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Machinery for residue management of different crops: A review

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Abstract
Burning of crop residue leads to adverse impacts on soil health, loss of organic carbon causes global warming. The major use of crop residues in India and other countries are as forage, cooking purpose, composting and use as energy source. The burning of crop residue is a major problem in all over world, the best practices for effective management of crop residues are cutting, chopping and incorporation of crop residue. Many researchers were found that incorporation of crop residue into agriculture field would add soil nutrients and increases the crop productivity per unit area of land. In this paper we have discussed regarding machinery used for residue management and their performance for different crops. So based on the overviews of past researchers there is a need of Residue Management Machines for their effective management in a single pass.

Keywords: Burning of Crop residue, incorporation, chopping and cutting

Introduction
Ministry of New and Renewable Energy (MNRE 2009) [27], Government of India estimated that about 500 MT of crop residue is generated every year. There is a large variability in the availability of crop residues and their use depending on the cropping intensity, productivity and crops grown in different states of India

Among different crops, cereals generate 352 MT residue followed by fibres (66 MT), oilseed (29 MT), pulses (13 MT) and sugarcane (12 MT). The cereal crops (rice, wheat, maize, millets) contribute 70% while rice crop alone contributes 34% of crop residues. Wheat ranks second with 22% of crop residues whereas fibre crops contribute 13% of residues produce from all crops. Sugarcane residues comprising tops and leaves generates 12 MT i.e., 2% of crop residues in India.

India produces about 500 MT of crop residues annually, processing of agricultural produce through milling and packaging also contributed substantial amount of crop residues. These residues are natural resource with tremendous value to farmers additionally as a source of income. These residues are used as animal feed, composting, thatching for rural homes and fuel for domestic and industrial use. About 25% of nitrogen, 25% phosphorus, 50% of sulphur and 75% of potassium uptake by cereal crops are retained in residues, making them valuable sources of nutrients. However, a large portion of the residues, about 140 MT burned in field primarily to clear the field from straw and stubble after harvest of the preceding crop, the problem is severe in irrigated agriculture, particularly in the mechanized rice-wheat system due to burning of crop residues in field by unavailability of labour, high cost for removing the residues and use of combines in rice-wheat cropping system especially in the Indo-Gangetic plains (IGP). Crop types whose residues are typically burned include rice, wheat, cotton, maize, millet, sugarcane, jute, rapeseed-mustard and groundnut. Farmers in northwest India dispose a large part of rice straw by burning in situ.

Open burning of rice straw in paddy fields releases pollutants into the atmosphere that contribute to enhance the greenhouse gasses (Kanokkanjana *et al* 2013) [24]. Burning of crop residues produce soot particles and smoke causing human health problems, loss of plant nutrients such as N, P, K and S, adverse impacts on soil properties and wastage of valuable organic carbon and energy rich residues.

There are several options which can be practiced those may enhance the soil health to avoid burning of crop residues such as composting, conversion to energy, production of bio-fuel and recycling in soil to manage the residues in a productive manner. Conservation agriculture (CA) offers a good promise in using these residues for improving soil health, increasing productivity, reducing pollution and enhancing sustainability and resilience of agriculture. The resource conserving technologies (RCTs) involving no- or minimum-tillage, direct seeding, bed planting and crop diversification with innovations in residue management are possible alternatives to the conventional energy and input intensive agriculture.In some countries crop residues are used as a source of energy, animal feed, composting mushroom cultivation or even burned in field (Table 1). In China 37% of crop residues are directly combusted by farmers, 23% used for forage, 21% discarded or directly burnt in the field, 15% lost during collection, 4% for industry materials and 0.5% for biogas (Liu *et al*., 2008).

Table 1: Mode of crop residue management in other countries

Mode of utilization	Country
Source of energy	Indonesia, Nepal, Thailand, Malaysia, Philippines, Indonesia, Nigeria
Composting	Philippines, Israel, China
Animal feed	Lebanon, Pakistan, Syria, Iraq, Israel, Tanzania, China, Africa
Mushroon cultivation	Vietnam
Burning	China, USA, Philippines, Indonesia

Chopped straw residues on or near the soil surface would increase the grain yields by reducing evaporation. The effect of straw treatment had no impact on the bulk density, total porosity, air porosity or pore size distribution of the soil for few years. Aggregate stability and size distribution showed more coarse aggregates as the amount of crop residues on the surface increased. Reduced tillage and direct drilling in combination with a high amount of chopped straw is feasible for spring-sown cereals on loams and silty clay soils in southeastern Norway (T. Bùrresen 1999) [22].

Incorporation of rice (*Oryza sativa* L.) straw, when compared with burning, affects soil nitrogen supply by increasing nitrogen and carbon inputs. Straw management did not significantly affect the uptake of residual fertilizer *15*N or of straw *15*N in the subsequent year. (Alison J *et al* 2001). Incorporation of high and medium amounts of wheat straw had significant effects on increasing the soil nitrogen, phosperous, and potassium, the AP levels and also enzyme activity and the incorporation of crop residues significantly increased the grain yields. Straw incorporation was the most effective practice for improving the soil properties and fertility, which can be recommended for dryland farming areas as a crop residue management system to enhance both agricultural productivity and sustainability (Wei *et al* 2015) [25].

Paddy straw has immense economic potential for the farmers, therefore an urgent need of residue management machine for paddy straw management (Roy and Kaur 2015) [26].

Review of Literature on Machinery Developed for Residue Management

JR Pilcher (1983) [1] was developed simple chopper harvester. He was concluded that Apart from the problems with the epicyclic and pump drive gearbox, the mini rotor was reasonably reliable but certain shortcomings were determined. The output of the machine disappointingly low, but even when conditions are good it is doubtful whether more than 25 tonnes cane per hour will be harvested or not. The wide range of field conditions in which the machine has operated and which are not ideal for chopper harvester is typical of South Africa. He was observed that the mini rotor was able to operate in these conditions but their effect on output and fuel consumption can be clearly, further development was required so that factors such as trash wrap and narrow row spacing can be overcome so that reliability can be improved.

A. Tajiuldin (1994) [2] was developed flail-mower as an attachment to the prime-mower of the selfpropelled reaper. The flail-mower was evaluated for harvesting of forage, the machine was found suitable for clearing bushy plants especially parihcnium. The effective field capacity of the mower was 0.20 ha/h and the operational cost of the mower was 140 Rs/ha.

C. Wanner (2002) [3] was developed severe duty vegetation shredder and performed well in all conditions. The construction platform used for the SDVS is not a vehicle normally associated with vegetation cutting, but did offer so advantages in terms of being able to push down the larger stalks in front of the shredder. In addition, the platform of this machine can carry other earth working tools for mine clearance which require the weight and drawbar available. He was tested compatible and complementary vegetation cutting capability for these tools they have observed that its performance was very effective. In addition the flexibility of the cutter in following ground contour and reaching across terrain features and up and down side slopes was an unexpected and most appreciated capability.

Garg I K (2004) [4] was developed rice straw chopper-cum-spreader for paddy crop. The machine in a single operation harvest the stubbles left after combing, chop into pieces and spreads on the ground. The chopped and spreaded stubbles are then easily buried in the soil by the use of single operation of rotavator or disc harrow and decayed after irrigation. Subsequently, wheat sowing is done as usual by the use of strip till drill, no-till drill or traditional drill. This machine consists of a rotary shaft mounted with blades named as flail to harvest the straw and chopping unit consisting of knives, it is operated by 45 hp tractor and has 228 cm width of cut. He was examined that initial trials on the machine have shown highly encouraging performance. This machine was chopped the paddy stubbles at flail speed of about 900 rpm and chopper speed of about 1500 rpm was found to vary between 7–10 cm, he mentioned that the cost of this machine is about Rs.40,000/-.

C J S Pannu (2005) [5] was developed both laboratory model and a functional prototype of tractor operated cross-conveyor straw thrower for simultaneous sowing of wheat crop. The lab model and functional prototype consisted of pick up reel, cross conveyor and straw distributor were designed and fabricated. The lab model was evaluated by the combine harvested paddy field conditions were stimulated in the laboratory. The pickup efficiency and straw distribution was found maximum at reel speed index of 4.2, conveyor speed index of 4.3 and cleat row spacing of 37.5 cm of conveyor belt. The functional prototype also performed best at same reel speed index (4.2) and conveyor speed index (4.3) in the field experiments. The belt width of designed cross conveyor was 60 cm. The effect of mulch created by straw thrower on the soil parameters, crop establishment parameters was also studied. The author observed that the germination obtained by sowing with experimental machine was not significantly different than the germination of crop sown by No-till drill in clean field. The soil temperature difference between maximum and minimum was narrow down by the mulch (2.77 °C) created by straw thrower than control (7.73 °C).

D. Adgidzi (2007) [6] was developed a forage chopper for crop residues like maize stovers, millet stovers, sorghum stovers, groundnut haulms, cowpea stems, potatoes stems, rice straws. The cutting blade parameters of the machine were knife edge thickness, $\delta = 80\mu m$, knife thickness, t= 4mm and sharpening angle (level angle) $\beta = 25^o$. The moisture content for the wet and dry materials was determined by oven dried method before chopping. The average chopping efficiencies for the wet and dry materials were 86 and 92% respectively. The average chopping rate for the dry materials was 24kg/hr and the average chopping rate for the wet materials was 15.6kg/hr. These values indicate that this machine performed better with dry materials than the wet materials. The average length of cut of the materials was observed 25mm. This machine requires only one person to operate it and can be used either in the rural or urban areas, using either a diesel or petrol engine of 8.5kW and above.

S.V. Pathak *et al* (2008) [7] were developed a tractor operated shredder require 35 hp, 540±10 PTO rpm tractor as a prime mower with a capacity of 300 Kg/hr and evaluated for horticultural pruned waste *viz*. mango, sapota, cashew, nutmeg branches and harvested grasses in order to utilize them as organic matter as well as industrial applications. He was observed that during testing, feeding unit, cutting unit and power transmission system worked satisfactorily for selected horticultural pruned waste and harvested grasses. At the optimum speed of the cutter head i.e. 450 rpm, more than 80 per cent cut pieces were observed in the length group of 20-40 mm and 40-60mm with a capacity for all five crop waste. The required operation period for 100 kg pruned branches of mango, sapota, cashew, nutmeg and grasses was 0.36, 0.40, 0.46, 0.51 and 0.32 hrs respectively. The total cost of developed machine (excluding tractor cost) was Rs. 33,800.

J. Honglei *et al* (2010) [8] were developed combined stalk–stubble breaking and mulching machine on the basis of analyzing the existing problems in stalk-breaking and stubble-breaking machines. They developed this combined stalk–stubble breaking and mulching machine with two frames fixed together, the stalk and stubble-breaking blade rotors were mounted respectively on the frames. This machine broke the maize (Zea mays L.) stalk and stubble and bury about onethird of the broken stalk and stubble in the soil, preventing them being blown away by wind. They described the structural features of the machine, the design of main working parts, determination of the parameters of the central position of the two blade rotors, and presents the performance test results in this paper. The tests showed that the machine had a stalk-breaking rate of 89% and the vegetation coverage rate reached 67.9%, which meets the agro-technical requirements in the dry farming area of northern China.

I. M. Bashir *et al* (2010) [9] were developed a stalk chopper. The major components of the machine are the hopper, the chopping knives, the chopping chamber, the frame and the prime mover which drives the chopping disc carrying the knives. They have tested that the material capacity of 45.69 kg/hr and cutting efficiency of 91%.

D. Anantha Krishnan and G.C. Jayashree (2012) [10] were developed tractor operated two row rotary sugarcane field shredder for better utilization of the trash by shredding and incorporation in the soil especially in ratoon crop without damaging the crop. The unit has two rotary members with swinging type blades. The rotary units can be sled inward or outward according to the row to row spacing of the standing sugarcane crop. The rotary speed of the rotary units is 1990 rpm. The field efficiency of the unit is 68.6 per cent. The unit shreds the sugar cane trash of size 600 mm to 900 mm into small pieces of about 75mm size. The cost of operation works out to Rs.1836 ha-1 and the cost of the unit is Rs. 80,000/-.

Jibrin M. U *et al* (2013) [11] were developed crop residue crushing machine of 10kw popular IMEX diesel engine was installed as a prime mower. They were tested prototype and found its performance satisfactory. However a cyclone which upper lighter discharge chute was covered with jute bag, added to improve the collection of the final product. Also a flywheel was attached to the hammer mill shaft to stop the lowering of the diesel engine speed noticed whenever much raw material was added to the chamber. They have decided that future commercialization shall incorporate a cyclone and a flywheel at the hammer mill shaft.

Nadeem Ahmad Malik (2013) [14] was developed a prototype of sugarcane trash chopper cum spreader to chop the trash and spread it to the field uniformly. The dimensions of the prototype were 4100 mm x 1840 mm x 1910 mm. The machine was tested at five levels of moisture content *viz*. M1, M2, M3, M4, M5 having values 18.75%, 16.54%,15.15%, 13.19% and 13.13% (db) respectively and four different velocities V1, V2, V3, V4 having corresponding values of 2.76, 2.8, 2.9 and 3.2 km h-1. The maximum shredding capacity of the machine was found to be 4.31 t h-1 at moisture content 13.13% and forward speed of 2.9 km h-1with maximum shredding efficiency of 90.4 per cent. The prototype chopped up sugarcane trash of about 4 to 12 cm length. The average field capacity of the machine was found out to be 0.40 ha/h with efficiency of 78.2 per cent and the uniformity of trash spreading varied from 0.90-0.95. The cost of operation of the machine was found to be Rs. 786/h. the benefit cost ration was 1.5 and payback period of the machine was 1.3 year if operated for 250 hours per year. The break-even point of machine was 17.7 ha.

Vineet Kumar Sharma (2014) [13] was developed a multi-toolbar no-till seed drill for surface managed loose straw conditions after combining. The machine no-till drills mounted with inverted-T type opener work satisfactory under anchored stubbles but clog frequently under loose straw conditions, to overcome this problem, he was developed a multi-toolbar no-till drill with optional residue handling device. The machine was evaluated in actual un-chopped and chopped field condition both in wheat and rice crop. The developed drill was utilized for sowing of wheat and also compared with other systems of wheat establishment.

Azeem Anjum *et al* (2015) [14] were modified the conventional wheat straw chopper by using locally available materials making it light weight and more efficient. The performance evaluation of wheat straw chopper was carried out for three wheat varieties with two different tractor forward speeds and two levels of moisture contents.

Sidhu HS was developed a new machine called the happy seeder. The Happy Seeder (HS) cuts and manages the standing stubble and loose straw in front of the furrow openers, retaining it as surface mulch and sows wheat in a single operational pass of the field. He was examined that operational costs for sowing of wheat about 50-60% lower with HS than with conventional sowing.

Nilesh Awate (2016) was developed mobile disintegrator for crop residues like cotton stalk available in agriculture field. He suggested to farmers that it has low operational cost and also starting investment cost is low.

Review of Literature on Performance Evaluation of Residue Management Machine

SS Thakur and I K Garg (2007) [16] were conducted a study on paddy straw management by chopping for sowing wheat in combine harvested field. They were taken fuel consumption and size of cut of paddy residue as performance parameters. In this study they were focused on parameters that are chopper speed, forward speed and moisture content against size of cut and fuel consumption. The results showed that Percent size of cut (less than 10 cm length) of paddy residue increased with the increase in the chopper speed and moisture content but decreased with increase in the forward speed. They were observed that the to get better performance of the stubble harvester-cum-chopper, it should be operated at 70% (wb) moisture content of the stubbles, with a forward speed of 2.00 kmph and at a chopper speed of 1500 rpm. They were suggested that chopping of paddy stubble was recommended immediately after combine harvesting because at higher moisture content chopping performance would found better.

El-Hanfy, E. H.* and S. A. Shalby (2009) [17] were evaluated performance of modified Japanese combine chopping unit during harvesting process. They were evaluated the performance of the this chopping unit under four forward speed (0.35, 0.55, 0.75 and 1 m/s), three cutting speed (450, 550, 650 rpm) and three distance overlapping between fixed and rotary knives (6.0, 8.0, 10.0cm). The results showed that the suitable forward and cutting speed and overlapping between fixed and rotary knives are (0.75 m/s, 550 rpm and 10 cm) respectively. Also data revealed that, the excessive of forward and cutting speed cause an increase combine trouble.

Verma *et al* (2009) [18] were developed an attachment for the existing combine, to evaluate performance of combine mounted straw managing system during rice crop harvesting, affected by various independent parameters. In this they were focused on parameters are three levels of number of rows of stationary blades (one, two & three rows), three levels of rotor speed index (30,35 & 40) and two levels of deflector angle (20· & 30· with horizontal) were selected on the basis of uniformity of straw thrown (C.V. basis). They have concluded that uniformity of straw thrown was improved significantly when number of rows of stationary blades was increased from one to three. Similar pattern was observed when rotor speed index was increased from 30 to 40. Deflector angle had non-significant effect on uniformity of straw thrown. Optimal combination, at which there was maximum uniformity of straw thrown i.e. C.V. 15.25% was observed at combination of three rows of stationary blades, rotor speed index of 40 and deflector angle of 20^0. They have examined that straw managing system was almost same as the performance of conventional no-till drill operated in clean field.

Elfatih *et al* (2010) [19] were evaluated the performance of the modified chopper for rice straw composting. The results showed that increasing the cutting drum linear speed from 56.6 m/s to 70.7 m/s, increased the cutting efficiency, the chopper productivity, and the power requirement by percentage of 3.7%, 2.8% and 0.9%, 57.5%, 55.9% and 41.7%, 36.8%, 28.6% and 35.9%, respectively, meanwhile, decreased the energy consumption by percentage of 32.7%, 38.4 and 9% for 35 mm, 25 mm, and 9 mm concave hole diameter, respectively. They were explored that the shortest composting period 95 days was resulted by using 25 mm concave holes diameter at 66 m/s cutting drum speed, meanwhile the longest period 140 days was resulted by using the 9 mm concave holes diameter at 70.7 m/s cutting drum speed. Also, it was resulted using the 35 mm concave holes diameter at 56.6 m/s cutting drum speed.

Singh *et al* (2011) [20] were evaluated the performance of tractor mounted straw chopper cum spreader for paddy straw management. In this study they were considered the main parameters are two levels of moisture content of paddy straw (30 &40%, wb), three levels of chopping speed (1300, 1450 & 1600 rpm) and three levels of forward speed (2.0, 2.5 & 3.0 km/h). They were selected optimal combination of variables on the basis of size of cut of straw, uniformity of straw spread (C.V. basis) and fuel consumption. They have observed that effect of moisture content on size of chopping was found to be non-significant and percent size of cut (up to 4 cm) of paddy straw increased with increase in chopper speed and decreased with increase in forward speed. None of the independent variables had a significant effect on uniformity of straw spread. Fuel consumption (l/h) at lower moisture content was low and it was increased with increase in chopping speed as well as with increase in forward speed. Effect of forward speed was more pronounced on fuel consumption than the effect of chopping speed. They have concluded that optimal combination was a chopping speed of 1450 rpm and a forward speed of 2.0 km/h.

Mahmood *et al* (2016) were conducted a study on evaluation of a wheat straw chopper. The results of their study revealed that a 75 hp tractor was suitable for operating this machine, average operating speed of chopper (2.7 Kmph), average effective field capacity of chopper (0.40 ha/h) and field efficiency (67.9%). The amount of chaff recovered was 2404 kg ha and chaff recovery from straw was 61.1%. The operating cost of chopper setup was Rs. 5,262 ha. Total worth of recovered chaff was Rs. 24042 ha (@ Rs. 10 kg). Net gain in terms of recovered wheat straw was Rs. 18780 ha. They were analysed the breakeven point (use) of this machine for harvesting own fields and rental fields was 77 h (31ha) and 266 h (105.5 ha), respectively.

Verma *et al* (2016**)** [21] were evaluated performance of tractor operated paddy straw mulcher. The results of their reserach showed that effective field capacity of the tractor operated paddy straw mulcher was 0.32 ha/h at forward speed of 2.64 km/h and average fuel consumption for the machine was 5.88 l/h. The percent chopped straw size by paddy straw mulcher up to 10 cm was 83.44%. No or very little straw accumulation was observed in operation of spatial no till drill for direct drilling of wheat after the operation of paddy straw mulcher. From their study it was explored that average grain yield for treatment T1 (Paddy straw mulcher + wheat sowing with spatial no-till drill) was 2.39 and 0.33% less than T2 (paddy straw chopper-cum-spreader + wet mixing with rotavator + no till drill) and T3 (clean field + disc harrow + cultivator x 2 + planter + traditional seed drill) respectively whereas the cost of operation for treatment T1 was 24.38 and 23.55% less than T2 and T3 respectively.

Conclusion

The chopping of paddy stubbles is recommended immediately after combine harvesting because at higher moisture content chopping was found effective. According to researchers investigation the machines developed for residue management of different crops at India and other countries are flail mower, straw chopper cum spreader, tractor operated cross conveyor paddy straw thrower, crop residue crushing machine, forage chopper, tractor operated shredder, stalk stubble breaking and mulching machine, tractor mounted sugar cane shredder, sugarcane trash chopper cum spreader, modified wheat straw chopper, stubble harvester cum chopper and happy seeder etc. The most of these machines which was used for residue management with rotary power type like flail mower, rotavator. The most important machine and field parameters involved in performance of these machines are forward speed of prime mower, width of cut, fuel consumption, rotary speed of machine, type of soil, moisture content of soil, trash size reduction, chopping capacity, energy requirement, density of trash, and moisture content of trash. On this basis of this review it was revealed that there is no successful machine is available so far paddy residue management, the respective field with which can perform effectively and efficiently cutting, chopping and incorporation of paddy residue in a single pass.

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