

ENERGETICS AND TECHNO ECONOMIC ASSESSMENT OF DIFFERENT PADDY STRAW DENSIFICATION PROCESSES

BY

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[2016AE05M]

*Thesis submitted to the Chaudhary Charan Singh
Haryana Agricultural University in partial fulfillment
of the requirements for the degree of*

MASTER OF TECHNOLOGY IN FARM MACHINERY AND POWER ENGINEERING



**DEPARTMENT OF FARM MACHINERY AND POWER ENGINEERING
COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY
CCS HARYANA AGRICULTURAL UNIVERSITY**

HISAR – 125004 (HARYANA)

2018

CERTIFICATE – I

This is to certify that this thesis entitled “**Energetics and techno economic assessment of different paddy straw densification processes**” submitted for the degree of **Master of Technology** in the subject of **Farm Machinery and Power Engineering** to the **Chaudhary Charan Singh Haryana Agricultural University, Hisar**, is a bonafide research work carried out by **Hemant Kumar (2016AE05M)** under my supervision and that no part of this dissertation has been submitted for any other degree. The assistance and help received during the course of investigation have been fully acknowledged.

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CERTIFICATE – II

This is to certify that this thesis entitled “**Energetics and techno economic assessment of different paddy straw densification processes**” submitted by **Hemant Kumar (2016AE05M)** to the **Chaudhary Charan Singh Haryana Agricultural University, Hisar** in partial fulfillment of the requirements for the degree of **Master of Technology** in the subject of **Farm Machinery and Power Engineering**, has been approved by the Student’s Advisory Committee after an oral examination on the same.

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ACKNOWLEDGEMENTS

A precious debt as that of learning is the only debt that is not only difficult but also impossible to repay except perhaps through gratitude. At the very outset, I bow my head with reverence and dedicatedly accord my recondite gratitude to the "Almighty" the merciful and compassionate whose grace, glory and blessings allowed me to complete this Endeavour. Without blessing of the "Almighty God" this efforts would have remained a far-fetched dream and a sheath of notes.

I feel immense pleasure in expressing my deep sense of gratitude with reverence to my Major advisor, Dr. Vijaya Rani (Associate Professor & Head, Department of Farm Machinery and Power Engineering). The research work undertaken would have remained unaccomplished without her valuable guidance, keen interest, continuous persuasion, and remarkable patience during the entire course of study. Her unceasing encouragement, untiring efforts, inspiration, ever-willing help, precise and constructive criticism and meticulous suggestions throughout the course of this investigation enabled me in executing my research work and preparation of this manuscript. Her affection and sincerity towards work has been much beyond her formal obligation as a major advisor for which I shall ever be indebted to her.

I feel profoundly delighted and prerogative to express my deep sense of gratefulness to my Co-major advisor, Er. Mukesh Jain, Asstt. Proff., Department of Farm Machinery and Power Engineering and advisory committee members, Er. Rajender Kumar, Asst. Proff. (Department of Basic Engg. COAE&T), Dr. B. K. Hooda, Proff. & Head, Math & Stat, COBS&H, Dean PGS nominee Dr. R. S. Dhillon, (Principal scientist, Department of Forestry) for their valuable suggestions, everlasting help, and ever-encouraging attitude.

I am extremely thankful to Dr. Amarjeet Kalra, Er. Anil Kumar, Er. Swapnil Chaudhari, Er. Naresh, Er. Bharat Patel, Dr. O. P. Shoran and Dr. R. K. Johrar who provided me vital information which forms the basis of the study. I thanks to all the faculty members of College of Agricultural Engineering and Technology, CCS HAU, Hisar for providing necessary facilities and help during the course of the experimental work.

The help extended by Mr. Manoj Kumar, Mr. Ravinder, Mr. Vinod Godara, Mr. Sharma, Ms. Kailash Sura and all other technical staff of the Department of Farm Power and Machinery, CCS HAU, Hisar in conducting the experiment is also sincerely acknowledged.

I owe my gratitude to my Father, Sh. Sewaram Verma, Mother Smt. Laxmi Verma and Sisters Padmini Verma, Nandini Verma, Suman Verma and Lata Verma for their sacrifice, faith, unconditional love and affection, inspiration, constant encouragement and friendly support. Without their love, care and encouragement I would not have come to this level. Their blessings and love are the source of my spirit every moment.

Most graciously warmest thanks and appreciation to my numerous intimate Seniors, colleagues, friends and well wishers mention a few to them Manish Jangra, Vinod Goadela, Preeti and Sonam for the affable assistance, arduous affection and cheerful company rendered by them during the course of study.

My vocabulary falls short to acknowledge with veneration the help, love and best wishes rendered to me by my friends and seniors were always helpful and co-operative and their kind encouragement during this study.

I wish to extent my gratitude for any person, my memory had failed to recall, to rendered their support and services in various capacities throughout the tenure of the studies.

I proudly take this opportunity to thank CCS Haryana Agricultural University for providing me facilities from time to time during my studies.

Date: June, 2018

(Hemant Kumar)

Place: Hisar

CONTENTS

Chapter No.	Description	Page No.
1.	INTRODUCTION	1 - 3
2.	REVIEW OF LITERATURE	4 - 11
2.1	Straw densification technology	
2.2	Energetics of straw densification	
2.3	Economics of straw densification	
3.	MATERIALS AND METHODS	12 - 29
3.1	Machine details	
3.2	Plan of study	
3.3	Soil parameter	
3.4	Crop parameter	
3.5	Performance parameter	
3.6	Energy	
3.7	Economics	
4.	RESULTS	30 - 44
4.1	Soil parameter	
4.2	Crop parameter	
4.3	Performance parameters	
4.4	Energy	
4.5	Economics	
5.	DISCUSSION	45 - 48
5.1	Performance parameters	
5.2	Energy	
5.3	Economics	
6.	SUMMARY AND CONCLUSIONS	49 - 51
	REFERENCES	i-iii
	APPENDIX	I-XII

LIST OF TABLES

Table No.	Description	Page No.
3.1	Specification of stubble shaver	16
3.2	Specification of hay rake	17
3.3	Specification of tractor operated field baler	18
3.4	Specifications of stationary baler (hydraulic press type) for full length straw	20
3.5	Specification of chaff cutter	21
3.6	Specification of stationary baler (hydraulic press type) for chopped straw	22
3.7	Work performed manually in different treatments	26
3.8	Energy input equivalents	27
4.1	Mean values of height, weight and length of standing stubble and loose straw	31
4.2	Treatment mean of actual field capacity	33
4.3	Treatment mean of baling capacity	34
4.4	Treatment mean of number of bales formed	35
4.5	Treatment mean of bale density	36
4.6	Treatment mean of volume compaction ratio	37
4.7	Treatment mean of time required in forming bales	38
4.8	Average Fuel / Electricity consumption of machineries	38
4.9	Treatment mean for energy requirement	40
4.10	breakeven points of machineries	43
4.11	Payback period of machineries	44
4.12	Benefit obtained under different treatments	44

LIST OF FIGURES

Fig. No.	Description	Page No.
3.1	Feeding unit of field baler	13
3.2	Tying mechanism in field baler	15
3.3	Front view of hay rake	17
3.4	Side view of field baler	19
3.5	Top view of field baler	19
4.1	Field capacity of baler under respective treatments	32
4.2	Baling capacity of baler under different treatments	33
4.3	Number of bales formed per hour under respective treatments	34
4.4	Bale density under different treatments	35
4.5	Volume compaction ratio of baler as obtained under different treatments	36
4.6	Time required for making bales under different treatments	37
4.7	Man-hour requirement under different treatment	39
4.8	Total energy required under different treatments	40
4.9	Energy distribution in T1 (Stubble shaver + tractor operated baler)	41
4.10	Energy distribution in T2 (Stubble shaver + hay rake + tractor operated baler)	41
4.11	Energy distribution in T3 (Field baler in stationary mode)	41
4.12	Energy distribution in T4 (Stationary baler for full straw densification)	42
4.13	Energy distribution in T5 (Stationary baler for chopped straw densification)	42
4.14	Cost of baling per tonne of straw	43

LIST OF PLATES

Plate No.	Description	Page No.
3.1	View of compression chamber of stationary baler	14
3.2	Poly propylene rope twine used for tying bale in stationary baler	15
3.3	View of stubble shaver attached to PTO of tractor for operation in field	16
3.4	Front view of field baler	19
3.5	Front view of stationary baler for full length straw densification	20
3.6	Side view of chaff cutter	21
3.7	Front view of stationary baler for densification of chopped straw	22
3.8	Height of standing stubble being recorded	24
3.9	Straw samples being weighed	25
3.10	View of units consumed being recorded with energy meter	27

ABBREVIATIONS

%	: Per cent
°	: Degree
ANOVA	: Analysis of variance
C.D.	: Critical Difference
CH ₄	: Methane
cm	: Centimeter
CV	: Coefficient of variation
d.f.	: Degree of freedom
db	: Dry basis
FAO	: Food and agriculture organization
Fig	: Figure
g	: Gram
h	: Hours
ha	: Hectare
hp	: Horse power
i.e	: That is
kg	: Kilogram
km	: Kilometer
kPa	: Kilo Pascal
kW	: Kilowatt
kW-h	: Kilowatt-hour
l	: Litre
m	: Meter
MJ	: Mega joule
mm	: Millimeter
MT	: Million tonne
M ha	: Million hectare
N	: Newton
N ₂ O	: Nitrous oxide
NO ₂	: Nitrogen dioxide
q	: Quintal
RBD	: Randomized block design
RPM	: Revolution per minute
Rs	: Rupees
s	: Second
SO ₂	: Sulphur dioxide
t	: Tonne
DM	: Dry matter
wb	: Wet basis
Yr	: Year
DC	: Deputy commissioner

The world is facing many problems regarding pollution and change in environment due to human activities like burning of agricultural waste, fossil fuel usage, chemical usage, nuclear waste etc. In agriculture sector, burning of crop residue is the major problem for the environment and for living beings. In India, a large portion of the residue is burnt on-farm primarily to clear the field for sowing of the succeeding crop. According to the report published by the Ministry of New and Renewable Energy (MNRE, 2009), Govt. of India has estimated that, about 500-550 million tonnes of crop residue is generated every year. From the total crop residue, cereal crops (rice, wheat, maize, and millets) contribute 70% while rice crop alone contribute 34% (Manjunatha *et al.*, 2015). The area under paddy in Haryana was 1.27 M ha and production was 7.65 million tonne in 2017. The scented variety of rice (*Basmati*) was grown in area of 0.65 M ha and production was 2.5 million tonne in 2017 (Kharif, 2017 Basmati Survey Report, Basmati Export Development Foundation APEDA, Agricultural and Processed Food Products Export Development Authority). The agricultural residue have tremendous use viz., animal feed, soil mulch, bio manure, covering for rural homes and as fuel for domestic and industrial use.

After paddy is harvested with combine harvester, straw is left behind in the form of standing stubbles and loose straw. The paddy straw has found no local economic use and remains unutilized. In such condition farmer has no option but to burn straw and with it, burn a source of additional revenue which may come from paddy straw. Moreover, there are other reasons of on-farm burning of crop residue viz., the window period between harvesting of paddy crop and sowing of succeeding crop is very less, there is shortage of farm labour who could remove straw from field, the cost of machinery for removal of straw from field is very costly and energy consuming, the farmers are not aware of the technology available for removal of straw from field, there is belief among farmers that if straw is not burnt the succeeding crop will be infected with disease present in paddy crop.

Open field burning of crop stubble results in the emission of many harmful gases in the atmosphere, like carbon monoxide, N₂O, NO₂, SO₂, CH₄ along with particulate matter and hydrocarbons (Kumar *et al.*, 2015). One tonne of paddy straw on burning releases approximate 60 kg carbon monoxide, 3 kg particulate matter, 199 kg ash, 1460 kg carbon dioxide and 2 kg sulphur dioxide (Gupta *et al.*, 2004). According to the FAO, burning - Crop Residues for all Crop in India was around 48.20 MT in 2014 and 49% of total was only due to paddy straw burning which was 23.8 MT and emissions of N₂O -1670.9 tonnes, CH₄ - 64449 tonnes, CO₂eq from N₂O - 517979 tonnes, CO₂eq from CH₄ - 1353429 tonnes. In recent

years, it has been observed that open burning of crop residues also contributes to emissions of harmful air pollutants which have significant toxicological properties and are notably potential carcinogens.

According to Kumar *et al.*, (2015), gaseous emissions from crop residue burning can result in serious health risk, chronic bronchitis, aggravating asthma, and decreased lung function. The nitrogen oxides formed during burning also interfere with the ozone shield in the stratosphere. These gases contribute towards global warming. The heat generated by the straw burning leads to loss of useful microbes in soil, adversely affecting soil properties. Burning causes almost complete nitrogen loss, phosphorus loss of about 25 per cent, potassium loss of 20 per cent, and sulphur loss of 5 to 60 per cent. The amount of nutrients lost depends on the method used to burn the straw (Doberman and Fairhurst, 2002).

Due to the above mentioned serious problems arising due to the burning of paddy residue, we need to find ways and means for efficient utilization of the surplus paddy residue produced for maintaining soil, human health, and animal health and increasing farmer's income. The farmers can adopt mechanized method of straw removal or in-situ management of crop residue. Straw removal method includes uses of stubble shaver, hay rake and baler where's in-situ management of paddy straw can be done by two methods i.e. residue incorporation and residue retention. In residue incorporation method, residue is chopped and mixed into the soil and in residue retention method, residue is left uniformly over the field. The straw removal by baling may provide an economical, attractive and environmentally safe option (Sharma and Chandel, 2016). The collection, gathering and baling of straw was considered to be a more appropriate approach of straw management to make the field free of loose straw without straw burning in the field (Mangaraj and Kulkarni, 2011). Baling or densification is the process of increasing the density of straw by applying force. It is also known as compaction.

The baling or densification of paddy straw can be done by field baler which is also called hay-baler. It is farm machine utilized to compress a cut and raked crop (such as straw, hay, salt marsh hay or silage) into compact bales that are simple to handle, store, and transport. The straw bale formed has wide usages in industry for making cardboard, papers and insulation material, in thermal power plant for power generation, for packing the materials, for mushroom cultivation, it can be processed as enriched feed by mixing molasses and oil cakes which can be fed to camels, goats, cattle, for ethanol and biogas generation and as fuel in brick kilns. Straw bale construction can be one of the most excellent choices for all kind of individuals for developing an economic building with a sustainable material (Bhattarai *et al.*, 2012).

Baling operation can be performed manually and mechanically. Manual densification (bulging) of loose straw or hay material is done by pressing it by feet and putting whole body

weight on it. Bulging gives about 20% of compaction to the loose material (Gupta *et al.*, 2005). Manual baling is not much effective, its efficiency is very low as compared to mechanical baling, there is more fatigue and it is a very slow process.

Mechanical densification of hay material is done by compacting it in a confined volume and this compaction is achieved by means of a pressure plate or arm operated by a crank using electrical or mechanical power. Huge round balers were designed within the late 1960s after the enhancements made in hydrodynamics.

Some of the densification machines available in the country are i) field balers that can perform under field conditions as well as can be installed at any place; ii) movable type that can be taken from one place to another; and iii) stationary type that are installed at one place. Each baler produce a different type of bale – cuboid or cylindrical, of various sizes, bound with twine, strapping, netting or wire. It becomes very difficult for the farmers to decide which baling machine or combinations of machines is suitable.

In view of these facts the present study on “Energetic and techno economic feasibility of paddy straw densification machines” was undertaken with following objectives:

- 1) Technical feasibility of different densification processes
- 2) Energetics and economic comparison of different densification processes.

Densification of loose paddy straw into high-density bales is necessary to reduce and facilitate handling transportation and storage costs. In this chapter, a brief review related to densification process in reference to straw densification technologies, bale properties, energy and cost of the baling has been discussed. This chapter deals with the review of the research work carried out by various researchers related to different densification methods. The available information on the subject is presented under headings

2.1 Straw densification technology

2.2 Energetics of straw densification

2.3 Economics of straw densification

2.1 Straw densification technology

Afify *et al.*, (2002) studied two methods of rice straw picking with a rectangular baler after harvesting with and without combine. The two methods were mechanical picking and feeding into baler at three forward speeds and manual picking up and feeding into baler at three feeding rates. Result indicated lowest baling power (75.7 kWh ha^{-1}) and total cost of baling (L.E. 219.7 ha^{-1}) (LE is livre egyptienne that is Egyptian pound) with mechanical picking after harvesting with combine at 4 km h^{-1} forward speed. The productivity of baler was highest for mechanical picking with speed of 6 km h^{-1} , bale density of (149 kg m^{-3}) and baler efficiency (86%) was obtained for manual pickup with feed rate of 2 t h^{-1} . Lowest fuel consumption (3.4 l h^{-1}) was obtained for manual pickup with feed rate of 2 t h^{-1} .

Bamaga and Thakur (2003) studied rice straw recovery by conventional field baler of $360 \text{ mm} \times 460 \text{ mm}$ cross sectional dimension. The study was carried out for two varieties of rice (pant dhan 4 and TDC 16-1) and two stubble height (a) 23cm and (b) 32cm, of Pant Dhan 4. The baled straw dry matter yield 1977 kg ha^{-1} and 1469 kg ha^{-1} , straw loss as stubble 2117 kg ha^{-1} and 3575 kg ha^{-1} , baler loss 6.10% and 1.30% of potential yield, baler loss 16.30% and 5.10% of effective straw availability, recovered baled straw 31.50% and 23.40% of potential yield, respectively for stubble height of 23cm and 32cm.

Kulkarni and Mangaraj (2005) studied baler, developed at Central Institute of Agricultural Engineering, Bhopal, India. They studied densification, baling and expansion characteristics of paddy straw and the distribution of time required for each activity. They observed that the time consumption was more in loading the straw in the chamber and in tying activity as compared to other activities. Maximum time required was for tying and it ranged from 43-46% of total time. It was also observed that there was difficulty to unload the bale from the

baler. In case of tying, the U-clip welding method was most economical and time saving was up to 80 per cent in comparison to the old method of tying (needle and rope).

Singh *et al.*, (2005) conducted study to evaluate the performance and economics of straw baler. In this study they used two field conditions. In the first case they used baler directly after combine harvester where's in second case stubble shaver was operated after combine harvester and then baler was operated. The forward speed of the baler was 2.0 km h⁻¹ in combine-harvested paddy field and 2.72 km h⁻¹ in the field where stubble shaver was operated before baling .The field capacity of the baler was 0.26 ha h⁻¹ in combine-harvested paddy field and 0.36 ha h⁻¹ in the field where stubble shaver was operated before baling. Fuel consumption was more in combine-harvested paddy field as compared to the field where stubble shaver was operated before baling. The size of bale varied from 80cm x 45cm x 45cm to 90cm x 45cm x 45cm, and accordingly the weight of bales varied from 18 to 28 kg in both the cases. The number of bales formed was 205 in combine-harvested paddy field and 425 in stubble-shaved paddy field.

Kumar and Thakur (2006) studied the performance of a conventional field baler for collecting paddy straw after combining. In this study an experiment was carried out to determine the recovery of paddy straw by baling and straw losses during baling. The field baler was operated with a 37.5 kW tractor. The average field capacity, field efficiency and fuel consumption of conventional field baler were found to be 1.09 ha h⁻¹, 70.97% and 3.255 l h⁻¹, respectively at forward speed of 3.41 km h⁻¹. The total straw loss was found minimum, 113.32 kg DM ha⁻¹ at the lowest speed of 2.89 km h⁻¹ and attained a maximum value of 131.86 kg DM ha⁻¹ at the highest speed of 4.50 km h⁻¹ (DM= Dry Matter). The reasons mentioned for significantly high baling losses was due to scattering of straw, poor performance of straw pickup unit due to frequent raising and lowering on bunds and ridges.

Sandhya *et al.*, (2007) evaluated the performance of the balers in the field. Experiment was conducted in combine harvested paddy field of variety PR 118 and in the field where stubble shaver was operated after operation of combine harvester. The speed of operation was 2.13 km h⁻¹ in combine harvested field whereas, it was 2.39 km h⁻¹ in stubble shaver operated paddy field. The height of stubble was 45-48 cm in combine harvested field whereas, it was 3-7 cm in stubble shaver operated paddy field. The effective field capacity of baler was 0.26 and 0.36 ha h⁻¹ in combine harvested and stubble shaver operated paddy fields, respectively. The fuel consumption of baler was 5.50 and 5.35 l h⁻¹ in combine harvested and stubble shaver operated paddy fields, respectively. Number of bales formed per hectare was 82 and 170 obtained in combine harvested and stubble shaver operated paddy fields, respectively. Weight of the bales varied from 20 - 27 kg and compaction ratio varied from 7 to 10 in both the field conditions.

Garas *et al.*, (2009) studied three different baling machines viz. field baler, mobile stationary baler and hydraulic press type fixed stationary baler. They found that the density of bales varied from 85-90 kg m⁻³, 122-129 kg m⁻³, 138-150 kg m⁻³, no. of bales 150-200, 70-100 and 50-70, average bale size (length × width × height) 95cm × 50cm × 37cm, 112cm × 46cm × 50cm and 100cm × 53cm × 51cm and average bale weight 14, 33 and 38 kg respectively for field baler, mobile stationary baler and hydraulic press type fixed stationary baler. Higher density, but poor outer shape of bales was obtained with mobile stationary baler.

Cundiff *et al.*, (2011) compared the performance of round baler and square baler. The square bale was 1.2 m wide x 1.2 m high x 2.4 m long and the round bale was 1.5 m in diameter and 1.2 m long. The baling was 9.36 ton h⁻¹ for the round baler and 15.8 ton h⁻¹ for the square baler. Field efficiency of round baler was 69.4% and for square baler it was 64.8%.

Kemmerer and Liu (2012) conducted study on baling large size bales and their handling for wheat straw. In this study, the field was raked with twin rotary rake at a field capacity of 8 ha h⁻¹. The average speed of the rake was 12 km h⁻¹. At this rate, the rake was able to process 28.66 ton h⁻¹ of straw. The baler was set to produce 2.44 m long bales that averaged 306 kg of wet matter. This resulted in an average bale density of 116 kg m⁻³ and 340 bales were produced in approximately 8 h. The actual baling capacity of the baler was 14.33 ton h⁻¹ (wet mass) at a ground speed of 11 km h⁻¹, resulting in an average of 43 bales per hour. The bales could be handled and transported at more than twice the rate at which they were produced.

Yasin (2012) developed straw baler at Agricultural Mechanization Research Institute (AMRI), Multan, Pakistan during the year 2003 and modified the same during 2004 and performance of the baler was evaluated during the year 2009. The baler was mounted on a small trolley which could be transported to threshing sites and bales were made right after threshing. The baler comprises of a feeding hopper, a compressing chamber, a hydraulic jack, a hydraulic pump, a gear box, main frame and power drive system. The baler has compression chamber of 2050 mm long, 300 mm wide and 425 mm high. The bhoosa or straw falls from feeding chute into the bale chamber and is held against the sliding compression plate of jack for compression. In the study baler was tested on wheat straw and power was provided by three different sources 50 hp tractor, 20 hp diesel engine and 14kW electric motor. The average size of bale was 391mm x 457.13 mm x 635 mm. The average weight and volume of bale was 34.6 kg and 0.11 m³, respectively. The baler took 4.3 minutes and required 17 men min to prepare a bale. The average output of baler was 20 bales per hour.

Sahay and Pathak (2012) compared performance of hay densification machines. In this study they used three types of densification machines viz. stationary baler, movable baler and field baler for densification of different hay materials. Field baler used in two different ways, first, moving in field whereas in second field baler was used in stationary mode. They found that the baling capacity for natural grass was highest 8.6 t h⁻¹ (874 bale h⁻¹) with field baler

operating in field, followed by 6.0 t h^{-1} (598 bale h^{-1}) with field baler under stationary condition, 2.1 t h^{-1} (166 bale h^{-1}) with movable baler and was lowest 0.45 t h^{-1} (41 bale h^{-1}) with the stationary baler. Maximum bale density (121.3 kg m^{-3}) was achieved with stationary type baling machine for natural grass, followed by field baler under stationary condition (109.2 kg m^{-3}), field baler operating in field (108.6 kg m^{-3}), and movable baler (104.8 kg m^{-3}). Man power requirement was highest (5, including tractor driver) for movable baler and field baler under stationary operation.

Bansal and Kumar (2014) studied role of farm machinery for crop residue management. In this study they compared the performance of straw baler when operated with and without prior operation of hay rake in paddy crop. When straw baler was operated, without hay rake the field capacity obtained was 0.47 ha h^{-1} field efficiency was 80% and fuel consumption measured was 4.0 l h^{-1} . The baler when operated after operation of hay rake, the field capacity recorded was 1.10 ha h^{-1} , fuel consumption 4.0 l h^{-1} and a field efficiency 80%.

Sharma *et al.*, (2014) studied the use of baler technology for rice straw management. The study was carried out in Mansa district of Punjab state for consecutive three years by KVK, Mansa. Tractor of 35 hp was used for operating hay rake and 45 hp tractor was used for operating baler. They concluded that the capacity of the baler varied from $0.30\text{-}0.36 \text{ ha h}^{-1}$ without using the hay rake and capacity increases two times when hay rake was used for windrowing the straw before operation of baler. The diesel required for operation of baler for one ha area ranged from 10.0 to 12.0 litres.

Martelli *et al.*, (2015) conducted economical and technical evaluation of harvest, storage and handling of round and square bales of giant reed and switch-grass. In this study two herbaceous perennial crops were considered, giant reed (*A. donax L.*) and switchgrass (*P. virgatum L.*). The baling was done with a KUHN VB2160 round baler and a KUHN LSB 1290 large square baler (KUHN S.A. Saverne, France). It was found that the round baler has greater field efficiency in the baling of switch-grass and actual field capacity of the square baler was 36% (giant reed) and 18% (switch-grass) higher than the round baler. The square baler produces higher bulk density of dry biomass 66% higher for giant reed and 23% higher for switch-grass than the round baler.

Sharma and Chandel (2016) conducted study on paddy crop field to evaluate performance of straw baler. The baler was operated in three different field conditions. In the first condition, the baler was operated directly in combine harvested field, second baler was operated after stubble shaver operation in combine harvested field and in third baler was operated after stubble shaver and hay rake operation in combine harvested field. They concluded that the mean forward speed of baler was 1.52 km h^{-1} , 2.42 km h^{-1} and 3.18 km h^{-1} for first, second and third condition, respectively. Field capacity of baler in first condition was 0.35 ha h^{-1} , in second 0.40 ha h^{-1} and in third condition it was 0.53 ha h^{-1} . Baling capacity of baler was 1.12,

2.85 and 4.22 t h⁻¹ obtained in first, second and third condition, respectively. Bale density obtained was highest for third condition (205 kg m⁻³) followed by second condition (185.72 kg m⁻³) and first condition (155.77 kg m⁻³). Fuel consumption was 5 l h⁻¹, 10 l h⁻¹ and 12 l h⁻¹ for first, second and third condition, respectively.

Van Nguyen *et al.*, (2016) conducted study in the Mekong River Delta of Vietnam to evaluate and demonstrate the use of the machines for collecting paddy straw. The machines used in the research included: (1) a roller baler pulled by a tractor which gathers the straw in a bale but leaves the bales in the field to be collected and transported to the side of the field in a separate operation; (2) three self-propelled balers, which take the rice straw to the side of the field; and (3) a self-propelled gathering machine, which collects rice straw in loose form without baling it. They concluded that the collection capacity was highest for gathering machine (2.47 t h⁻¹) followed by baler pulled by tractor (2.20 t h⁻¹), self-propelled baler 1 (1.75 t h⁻¹), self-propelled baler 2 (1.58 t h⁻¹) and self propelled baler 3 (0.87 t h⁻¹). Diesel consumption was highest for self propelled baler 3 (11.92 l t⁻¹) followed by self-propelled baler 2 (7.26 l t⁻¹), self-propelled baler 1 (6.57 l t⁻¹), gathering machine (4.18 l t⁻¹) and baler pulled by tractor (2.61 l t⁻¹). Specific weight of bale was highest for self-propelled baler 2 (104 kg m⁻³) followed by baler pulled by tractor (93 kg m⁻³), self propelled baler 3 (75 kg m⁻³) and self propelled baler 1 (73 kg m⁻³).

Senthilkumar *et al.*, (2016) studied the performance of round type rice straw balers. In this study the balers of two different makes (Baler I and Baler II) were used for their performance evaluation. These balers were used in combine harvested ADT 43 and ADT 45 varieties of paddy fields. They concluded that field capacity was 0.11 ha h⁻¹ at the forward speed of 1.7 to 1.8 km h⁻¹ for Baler I and 0.27 ha h⁻¹ at the forward speed of 1.8 to 2 km h⁻¹ for Baler II. The average fuel consumption was 2.3 l h⁻¹ for Baler I, in the case of Baler II it was 2.125 l h⁻¹. The highest baling efficiency of 96% was obtained for Baler II and the efficiency of Baler I was 85%. The performance of Baler II was better than the Baler I.

Maski (2017) conducted studied on baler for managing rice straw. In the study, field trials were conducted for three forward speeds (1.5, 2.5 and 3.5 km h⁻¹) and three moisture content (12, 14 and 16%) of rice straw to assess the performance of tractor operated square baler with rake wheel and without rake wheel. The study revealed maximum bale output at a forward speed of 2.5 km h⁻¹ with 12% moisture content of paddy straw. At low moisture content of straw, the bale output was high due to higher straw pickup efficiency and easy flow-ability of dried straw into the baler. The number of bales produced by baler after raking was more than without raking. Straw output was almost 2.5 times more with raking in comparison to without raking. The densification increases by 8.5 folds of baled straw compared to un-baled straw.

2.2 Energetics of straw densification

Van Nguyen *et al.*, (2016) conducted study in the Mekong River Delta of Vietnam to evaluate energy consumption for collecting paddy straw. The machines used in the research included: (1) a roller baler pulled by a tractor, which gathers the straw in a bale but leaves the bales in the field to be collected and transported to the side of the field in a separate operation; (2) three self-propelled balers, which take the rice straw to the side of the field; and (3) a self-propelled gathering machine, which collects rice straw in loose form without baling it. Total energy consumption consisted of fuel used for the production and maintenance of machines and manual labour used for driving tractors and balers and handling straw. They concluded that the energy consumption was lowest for self-propelled gathering machine (331 MJ t^{-1}) followed by baler pulled by a tractor (431 MJ t^{-1}) and self propelled baler (588 MJ t^{-1}).

Maski (2017) studied the techno-economics of baling biomass. In the study, field trials were conducted for evaluation of tractor operated square baler with rake wheel and without rake wheel under combine harvested paddy field. Three forward speeds and three moisture content of rice straw was selected for the study. In case of baling with raking, energy required per tonne of baling is almost half than that of the baling without raking. The total energy required (includes straw collection, transport, loading and unloading) was 186.8 MJ t^{-1} for baling without raking and 100.78 MJ t^{-1} for baling with raking.

2.3 Economics of straw densification

Afify *et al.*, (2002) studied two methods of rice straw picking with a rectangular baler after harvesting with and without combine. The two methods were mechanical picking and feeding into baler at three forward speed and manual picking up and feeding into baler at three feeding rates. These include the mechanical picking up at three forward speeds and manual picking up at three feeding rates after harvesting with and without combine, respectively. They found that the total cost of baling was $\text{L.E.}682.5 \text{ ha}^{-1}$ (LE is livre egyptienne that is Egyptian pound) which was highest at the lowest level of the baler-feeding rate i.e. 1.5 ton h^{-1} . The total cost of baling decreased by about 30% when the baler-feeding rate increased from 1.8 to 2.2 ton h^{-1} .

Singh *et al.*, (2005) studied the performance of straw baler. Experiments were conducted in combine-harvested paddy field. The baler was operated under two conditions viz., in first case baler was directly operated in combine harvested field where's in second case baler was operated after the operation of stubble shaver. In first case the cost of operation of all implement was $\text{Rs } 2008 \text{ ha}^{-1}$ including twine cost where's in second case it was $\text{Rs } 2276 \text{ ha}^{-1}$ including twine cost. They concluded that very high transportation cost is the only reason due to which the baler is not gaining popularity.

Thakur *et al.*, (2007) conducted study on “Management of crop residues after combining and its utilization as livestock feed under Indian conditions”. Five models of conventional field balers i.e. CLASS, New Holland, Galignani (Italy), Kartar (India) and Sukhdev (India) were studied. These balers produced rectangular bales of 36 x 46 x 110 cm size and bulk density varied from 115 to 150 kg m⁻³. These balers could recover only 25-30% of potential straw yield after combining depending upon the height of cut which normally varied from 30-40 cm. The total cost of operation including baling, collection, transportation (5 km) and stacking was found to be \$ 32.5 ha⁻¹ (baling cost \$20 and other cost \$ 12.5 ha⁻¹) or approximately \$ 16.25 t⁻¹ of straw.

El-Gindy *et al.*, (2009) studied threshing and straw baling to reduce environmental pollution in Egypt. The main objective of the study was design, fabrication and evaluation of the mechanical system where baling was immediately done after harvesting. Increasing the baler feed rate to 2 ton h⁻¹ by using the proposed mechanical system it was found that the total cost of baling was LE 85 h⁻¹ (LE is livre egyptienne that is Egyptian pound). This cost of baling was less than the traditional processes. The mechanical system leads to reduced cost of baling.

Cundiff *et al.*, (2011) compared bale operation for small production fields in the southeast. In the study, they compared baling cost for a round baler (1.5 m x 1.2 m) and square baler (1.2 m x 1.2 m x 2.4 m). They found that the average baling cost was \$1.59 Mg⁻¹ for round and \$4.06 Mg⁻¹ for square baler. According to them 2.5 times higher ownership cost for the square baler is a significant disadvantage for landowners.

El-Khateeb *et al.*, (2011) compared the performance of pick-up and stationary baler for baling paddy straw. Field experiments were carried out at four forward speeds (1.5, 3.0, 4.5 and 5.5 km h⁻¹), four material moisture contents (11, 15, 19 and 24%) for rice straw. It was found that increasing forward speed of field baler from 1.5 km h⁻¹ to 5.5 km h⁻¹ tends to decrease operating cost from LE 171.4 to 50.1 fed⁻¹. They compared cost of stationary balers and field baler and found LE 90.5 fed⁻¹ for stationary baler and 100 LE fed⁻¹ for pick-up baler. (1 fed = 1.038 acre) (LE is livre egyptienne that is Egyptian pound)

Yasin (2012) developed straw baler at Agricultural Mechanization Research Institute (AMRI), Multan, Pakistan during the year 2003 and modified the same during 2004 and performance of the baler was evaluated during the year 2009. The baler was mounted on a small trolley which could be transported to threshing sites and bales were made right after threshing. The baler comprises a feeding hopper, a compressing chamber, a hydraulic jack, a hydraulic pump, a gear box, main frame and power drive system. The baler was tested for wheat straw to make bales and data was recorded. He found the operational cost of straw baler, (10 year life, annual use = 2400 hours) when operated with diesel engine was Rs 332 h⁻¹

¹, with electric motor Rs 209 h⁻¹, with rented tractor Rs 1075 h⁻¹ (Rs 950 hr⁻¹ hiring rate), with own tractor Rs 766 h⁻¹ (50 hp tractor).

Bansal and Kumar (2014) in the study entitled role of farm machinery for crop residue management compared the performance and economics of straw baler with and without hay rake in paddy crop (Pusa 1121), stubble shaver was operated in both cases after combine harvester. The cost of operation without hay rake was Rs 2350 ha⁻¹ and cost of operation with hay rack was as Rs 1960 ha⁻¹.

Van Nguyen *et al.*, (2016) conducted study in the Mekong River Delta of Vietnam to evaluate economics of the machines for collecting paddy straw. The collection machines used in the research included: (1) a roller baler pulled by a tractor, which gathers the straw in a bale but leaves the bales in the field to be collected and transported to the side of the field in a separate operation; (2) three self-propelled balers, which take the rice straw to the side of the field; and (3) a self-propelled gathering machine, which collects rice straw in loose form without baling it. They concluded that the lowest total cost for operation was obtained for self propelled baler 1 (\$US 1.51 t⁻¹) followed by self propelled baler 3 (\$US 1.68 t⁻¹), self propelled baler 2 (\$US 3.04 t⁻¹), baler pulled by a tractor (\$US 3.37 t⁻¹) and self-propelled gathering machine (\$US 6.08 t⁻¹).

Sharma and Chandel (2016) conducted study for evaluation of paddy straw baler. The baler was operated in three different field conditions. In the first condition, the baler was operated directly in combine harvested field, second baler was operated after stubble shaver operation in combine harvested field and in third baler was operated after stubble shaver and hay rake operation in combine harvested field. Total cost of operation including only baling and twine cost for first condition was Rs 793 t⁻¹ for second Rs 560 t⁻¹ and for third Rs 455 t⁻¹. Benefit cost ratio 1.16:1 (maximum) was obtained for third field condition, for second it was 1.06:1 and for first 0.85:1, respectively.

Lohan *et al.*, (2018) conducted study on balers for paddy residue management in north-west states of India. They used rectangular baler in combine harvested field. The baler could recover about 200-250 bales, weighing between 15 and 30 kg (depending upon moisture and field condition) and size of bales was 460×360 mm. The cost of operation was \$ 88.13 ha⁻¹.

The study was conducted to assess the energetics and techno economics of different paddy straw densification processes during kharif, 2017. The methodology followed to complete the objective of the study are discussed under following headings:

- 3.1 Machine details**
- 3.2 Plan of study**
- 3.3 Soil parameter**
- 3.4 Crop parameter**
- 3.5 Performance parameter**
- 3.6 Energy**
- 3.7 Economics**

The experiments were conducted at village Ramba, Distt. Karnal (Haryana), situated at 29°47'36.2"N, 76°59'02.5"E at an altitude of 253 m above sea level and at village Pai, District Kaithal (Haryana), situated at 29°42'28.8"N 76°32'09.3"E at an altitude of 224 m above sea level. Karnal and Kaithal have a semi-arid and sub-tropical climate with hot summers and cool winters. The soil of the experimental farm is classified as alluvial soil group having sandy loam texture.

3.1 Machine details

3.1.1 Machine parameters

The details of machine parameter recorded are specified under section 3.1.2

3.1.1.1 Overall length

The method for the determination of length of machine, recommended by the Indian standards institution (I.S.), as set out in "IS: 9939-1981: was followed. The distance between two vertical planes at right angles to the median plane of the machine and touching its front and rear extremities is known as overall length of the machine. The overall length of machine was measured with the help of measuring tape having a least count 1 mm.

3.1.1.2 Overall width

The method for the determination of width of machine, recommended by the Indian standards institution (I.S.), as set out in "IS: 9939-1981: was followed. The distance between two vertical planes parallel to the median plane of the machine, each plane touching the outer most point of the machine on its respective sides is known as overall width of the machine. The overall width of machine was measured with the help of measuring tape having a least count 1 mm.

3.1.1.3 Overall height

The method for the determination of height of machine, recommended by the Indian standards institution (I.S.), as set out in “IS: 9939-1981: was followed. The distance between a firm horizontal supporting surface and the horizontal plane touching the upper most part of machine known as height of machine. The overall height of machine was measured with the help of measuring tape having a least count 1 mm.

3.1.1.4 Feeding system

Feeding system indicates the method of feeding straw into the compression chamber of the baler. The field baler has pick up unit for picking up straw from field and side conveyor unit for conveying the picked straw into the compression chamber (Fig 3.1). Pick up unit has reel with tines mounted between the plates provided with shock absorbers and tensional spring at the rear side. Pick up unit has four bars and each bar has 22 tines. Side conveyor unit consists of 2 crank arms which carry three feeder fingers for side-way conveying of the hay to bale compression chamber.

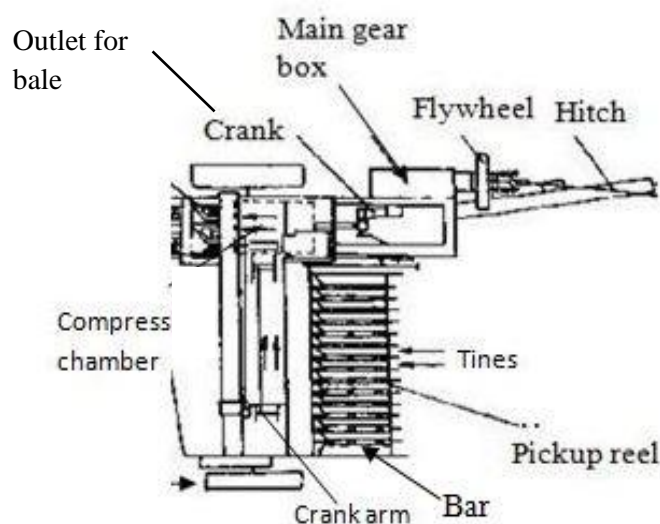


Fig 3.1 Feeding unit of field baler

The feeding in stationary baler (hydraulic press type) was done manually. The straw was gathered manually and loaded into compression chamber (Plate 3.1).

3.1.1.5 Cross section area of hydraulic press type compression chamber

The chopped or full length paddy straw is compressed in the compression chamber. The cross section area of the compression chamber of field baler (Fig 3.1) and stationary baler (hydraulic press type, Plate 3.1) was measured with the help of measuring tape having a least count 1 mm.



Plate 3.1 View of compression chamber of stationary baler

3.1.1.6 Bale length variation

The length of bale can be controlled in a field baler by a set of quadrant spur gear and a star wheel (spur gear) provided on top of compression chamber mounted on a wheel shaft. By controlling the time of quadrant spur gear with star wheel (spur gear), the length of bale is controlled through a spring. With the help of this unit we can make various size of bale according to need. In stationary baler (hydraulic press type), bale length cannot be varied but, height can be varied.

3.1.1.7 Bale density

Bale density is the ratio of mass to volume of bale. The density of bale could be adjusted in both field and stationary baler (hydraulic press type). In field baler, a hand lever is provided to increase or decreases the spring pressure which intends to control bale density through controlled convergence of the bale chamber at rear side. In stationary baler, the bale density can be varied by varying the force acting on hydraulic press. In this study force of 1500 kPa cm^{-2} and 1000 kPa cm^{-2} pressure was applied in stationary baler to compress the full length straw and chopped straw, respectively.

3.1.1.8 Tying and knotting system

In the field baler, automatic knotting mechanism is provided which ties the twine around the bale. Two knotters are operated by twin arm lever arrangement which engage or disengage the revolution of knotter shaft (Fig 3.2). Tying mechanism of field baler is activated when the quadrant spur gear is engaged with spur gear of the star wheel shaft, it actuate the shift lever which in turn engage the rotating bull gear with the knotter shaft which has a bell crank mechanism at other end which actuates two aluminium alloy needles spaced 180 mm apart. In field baler, poly propylene rope having diameter of 2 mm and tensile strength of 580 N was used.

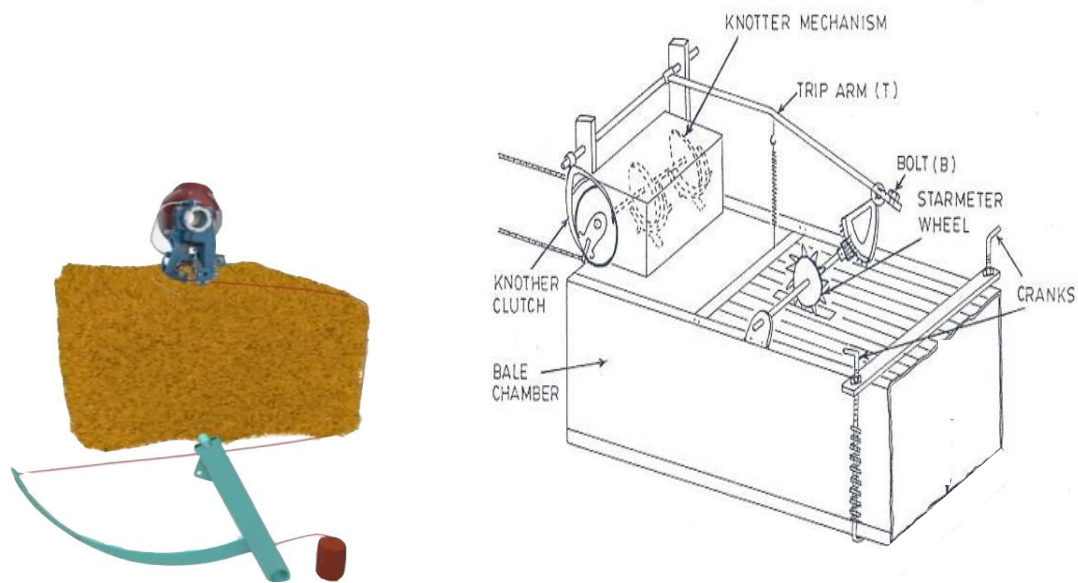


Fig 3.2 Tying mechanism in field baler

In stationary baler (hydraulic press type), the bales were tied manually by placing round twine around the bale through channels provided in the base plate and top plate of the compression chamber. In stationary baler round twine having diameter of 6 mm and break strength of 5700 N was used (Plate 3.2).



Plate 3.2 Poly propylene rope twine used for tying bale in stationary baler

3.1.1.9 Power requirement

It is the amount of power required to operate the machine. Field baler, hay rake and stubble shaver were operated with tractor and the stationary baler were operated with an electric motor.

3.1.2 Machine operating mechanism and specification

3.1.2.1 Stubble shaver

Stubble shaver is a tractor operated implement. There are two rotating blades underneath a rectangular metal frame which slashes the standing stubbles in the field. Power

to the two rotating blade is provided by PTO of tractor. The heavy duty gear box and rugged frame provided is capable of withstanding high load conditions like rough & tough wild grass, anchored straw and bushes. In this study FKRSSTO-6 model of Fieldking stubble shaver was used. Front view of stubble shaver is shown in Plate 3.3 and specification of the stubble shaver is given in Table 3.1.



Plate 3.3 View of stubble shaver attached to PTO of tractor for operation in field

Table 3.1 Specification of stubble shaver

Sr. No.	Specification	Stubble shaver
1	Length, m	2.03
2	Width, m	1.92
3	Height, m	0.93
4	Working width, m	1.59
5	Power requirement, hp	45 and above
6	Type of blade	Vertical axis blade
7	Length of blade, m	0.41
8	Reduction ratio at gear box	1:0.68
9	RPM of rotating blade	789

3.1.2.2 Hay rake

The hay rake is an agricultural implement which windrows the straw for further collection by a baler, loader wagon etc. It is also designed to fluff up the hay and turn it over so that it may dry. In this study FKHR-Z-510 model of Fieldking hay rake was used. Fig 3.3 shows the front view of hay rake and detailed specification is given in Table 3.2.

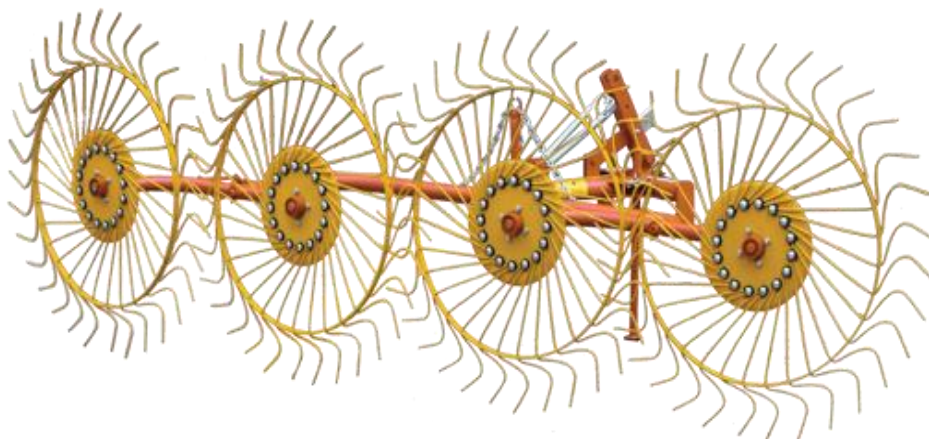


Fig 3.3 Front view of hay rake

Table 3.2 Specification of hay rake

Sr. No.	Specifications	Hay rake
1	Length, m	2.05
2	Width, m	3.25
3	Height, m	1.17
4	Total weight, kg	122
5	Power requirement, hp	25-35
6	Number of raking wheel	Four
7	Diameter of raking wheel, m	1.16
8	Spacing between the centres of two raking wheel at 90 ⁰ to the direction of travel, m	0.760
9	Spacing between the centres of two raking to the direction of travel, m	0.265
10	Inclination of rake wheel to the direction of travel	54 ⁰
11	Tilt angle of rake wheel	8 ⁰
12	Working width, m	1.5

3.1.2.3 Field baler

The field baler is an agricultural machine that is used to make bales out of loose straw from field. The field baler is operated by a tractor and its baling unit is powered by tractor PTO. The pickup unit of baler picks up loose straw from field and conveys the loose straw to cross feeder unit. The cross feeder unit feeds the straw to compression chamber. As the straw is confined into the chamber, it is compressed by a plunger. A counter shear blade on the rear of the opening of chamber cuts the charge of straw. The tying mechanism is actuated through a star wheel located on the top of the bale chamber which puts twine around the bale and ties a knot when bale of sufficient length is formed. The bale thus formed is pushed out by subsequent charge of straw in the compression chamber. Two pneumatic wheels are provided

for transportation. In this study FKSB-511 model of Fieldking baler was used. Plate 3.4, Fig 3.4 and Fig 3.5 show the front, side and top view of baler and the specification of baler is given in Table 3.3 and.

Table 3.3 Specification of tractor operated field baler

Sr. No.	Specifications	Tractor operated baler
1	Length, m	4.22
2	Width, m	2.55
3	Height, m	1.63
4	Weight, kg	1330
5	Power requirement, hp	50 and above
6	Feeding system	Tines mounted on a rotating shaft
7	Cross sectional area of compression chamber (w x h), mm	460 × 360 length can be varied
8	Bale length, m	0.3-1.3 by varying running length of tying mechanism
9	Bale density	Can be varied
10	Tying mechanism	Automatic
11	Tying material	Twine
12	Working width, m	1.85

3.1.2.4 Stationary baler (hydraulic press type) for full length straw

(1.02 m³ compression chamber)

The stationary baler (hydraulic press type) compresses full length straw to make bales and is operated by electric motor. The electric motor supplies power to the hydraulic pump which operates the plunger. There are two compression chambers in the stationary baler and with only plunger. Full length paddy straw is first fed manually in one of the chamber and is compressed by plunger. The bale is then tied manually with a twine. Paddy straw is meantime fed into other chamber after feeding the plunger is rotated and it compresses the straw in second compression chamber. Plate 3.5 shows the front view of stationary baler and the specification is given in Table 3.4.

3.1.2.5 Chaff cutter

A chaff cutter is a agricultural machine for cutting straw or hay into small pieces. It can be operated by electric motor or PTO shaft of tractor. The feeding of full length straw is done through a trough. The trough has conveyer belt at bottom which conveys the feed to the cutting chamber. The cutting blades chop the full length straw into small pieces. Plate 3.6 shows the side view of chaff cutter and the specification is given in Table 3.5.



Plate 3.4 Front view of field baler

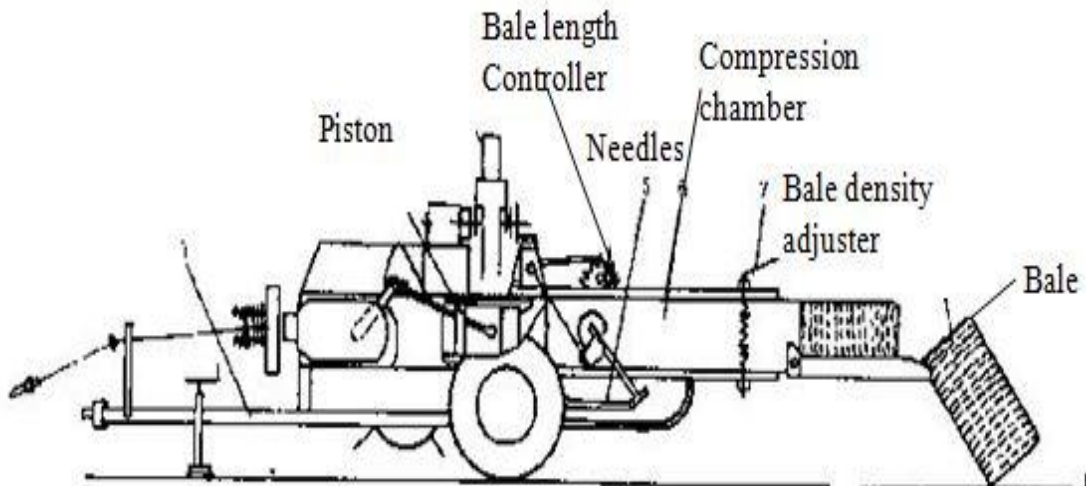


Fig 3.4 Side view of field baler*

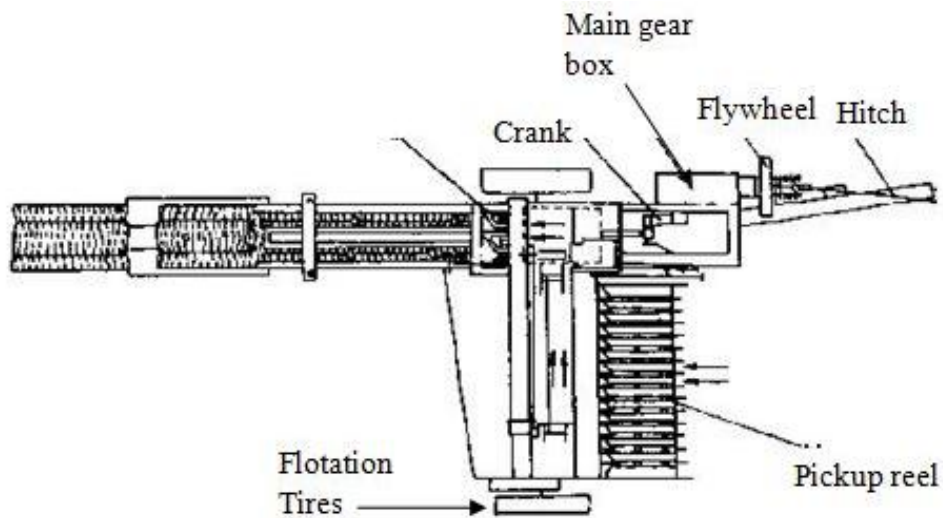


Fig 3.5 Top view of field baler*

* (FAO - <http://www.fao.org/docrep/005/Y1936E/y1936e0b.htm>)



Plate 3.5 Front view of stationary baler for full length straw densification

Table 3.4 Specifications of stationary baler (hydraulic press type) for full length straw

Sr. No.	Specification	Stationary baler for full length straw
1	Length, m	1.15
2	Width, m	2.83
3	Height, m	5.1
4	Total mass, kg	4000
5	Power source	Electric motor
6	Power requirement, hp	10
7	Feeding system	Manual
8	Cross sectional area of compression chamber (l×w×h), cm	68 × 118 × 128
9	Bale height variations	By putting plank manually
10	Tying mechanism	Manual, by passing long needle through channels provided in the top and base plate of compression chamber
11	Tying material	Nylon twine



Plate 3.6 Side view of chaff cutter

Table 3.5 Specification of chaff cutter

Sr. No.	Specification	Chaff cutter
1	Length, m	3.90
2	Width, m	1.55
3	Height, m	1.50
4	Weight, kg	900
5	Power requirement, hp	30
6	Number of blades	3
7	Diameter of flywheel or cylinder, m	0.75
8	Type of feeding	Conveyor belt

3.1.2.6 Stationary baler (hydraulic press type) for chopped straw (0.3 m³ compression chamber)

The stationary baler (hydraulic press type) is used to make bales of chopped straw. It has one compression chamber. Electric motor provides power to the hydraulic pump which operates the plunger of the baler. The chopped straw is fed manually into the compression chamber and compressed by the plunger. The bale formed is wrapped in a plastic sac and is tied with the help of twine. Plate 3.7 shows the front view of stationary baler and the specification is given in Table 3.6.

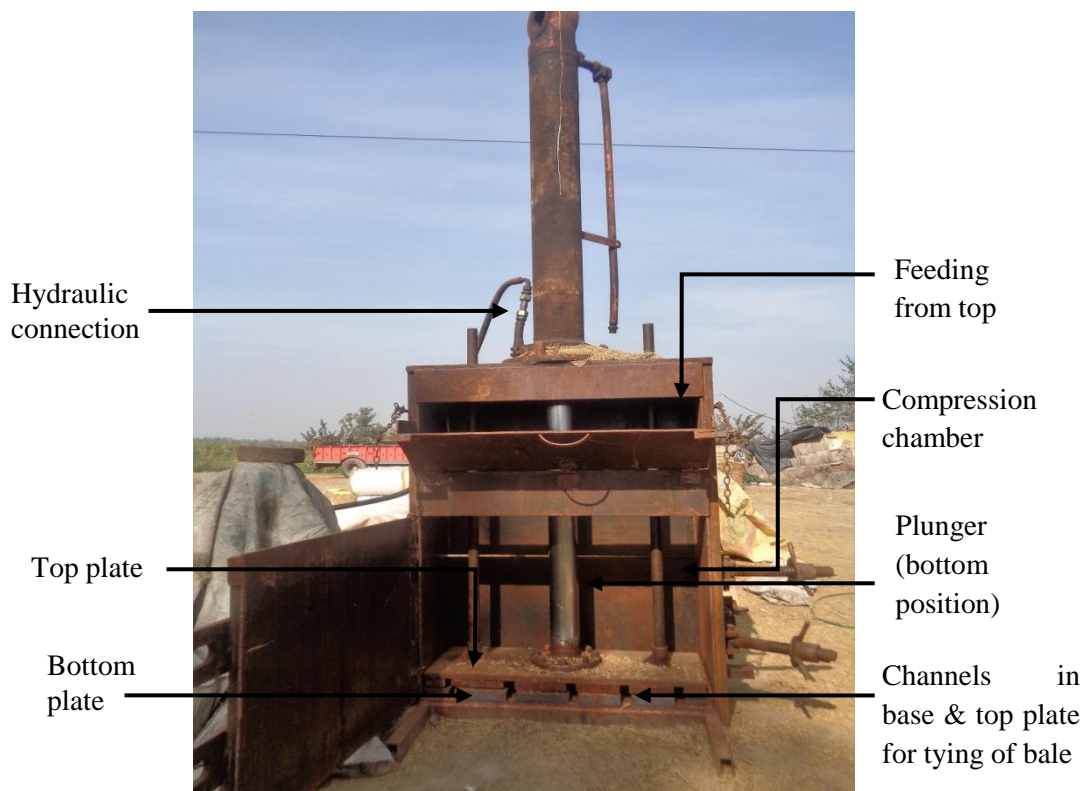


Plate 3.7 Front view of stationary baler for densification of chopped straw

Table 3.6 Specification of stationary baler (hydraulic press type) for chopped straw

Sr. No.	Specification	Stationary baler
1	Length, m	0.75
2	Width, m	1.2
3	Height, m	3.4
4	Power source	Electric motor
5	Power requirement, hp	10
6	Cross sectional area of compression Chamber (l×w×h), cm	43 × 104 × 71
7	Tying mechanism	Manual
8	Tying material	Sac and poly propane twine
9	Feeding	Manual
10	Bale height	Can be varied by putting plank manually

3.2 Plan of study

The study was planned with 5 different densification processes which are described below. The harvesting of paddy in selected field was done with combine

T1 = Straw is baled by tractor operated field baler after single operation of stubble shaver.

T2 = Straw is baled by tractor operated field baler after single pass of stubble shaver and single operation hay rake. The harvesting of paddy was done with combine.

T3 = Field baler was used in stationary mode. The straw was manually collected from the field and fed manually into field baler.

T4 = Stationary baler for densification of full length straw.

T5 = Stationary baler for densification of chopped straw. Chopping of straw was done with chaff cutter.

For treatment T4 and T5, the paddy straw used, was of full length. The harvesting of this paddy straw was done manually and dumped outside the field by farmer. Hence, the man and energy involved in collection of straw from field is not taken into account in the study.

The treatments were replicated 4 times and single factor RBD design of experiment was used for statistical analysis of data.

3.3 Soil Parameter

3.3.1 Moisture content

The method for the determination of moisture content, recommended by the Indian standards institution (I.S.I.), as set out in “IS: 2720(Part-II)-1964: Methods of test for soils-Part-II Determination of Moisture Content.” was followed. The samples of soil taken from different locations of the field and moisture content were determined by oven drying method. In this method weight of the soil sample was measured by weighing balance after that samples were placed in oven for 24 h at 110 ± 5 °C and weights of dried samples were taken. The moisture content on wet basis was determined by the formula given below:

$$M_{wb} (\%) = \frac{W - W_d}{W} \times 100$$

Where,

M_{wb}	=	Moisture content on dry basis, %
W	=	Wet weight of sample, g
W_d	=	Weight of dry sample, g

3.4 Crop Parameters

The variety of paddy straw used in study was HKR 126. It is a semi dwarf (110 cm) high yielding Indica rice variety with stiff straw. It is grown in irrigated areas of the Haryana state mainly in the districts of Kaithal, Karnal, Kurukshetra, Jind, Sonapat, Ambala, Fatehabad, Panipat, Yamunanagar and Sirsa. HKR 126 has long slender grains (super fine), resistant to WBPH (white backed planthopper) and stem rot and tolerant to mild drought and bacterial leaf blight. It takes about 142 days to mature. It has average grain yield of 68.5 q ha^{-1} and potential yield 101.6 q ha^{-1} .

3.4.1 Height and weight of standing stubbles

The combine harvester harvests the paddy crop from top 60 cm, the remaining part of the straw is left as such grounded in the field. The height of grounded (standing) stubble was measured by scale having 1 mm least count. This measurement was taken randomly at 20 locations. Plate 3.8 shows the view of observation being taken for standing stubble.

The stubble which remained standing in the field after operation of combine harvester, were cut with a sickle from bottom in an area of 1 m². These were then weighed on a weighing balance having least count of 1 gm. The observations were recorded randomly from 20 locations.



Plate 3.8 Height of standing stubble being recorded

3.4.2 Length and weight of loose straw

The straw walker unit of combine harvester throws straw in the field after grain is threshed from the cut portion of paddy crop. This straw is termed as loose straw. The loose straw was collected from an area of 1 m² from the field. The sample was weighed by weighing balance having least count 1 gm.

The length of loose straw was also measured with measuring scale having 1 mm least count. The observations were recorded randomly from 20 locations.

3.4.3 Bulk density of loose straw

The loose straw in the field was collected and filled in a box of 1×1×1 m³ dimension without compacting. It was then weighed and bulk density was calculated as

$$C = \frac{m}{V}$$

Where,

C = Bulk density, g cm⁻³

m = Mass of sample, g

V = Volume, cm³

3.4.4 Moisture content of straw

The moisture content of biomass is defined as the quantity of water per unit mass of the wet sheath. The moisture content of biomass was measured by oven dry method. Initially the sample with the known weight was kept in oven at 100±2 °C for 2 hours. The oven dry

sample is then weighed (Plate 3.9). The moisture content of sample was calculated by the following formula (Indian Standard, 7897 - 1975)

$$M.C = \frac{100 \times (W1 - W2)}{(W1 - W)}$$

Where,

M.C.	=	Moisture content of biomass, per cent
W1	=	Weight of the dish with the material before drying, g
W2	=	Weight of the dish with dried material, g
W	=	Weight of the empty dish, g



Plate 3.9 Straw samples being weighed

3.5 Performance Parameter

3.5.1 Field capacity of field baler

Effective / Actual field capacity is the actual average rate of coverage by the machine. It includes actual operating time along with time lost during turning and overlapping, during operation of baler in field etc. It is usually expressed as hectare per hour (Kepner *et al.*, 1978).

$$EFC = \frac{A}{T_p + T_I}$$

Where,

EFC	=	Effective field capacity, ha h ⁻¹
A	=	Actual area covered, ha
T _p	=	Total work time, h
T _I	=	Non-productive time, h

3.5.2 Baling capacity

The baling capacity indicates the capacity of baler to make bales per hour or per unit area. The baling capacity depends on moisture content, variety of paddy crop, crop density, picking efficiency etc.

3.5.3 Size, weight and number of bales formed by baler

The length, width and height of bales formed by field baler was recorded. The width

and height of bale formed is fixed but the length can be varied. The length and width of bale formed by stationary baler depends upon the dimension of compression chamber of the baler and the height depends on pressure applied by plunger. The size of the bale was specified in terms of length, width and height.

The weight of bales formed by field baler and stationary baler for different treatments was recorded using weighing balance. The least count of weighing balance was 0.1 kg.

The number of bales formed by different balers in an hour was recorded. There is automatic counting mechanism in field baler which indicates number of bales formed in a hour. The number of bales formed was counted manually while for field baler.

3.5.4 Volume compaction ratio

It is the ratio of bulk density of straw, before compression and after the compression. Density of compacted bale was measured by dividing the weight of bale to the volume of bale. This ratio increases with the increases in compression.

$$\text{Volume compaction ratio} = \frac{\text{Density of compacted bale}}{\text{Density of loose straw}}$$

3.6 Energy

3.6.1 Man hours required

Number of man hours required to perform a task was recorded and expressed as man-h t⁻¹. Man-hour depended on amount of work, type of work, type of baler used etc. Table 3.7 specifies the specific work performed manually in different treatments.

Table 3.7 Work performed manually in different treatments

Treatment	Baling	Collection & loading of bale
T1 & T2	The man-h were recorded for tractor operator for operation of stubble shaver (T1 & T2), hay rake (T2) and baler (T1 & T2)	The man-h were recorded for collection of bales produced by baler and left at different location in the field and then loading the same in truck
T3	The man-h were recorded for collection of loose straw left by straw walker of the combine harvester and feeding of collected straw into the field baler	The man-h were recorded for loading of bales from single location into truck
T4	The man-h were recorded for feeding of full length straw into the straw baler and tying bale. The man-h for collection of full straw from the field is not included in this as the manually harvested paddy was dumped outside the field as waste by the farmer and this was utilized to make bales	The man-h were recorded for loading of bales from single location into truck
T5	The man-h were recorded for chopping of the full length straw and then feeding the straw into baler.	The man-h were recorded for loading of bales from single location into truck

3.6.2 Fuel and electricity consumption

For measuring the fuel consumption of tractor, the fuel tank was filled up to neck before and after the operation at the same place. The amount of refilling measured after the test was the fuel consumption for operation and it was expressed in litre per hour.

Electricity consumption was measured using three phase digital energy meter. The energy meter was connected between the input supply and electric motor (Plate 3.10).



Plate 3.10 View of units consumed being recorded with energy meter

3.6.3 Total energy required

The energy required was calculated by including the direct energy sources viz. human, fuel, electricity and indirect energy sources viz. tractor and machinery.

Table 3.2 Energy input equivalents

Sr. No.	Energy input sources	Unit energy
1	Man	1.96 MJ h ⁻¹
2	Diesel	56.71 MJ l ⁻¹
3	Electricity	11.93 MJ h ⁻¹
4	Tractor	64.80 MJ h ⁻¹
5	Machinery	62.70 MJ h ⁻¹

Pardhan *et al.*, 2015

Total energy was calculated by multiplying the quantified man-h, diesel, electricity, tractor and machinery with their energy equivalents.

3.7 Economics

The economics included summing the cost of operation of machine, the fixed cost and variable cost. Fixed cost includes depreciation, interest, insurances, taxes and housing. Variable cost includes fuel, electricity, lubricates, operator's wages and repair and maintenance cost.

3.7.1 Fixed cost

3.7.1.1 Depreciation

It was a measure of the amount by which value of the machine decreased with the passage of the time, Kepner *et al.*, (1978).

$$D = \frac{C - S}{L * H}$$

Where,

D	=	Depreciation per hour
C	=	Capital investments (Rs)
S	=	Salvage value, 10% of capital investment (Rs)
L	=	Life of machine in years
H	=	Annual use, h

3.7.1.2 Interest

Interest is calculated on the average investment of the machine taking into consideration the value of the machine in the first and last year, Kepner *et al.*, (1978).

$$I = \frac{C + S}{2} * \frac{i}{H}$$

Where,

I	=	Interest per hour
C	=	Capital investments (Rs)
S	=	Salvage value, 10% of capital investment (Rs)
H	=	Annual use, h
i	=	Rate of interest (8%)

3.7.1.3 Taxes, insurances and housing

The taxes, insurance and housing were calculated as 3 % of the purchase price of the machine and are expressed in Rs h⁻¹.

3.7.2 Variable cost

3.7.2.1 Repair and maintenance

The repair and maintenance cost is calculated as 2.5 % of purchase price of machine (Kepner *et al.*, 1978 and Kamboj *et al.*, 2012).

3.7.2.2 Fuel

Fuel cost is calculated based on actual fuel consumption and cost of fuel per litre for the operation. It is expressed in Rs l⁻¹.

3.7.2.3 Electricity cost

Electricity cost is calculated based on actual electricity consumption for operation and is expressed as Rs per kW-h.

3.7.2.4 Lubricants

Lubrication cost is taken as 30% of fuel cost and is expressed in Rs h⁻¹ (Kamboj *et al.*, 2012).

3.7.2.5 Wages

Wages are calculated in terms of Rs h⁻¹. In the present study DC rate was considered for calculation of wages.

3.7.3 Total cost of operation

The total cost of operation per hour is the summation of total fixed cost per hour with total variable cost per hour.

$$\text{Total cost h}^{-1} = \text{Fixed cost per hour} + \text{variable cost per hour}$$

3.7.4 Breakeven point

Breakeven point was calculated as

$$\text{BEP} = \frac{\text{AFC}}{(\text{CH} - \text{C})}$$

Where,

BEP is the break-even point, h yr⁻¹

AFC is the annual fixed cost of the machine, Rs yr⁻¹

CH is the custom fee, Rs h⁻¹

C is the operating cost, Rs h⁻¹

$$\text{CH} = (1.25 \times \text{C}) + (0.25 \times 1.25 \times \text{C})$$

3.7.5 Payback period

$$\text{PBP} = \frac{\text{IC}}{\text{ANP}}$$

Where,

PBP = Payback period, yr.

IC = Initial cost of machine, Rs,

ANP (Average net annual profit, Rs.yr⁻¹) = (CH - C) x AU

Where,

AU = Annual use, h yr⁻¹

The results of study on “**Energetics and techno economic assessment of different paddy straw densification processes**” conducted during *Kharif* season of year 2017 are presented in this chapter with the help of appropriate table and graphs. The results are classified under following sub heads keeping in the view the specific objectives of study under taken:

4.1 Soil parameter**4.2 Crop parameter****4.3 Performance parameters****4.4 Energy****4.5 Economics****4.1 Soil Parameter****4.1.1 Moisture content of soil**

The average moisture content of the soil in field where field baler was operated was 17.23% (wb). The value of moisture content of soil ranged from 16.67 % to 17.95 %. The details of the moisture content of soil are presented in appendix A.

4.2 Crop Parameters**4.2.1 Height and weight of standing stubble**

Height of the standing stubble in the paddy field harvested with combine was taken randomly at 20 different locations in the field. The height of standing stubble before operation of stubble shaver varied from 36.24 cm to 48.22 cm. The mean value, standard deviation and coefficient of variance of height of standing stubble was 41.8 cm, 3.38 and 0.08, respectively. The height of standing stubble after operation of stubble shaver varied from 6 cm to 9.5 cm. The mean value, standard deviation and coefficient of variance of height of standing stubble was 7.2 cm, 0.93 and 0.13, respectively. Reduction of stubble height after operation of stubble shaver varied from 78.23 % to 85.52 %. The details of the height of standing stubble before and after operation of stubble shaver are presented in Appendix B-1 and the values are summarized in Table 4.1.

Weight of standing stubble (Table 4.1) of paddy was taken randomly at 20 different locations in the field harvested with combine harvester. The weight of standing stubble varied from 66 q ha⁻¹ to 80 q ha⁻¹. Mean value, standard deviation and coefficient of variance of weight of standing stubble was 74, 4.07 and 0.05, respectively

4.2.2 Length and weight of loose straw

Length of the loose straw before operation of stubble shaver in paddy field harvested by combine was measured by taking random samples from 20 different locations of the field and

it varied from 15 cm to 56 cm. The mean value, standard deviation and coefficient of variance of length of loose straw were 37.2 cm, 11.14 and 0.30, respectively. The subsequent length of loose straw obtained after the operation of stubble shaver varied from 10 cm to 51 cm. The mean value, standard deviation and coefficient of variance of length of loose straw after of stubble shaver operation were 32.1 cm, 10.84 and 0.34, respectively.

Weight of loose straw after operation of combine harvester and weight of loose straw after operation of stubble shaver were measured by taking random samples from 20 different locations of the field. The weight of loose straw obtained after the operation of combine harvester varied from 29 q ha⁻¹ to 41 q ha⁻¹. The mean value, standard deviation and coefficient of variance of weight of loose straw after combine harvester operation were 34.22 q ha⁻¹, 3.16 and 0.09, respectively. The weight of loose straw obtained after the operation of stubble shaver varied from 79 q ha⁻¹ to 115 q ha⁻¹. The mean value, standard deviation and coefficient of variance of weight of loose straw after stubble shaver operation were 97.40 q ha⁻¹, 8.82 and 0.09, respectively. Details of length and weight of loose straw are given in Appendix B-2 and summarized in Table 4.1.

4.2.3 Length of straw used in stationary baler

The length of straw used for stationary baler varied from 87 cm to 106 cm. The mean value, standard deviation and coefficient of variance of length of straw used for stationary

Table 4.1 Mean values of height, weight and length of standing stubble and loose straw

Sr. No.	Measured parameter	Range	Mean	Coeff. of variation
1	Height of standing stubbles after operation of combine harvester, cm	36.24-48.22	41.80	0.08
2	Height of standing stubbles after operation of stubble shaver in combine harvested field, cm	6.00-9.50	7.20	0.13
3	Per cent reduction in height of stubble due to operation of stubble shaver	78.23-85.52	82.80	0.02
4	Weight of standing stubble after operation of combine harvester, q ha ⁻¹	66-80	74.00	0.05
5	Length of loose straw after operation of combine harvester, cm	15-56	37.20	0.30
6	Length of loose straw after operation of stubble shaver, cm	10-51	32.10	0.34
7	Weight of loose straw after operation of combine harvester, q ha ⁻¹	29-41	34.22	0.09
8	Weight of loose straw after operation of stubble shaver, q ha ⁻¹	79-115	97.40	0.09
9	Length of straw used for stationary baler, cm	87-106	99.00	0.05

baler were 99 cm, 5.37 and 0.05, respectively. Details of length of straw are presented in appendix B-2 and summarized in Table 4.1. The straw used in stationary baler was harvested manually

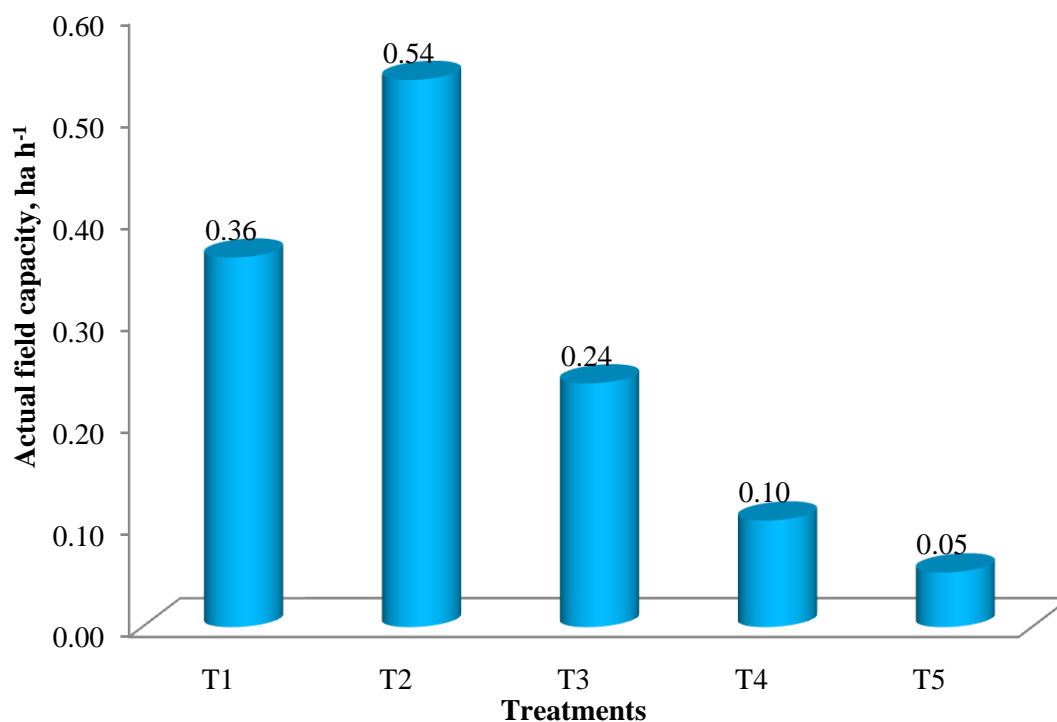
4.2.4 Moisture content of straw, % (wb)

The average value of moisture content of straw collected from field was 21.03% (wb). The moisture of straw varied from 19.11 % to 22.93 %. It was calculated after 15 days of harvesting of crop. The detail values for moisture content of straw are given in appendix B-3.

4.3 Performance parameters

4.3.1 Field capacity

The field capacity of balers used in different treatments is plotted in Fig 4.1 and the details are given in Appendix C-2. Field capacity of balers under different treatment ranged from 0.05 ha h⁻¹ to 0.54 ha h⁻¹. The maximum field capacity was obtained for T2 (0.54 ha h⁻¹) followed by T1 (0.36 ha h⁻¹), T3 (0.24 ha h⁻¹), T4 (0.10 ha h⁻¹) and T5 (0.05 ha h⁻¹). For the stationary balers under treatment T4 and T5, time was recorded and capacity was computed in terms of ha h⁻¹ for comparison with other treatments. The statistical analysis of data indicates the field capacity for different treatments was highly significant with respect to each other (Appendix D-1). The coefficient of variance was 4.31 %. The details of treatment mean are presented in Table 4.2. The details of analysis of variance are included in Appendix D-1.



T1 = Stubble shaver + tractor operated baler, T2 = Stubble shaver + hay rake + tractor operated baler, T3 = Field baler in stationary mode, T4 = Stationary baler for full straw densification, T5 = Stationary baler for chopped straw densification

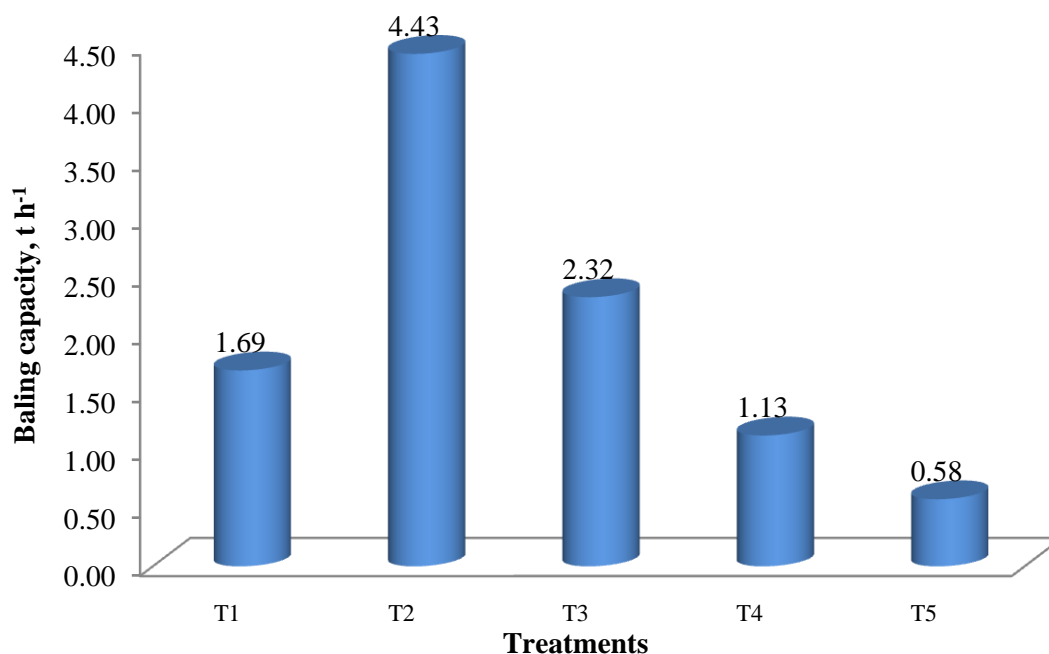
Fig 4.1 Field capacity (ha h⁻¹) of baler under respective treatments

Table 4.2 Treatment mean table for actual field capacity

Treatment Name	Treatment of
T1	0.36 ^B
T2	0.54 ^A
T3	0.24 ^C
T4	0.10 ^D
T5	0.05 ^E
General mean	0.26
p-Value	<.0001
CV (%)	4.82
C.D.	0.022

4.3.2 Baling capacity

The mean values of baling capacity of balers (includes just the operation time of balers) under different treatments are plotted in Fig 4.2 and the details are given in Appendix C-3. Baling capacity of baler ranged from 4.43 t h⁻¹ to 0.58 t h⁻¹. The maximum baling capacity was obtained for T2 (4.43 t h⁻¹) followed by T3 (2.32 t h⁻¹), T1 (1.69 t h⁻¹), T4 (1.13 t h⁻¹) and T5 (0.58 t h⁻¹). The field baler under T2 has highest baling capacity where's stationary baler under T5 has lowest baling capacity. The statistical analysis of data indicates the baling capacity for the treatments was highly significant with respect to each other. Coefficient of variance was 3.38 %. The details of analysis of variance are included in Appendix D-2. The details of treatment mean are given in Table 4.3.



T1 = Stubble shaver + tractor operated baler, T2 = Stubble shaver + hay rake + tractor operated baler, T3 = Field baler in stationary mode, T4 = Stationary baler for full straw densification, T5 = Stationary baler for chopped straw densification

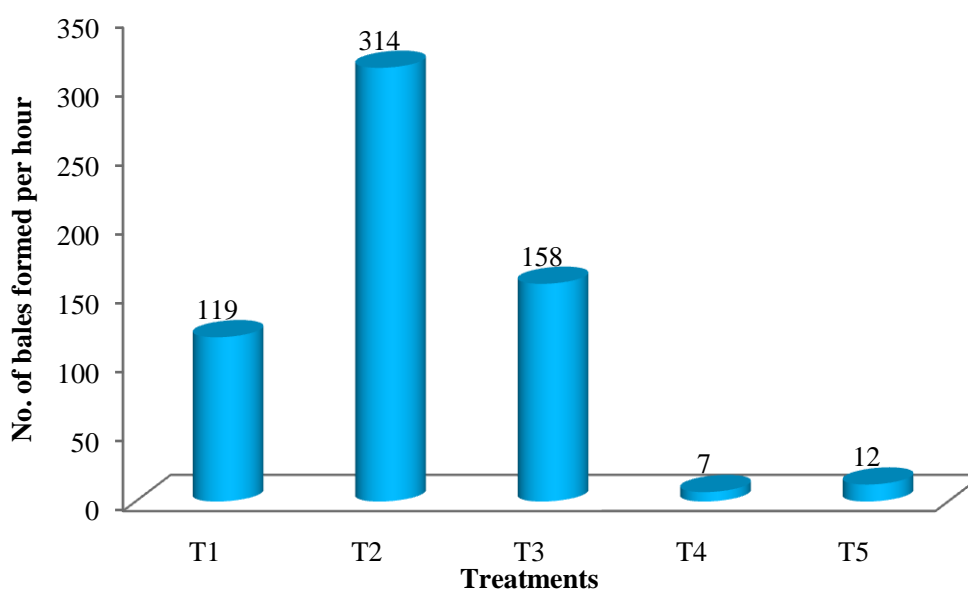
Fig 4.2 Baling capacity (t h⁻¹) of baler under different treatments

Table 4.3 Treatment mean table for baling capacity

Treatment Name	Bailing capacity
T1	1.69 ^C
T2	4.43 ^A
T3	2.32 ^B
T4	1.13 ^D
T5	0.58 ^E
General mean	2.03
p-value	<.0001
CV (%)	3.38
C.D.	0.107

4.3.3 Number of bales formed

Number of bales formed under the treatments is plotted in Fig 4.3 and the details are presented in Appendix C-4. Number of bales formed by balers under different treatments ranged from 7 to 314 per hour. The maximum number of bales was obtained for T2 (314) followed by T3 (158), T1 (119), T5 (12) and T4 (7) per hour. The field baler of T2 has highest bale forming capacity where's stationary baler of T4 has lowest bale forming capacity. The statistical analysis of data for number of bales formed shows the treatments were highly significant among themselves except for treatment T4 and T5, which were non-significant with respect to each other. The coefficient of variance was 5.29 %. The details of analysis of variance in included is Appendix D-3. The detail of treatment mean is given in Table 4.4.



T1 = Stubble shaver + tractor operated baler, T2 = Stubble shaver + hay rake + tractor operated baler, T3 = Field baler in stationary mode, T4 = Stationary baler for full straw densification, T5 = Stationary baler for chopped straw densification

Fig 4.3 Number of bales formed per hour under respective treatments

Table 4.4 Treatment mean of number of bales formed

Treatment name	Number of bales
T1	119.05 ^C
T2	314.25 ^A
T3	157.74 ^B
T4	6.83 ^D
T5	12.30 ^D
General mean	122.03
p-value	<.0001
CV (%)	5.29
C.D.	10.05

4.3.4 Bale density

The mean value of density of bales obtained from different treatments is plotted in Fig 4.4 and the details are presented in Appendix C-5. Density of bales obtained from different treatments ranged from 129.77 kg m⁻³ to 213.97 kg m⁻³. The maximum density was obtained for T4 (213.97 kg m⁻³) followed by T5 (177.66 kg m⁻³), T3 (137.51 kg m⁻³), T2 (135.04 kg m⁻³) and T1 (129.77 kg m⁻³). The length and weight of bale in field baler varied from 600 mm to 700 mm and 13 kg to 16 kg, respectively. The height and weight of bale for stationary baler (Full length straw) varied from 800 mm to 950 mm and 160 kg to 172 kg, respectively. The height and weight of bale for stationary baler (chopped straw) varied from 510 mm to 590 mm and 42 kg to 50 kg, respectively. The statistical analysis of data for bale density indicated the treatments T1 & T4, T1 & T5, T2 & T4, T2 & T5, T3 & T4, T3 & T5 and T4 & T5 were highly significant with respect to each other. Treatments T1, T2 and T3 were non-significant with each respect to each other. Coefficient of variance was 6.21 %. The detail of analysis of variance is included in Appendix D-4. The details of treatment mean are given in Table 4.5.

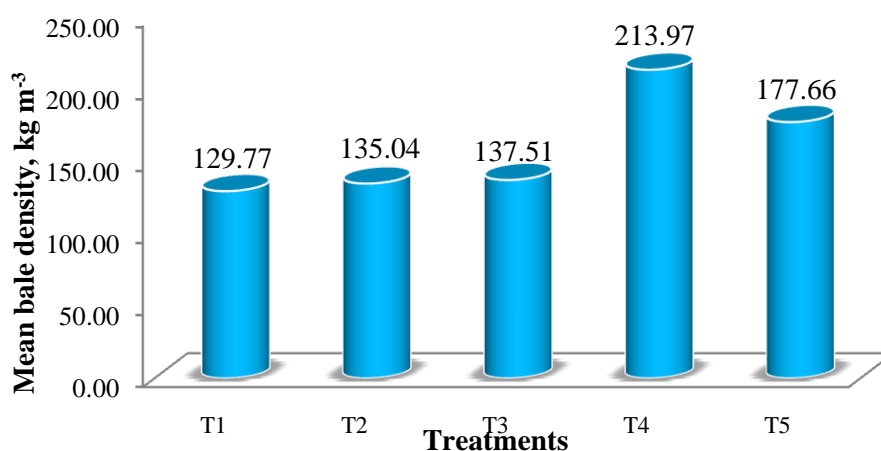


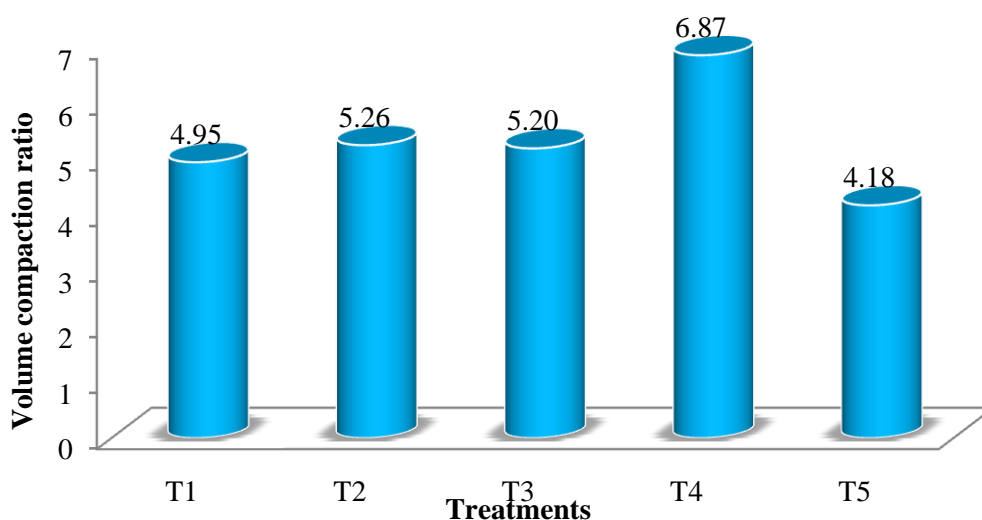
Fig 4.4 Bale density under different treatments

Table 4.5 Treatment mean of bale density

Treatment Name	Bale density
T1	129.77 ^C
T2	135.04 ^C
T3	137.51 ^C
T4	213.97 ^A
T5	177.66 ^B
General mean	158.79
p-value	<.0001
CV (%)	6.21
C.D.	15.36

4.3.5 Volume compaction ratio

Volume compaction ratio of bales calculated for different treatments is shown in Fig 4.5 and the details are included in AppendixC-6. Volume compaction ratio obtained from different treatments ranged from 4.18 to 6.87. The maximum volume compaction ratio was obtained for T4 (6.87) followed by T2 (5.26), T3 (5.20), T1 (4.95) and T5 (4.18). The volume compaction ratio of bale obtained from T4 was highest where's T5 has lowest volume compaction ratio. The statistical analysis of data for bale density indicated treatments T1 & T4, T1 & T5, T2 & T4, T2 & T5, T3 & T4, T3 & T5 and T4 & T5 were highly significant. Treatments T1, T2 and T3 were non-significant with respect to each other. The coefficient of variance was 7.07 %. The details of analysis of variance of volume compaction ratio are given in Appendix D-5. The details of treatment mean are given in Table 4.6.



T1 = Stubble shaver + tractor operated baler, T2 = Stubble shaver + hay rake + tractor operated baler, T3 = Field baler in stationary mode, T4 = Stationary baler for full straw densification, T5 = Stationary baler for chopped straw densification

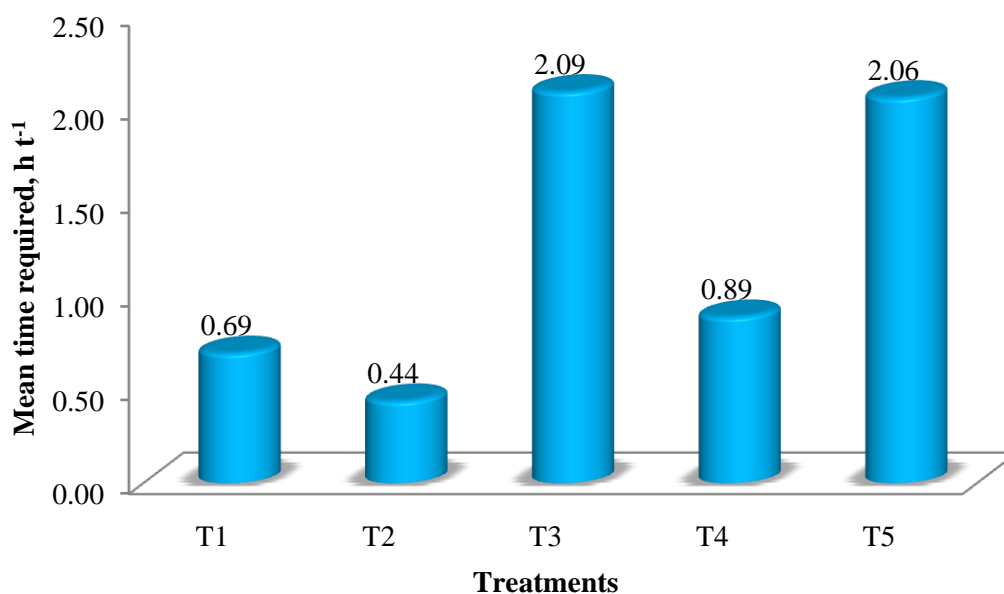
Fig 4.5 Volume compaction ratio of baler as obtained under different treatments

Table 4.6 Treatment mean of volume compaction ratio

Treatment Name	Volume compaction ratio
T1	4.95 ^B
T2	5.26 ^B
T3	5.20 ^B
T4	6.87 ^A
T5	4.18 ^C
General mean	5.29
p-value	<.0001
CV (%)	7.07
C.D.	0.60

4.3.6 Time required in forming bales

The time required includes only the operation time for collection of straw (Only for T3), making bales and picking of bales. The time required for making bale of one tone of straw in different treatments is plotted in Fig 4.5 and the details are included in Appendix C-7. Time requirement of different treatments ranged from 0.44 h to 2.09 h. The minimum time requirement was obtained for T2 (0.44 h) followed by T1 (0.69 h), T4 (0.89 h), T5 (2.06 h) and T3 (2.09 h). The statistical analysis of data for time requirement indicated highly significance amongst all the treatments except for T2 & T3 which were non-significant amongst themselves. The coefficient of variance was 3.84 %. The detail of analysis of variance of time requirement under different treatment is given in Appendix D-6. The details of treatment mean are given in Table 4.7.



T1 = Stubble shaver + tractor operated baler, T2 = Stubble shaver + hay rake + tractor operated baler, T3 = Field baler in stationary mode, T4 = Stationary baler for full straw densification, T5 = Stationary baler for chopped straw densification

Fig 4.6 Time required for making bales under different treatments

Table 4.7 Treatment mean of time required in forming bales

Treatment name	Time required
T1	0.69 ^C
T2	0.44 ^D
T3	2.09 ^A
T4	0.89 ^B
T5	2.06 ^A
General mean	1.23
p-value	<.0001
CV (%)	3.84
C.D.	0.073

4.4 Energy

4.4.1 Fuel / electricity consumption

Table 4.8 shows the mean value of fuel and electricity consumption. In treatment T1 (Stubble shaver + tractor operated baler) 6.46 l h⁻¹ diesel was used, T2 (Stubble shaver + hay rake + tractor operated baler) 10.2 l h⁻¹ diesel, T3 (Field baler in stationary mode) 3.48 l h⁻¹, T4 (Stationary baler for full straw densification) 1.65 unit h⁻¹ of electricity was consumed and T5 (chaff cutter) used 4.01 l h⁻¹ of diesel and (Stationary baler for chopped straw) consumed 1.79 unit h⁻¹ electricity. The lowest diesel was consumed by T5 and highest by T2. Details of fuel/electricity consumption are presented in Appendix E-1.

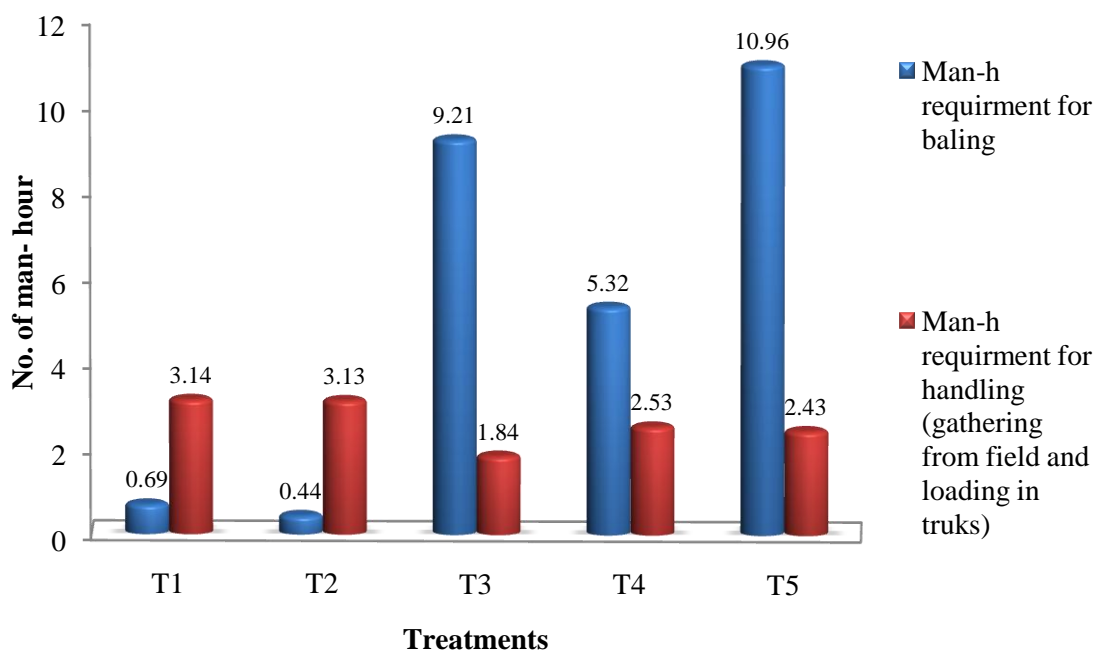
Table 4.8 Average Fuel / Electricity consumption of machineries

Treatments	Machinery operation	Fuel / Electricity consumption
T1	Stubble shaver + tractor operated baler , (Diesel, l h ⁻¹)	6.46
T2	Stubble shaver + hay rake + tractor operated baler, (Diesel, l h ⁻¹)	10.12
T3	Field baler in stationary mode, (Diesel, l h ⁻¹)	3.48
T4	Stationary baler for full straw densification, (Electricity, unit h ⁻¹)	1.65
T5	Chaff cutter, (Diesel, l h ⁻¹) + Stationary baler for chopped straw densification, (Electricity, unit h ⁻¹)	4.01 1.79

4.4.2 Man-hour requirement

The total man-h requirement per tonne (in accordance to Table 3.7) for baling operation and handling (gathering straw from field and loading bales into truck) operation for treatment T1, T2, T3, T4 and T5 were 3.83, 3.57, 11.05, 7.85 and 13.39, respectively (Appendix E-2). The minimum man-h for **baling** a tonne of straw was obtained for T2 (0.44) followed by T1 (0.69), T4 (5.32), T3 (9.21) and T5 (10.96). The minimum man-h for **gathering and loading** one tonne of straw was obtained for T3 (1.84) followed by T5 (2.43), T4 (2.53), T2 (3.13) and

T1 (3.14). Fig 4.7 shows the man-hour requirement per tonne for baling and handling (gathering + loading). The details of total man-hour are presented in Appendix E-2.



T1 = Stubble shaver + tractor operated baler, T2 = Stubble shaver + hay rake + tractor operated baler, T3 = Field baler in stationary mode, T4 = Stationary baler for full straw densification, T5 = Stationary baler for chopped straw densification

Fig 4.7 Man-hour requirement under different treatment

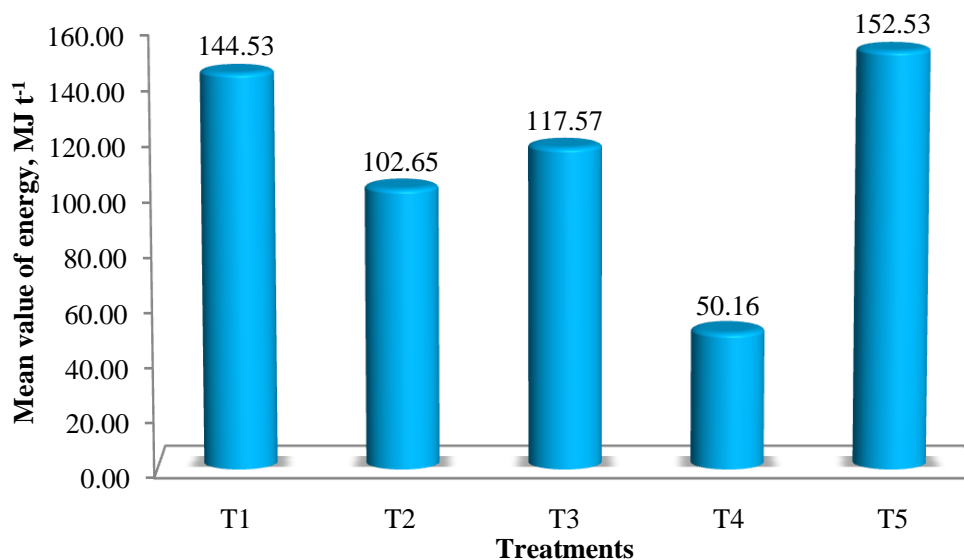
4.4.3 Energy

Energy required for the treatments is plotted in Fig 4.8 and the details are given in Appendix E-3. Energy requirement for different treatments ranged from 50.16 to 152.53 MJ t⁻¹. Minimum energy was required for T4 (50.16 MJ t⁻¹) followed by T2 (102.65 MJ t⁻¹), T3 (117.57 MJ t⁻¹), T4 (144.53 MJ t⁻¹) and T5 (152.53 MJ t⁻¹). The statistical analysis of data on energy requirement was highly significant for all the treatments except for treatment T2 & T3 which were non-significant. The coefficient of variance was 3.01 %. The details of analysis of variance are given in Appendix D-7. The details of treatment mean are given in Table 4.9.

4.4.4 Energy Distribution

Per cent energy consumed by various sources like human, diesel, electricity, tractor and machineries was calculated for each treatment. For T1 the per cent energy consumption by human, diesel, electricity, tractor and machineries was 1, 83, 0, 7 and 9, respectively (Fig 4.9). For T2 the per cent energy consumption by human, diesel, electricity, tractor and machineries was 1, 88, 0, 6 and 5, respectively (Fig 4.10). For T3 per cent energy consumption by human, diesel, electricity, tractor and machineries was 15, 72, 0, 5 and 8, respectively (Fig 4.11). For T4 per cent energy consumption by human, diesel, electricity, tractor and machineries was 21, 0, 35, 0 and 44, respectively (Fig 4.12). For T5 per cent

energy consumption by human, diesel, electricity, tractor and machineries was 14, 49, 24, 3 and 10, respectively (Fig 4.13).



T1 = Stubble shaver + tractor operated baler, T2 = Stubble shaver + hay rake + tractor operated baler, T3 = Field baler in stationary mode, T4 = Stationary baler for full straw densification, T5 = Stationary baler for chopped straw densification

Fig 4.8 Total energy required under different treatments

Table 4.9 Treatment mean of energy requirement

Treatment name	Energy requirement
T1	144.53 ^B
T2	102.65 ^D
T3	117.57 ^C
T4	50.16 ^E
T5	152.53 ^A
General mean	110.72
p-value	<.0001
CV (%)	3.01
C.D.	5.31

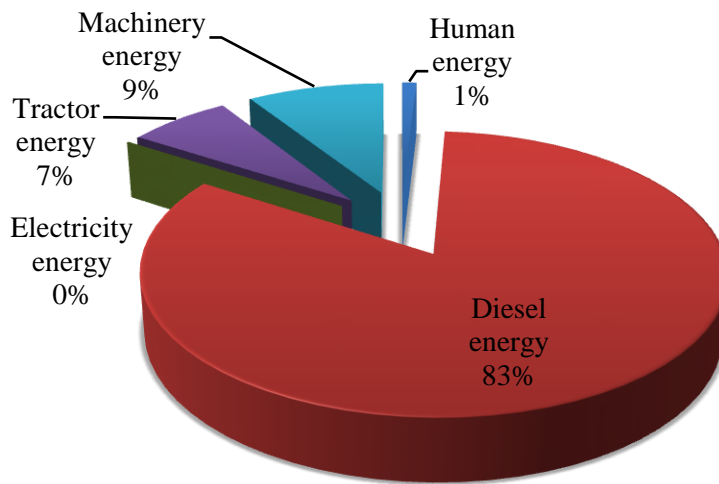


Fig 4.9 Energy distribution in T1 (Stubble shaver + tractor operated baler)

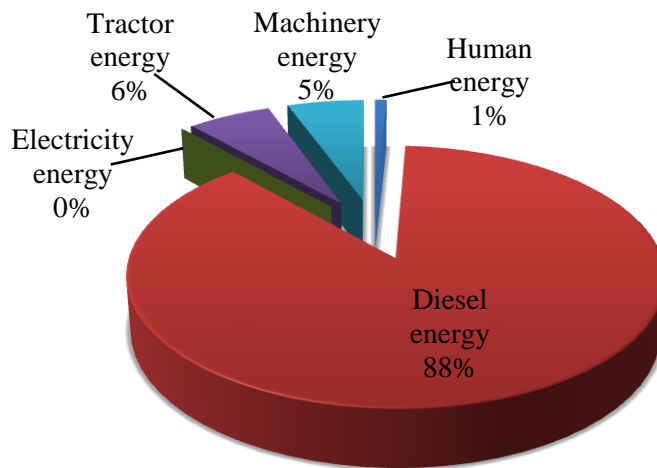


Fig 4.10 Energy distribution in T2 (Stubble shaver + hay rake + tractor operated baler)

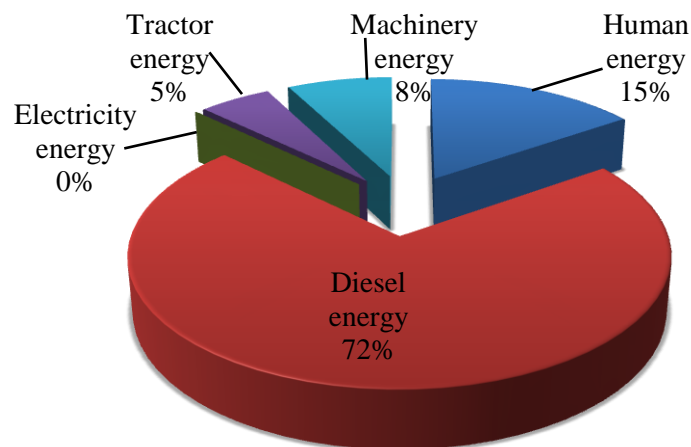
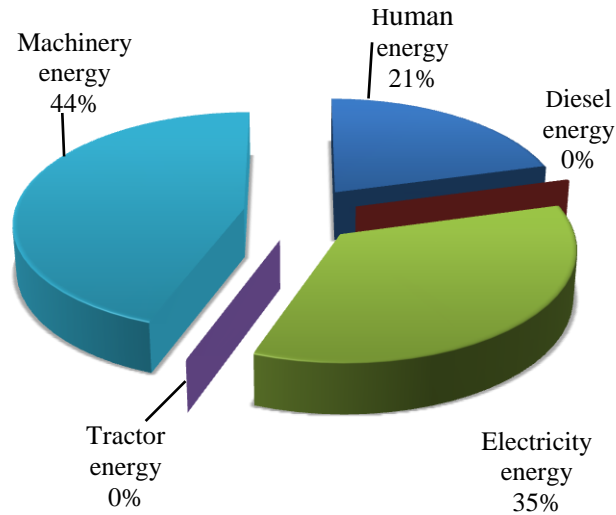
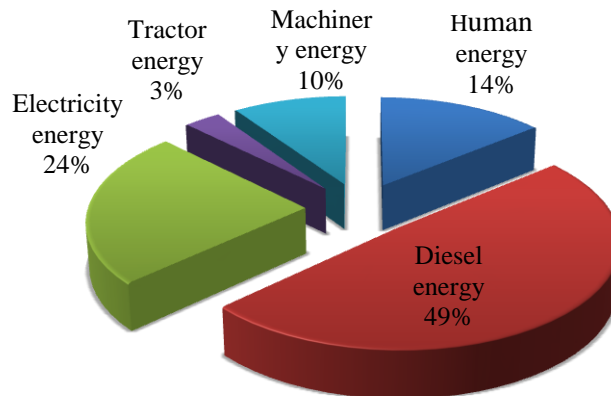


Fig 4.11 Energy distribution in T3 (Field baler in stationary mode)



**Fig 4.12 Energy distribution in T4
(Stationary baler for full straw densification)**



**Fig 4.13 Energy distribution in T5
(Stationary baler for chopped straw densification)**

4.5 Economics

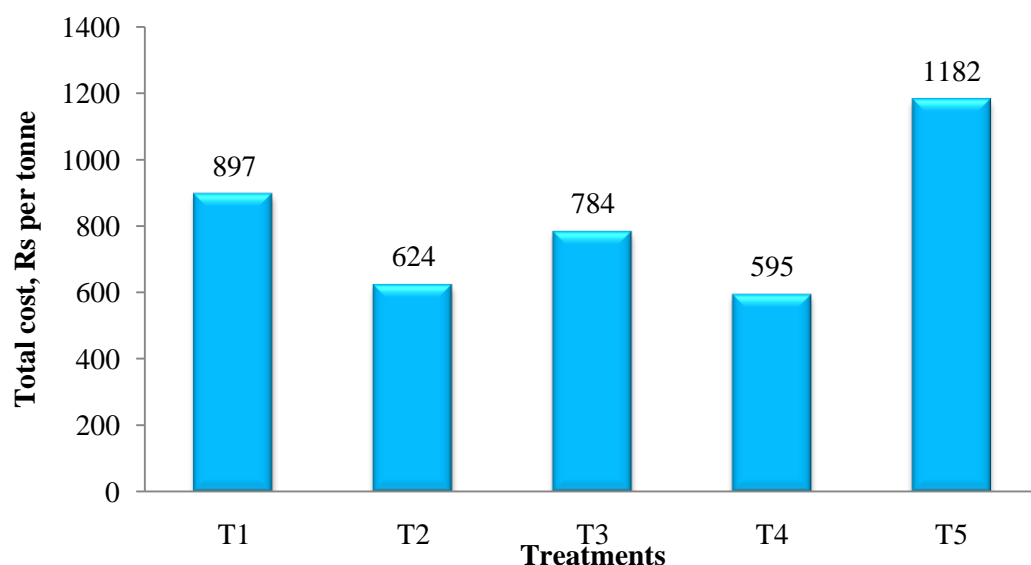
4.5.1 Total Cost

The cost for making bales includes cost for baling, gathering and loading operation for different treatments and is plotted in Fig 4.14 and the details are given in Appendix F-1 & F-2. The cost of baling for different treatments ranged from Rs 595 per tonne to Rs 1182 per tonne. The minimum cost per tonne of straw obtained was for T4 (Rs 595) followed by T2 (Rs 624), T3 (Rs 784), T1 (Rs 897) and T5 (Rs 1182).

4.5.2 Breakeven point

Breakeven point of different machineries stubble shaver, hay rake, field baler used in first treatment was 31.68 h yr⁻¹, 43.23 h yr⁻¹ and 171.39 h yr⁻¹, respectively. For field baler used in second treatment the breakeven point was 164.10 h yr⁻¹. Field baler in stationary mode

(T3) the breakeven point was 142.56 h yr⁻¹. Stationary baler for full length straw (T4), tractor operated chaff cutter and stationary baler for chopped straw used for treatment T5 was calculated 243.59 h yr⁻¹, 101.36 h yr⁻¹ and 200.29 h yr⁻¹, respectively. The breakeven point of different machineries is summarized in Table 4.10 and the details are given in Appendix F-1.



T1 = Stubble shaver + tractor operated baler, T2 = Stubble shaver + hay rake + tractor operated baler, T3 = Field baler in stationary mode, T4 = Stationary baler for full straw densification, T5 = Stationary baler for chopped straw densification

Fig 4.14 Cost of baling per tonne of straw

Table 4.10 Breakeven points of machineries

Machineries	Breakeven point, h yr ⁻¹
Stubble shaver	29.11
Hay rake	40.74
Field baler (T1)	166.83
Field baler (T2)	158.00
Field baler in stationary mode (T3)	142.56
Stationary baler (T4), 10 hp	243.59
Tractor operated chaff cutter	97.48
Stationary baler for chopped (T5), 10 hp	200.29

4.5.3 Payback period, years

Payback period of different machineries stubble shaver, hay rake, field baler used in the study was 0.52 yr, 0.74 yr and 4.57 yr, respectively. For field baler used in second treatment the payback period was 4.24 yr. Field baler in stationary mode (T3) the payback period was 3.38 yr. Stationary baler for full length straw (T4), tractor operated chaff cutter and stationary baler for chopped straw used for treatment T5 was calculated 1.96 yr, 1.04 yr and 1.53 yr, respectively. The Payback period of different machineries is summarized in Table 4.11 and the details are given in Appendix F-1.

Table 4.11 Payback period of machineries

Machineries	Payback period, year
Stubble shaver	0.48
Hay rake	0.69
Field baler (T1)	4.36
Field baler (T2)	3.98
Field baler in stationary mode (T3)	3.38
Stationary baler, 10 hp	1.96
Tractor operated chaff cutter	0.99
Stationary baler for chopped, 10 hp	1.53

4.5.4 Benefit

The benefit was calculated for different treatments by subtracting the baling, gathering, loading and transportation cost from total selling price of bale. Transportation cost was Rs 18000 for 200 km. Selling price of bale was Rs 4400 t⁻¹ for T1, T2, T3 and T4 and Rs 5000 t⁻¹ for T5. Highest benefits are obtained in T4 (2005) followed by T5 (1568), T2 (1006), T3 (889) and T1 (503), respectively. Total weight of bales loaded in truck for treatment is different just because of bale density difference. Table 4.12 shows the detail related to benefit calculation.

Table 4.12 Benefits obtained under different treatments

Sr. No.	Parameter	T1	T2	T3	T4	T5
1	Baling + gathering + loading cost, Rs t ⁻¹	897	624	784	595	1182
2	Total weight of bales loaded in truck, tonne*	6.0	6.5	6.6	10.0	8.0
3	Transportation cost, 200 km	18000	18000	18000	18000	18000
4	Total cost, Rs	23384	22034	23170	23950	27458
5	Selling price, Rs t ⁻¹	4400	4400	4400	4400	5000
6	Total selling cost, Rs	26400	28600	29040	44000	40000
7	Total benefit, Rs t ⁻¹	503	1006	889	2005	1568

T1 = Stubble shaver + tractor operated baler, T2 = Stubble shaver + hay rake + tractor operated baler, T3 = Field baler in stationary mode, T4 = Stationary baler for full straw densification, T5 = Stationary baler for chopped straw densification.

*The truck of same volume carries the above mentioned load (depends on size of bale) at one time

The experimental findings of the study entitled “Energetics and techno economic assessment of different paddy straw densification processes” embodied in preceding chapter are being discussed in the present chapter with the help of observations recorded in the present study and findings of other researchers.

5.1 Performance parameters

5.1.1 Field capacity of balers

The maximum field capacity of baler was obtained for treatment T2 (0.54 ha h⁻¹) followed by T1 (0.36 ha h⁻¹), T3 (0.24 ha h⁻¹), T4 (0.10 ha h⁻¹) and T5 (0.05 ha h⁻¹) (Fig 4.1). The field baler for T2 had higher field capacity than T1 because hay rake was operated prior to the field baler which reduced the 3.2 meter width of straw to 1.8 meter or we can say it reduced the length of travel of baler. The treatment T3, under which field baler was used in stationary mode had lower field capacity than T1 and T2 because of manual feeding of straw into the baler. Manual feeding is tiresome and efficiency of manual feeding reduces after some time because of hot weather. The field capacity of stationary baler for both full straw and chopped straw is lower than the field balers as it takes time to fill the compression chamber manually with straw. After compression of straw, tying of bale manually also consumes time. The field capacity of field balers under treatment T1 and T2 are confirming with earlier studies by Sharma and Chandel (2016) and Sharma *et al.*, (2014). The result of treatment T1 for field capacity are also similar to that obtained by Sandhya *et al.*, (2007) and Singh *et al.*, (2005).

5.1.2 Baling capacity

The baling capacity indicates how much of paddy straw (tonne) could be densified into a bales in an hour. The maximum baling capacity was obtained for treatment T2 (4.43 t h⁻¹) because hay rake was operated prior to baling which increased the amount of straw fed into baler, as straw from a width of 3.2 meter was windrowed in 1.8 meter. Treatment T3 (2.32 t h⁻¹) has second highest value for baling capacity because straw was continuously fed in bulk into the baler manually. The treatment, T1 (1.69 t h⁻¹) has lower baling capacity than T3 (2.32 t h⁻¹) because straw was scattered in the field and amount of straw fed was lesser. The treatment T4 (1.13 t h⁻¹) and T5 (0.58 t h⁻¹) had lower baling capacity because of manual feeding, manual tying and then bale was taken out manually from the compression chamber. The results of treatment T2 are similar as observed by Sharma and Chandel (2016). Fig 4.2 shows the baling capacity obtained under different treatments.

5.1.3 Number of bales formed

The number of bale formed by a baler is dependent on dimension of bale in terms of length, width and height, density of bale formed, feeding rate, type of baler etc. Number of bale formed by the field baler under treatments T1 (119), T2 (314) and T3 (158) was higher in comparison to T4 (7) and T5 (12) because of mechanical feeding, mechanical tying method and small size of bale. Fig 4.3 shows the number of bales formed by different treatment.

5.1.4 Bale density

The results of bale density in Fig 4.4 indicate that the stationary baler compressed the full straw length to a maximum, T5 (177.66 kg m^{-3}) which was followed by stationary baler used for compressing chopped straw T4 (213.97 kg m^{-3}). It may be due to reason that in both of the stationary baler the pressure applied was very high 1500 kPa for compression of full length straw and 1000kPa for compressing chopped straw. The bale density for treatment T1 (129.77 kg m^{-3}), T2 (135.04 kg m^{-3}) and T3 (137.51 kg m^{-3}) were non-significant amongst themselves and lower than stationary baler. Similar trends reported by Garas *et al.*, (2009) and Sahay and Pathak (2012) for field baler and stationary baler.

5.1.5 Volume compaction ratio

The volume compaction ratio for the treatments ranged from 4.18 to 6.87, Fig 4.4. The maximum volume compaction ratio was obtained for T4 (6.87) followed by T2 (5.26), T3 (5.20), T1 (4.95) and T5 (4.18). Volume compaction ratio depends on the pressure applied and length of straw. The highest compression ratio was obtained for T4 (6.87), as the pressure applied was 1500 kPa and length of straw was more than others. The statistical analysis (Table 4.5) of data shows that the volume compaction ratio of T1, T2 and T3 were non-significant with each other. Treatment T5 has lower volume compaction ratio than T₄ because chopped straw has higher density than full length straw (Appendix C-6). The results obtained for T1 and T2 differed from results reported by Sandhya *et al.*, (2007) and Maski (2017)

5.1.6 Time requirement

The minimum time requirement was obtained for treatment T2 (0.44 h) followed by T1 (0.69 h), T4 (0.89 h), T5 (2.06 h) and T3 (2.09 h) as shown in Fig 4.6. The time requirement was maximum for treatment T3 because it took time to collect straw from the field and feeding manually into field baler. Treatment T5 has second highest value because the full length straw was initially chopped and then fed manually into the stationary baler, the tying also took time as it was done manually. The treatment T4 took less time than T5 as full length straw was fed into stationary baler. Treatment T2 required lowest time for making bale of one tonne of straw because in this treatment hay rake was operated before baling which windrowed the straw from 3.2 m to 1.8 m and travelling time of baler was reduced. Treatment T1 required more time than treatment T2 because the straw was not windrowed due to which travelling time of baler increased.

5.2 Energy

5.2.1 Fuel consumption and electricity consumption

The increase in fuel and electricity consumption increases the cost of operation. The treatment T2 included operation of hay rake prior to operation of field baler and thus has higher fuel consumption than T1. Moreover, after operation of hay rake the straw load increased which increased load on tractor and thus increased fuel consumption. The treatment T3 has lower fuel consumption than T1 as stubble shaver was not used in this field and baler was stationary. Treatment T5 recorded higher electricity consumption than T4 due to reason that higher pressure was needed to densify full length straw than chopped straw.

5.2.2 Man-hour requirement

The man-hour required per tonne of straw depend on handling of straw, usage of machinery, tying operation of bale, picking of bales from field/ pushing of bale out of compression chamber in stationary baler etc. The total man-hour required (Appendix E-2) for baling was almost equal for T1 (3.83) and T2 (3.57). In T2 an additional operation of hay rake was conducted but it reduced time and increased efficiency of baler. In treatment T3 (11.05), maximum man-hour was required for collecting straw from field. In treatment T4 (7.85) and T5 (13.39) all the operation was done manually hence man-hour requirement increased. The values of man-hour requirement for different treatment are shown in Fig 4.7.

5.2.3 Energy requirement

Energy required depends on fuel and electricity consumption, man-hour requirement, type of machine required to perform the different treatment. The energy required for producing bale was minimum for T4 (50.16 MJ t⁻¹) because it required very less electricity. Treatment T4 was followed by treatment T2 (102.65 MJ t⁻¹) as it required lowest man-hour and also less fuel energy than the treatment T1. The treatment T3 (117.57 MJ t⁻¹) required higher energy than T2 (102.65 MJ t⁻¹) because more energy was required for straw collection from field. The maximum energy was required by treatment T5 (152.53 MJ t⁻¹) for making bale of one tonne of straw because it required more human-hour and there was higher electricity consumption. The results reported by Maski (2017) for baling with and without hay rake had same trend as for treatment T1 and T2. Total energy requirement of different treatments are shown in Fig 4.8.

5.2.4 Economics

5.2.5 Cost for making bales

Cost for making bales was calculated in terms of per tonne of straw baled. The minimum cost was calculated for T4 (Rs 595) followed by T2 (Rs 624), T3 (Rs 784), T1 (Rs 897) and T5 (Rs 1182). T4 required very less electricity and no diesel for baling and also less man-h required for making bale which reduced its total cost. Treatment T2 could handle one tonne of straw in very less time which reduced its total cost. For the treatment T3, though the

baling capacity is higher than T1 but man-hour requirement for collection of straw and feeding straw into baler manually increased its total cost. For the treatment T1, the diesel requirement was higher than T3 which increases its total cost in comparison to T3. Treatment T5 requires more man-hour for chopping the straw and the stationary baler has very low baling capacity which increases its cost of baling in comparison to other treatments. Fig 4.14 shows the cost of baling. Bansal and Kumar (2014) and Sharma and Chandel (2016) reported same trend for T1 and T2. Singh *et al.*, (2005) reported that the high transportation cost is the reason due to which baler is not gaining popularity.

5.3 Benefit

Highest benefit obtained from T4 (Rs 2005 t⁻¹), because it required lower cost of operation and the bale formed by treatment T4 had high density and we can transport more weight in one go. Second highest benefit obtained from T5 (Rs 1568 t⁻¹) reason was bale formed by T4 had high density and we could transport more weight in one go same as T4 and also its selling price is high but it has higher baling cost and lower bale density than T4. In T1, T2 and T3 the bale density, selling price and transportation cost were similar but cost of operation was different which makes different between them. In T2 cost of operation is low that's why its profit is higher than the T1 and T3. Same as T2 (Rs 1006 t⁻¹) we can say that benefit is higher for T3 (Rs 889 t⁻¹) than T1 (Rs 503 t⁻¹) because operating cost of T3 is lower than the T1. Table 4.12 shows the detail about the benefits calculation.

Paddy straw management is the biggest challenge for the farmers. Generally farmers use some of the straw as feed for the animals but high per cent of straw is unused and difficult to clear from the field. The straw also poses a problem for storage and transportation. In such condition farmers have no option but to burn straw in the field for sowing succeeding crop. The burning of straw creates major problem for the human/animal health, soil nutrients and environment. There is a need for finding ways and means for efficient utilization of the surplus paddy residue produced for maintaining soil, human and animal health and increasing farmer's income. The farmers can adopt mechanized method for straw removal or straw incorporation into field. The experimental study "Energetics and techno economic feasibility of paddy straw densification machines" was conducted during kharif, 2017 is based on mechanized method of straw removal and making bales of this straw by using different types of straw densification process. The baled straw can be utilised for animal feed, paper industry, power generation plants, brick kiln etc. Moreover, the bales are easy to handle, transport and store than loose straw. The study was conductive with objectives given below:

1. Technical feasibility of different densification processes
2. Energetics and economic comparison of different densification processes.

The study was conducted in combine and manual harvested paddy field. The straw thrown away by straw walker is termed as loose straw and a portion of straw which is left grounded in field is known as standing stubble, the height of which varied from 36.24 cm to 48.22 cm. The moisture content of straw varied from 19.11% to 22.93%. The loose straw thrown out by straw walker of combine was weighed which varied from 29 q ha⁻¹ to 41 q ha⁻¹. This loose straw was collected manually at one location for the treatment (T3) and used for making bales using field baler (in stationary mode). The feeding was done manually and the bales made were loaded in trucks. In treatments (T1 and T2) stubble shaver was operated in the combine harvested paddy field, which slashed the standing stubble to a height varying from 6 cm to 9.5 cm and reduced the length of standing stubble by 78.23% to 85.52%. The weight of loose straw available in field after operation of stubble shaver varied from 79 q ha⁻¹ to 115 q ha⁻¹. In the treatment (T1) field baler was operated after stubble shaver and bales were collected manually from whole field and then loaded in trucks. In treatment (T2) hay rake was operated after the stubble shaver which windrowed the loose straw in a row of 1.8 m from 3.2 m after which the field baler was operated to make bales. The operation of hay rake

increased efficiency and reduced travelling distance of baler. The bales thus formed were collected manually from entire field and then loaded in trucks.

In treatment T4 full length straw was used for making bales which is generally dumped by farmer outside the field after manual harvesting of paddy. The length of straw varied from 87 cm to 106 cm. The time and man-hr required for collection of full length straw are not included in the study because it was already dumped out of field by farmer. The bales then formed by stationary baler (Hydraulic pressed type) at single location were loaded in trucks. For treatment T5 the full length straw was chopped using chaff cutter and then bale were made out of chopped straw using stationary baler (Hydraulic press type) at one location which were then loaded in trucks. Cost of straw is not included in study as it is free of cost to farmer.

The conclusions of study are mentioned below:

- The maximum field capacity of 0.54 ha h^{-1} was obtained for T₂ (straw is baled by tractor operated field baler after single pass of stubble shaver and single operation hay rake) with maximum baling capacity of 4.43 t h^{-1} , maximum number of bale 314 due to small size of bale, volume compaction ratio of 5.26 with minimum time and man-h requirement of 0.44 h and cost of baling was Rs 624 per tonne. The benefit was Rs 1006 per tonne. This process is most appropriate for straw removal for large land holding farmers, where the paddy is harvested with combine. The treatment T2 also increases the baling efficiency and reduces travel distance of baler in comparison to T1 (Straw is baled by tractor operated field baler after single operation of stubble shaver).
- The treatment T4 (stationary baler for densification of full length straw) has maximum benefit of Rs 2005 per tonne due to maximum bale density of 213.97 kg m^{-3} and volume compaction ratio of 6.87 with minimum cost of operation of Rs 595 per tonne and minimum energy requirement of 50.16 MJ t^{-1} . It will be beneficial for farmers of less land holding wherein the paddy is harvested manually. Due to its low baling capacity of 1.13 t h^{-1} , the farmers with large land holding will not be much benefited.
- Though the benefit in treatment T5 (Stationary baler for densification of chopped straw. Chopping of straw was done with chaff cutter) is Rs 1568 per tonne, the bailing capacity is minimum, 0.58 t h^{-1} , volume compaction ratio is also least, 4.18, man-h requirement and energy for baling are maximum with value of 13.39 and 152.53 MJ t^{-1} . The farmers can adopt this process as demand for chopped straw is higher than the full length straw where it is used as animal feed.
- The treatment T3 (Field baler was used in stationary mode, straw was manually collected from the field and fed manually into field baler) can work out for water logged areas where it is difficult to operate the baler. The loose straw can be taken out

manually from field and baled with field baler. The time requirement for a tonne in this treatment is very high with a value of 2.09 h.

Recommendations

1. The field baler may be recommended to be used after operation of stubble shaver and hay rake in paady harvested fields with combine.
2. The farmers with small land holdings wherein the paddy is harvested manually, the hydraulically pressed stationary balers can be adopted.

Suggestions

- i. This study can be extended to other crop residues like wheat, barley, cotton etc.
- ii. Studies on small pellet making machines out of crop residue can be done at farmer's field for its adoptability.
- iii. The baler can be modified by making the outlet of bale at rear of machine because in the baler in study drops the bale in area where the straw is to be picked.

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Moisture content of soil

Sr. No.	Weight of soil before drying, g	Weight of soil after drying, g	Moisture content (wb) %
1	117	96	17.95
2	333	275	17.42
3	216	180	16.67
4	175	145	17.14
5	165	137	16.97
Average moisture content of soil			17.23

Height and weight of standing stubble

Standing stubble sample	Height of standing stubbles after harvesting by combine	Height of standing stubbles after operation of stubble shaver in combine harvested paddy field	Per cent reduction in height of stubble due to operation of stubble shaver	Weight of standing stubble
Sr. No.	cm	cm	%	q ha ⁻¹
1	42.0	7.0	83.33	76.0
2	46.0	8.0	82.61	68.0
3	41.0	7.0	82.93	74.0
4	38.0	6.0	84.21	78.0
5	42.0	7.5	82.14	76.0
6	36.2	6.2	82.89	69.0
7	45.2	7.8	82.75	77.0
8	41.3	6.4	84.50	75.0
9	42.9	6.9	83.93	79.0
10	38.5	7.1	81.56	68.0
11	39.2	7.0	82.15	66.0
12	37.2	8.1	78.23	80.0
13	48.2	9.5	80.30	75.0
14	46.6	9.1	80.45	73.0
15	44.2	6.4	85.52	76.0
16	43.6	6.9	84.18	73.0
17	39.7	6.5	83.63	77.0
18	37.5	6.1	83.73	73.0
19	42.1	7.1	83.14	69.0
20	44.2	7.2	83.73	78.0
Mean	41.8	7.2	82.80	74.0
Maximum	48.22	9.50	85.52	80.00
Minimum	36.24	6.00	78.23	66.00
Standard deviation	3.38	0.93	1.68	4.07
Coefficient of variance	0.08	0.13	0.02	0.05

Length and weight of loose straw

Loose straw sample of paddy	Length of loose straw after harvesting by combine	Length of loose straw after operation of stubble shaver *	Weight of loose straw before operation of stubble shaver	Weight of loose straw after operation of stubble shaver *	Length of straw used for stationary baler **
Sr. No.	cm	cm	q ha ⁻¹	q ha ⁻¹	cm
1	55.0	24.0	32.1	103.0	106.0
2	32.0	35.0	34.4	91.0	101.0
3	48.0	51.0	33.1	94.0	95.0
4	17.0	32.0	36.7	102.0	105.0
5	41.0	45.0	34.8	97.0	102.0
6	29.0	21.0	38.0	100.0	87.0
7	56.0	10.0	31.0	97.0	103.0
8	47.0	27.0	36.0	91.0	101.0
9	39.0	42.0	41.0	95.0	95.0
10	39.0	34.0	29.0	115.0	96.0
11	37.0	28.0	34.0	96.0	97.0
12	35.0	19.0	36.0	82.0	99.0
13	41.0	29.0	31.0	79.0	101.0
14	32.0	42.0	31.0	94.0	99.0
15	22.0	39.0	38.0	112.0	104.0
16	32.0	14.0	34.0	100.0	100.0
17	15.0	44.0	29.0	99.0	87.0
18	41.0	41.0	37.0	111.0	94.0
19	49.0	31.0	35.0	96.0	103.0
20	36.0	34.0	36.0	94.0	104.0
Mean	37.2	32.1	34.22	97.40	99.00
Maximum	56.00	51.00	41.00	115.00	106.00
Minimum	15.00	10.00	29.00	79.00	87.00
Standard deviation	11.14	10.84	3.16	8.82	5.37
Coefficient of variance	0.30	0.34	0.09	0.09	0.05

*The stubble shaver was operated to slash the standing stubble in combine harvested field so as to reduce size of standing stubble and loose straw

**The paddy field was harvested manually

Appendix B-3

Moisture content of straw

Sr. No	Weight of straw before drying, g	Weight of straw after drying, g	Moisture content of straw, %
1	4.80	3.80	20.83
2	5.60	4.53	19.11
3	4.50	3.55	21.11
4	6.80	5.36	21.18
5	7.50	5.78	22.93
Average moisture content			21.03

Appendix C-1

Forward speed of machinery used in study

Machine	Forward speed, km h ⁻¹				Mean forward speed km h ⁻¹
	R-1	R-2	R-3	R-4	
Stubble shaver	6.69	6.77	6.92	6.96	6.84
Hay rake	7.21	6.85	6.42	6.62	6.78
Field baler (T1)	2.68	2.68	2.89	2.67	2.73
Field baler (T2)	2.62	2.58	2.72	2.56	2.62

Appendix C-2

Effective/Actual field capacity of balers under different treatments

Treatments	R1	R2	R3	R4	Mean effective field capacity, ha h ⁻¹
T1	0.38	0.37	0.36	0.34	0.36
T2	0.53	0.52	0.56	0.54	0.54
T3	0.24	0.25	0.22	0.25	0.24
T4	0.10	0.10	0.10	0.11	0.10
T5	0.05	0.06	0.05	0.05	0.05

Appendix C-3

Baling capacity of balers under different treatments

Treatment	Baling capacity, t h ⁻¹				Mean baling capacity t h ⁻¹
	R1	R2	R3	R4	
T1	1.65	1.71	1.73	1.68	1.69
T2	4.36	4.41	4.53	4.41	4.43
T3	2.29	2.38	2.19	2.44	2.32
T4	1.10	1.13	1.07	1.22	1.13
T5	0.57	0.61	0.59	0.55	0.58

Appendix C-4

Number of bales formed of balers under different treatments

Treatment	Bales formed h ⁻¹				Mean bales formed h ⁻¹
	R1	R2	R3	R4	
T1	113.95	116.90	126.36	118.98	119.05
T2	300.00	310.00	333.00	314.00	314.25
T3	156.00	161.11	153.85	160.00	157.74
T4	6.67	7.00	6.50	7.14	6.83
T5	11.33	13.00	12.00	12.86	12.30

Appendix C-5

Bale density of bales under different treatments

Treatment	Bale density, kg m ⁻³				Mean bale density kg m ⁻³
	R1	R2	R3	R4	
T1	138.01	136.81	115.55	128.70	129.77
T2	138.30	136.50	131.48	133.88	135.04
T3	134.07	137.36	136.54	142.07	137.51
T4	202.60	210.82	214.63	227.83	213.97
T5	169.16	174.37	196.75	170.43	177.66

Volume compaction ratio of different balers under different treatments

Treatment	Bale density, kg m ⁻³				Density of loose straw, kg m ⁻³				Volume compaction ratio				Mean volume compaction ratio
	R1	R2	R3	R4	R1	R2	R3	R4	R1	R2	R3	R4	
T1	138.01	136.81	115.55	128.70	26	27	27	25	5.31	5.07	4.28	5.15	4.95
T2	138.30	136.50	131.48	133.88	26	24	27	26	5.32	5.69	4.87	5.15	5.26
T3	134.07	137.36	136.54	142.07	27	28	25	26	4.97	4.91	5.46	5.46	5.20
T4	202.60	210.82	214.63	227.83	32	28	31	34	6.33	7.53	6.92	6.70	6.87
T5	169.16	174.31	196.75	170.43	42	41	45	42	4.03	4.25	4.37	4.06	4.18

Appendix C-7

Time requirement for formation of bales under different treatments

Treatments	Time required, h t ¹				Mean time required, h t ⁻¹
	R1	R2	R3	R4	
T1	0.70	0.70	0.68	0.69	0.69
T2	0.43	0.45	0.43	0.44	0.44
T3	2.06	2.10	2.05	2.16	2.09
T4	0.91	0.89	0.93	0.82	0.89
T5	2.08	1.98	2.05	2.14	2.06

Appendix D-1

Analysis of variance of actual field capacity

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Significant
Block	3	0.0000	0.0000	0.0130	0.9979	NS
Treatment	4	0.6163	0.1541	989.4286	<.0001	**
Error	12	0.0019	0.0002	.	.	-
Corrected Total	19	0.6182	.	.	.	-
**Significant at 1%, NS - Non significant						

Appendix D-2

Analysis of variance of bailing capacity

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Significant
Block	3	0.0128	0.0043	0.9043	0.4677	NS
Treatment	4	35.4224	8.8556	1874.834	<.0001	**
Error	12	0.0567	0.0047	.	.	-
Corrected Total	19	35.4919	.	.	.	-
**Significant at 1%, NS - Non significant						

Appendix D-3

Analysis of variance of number of bales formed per hour

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Significant
Block	3	194.01	64.67	1.5535	0.2517	NS
Treatment	4	254181.63	63545.4073	1526.407	<.0001	**
Error	12	499.5684	41.6307	.	.	-
Corrected Total	19	254875.2132	.	.	.	-
**Significant at 1%, NS - Non significant						

Appendix D-4

Analysis of variance of bale density

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Significant
Block	3	44.8850	14.9617	0.1537	0.9253	NS
Treatment	4	21039.9854	5259.9963	54.0471	<.0001	**
Error	12	1167.8700	97.3225	.	.	-
Corrected Total	19	22252.7404	.	.	.	-
**Significant at 1%, NS - Non significant						

Appendix D-5

Analysis of variance of volume compaction ratio

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Significant
Block	3	0.3063	0.1021	0.6838	0.5789	NS
Treatment	4	15.4511	3.8628	25.8731	<.0001	**
Error	12	1.7916	0.1493	.	.	-
Corrected Total	19	17.5490	.	.	.	-
**Significant at 1%, NS - Non significant						

Appendix D-6

Analysis of variance of time required per tonne of bale formed

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Significant
Block	3	0.0020	0.0007	0.2909	0.8312	NS
Treatment	4	9.8434	2.4609	1094.674	<.0001	**
Error	12	0.0270	0.0022	.	.	-
Corrected Total	19	9.8723	.	.	.	-
**Significant at 1%, NS - Non significant						

Appendix D-7

Analysis of variance of energy requirement

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Significant
Block	3	128.1043	42.7014	3.6610	0.0441	NS
Treatment	4	26529.1266	6632.2817	568.6139	<.0001	**
Error	12	139.9673	11.6639	.	.	-
Corrected Total	19	26797.1983	.	.	.	-
**Significant at 1%, NS - Non Significant						

Appendix E-1

Fuel / electricity consumption

Treatment	Fuel, l h ⁻¹ / Electricity unit h ⁻¹ consumption				Mean fuel (l h ⁻¹) / Electricity (unit h ⁻¹) consumption
	R-1	R-2	R-3	R-4	
T1 (Diesel)	6.61	6.25	6.80	6.17	6.46
T2 (Diesel)	9.87	9.64	10.96	10.00	10.12
T3 (Diesel)	3.44	3.41	3.46	3.60	3.48
T4 (Electricity)	1.67	1.60	1.70	1.64	1.65
T5 (Diesel)	4.14	3.68	4.14	4.08	4.01
T5 (Electricity)	1.87	1.80	1.70	1.79	1.79

Man-hour requirement for baling a tone of straw

Treatment	Man-h requirement for baling a tone of straw		Total Man-h requirement
	For baling	For handling (gathering and loading)	
T1	0.69	3.14 (picking and loading of bale from entire field)	3.93
T2	0.44	3.13 (picking and loading of bale from entire field)	3.57
T3	9.21 (includes loose straw collection from the field and baling)	1.84 (loading bale from one location)	11.05
T4	5.32	2.53 (loading bale from one location)	7.85
T5	10.96 (includes straw chopping and baling)	2.43 (loading bale from one location)	13.39

Mean energy requirement by different treatments

Sr. No.	Items	T1		T2		T3		T4		T5	
		Quantity	Total	Quantity	Total	Quantity	Total	Quantity	Total	Quantity	Total
1	Human, h t ⁻¹	0.69	1.36	0.44	0.86	9.21	18.06	5.32	10.43	10.96	21.48
2	Diesel, l h ⁻¹	2.13	120.22	1.60	89.91	1.50	84.40	-	-	1.33	74.89
3	Electricity, unit h ⁻¹	-	-	-	-	-	-	1.44	17.21	3.09	36.87
4	Tractor, h t ⁻¹	0.14	9.87	0.09	6.20	0.09	6.13	-	-	0.07	4.72
5	Machinery, h t ⁻¹	0.21	13.09	0.09	5.68	0.14	8.98	0.35	22.24	0.23	14.57
Total energy, MJ t⁻¹		-	144.53	-	102.65	-	117.57	-	50.16	-	152.53

Economics calculation

S.No.	Items	Tractor	Stubble shaver	Field Baler (T1)	Hay Rake	Field Baler (T2)	Field Baler in stationary mode	Stationary baler, 10 hp	Chaff cutter	Stationary baler for chopped, 10 hp
1	Assumption									
	a) Initial cost (C), Rs.	700000	75000	1150000	95000	1150000	1150000	400000	350000	250000
	b) Salvage value (S), 10% of C	70000	7500	115000	9500	115000	115000	40000	35000	25000
	c) Service Life (L), Years	10	10	10	10	10	10	10	8	10
	d) Annual use (H), hour	1000	400	400	400	400	400	1000	625	1000
	e) Interest rate per year (I), %	8	8	8	8	8	8	8	8	8
	f) Number of operator required	-	1	1	1	1	1	1	1	1
	g) Number of labour required	-	-	-	-	-	7	5	6	4
	h) Electricity Rate, Rs kW ⁻¹	-	-	-	-	-	-	7		7
	i) Fuel Rate, Rs l ⁻¹	60	60	60	60	60	60	60	60	60
	j) Labour wages, Rs day ⁻¹	350	350	350	350	350	350	350	350	350
	k) Operator wages, Rs day ⁻¹	450	450	450	450	450	450	450	450	450
2	Fixed Cost									
	a) Depreciation (D), Rs hr ⁻¹	63	16.875	258.75	21.375	258.75	258.75	36	63	22.5
	b) Interest (I), Rs h ⁻¹	30.8	8.25	126.5	10.45	126.5	126.5	17.6	24.64	11
	c) Insurances @1%, Rs h ⁻¹	7	1.875	28.75	2.375	28.75	28.75	4	5.6	2.5
	d) Taxes @1%, Rs h ⁻¹	7	1.875	28.75	2.375	28.75	28.75	4	5.6	2.5
	e) Housing @1%, Rs h ⁻¹	7	1.875	28.75	2.375	28.75	28.75	4	5.6	2.5
	Total fixed cost, Rs h⁻¹	114.8	30.75	471.5	38.95	471.5	471.5	65.6	104.44	41
3	Variable Cost									
	a) Repair 2.5% per year, Rs h ⁻¹	17.5	4.6875	71.875	5.9375	71.875	71.875	10	14	6.25
	b) Operator's wages, Rs h ⁻¹	0	56.25	56.25	56.25	56.25	56.25	56.25	56.25	56.25
	c) labour wages, Rs h ⁻¹	-	-	-	-	-	306.25	218.75	262.5	175
	d) fuel consumed by machine l h ⁻¹	0	3.44	3.02	2.22	4.46	3.48	-	2.58	-

	e) Fuel cost, Rs h ⁻¹	0	206.4	181.2	133.2	267.6	208.8	-	154.8	-
	f) chaff cutter blade cost, Rs h ⁻¹	-	-	-	-	-	-	-	30	-
	g) Lubrication@30% fuel Rs h ⁻¹	-	61.92	54.36	39.96	80.28	62.64	-	46.44	0
	h) Electricity consumed unit h ⁻¹	-	-	-	-	-	-	1.65	-	1.79
	i) Electricity cost, Rs h ⁻¹	-	-	-	-	-	-	11.55	-	12.53
	Total variable cost, Rs h ⁻¹	17.5	339.26	363.69	235.35	476.01	705.82	296.55	563.99	250.03
	Fixed + variable cost	132.3	492.31	967.49	406.6	1079.8	1309.6	362.15	800.73	291.03
	Total cost of operation, Rs h⁻¹	132.3	377.51	852.69	291.8	965.01	1194.8	362.15	685.93	291.03
4										
	Annual fixed cost, Rs yr ⁻¹	114800	12300	188600	15580	188600	188600	65600	65275	41000
	Custom hiring, Rs h ⁻¹	-	729.23	1511.7	635.31	1687.2	2046.3	565.86	1251.1	454.73
	Breakeven point, h yr⁻¹	-	29.11	166.83	40.73	158	142.56	243.59	94.47	200.29
	Pay Back period, years	-	0.48	4.36	0.69	3.98	3.38	1.96	0.99	1.53

Appendix F-2

Total cost

Total cost		T1	T2	T3	T4	T5
1	Total baling cost, Rs t⁻¹					
	Cost of treatment, Rs t ⁻¹	620	342	563	322	824
	Cost of twine Rs t ⁻¹	140	140	140	162	252
	Total cost of baling, Rs t⁻¹	760	482	703	484	1076
2	Total handling (gathering and loading of bale) cost, Rs t⁻¹					
	Number of labour	5	5	4	7	6
	Labour charges/ 8h	350	350	350	350	
	Total Labour charges, Rs h ⁻¹	219	219	175	306	263
	Working time, h t ⁻¹	0.63	0.63	0.45	0.36	0.41
	Total handling cost, Rs t⁻¹	137	142	81	111	106
3	Total cost, Rs t⁻¹	897	624	784	595	1182

ABSTRACT

Title of Thesis : **Energetics and techno economic assessment of different paddy straw densification processes**

Full Name of the Degree Holder : **Hemant Kumar**

Admission Number : 2016AE05M

Title of the Degree : **Master of Technology**

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Year of Award of Degree : 2018

Major Subject : Farm Machinery and Power Engineering

Total Number of Pages in Thesis : 51 + iii + XII

Number of Words in Abstract : 298

Key words : Paddy straw, baler, densification

(An abstract of the thesis submitted to CCS Haryana Agricultural University, Hisar, in partial fulfillment of the requirements for the degree of Master of Technology in Farm Machinery and Power Engineering)

In India, a large portion of the residue is burnt on-farm primarily to clear the field for sowing of the succeeding crop. The burning of straw creates health, soil and environment hazards. From the total crop residue, cereal crops (rice, wheat, maize, and millets) contribute 70% while rice crop alone contribute 34%. Management of this huge amount of paddy straw becomes difficult for farmers. Many solutions are being tried to manage the paddy straw one of them is straw removal from field by making bales which can be easily handled and transported for animal feed, power generation, brick kiln etc. In the present study different densification process viz., using field baler after operation of stubble shaver with and without operation of hay rake. In third case loose straw was directly collected from field and baled by field baler in stationary mode. Further, full length straw and chopped by chaff cutter was used to make bale in hydraulic pressed type fixed stationary. In the study it was found that, if the harvesting of paddy is done by combine, then operating field baler after operation of stubble shaver and hay rake was most appropriate providing a maximum field capacity of 0.54 ha h^{-1} , baling capacity 4.43 t h^{-1} , volume compaction ratio of 5.26 with minimum time required of 0.44 h, man-h 3.57, energy of 102.65 MJ t^{-1} and cost of baling Rs 624 t^{-1} . The scented variety of rice is mostly harvested manually for which the full length densification by a hydraulic press type fixed baler is appropriate with baling capacity 1.13 t h^{-1} , maximum volume compaction ratio 6.87 and lowest cost of operation Rs 595 t^{-1} . The transportation, storage become easy and safe with bales than loose straw. Maximum benefit was obtained with stationary baler for full length straw.

MAJOR ADVISOR

SIGNATURE OF THE STUDENT

HEAD OF DEPARTMENT

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- (a) Name : **Hemant Kumar**
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- (i) **Academic Qualification**



Education	Univ./Board	Year of Passing	Percentage of marks	Subjects
M. Tech.	CCS HAU, Hisar	2018	77.23	Major :Farm Machinery and Power Engineering Minor: Basic Engineering.
B .Tech.	IGKV, Raipur	2016	73.00	Agricultural Engineering
12th	CG Board	2012	88.2	Mathematics, Physics, chemistry, Hindi and English
10th	CG Board	2010	81.0	Mathematics, Science, Hindi, English, S. Science and Sanskrit

(j) **Co-Curricular Activities**

- Oral Presentation on “Drone technology for precision farming” in 51st Annual Convention of ISAE.
- Participated in NSS at collage level.

(k) **Medals / Honors received**

- Bronze Medal in 4x100 meter relay during Inter-Collegiate (North Zone) Sports and Games Competition 2013-14.
- Gold Medal in Football during Inter-Collegiate (North Zone) Sports and Games Competition 2013-14.
- Silver Medal in 4x100 meter relay during Inter-Collegiate Sports and Games Competition 2014-15.

(I) Trainings

ACADEMIC TRAININGS		
Training: I	Institute	Northern Region Farm Machinery Training and Testing Institute, Hisar (Haryana)
	Objective	Study, selection, operation, maintenance, trouble shooting & repair of tractor agriculture implements, I.C. engine, straw & grain combine harvesters etc. Field practice on tractor operation with different matching implements. Study, operation, adjustment and maintenance of various agricultural implements, machines plant protection equipments and irrigation pumps.
	Duration	26 days
Training: II	Institute	North Eastern Region Farm Machinery Training and Testing Institute, Biswanath Chariali (Assam)
	Objective	Field practice on Tractor and Power Tiller attached with different modern/improved agricultural implements/machineries. Study, maintenance, troubleshooting & repair of Multi-Cylinder Engine, Irrigation pumps, plant protection equipments/machineries.
	Duration	26 days
Training: III	Institute	Vardhman Rice Mill, Mungeli (C.G.)
	Objective	To know about the rice-mill processes, repair and maintenance of rice mill machine & equipments
	Duration	10 days
Training: IV	Institute	Bharat Dal Mill (Pulse Mill), Mungeli (C.G.)
	Objective	To know about the Dal mill processes, repair and maintenance of dal mill machines & equipments
	Duration	10 days
Training: V	Institute	M/S Tirth Agro Technology Pvt. Ltd., Rajkot, 360311
	Objective	To know about the agricultural machinery manufacturing process and detail about the machineries and manufacturing techniques
	Duration	30 days
OTHER TRAININGS		
Training: I	Institute	National Adventure Exploration & Disaster Management Institute
	Objective	Training on Rock Climbing, Personality development & Disaster Management Programme
	Duration	10 days
Training: II	Institute	CCS HAU , Hisar
	Objective	Statistical Data Analysis for Research scholar
	Duration	10 days
Training: III	Institute	CCS HAU , Hisar
	Objective	Personality Development
	Duration	14
Training: IV	Institute	CCS HAU , Hisar
	Objective	Training-cum-Awareness Programme on Protection of plant varieties and Farmer's Right Act, 2001
	Duration	One day programme

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