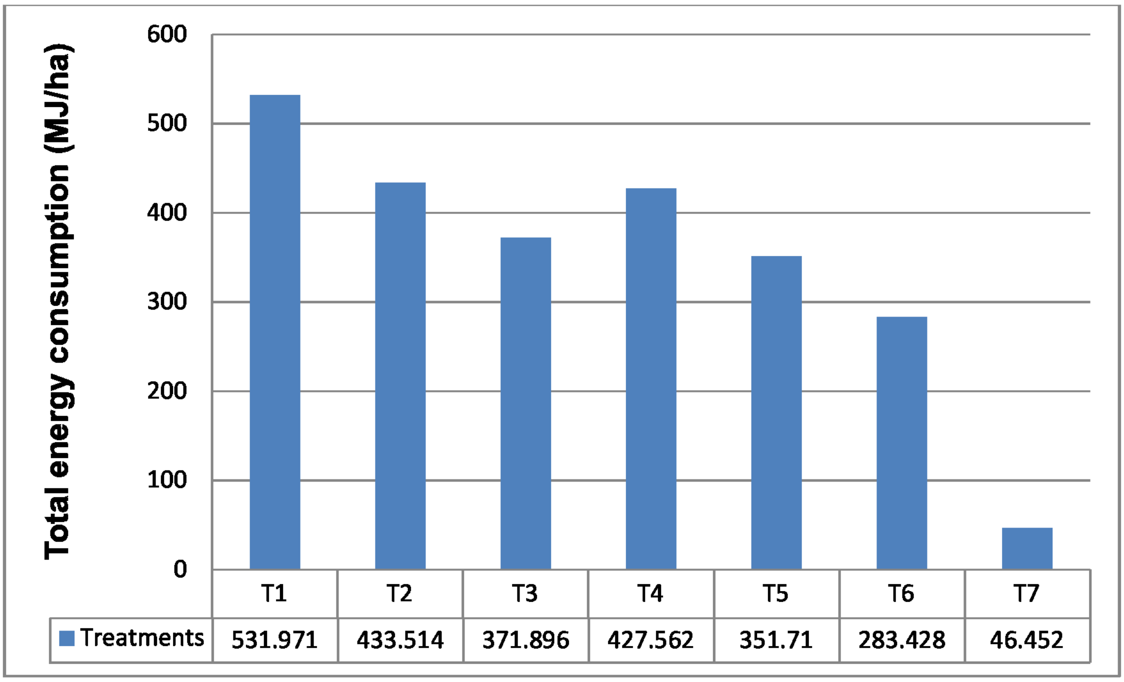


Fig. 4.14 Total energy consumed by different treatments

4.6 Cost of operation

The cost analysis presented in appendix O shows the cost of operation for different treatments. It is evident from the table 4.11 and fig. 4.15 that the cost of operation is lowest for the Treatment T_6 and highest for the treatment T_1 that is 1408.74 Rs/ha and 2452.20 Rs/ha respectively.

Table 4.11 Cost of operation for different treatments

Treatment	Fixed cost (Rs/h)	Variable cost (Rs/h)	Total cost	
			(Rs/h)	(Rs/ha)
T_1	294.875	850.48	1145.35	**2452.20**
T_2	294.875	821.09	1115.96	**2166.08**
T_3	294.875	774.08	1068.95	**2016.04**
T_4	294.875	717.08	1012.61	**1851.06**
T_5	294.875	650.58	945.45	**1621.42**
T_6	294.875	648.06	942.93	**1408.74**
T_7	98.384	-	98.38	**2331.70**

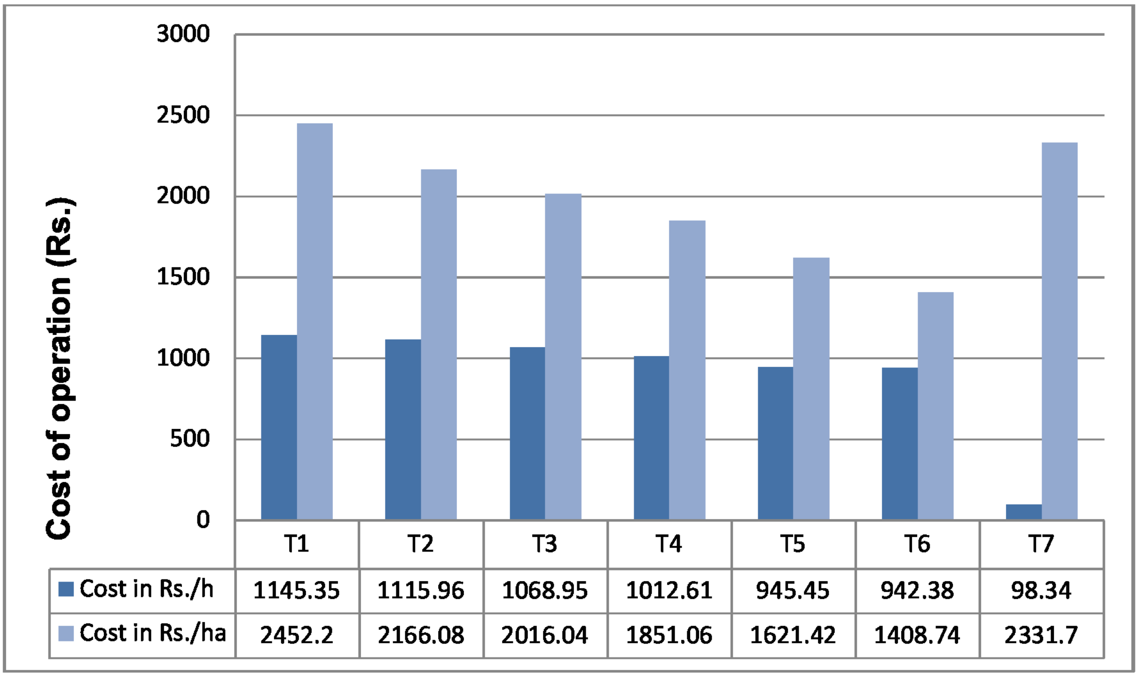


Fig. 4.15 Cost of operation for different treatments

4.7 Best result of baling operation

After critical evaluation of tractor drawn round straw baler in the laboratory and field it was found that the best combination of moisture content and speed of baling operation with paddy straw of Kranti variety was found in T_6. The energy required was also lowest (i.e. 283.42 MJ/ha) for this combination. As per the cost economic of the machine, the T_6 required lowest (i.e. 942.38 Rs./h).

The details for T_6 depicted in table 4.12 and fig. 4.16 shows the components of the baling cost of T_6.

Table 4.12 Component of baling cost for T_6

S. No.	Particular	Cost (Rs/h)
1.	Depreciation	166.25
2.	Interest	110.25
3.	Insurance, taxes & shelter	18.37
4.	Repair & maintenance	87.50
5.	Fuel	229.95
6.	Lubrication	34.49
7.	Labour	46.12
8.	Twine	250
9.	**Total**	**942.93**

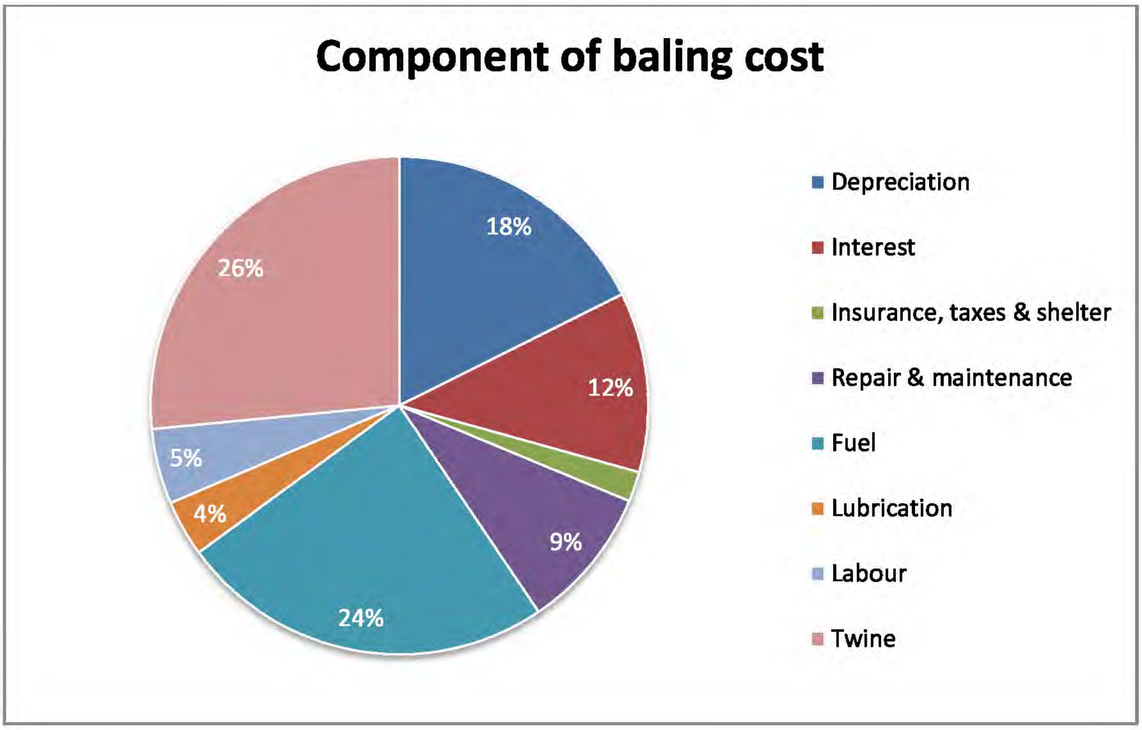


Fig. 4.16 Component of baling cost for T_6

Table 4.13 Comparison of performance of baler at different moisture content

S. No.	Particular	T_3	T_6	T_7
1.	Moisture content (%)	29-31	19-21	29-31
2.	Actual field capacity (ha/h)	0.530	0.669	0.0281
3.	Field efficiency (%)	51.96	68.52	-
4.	Straw recovery (%)	92.34	94.42	96.083
5.	Time Required (h/ha)	1.886	1.494	23.7
6.	Fuel consumption (l/h)	3.35	3.12	-
7.	Weight (kg)	23.53	15.32	9.35
8.	Density (kg/m^3)	132.21	86.10	-
9.	Number of bale per hour	41	46	-
10.	Cost (Rs/h)	1068.95	942.93	2331.70

4.8 Comparison of performance of baler at different moisture content

The results was also critically examined for the different moisture content of straw. Table 4.13 shows that at maximum moisture content of straw i.e. range between the 29-31% after the harvesting of paddy, the baler is required more time for baling one bale. It may be due to the more density of straw. Whereas, for less moisture content of straw i.e. 19-21% the machine performance parameters were found to be better than maximum moisture content i.e. 29-31% of straw. But it was found that there is no significant difference in cost of baling at different moisture content of straw.

It was concluded by data if farmer can use this baler just after the harvesting of paddy, they may save the 12-15 days of time. It is plus point in hand of farmer so, they may use this time for other activities.

4.9 Economics of baling operation

Break even point and payback priod was found to be cost effective for T_6 that is 5.67 year and 2.5 years respectively for single crop. If we operate for both season crops then it would be 2.83 years and 1.25 years respectively.

4.10 Recommendation

Therefore, tractor drawn round straw baler is recommended for baling of paddy (Kranti variety), which may enhance the environment conditions and the income of farmers.

SUMMARY AND CONCLUSIONS

An experiment was conducted to study the performance of straw baler machine for paddy crop at JNKVV, University Farm Jabalpur. The treatments were combination of two different moisture contents and three speed one treatment is traditional method of straw collection. The different parameters were measured which include field capacity, field efficiency, fuel consumption, straw recovery, cost of operation, energy requirement, economic analysis.

The actual field capacity is affected by many factors such as effective width of the machine, forward speed of machine and moisture content of straw. The following conclusions have been drawn from the study.

5.1 Straw parameters

a) The bulk density of loose straw found be 39.733 kg/m^3.

b) The moisture content took a major role resulting in the same volume of straw having less weight the bale. This makes easy handling of bales due to light weight.

c) The straw population also played important role in this operation. There was a good plant population in Kranti variety of paddy. So that, it makes economic operation due to less run to make one bale.

5.2 Machine parameters

a) The theoretical field capacity was found to be 0.612, 0.816, and 1.020 ha/h when speed of operation was 1.8, 2.4, and 3.0 km/h respectively.

b) The maximum actual field capacity (i.e. 0.669 ha/h) was found to be in case of T_6 having lowest moisture content (i.e. 19-21%) and highest speed (i.e. 3.0 km/h) and minimum actual field capacity (i.e. 0.0281 ha/man-h) was found to be in T_7 which was manual collection method. The actual field capacity of T_1, T_2, T_3, T_4, T_5 was found to be 0.467, 0.515, 0.530, 0.547, and 0.583 ha/h respectively.

c) The maximum field efficiency (i.e. 89.37%) was found to be in case of T_4 having lowest moisture content (i.e. 19-21%) and lowest speed (i.e. 1.8 km/h) and minimum field efficiency (i.e. 51.96 %) was found in T_3 having highest moisture content (i.e. 29-31%) and highest speed (i.e. 3.0 km/h). The field efficiency of T_1, T_2, T_4, and T_5 was found to be 76.30, 63.11, 71.44 and 68.52% respectively.

d) The maximum straw recovery (i.e. 96.083%) was found to be in case of T_7 which was manual collection method and minimum straw recovery (i.e. 92.409%) was found in T_1 having highest moisture content (i.e. 29-31%) and lowest speed (i.e. 1.8 km/h). The straw recovery of T_2, T_3, T_4, T_5, and T_6 was found to be 92.103, 92.344, 93.674, 93.752, and 94.423% respectively.

e) The fuel consumption was minimum (i.e. 3.122 l/h) in case of T_6 having lowest moisture content (i.e. 19-21%) and highest speed (i.e. 3.0 km/h) and maximum (i.e. 6.654 l/h) in T_2 having higher moisture content (i.e. 29-31%) and lower speed (i.e. 2.4 km/h) and it was inconsiderable in case of manual collection. The fuel consumption of T_1, T_3, T_4, and T_5 was found to be 4.167, 3.35, 3.907 and 3.395 l/h respectively.

f) The time required was minimum (i.e. 1.494 h/ha) in case of T_6 having lowest moisture content (i.e. 19-21%) and highest speed (i.e. 3.0 km/h) and maximum (i.e. 23.7 man-h/ha) in T_7 which was manual collection method. The time required for T_1, T_2, T_3, T_4, and T_5 was found to be 2.141, 1.941, 1.886, 1.828, and 1.715 h/ha respectively.

5.3 Bale parameters

a) The heaviest bale (i.e. 23.535 kg) was found in T_3 and lightest bale (i.e. 13.915 kg) was found in case of T_4. The weight of bale was found to be only 9.35 kg in manual collection method. Weight of bale for T_1, T_2, T_5, and T_6 was found to be 22.76, 23.143, 14.21 and 15.326 kg respectively.

b) The maximum density (i.e. 132 kg/m^3) of bale was found to be in case of T_3 and minimum density (i.e. 78.174 kg/m^3) of bale was found in case of T_4. The density in case of the manual collection was found to be only 21.16 kg/m^3. The density of bale for T_1, T_2, T_5, and T_6 was found to be 127.77, 130.01, 79.83, and 86.101 kg/m^3 respectively.

c) The maximum bale output (i.e. 46 bale/h) was found to be in case of T_6 having the lowest moisture content range (i.e. 19-21%) and highest speed (i.e. 3 km/h) and minimum (i.e. 38 bale/h) was found in case of T_1 having highest moisture content range (i.e. 29-31%) and lowest speed (i.e. 1.8 km/h).

The bale output in case of T_1, T_2, T_5, and T_6 was found to be 1368.24, 1627.795, 651.76, and 666.25 kg/h respectively.

5.4 Percentage saving in volumetric space

It was maximum in case of T_6 and minimum in case of T_7 which was found to be only 16.01% manual collection method with respect to T_6. The percentage saving in space for T_1, T_2, T_4, T_5, and T_6 was found to be 96.65, 98.34, 59.13, 60.39 and 65.39% respectively with respect to T_3.

5.5 Labour requirement

The labour requirement was found to be maximum (i.e. 23.7 man-h/ha) in case of T_7 which was manual collection method and minimum (i.e. 1.76 man-h/ha) in T_6 having lowest moisture content range (i.e.19-21%) and highest speed (i.e. 3 km/h).

5.6 Energy requirement

Energy requirement was found be maximum (i.e. 531.971 MJ/ha) in case of T_1 and minimum (i.e. 46.452 MJ/ha) in case of T_7 which was manual collection method. The energy requirement for T_2, T_3, T_4, T_5, and T_6 was found to be 433.514, 371.896, 427.562, 351.710, and 238.428 MJ/ha respectively and were 18.50, 30.09, 19.62, 33.88, and 46.71% less compared to T_1.

5.7 Economic analysis

On the basis of study it can be concluded that the cost of operation was minimum (i.e. 1408.74 Rs/ha) in case of T_6 having lowest moisture content ranges (i.e. 19-21%) highest speed (I.e. 3.0 km/h) and maximum (i.e. 2452.20 Rs/ha) in T_1 having highest moisture content ranges (i.e. 29-31%) lowest speed (I.e. 1.8 km/h). Whereas, the cost for T_2, T_3, T_4,T_5, and T_7 was found to be 2166.08, 2016.04, 1851.06, 1621.42 and 2331.70 Rs/ha which is 11.66, 17.78, 24.51, 33.87, and 4.9% less than T_1 respectively. Data revealed that tractor drawn round straw baler for baling of Kranti variety of paddy crop give better performance with T_6.

Break even point and payback priod was found to be cost effective for T6 that is 5.67 year and 2.5 years respectively for single crop. If we operate for both season crops then it would be 2.83 years and 1.25 years respectively.

It was concluded by data if farmer can use this baler just after the harvesting of paddy, they may save the 12-15 days of time. It is plus point in hand of farmer so, they may use this time for other activities.

SUGGESTIONS FOR FURTHER WORK

The following suggestions are given for further research:-

1. Performance comparison may also be done with Square baler.
2. This operation may also perform in a combination of machines like stubble shaver + straw baler of any one type or both type then compare their performance in view of cost and energy.
3. Performance of machine may also be evaluate after using of hay rake.
4. This operation can be done with different crop moisture content and variety.
5. Operation can also perform with different stubble heights.
6. This operation can also perform with different power of tractor and compare them.

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APPENDICES

APPENDIX A: Crop height, stubble height and plant population

Speed (S_1), km/h			Speed (S_2), km/h			Speed (S_3), km/h		
Number of day after harvesting (M_1)								
Crop height (cm)	Stubble height (cm)	Plant population (no/m²)	Crop height (cm)	Stubble height (cm)	Plant population (no/m²)	Crop height (cm)	Stubble height (cm)	Plant population (no/m²)
85	30	15	73	31	17	76	34	16
82	34	16	81	34	18	79	29	18
80	20	18	83	28	14	80	25	17
76	23	17	78	25	16	73	34	18
73	30	16	83	32	17	84	31	15
15 days after harvesting (M_2)								
81	31	17	73	23	18	86	29	18
80	25	17	80	34	15	81	27	17
79	26	18	87	31	16	82	35	16
89	30	15	84	32	18	79	34	16
84	35	16	72	28	17	81	29	17
80.9	**28.3**	**16.5**	**79.4**	**29.8**	**16.6**	**80.1**	**30.7**	**16.8**
Average crop height = 80.13								
Average stubble height = 29.6								
Average plant population = 16.63 ≈ 17								

APPENDIX B: Straw grain ratio

Treatment	Replication				Average
	R1	R2	R3	Average	
T_1	2.105	2.104	1.980	**2.039**	**2.013**
T_2	2.103	1.875	2.102	**2.026**	
T_3	1.960	1.859	2.110	**1.976**	
T_4	1.890	1.789	2.104	**1.927**	**1.985**
T_5	2.050	1.908	2.101	**2.019**	
T_6	2.110	2.013	1.908	**2.010**	

APPENDIX C: Moisture content in straw (%)

Treatment	Replication				Average (%)
	R1	R2	R3	Average (%)	
M_1	29.267	28.993	30.243	**29.501**	**30.818**
M_2	30.997	31.456	31.234	**31.229**	
M_3	32.803	30.987	31.385	**31.725**	
M_4	19.272	18.454	18.334	**18.686**	**19.455**
M_5	19.625	19.735	20.042	**19.800**	
M_6	19.581	20.123	19.938	**19.880**	

APPENDIX D: Bulk density of loose straw

Treatment	Replication				Average (kg/m^3)
	R1	R2	R3	Average	
T_1	34.177	39.977	36.047	**36.733**	**39.143**
T_2	42.127	39.771	41.061	**40.986**	
T_3	37.034	39.977	42.127	**39.712**	
T_4	26.471	26.142	28.451	**27.021**	**27.796**
T_5	29.452	25.473	27.284	**27.403**	
T_6	26.744	27.523	29.625	**28.964**	

APPENDIX E: Time required between 2 bale (sec)

Treatment	Replication (second)				
	R1	R2	R3	R4	Average (sec)
T_1	73	78	76	78	**76**
T_2	70	66	72	68	**69**
T_3	69	72	61	66	**67**
T_4	65	67	62	66	**65**
T_5	63	62	58	62	**61**
T_6	54	50	57	52	**53**

APPENDIX F: Actual field capacity (ha/h)

Treatment	Replication				
	R1	R2	R3	R4	Average (%)
T_1	0.488	0.382	0.467	0.456	**0.467**
T_2	0.508	0.539	0.494	0.523	**0.515**
T_3	0.515	0.494	0.571	0.539	**0.530**
T_4	0.547	0.530	0.573	0.647	**0.547**
T_5	0.565	0.573	0.614	0.573	**0.583**
T_6	0.659	0.712	0.624	0.684	**0.669**
T_7	0.0287	0.0290	0.0275	0.0272	**0.0281**

APPENDIX G: Field efficiency (%)

Treatment	Replication				
	R1	R2	R3	R4	Average (%)
T_1	79.73	62.41	76.30	74.50	**76.3**
T_2	62.25	66.05	60.53	64.09	**63.11**
T_3	50.49	48.43	55.98	52.84	**51.96**
T_4	89.37	86.60	93.62	90.44	**89.37**
T_5	69.24	70.22	75.24	70.22	**71.44**
T_6	64.60	69.80	61.17	67.05	**68.52**

APPENDIX- H: Straw recovery (%)

Treatment	Replication				
	R1	R2	R3	R4	Average (%)
T_1	94.410	92.156	91.570	91.502	**92.409**
T_2	93.453	92.310	90.234	92.416	**92.103**
T_3	93.346	91.854	92.321	91.856	**92.344**
T_4	94.375	93.745	93.564	93.012	**93.674**
T_5	92.345	94.295	95.152	93.216	**93.752**
T_6	94.234	95.029	93.856	94.576	**94.423**
T_7	95.453	96.537	96.280	96.059	**96.083**

APPENDIX I- Fuel consumption (l/h and l/ha)

Treatment	Replication					
	R1	R2	R3	R4	Average (l/h)	Average (l/ha)
T_1	4.0	4.1	4.2	4.37	**4.16**	**8.92**
T_2	3.5	3.47	3.9	4.02	**3.72**	**7.22**
T_3	3.25	3.39	3.3	3.46	**3.35**	**6.31**
T_4	3.75	3.9	4.0	3.98	**3.90**	**7.14**
T_5	3.35	3.45	3.6	3.18	**3.39**	**5.82**
T_6	3.09	3.15	3.1	3.15	**3.12**	**4.66**

APPENDIX J: Bale parameters

Treatment	Parameter				
	Height (cm)	Diameter (cm)	Weight (kg)	Volume (m^3)	Density (kg/m^3)
T_1	62	62	22.760	0.186	122.075
T_2	65	64	23.143	0.208	111.264
T_3	63	63	23.535	0.195	120.692
T_4	65	64	13.915	0.209	66.578
T_5	63	65	14.210	0.209	67.990
T_6	64	64	15.326	0.205	74.760

APPENDIX K- Bale output

Treatment	Replication							
	R1		R2		R3		Average (%)	
	No of bale/h	Bale output (kg/h)	No of bale/h	Bale output (kg/h)	No of bale/h	Bale output (kg/h)	No of bale/h	Bale output (kg/h)
T_1	38	864.88	37	842.12	39	887.64	**38**	**864.88**
T_2	40	910.40	39	887.64	41	933.16	**40**	**910.40**
T_3	41	933.16	40	910.40	42	955.92	**41**	**933.16**
T_4	44	637.28	43	622.79	45	651.76	**44**	**637.28**
T_5	45	651.76	44	637.28	46	666.25	**45**	**651.76**
T_6	44	637.28	46	666.25	47	680.73	**46**	**666.25**

APPENDIX L: Baler Performance

Treatment	Parameters						
	Theoretical field capacity (ha/h)	Actual field capacity (ha/h)	Field Efficiency (%)	Straw recovery (%)	Fuel consumption (l/h)	No of Bale/hour	Bale output (kg/h)
T_1	0.612	0.467	76.30	92.712	4.1	38	864.88
T_2	0.816	0.515	63.11	91.999	3.63	40	910.40
T_3	1.02	0.530	51.96	92.507	3.31	41	933.16
T_4	0.612	0.547	89.37	93.894	3.88	44	637.28
T_5	0.816	0.583	71.44	93.930	3.46	45	651.76
T_6	1.02	0.669	68.52	94.373	3.11	46	666.25

APPENDIX M: Energy requirement for round type straw baler

(i) Energy consumed by man for T_1

M = Energy coefficient of man × Hour use.

= 1.96 MJ/man-h × 2.141 man-h/ha

M = 4.196 MJ/ha

(ii) Fuel consumption in round type straw baler (l/ha)

$$FC = \frac{LCF \times SFC\ (ml/hp\text{-}h) \times Hp\ of\ baler \times hour\ of\ use\ (h/ha)}{1000}$$

$$FC = \frac{0.6 \times 133.5 \times 52 \times 2.141}{1000}$$

FC = 8.91 l/ha

(iii) Energy consumed by diesel for bailing

D = Energy Coefficient of diesel × fuel consumption.

= 56.31 MJ/l × 8.91 l/ha

D = 502.155 MJ/ha

(iv) Energy consumption from machinery for bailing

$$T = \frac{Energy\ cofficient\ of\ machine \times weight\ of\ machine \times hour\ use}{life\ of\ machine}$$

$$T = \frac{68.4 \times 700 \times 2.141}{4000}$$

T = 25.62 MJ/ha

(i) Energy consumed by man for T_2

M = Energy coefficient of man × Hour use.

= 1.96 MJ/man-h × 1.941 man-ha

M = 3.804 MJ/ha

(ii) Fuel consumption in round type straw baler (l/ha)

$$FC = \frac{LCF \times SFC\ (ml/hp\text{-}h) \times Hp\ of\ baler \times hour\ of\ use\ (h/ha)}{1000}$$

$$FC = \frac{0.6 \times 119.2 \times 52 \times 1.941}{1000}$$

FC = 7.22 l/ha

(iii) Energy consumed by diesel for bailing

D = Energy Coefficient of diesel × fuel consumption.

= 56.31 MJ/l × 7.22 l/ha

D = 406.48 MJ/ha

(iv) Energy consumption in machine for bailing

$$T = \frac{\text{Energy cofficient of machinery} \times \text{weight of machine} \times \text{hour use}}{\text{life of machine}}$$

$$T = \frac{68.4 \times 700 \times 1.94}{4000}$$

T = 23.23 MJ/ha

(i) Energy consumed by man for T_3

M = Energy coefficient of man × Hour use.

= 1.96 MJ/man-h × 1.886 man-h

M = 3.696 MJ/ha

(ii) Fuel consumption in round type straw baler (l/ha)

$$FC = \frac{LCF \times SFC\ (ml/hp\text{-}h) \times Hp\ of\ baler \times hour\ of\ use\ (h/ha)}{1000}$$

$$FC = \frac{0.6 \times 107.3 \times 52 \times 1.886}{1000}$$

FC = 6.318 l/ha

(iii) Energy consumed by diesel for bailing

D = Energy Coefficient of diesel × fuel consumption.

= 56.31 MJ/l × 6.318 l/ha

D = 345.63 MJ/ha

(iv) Energy consumption in machine for bailing

$$T = \frac{\text{Energy cofficient of machine} \times \text{weight of machine} \times \text{hour use}}{\text{life of machine}}$$

$$T = \frac{68.4 \times 700 \times 1.886}{4000}$$

T = 22.57 MJ/ha

(i) Energy consumed by man for T_4

M = Energy coefficient of man × Hour use.

= 1.96 MJ/man-h × 1.828 man-ha

M = 3.582 MJ/ha

(ii) Fuel consumption in round type straw baler (l/ha)

$$FC = \frac{LCF \times SFC \times \text{Hp of baler} \times \text{hour of use}}{1000}$$

$$FC = \frac{0.6 \times 125.2 \times 52 \times 1.828}{1000}$$

FC = 7.141 l/ha

(iii) Energy consumed by diesel for bailing

D = Energy Coefficient of diesel × fuel consumption.

= 56.31 MJ/l × 7.141 l/ha

D = 402.10 MJ/ha

(iv) Energy consumption in machine for bailing

$$T = \frac{\text{Energy cofficient of machine} \times \text{weight of machine} \times \text{hour use}}{\text{life of machine}}$$

$$T = \frac{68.4 \times 700 \times 1.828}{4000}$$

T = 21.88 MJ/ha

(i) Energy consumed by man for T_5

M = Energy coefficient of man × Hour use.

= 1.96 MJ/man-h × 1.715 man-ha

M = 3.36 MJ/ha

(ii) Fuel consumption in round type straw baler (l/ha)

$$FC = \frac{LCF \times SFC \times \text{Hp of baler} \times \text{hour of use}}{1000}$$

$$FC = \frac{0.6 \times 108.8 \times 52 \times 1.715}{1000}$$

FC = 5.822 l/ha

(iii) Energy consumed by diesel for bailing

D = Energy Coefficient of diesel × fuel consumption.

= 56.31 MJ/l × 5.822 l/ha

D = 327.83 MJ/ha

(iv) Energy consumption in machine for bailing

$$T = \frac{\text{Energy cofficient of machine} \times \text{weight of machine} \times \text{hour use}}{\text{life of machine}}$$

$$T = \frac{68.4 \times 700 \times 1.715}{4000}$$

T = 20.52 MJ/ha

(i) Energy consumed by man for T_6

M = Energy coefficient of man × Hour use.

= 1.96 MJ/man-h × 1.494 man-ha

M = 2.928 MJ/ha

(ii) Fuel consumption in round type straw baler (l/ha)

$$FC = \frac{LCF \times SFC \times \text{Hp of baler} \times \text{hour of use}}{1000}$$

$$FC = \frac{0.6 \times 100 \times 52 \times 1.494}{1000}$$

FC = 4.664 l/ha

(iii) Energy consumed by diesel for bailing

D = Energy Coefficient of diesel × fuel consumption.

= 56.31 MJ/l × 4.664 l/ha

D = 262.62 MJ/ha

(iv) Energy consumption in machine for bailing

$$T = \frac{\text{Energy cofficient of machine} \times \text{weight of machine} \times \text{hour use}}{\text{life of machine}}$$

$$T = \frac{68.4 \times 700 \times 1.494}{4000}$$

T = 17.88 MJ/ha

Table - Energy consumption by different sources

Treatment	Energy consumed by human (MJ/ha)	Direct energy (energy consumed by diesel) (MJ/ha)	Indirect energy (energy consumed by machinery) (MJ/ha)	Total energy consumed (MJ/ha)
T_1	4.196	502.155	25.62	**531.971**
T_2	3.804	406.48	23.23	**433.514**
T_3	3.696	345.63	22.57	**371.896**
T_4	3.582	402.10	21.88	**427.562**
T_5	3.360	327.83	20.52	**351.71**
T_6	2.928	262.62	17.88	**283.428**

APPENDIX N: Calculation of energy requirement for manual operation

(i) Energy consumed by man for collection of straw

M = Energy coefficient of man × Hour use

= 1.96 MJ/man-h × 23.7 man-h/ha

M = 46.45 MJ/ha

(ii) Energy consumed by woman for collection of straw

W = Energy coefficient of woman × Hour use

= 1.57 MJ/h × 35 h/ha

W = 54.95 MJ/ha

APPENDIX O: Cost evaluation

Assumptions

D = Depreciation cost, average per year (Rs/h);

P = Purchase price of the machine (Rs);

S = Salvage value of the machine 5% of the purchase price and;

L = Useful life of the machine in years;

H = Expected life of machine in hour per year;

I = Interest (Rs/h);

I = Interest rate 9% of the average life of machine (%);

ITS = Insurance, taxes (%) and shelter 2% of the average life of machine;

RM = Repair and maintenance cost (Rs/h);

rm = Percentage of purchase price of machine (%).

(a) Fixed cost (Rs/h)

(i) Depreciation (Rs/h)

$$D = \frac{P - S}{L - H}$$

$$D = \frac{350000-17500}{10 \times 200}$$

D = 166.25/- Rs/h

(ii) Interest (Rs/h)

$$I = \frac{P+S}{2} \times \frac{i}{H}$$

$$I = \frac{350000+17500}{2} \times \frac{0.12}{200}$$

I = 110.25/- Rs/h

(iii) Insurance, taxes and shelter (Rs/h)

$$ITS = \left[\frac{P+S}{2}\right] \times \frac{its}{h}$$

$$ITS = \left[\frac{350000+17500}{2}\right] \times \frac{0.02}{200}$$

ITS = 18.375 Rs/h

Fixed cost (Rs/h) = [Depreciation cost + interest cost + Insurance, taxes and shelter cost] Rs/h

Fixed cost (Rs/h) = [166.25 + 110.25 + 18.375]

Fixed cost (Rs/h) = 294.875

(b) Variable cost (Rs/h)

(i) Repair and maintenance cost (Rs/h)

The repair and maintenance cost of tractor per hour is the 0.025% of the purchase price.

$$RM = \text{Initial cost} \times \frac{RM}{100}$$

$$RM = 350000 \times \frac{0.025}{100}$$

RM = 87.5/- Rs/h

(ii) Fuel cost (Rs/h)- (Cost of fuel 73 Rs/l)

Treatment	Fuel cost (Rs/h)	
	Mathematical operation	
T_1	73 * 4.37 =	**319.01**
T_2	73 * 4.02 =	**293.46**
T_3	73 * 3.46 =	**252.58**
T_4	73 * 3.98 =	**290.54**
T_5	73 * 3.18 =	**232.14**
T_6	73 * 3.15 =	**229.95**

(iii) Cost of lubricant (Rs/h)

Cost of lubricant cost is the 15% of the diesel cost

Treatment	**Fuel cost**
	Mathematical operation
T_1	$\frac{15}{100} \times 319.01 = 47.85$
T_2	$\frac{15}{100} \times 293.46 = 44.01$
T_3	$\frac{15}{100} \times 252.58 = 37.88$
T_4	$\frac{15}{100} \times 290.54 = 43.58$
T_5	$\frac{15}{100} \times 232.14 = 34.82$
T_6	$\frac{15}{100} \times 229.95 = 34.49$

(iv) Labour cost = Rs 369/8 hr

= Rs 369/8 h = 46.125/- Rs/man-h

(v) Twine bundle cost (@ 415/- each) = 350/- Rs/h

Variable cost (Rs/h) = Repair and maintenance cost + fuel cost + lubricant cost + labour cost + twine bundle cost

T_1 = 87.50 + 319.01 + 47.85 + 46.12 + 350 = 850.48

T_2 = 87.50 + 293.46 + 44.01 + 46.12 + 350 = 821.09

T_3 = 87.50 + 252.58 + 37.88 + 46.12 + 350 = 774.08

T_4 = 87.50 + 290.54 + 43.58 + 46.12 + 250 = 717.74

T_5 = 87.50 + 232.14 + 34.82 + 46.12 + 250 = 650.58

T_6 = 87.50 + 229.95 + 34.49 + 46.12 + 250 = 648.06

Cost of operation (Rs/h) = Fixed cost + Variable cost (Rs/h)

T_1 = 294.875 + 850.48 = 1145.35

T_2 = 294.875 + 821.09 = 1115.96

T_3 = 294.875 + 774.08 = 1068.95

T_4 = 294.875 + 717.74 = 1012.61

T_5 = 294.875 + 650.58 = 945.45

T_6 = 294.875 + 648.06 = 942.93

Cost of operation (Rs/ha)

T_1 = 1145.355 Rs/h × 2.141 h/ha = 2452.20/- Rs/ha

T_2 = 1115.965 × 1.941 = 2166.08

T_3 = 1068.955 × 1.886 = 2016.04

T_4 = 1012.615 × 1.828 = 1851.06

T_5 = 945.455 × 1.715 = 1621.42

T_6 = 942.935 × 1.494 = 1408.74

Treatment	Fixed cost (Rs/h)	Variable cost (Rs/h)	Total cost	
			(Rs/h)	(Rs/ha)
T_1	294.875	850.48	1145.35	**2452.20**
T_2	294.875	821.09	1115.96	**2166.08**
T_3	294.875	774.08	1068.95	**2016.04**
T_4	294.875	717.08	1012.61	**1851.06**
T_5	294.875	650.58	945.45	**1621.42**
T_6	294.875	648.06	942.93	**1408.74**
T_7	98.384	-	98.38	**2331.70**

(c) Break-even point for T_6

$Fc + Vc(X) = B(X)$

Where,

Fc= Annual cost in rupees per year ,

Vc = Variable cost in rupees per hour,

X = Break-even point in hour and

B = Benefits (Income from thresher rental in Rs/h)

According to department of farmers welfare and agriculture development (govt. of Madhya Pradesh) rental charge for baling operation is Rs.700/h is taken for calculation.

$(295 \times 200) + 648 (X) = 700 (X)$

X = 1134.615 hours

X = 5.67 years

If we operate baler for both crop (rabi & kharif) then X is divided by 2

Then,

X = 2.83 years

(d) Payback period for T_6

PBP = I/E

Where,

PBP = payback period in years;

I = Investment in rupees;

E = Annual net cash revenue in rupees

$PBP = 350000/(700 \times 200)$

PBP = 2.5 years

If we operate baler for both crop (rabi & kharif) then X is divided by 2

PBP = 1.25 years

CURRICULUM VITAE

The author, Miss Kumudini Verma D/o Shri Tejprakash Verma was born on November 11th, 1995 at Suhela, (C.G.). She passed intermediate Examination (C.G. Borad) in 2013 with first division (74%) markes from Saraswati Shishu Mandir Higher Secondary School, Bhatapara, (C.G.).

In the year 2013, she was admitted to B. Tech (Agri.Engg.) Degree course at Bhartiya College of Agricultural Engineering, Durg affiliated to I.G.K.V. Raipur, (C.G.). She has completed the degree with first division (74.3%) in 2017.

In the year 2017 she joined "Master of Technology" two year post Graduation degree programme in the Department of Farm Machinery & Power Engineering at College of Agricultural Engineering, JNKVV, Jabalpur (M.P). After completing the entire prescribed course work successfully, she has submitted the thesis entitled "Performance Evaluation of Tractor Drawn Round Straw Baler for Paddy" in partial fulfilment for the award of degree of "Master of Technology".

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