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On-the-go urea spraying system of baler for enhancing the nutritional quality of paddy straw

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Abstract
Urea treatment of straw is generally done manually in conventional practice, which needs a lot of time, labour and storage area. To overcome these problems, a urea solution spraying system for paddy straw baler (rectangular type) was developed. This system was used as the go spraying of urea solution on loose paddy straw during conveying to compression chamber of the baler. The nutritive values of straw *viz.*, crude protein, *in vitro* dry matter digestibility and metabolizable energy were improved as compared to the untreated straw. The crude protein in untreated paddy straw was 6.61%, which was increased to 12.28% after urea treatment. The value of metabolizable energy was also improved by 3% and *in vitro* dry matter digestibility by 6% as compared to untreated straw.

Keywords: Nutritional value, Paddy straw, Straw baler, Urea treatment

Introduction
Crop residue is the part of the plant that is left in the field after crop harvest and includes stalks, leaves and seed pods. Such crop leftovers are generally utilized as bio manure, animal feed, soil mulch and industrial and domestic use, thereby making crop residues quite important for farmers. It is estimated that about 500 Mt crop residue is produced every year; most of the residue is produced by cereal crops (352 Mt), which includes paddy (34%) (IARI, 2012). Conventionally for the sowing of the next crop, the existing crop stubbles are set on fire to clean agriculture lands and to ease out tillage practices (Jain *et al.,* 2014; Jat *et al.,* 2020). Paddy straw burning results in loss of soil nutrients such as nitrogen, phosphorus, potassium and organic carbon. Blazing of farm remnants in addition emits gases like CO_2, NO_2, SO_2 and an immense amount of particulate matters (PM_{10} and $PM_{2.5}$) into the atmosphere giving rise to peculiar effects in the atmosphere (Singh, 2018; Zhang *et al.,* 2011; Mittal *et al.,* 2009).

In general, 99 percent of farmers feed their animals paddy straw with or without green fodder. The straw is mainly composed of fiber, including cellulose and hemicelluloses. Lignocellulosic compounds (cellulose, hemicelluloses and lignin) present in straw are resistant to microbial fermentation in the rumen. In developed countries, anhydrous or aqueous forms of ammonia is used for chemical treatment, which is a very common practice for boosting the nutritional value of feed straw (Han, 1983). In Asia on account of its adaptability with the farmers, safe handling, availability and cheapest way of enhancing protein content, urea-ammoniation is considered as the best substitute for treating cereal straw. The treatment of straw by urea increased nitrogen content, enhanced palatability and straw digestibility significantly. Several studies conducted on manual urea treatment of straw have shown that ammonia (urea) treatment of cereal straw increased digestibility and nutrient uptake, improved the animal growth and milk yield, consequently increased the feed value (Kiangi *et al.,* 1981; Agrawal *et al.,* 1989; Schiere *et al.,* 1989; Chandrasekharaiah *et al.,* 1996; 1997). Prasad *et al.* (1998) conducted an experiment with feeding baled and stacked urea treated rice straw to record the performance of crossbred cows. The digestibility coefficients of organic matter, protein and fiber were higher (<0.05) on urea treated rice straw as compared to untreated rice straw. Urea treatment of straw was also carried out by using the sprayer on wheat thresher and dripping methods on stack of the bales (Kumar *et al.,* 2010; Sahay *et al.,* 2016; Das *et al.,* 2017). The nutritional value of straw could be enhanced through ammonia treatment using urea as a source of ammonia. It is generally recommended to raise the moisture content of straw by 40-50% for ammonia (urea) treatment (Bamaga *et al.,* 2000). There is no significant difference between dry matter digestibilities of treated straw in mechanized methods as compared to the conventional method (Walli *et al.,* 1988). But the conventional manual urea treatment process is a laborious, tedious and time-consuming task and is not used by farmers on a large scale. The handling and mixing of a large quantity of straw make the treatment process laborious and tedious. It was, therefore, essential to facilitate or eliminate some of these operations by using machines (Raisianzade *et al.,* 2005). Hence, an effort was made to develop a urea solution spraying system for the straw baler to pretreat paddy straw during the baling operation.

Materials and Methods

Development of urea spraying system for straw baler: The rectangular baler (Markant 55, Class India) and tractor of 41 kW (New Holland 3630) were used for the study. The preliminary evaluation of straw baler was carried out at combine harvested paddy straw field to check the working function of each component. During the evaluation of baler, some basic data of machine and field were recorded for the design of urea solution spraying system. During the field evaluation, forward speed, fuel consumption, working width, size of bales, weight of bales, moisture content, bale output, bale dimensions, bale weight, height of stubbles, baling time etc., were measured. Urea treatment system (UTS) was developed based on field observation data and standard application rate of urea treatment. The main components used in urea spraying system were urea solution tank, sprayer boom with flat fan nozzles, heated triple pump (HTP), strainer, relief valve, oil type pressure gauge, boom arm, belt and pulley etc. The belt and pulley were selected based on required rpm to operate the HTP pump with help of baler flywheel through tractor PTO (power take-off) power. The baler was operated by tractor PTO power and drawbar hitch point in the field. Baler flywheel was attached with tractor PTO shaft with the help of a universal joint. The developed urea spraying system was retrofitted at straw baler. Urea solution tank was mounted on baler top section.

Calibration of nozzles of urea spraying system: The calibration of nozzles was carried out at different pressures. Nozzles were attached to the boom to maintain the required moisture level and uniformity pattern. Nozzles were calibrated with plain water at different pressures for varying nozzle discharge rates. The pump was operated at 820 rpm with tractor PTO with the help of a belt and pulley. The pump was operated at different pressures and corresponding nozzle discharges were measured with a measuring cylinder. The uniformity test of nozzles was carried out on patternator. The pressure was adjusted on the pressure gauge at 40 psi pressure and nozzle gave exact discharge on discharge meter after 60 seconds.

Evaluation of urea treatment system (UTS): UTS was evaluated at combine harvested paddy field. Three levels of urea concentration (6%, 8% and 10%) were selected; the moisture levels selected were 50%, 60% and 70%. The speed of operation was kept constant at 2.5 km/h. The treated urea straw was used for nutritional analysis as per the standard methods. Indeed, UTS was evaluated in the *Kharif* season for paddy crop. The availability of loose straw per unit area was calculated. The baler was initially operated in paddy straw field and the average weight of ten untreated bales was noted down. The concentration of urea solution was calculated by assuming a ratio of urea to dry matter (W/W) straw which is recommended for ammonia (urea) treatment, keeping in view the toxicity of excess urea to the cattle. Urea solution was prepared at different levels *i.e.,* urea concentration of 6% (6 kg of urea in 100 litre of water), similar urea solution was prepared for 8% and 10% concentration level for treatment separately. The experiment was conducted separately for individual concentration levels. The prepared urea solution was filled in spraying tank mounted on baler for each urea concentration level. The moisture level of straw was increased by nozzles discharge rate with the help of a relief valve of pump. Urea solution was sprayed on loose straw during conveying to the compression chamber of baler.

The water treated bales were collected from baler outlet point and the weight of water sprayed on bales was noted. The retention efficiency and moisture content of bales were calculated by equations 1 and 2. The liquid retaining efficiency of bales was the ability of bales to retain the liquid applied into it at given values of treatment parameters such as discharge rate of liquid applicator and duration of treatment. It was defined as follows:

$$R_e = \left(\frac{Q_s - R_s}{Q_s} \right) \times 100 \qquad (1)$$

Where, Re is the liquid retaining efficiency in %, Qs is the total amount of liquid applied into stack in kg and Rs is the total amount of runoff from stack in kg. The final moisture content of bales was calculated before and after the discharge of urea solution by the equation-

$$MC = \left(\frac{Ww}{W_t}\right) \times 100 \qquad (2)$$

Where, MC was the final moisture content of bale in % (wet basis, wb), W_w was the weight of water in kg, W_t was the weight of wet bale after spraying in kg. Also, $W_t = W_w + W_d$. Where, W_d was the weight of dry sample in kg.

Nutritional analysis of urea treated paddy straw bales: After urea solution spraying, the treated bales were wrapped with polyethylene sheets and stored for three weeks at room temperature for curing. After three weeks, the baled rice straw samples were subjected to nutritional analysis at the laboratory of ICAR-NIANP, Bangalore. The crude protein was analysed by Kjeldahl method using semi-automatic protein analyser (AOAC, 2000) and *in vitro* dry matter digestibility (IVDMD) was done by conducting *in vitro* gas production test (IVGPT). Metabolizable energy (ME) of the straw was calculated based on 24-hour gas production and crude protein level in treated straws (Menke and Steingass, 1988).

Results and Discussion

Laboratory evaluation of urea treatment system: The UTS was evaluated in laboratory for nozzles calibration and straw moisture retention efficiency. Flat fan nozzles were calibrated in laboratory for relation between pressure and discharge rate. The relationship was used to decide the pressure of pump to increase the moisture content of paddy straw during baling operation. The actual discharge rate of each nozzle was calculated at five different pressures. The total liquid discharge by the application rate and number of nozzles gave the actual inflow rate of each nozzle. The pressure was adjusted at 1.5, 3.5, 7, 9 and 14 kg/cm^2 with the help of pressure relief valve of pump. The actual discharge rate of nozzles was found to be 12.24, 14.10, 17.34, 19.19 and 23.81 l/min at the corresponding pressure of 1.5, 3.5, 7, 9 and 14 kg/cm^2, respectively. The calibration equation showed a linear relationship with R^2 of 1. It was observed that discharge rate increased with the increase in pressure (Fig 1). The performance evaluation of the UTS was carried out at a required pressure to increase the moisture level of dry matter on weight basis. However, the number of nozzles and pressure ratings were changed according to paddy straw dry matter weight and enhancement of moisture level of dry matter as per discharge rate of the pump.

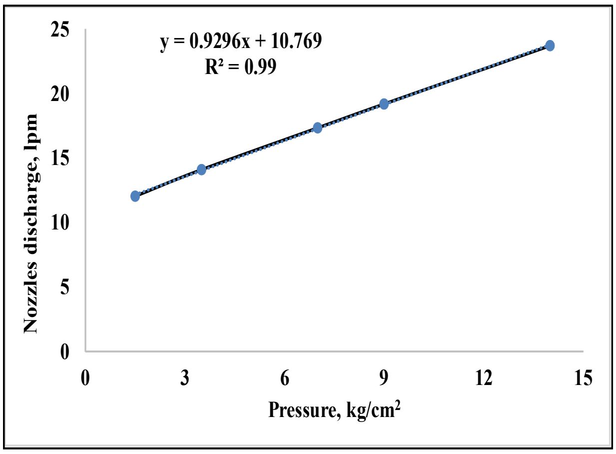

Fig 1. Calibration graph of nozzles

The UTS was evaluated in laboratory conditions for moisture retention efficiency of straw (Table 1). The initial moisture content of paddy straw was 10% (wb). The baling interval was found to be 33 sec in manual feeding of straw in baler at laboratory condition. The discharge rate of nozzles was 9.75 l/min. The average discharge rate was set to 5.36 l/bale to increase the average weight of bale by 50% and average moisture content of straw was found to be in the range of 40-50%. It was found that the average bale weight (dry bale) was 10.98 kg (SE: ±0.16 kg) and water sprayed bale weight was 15.9 kg (SE: ±0.40 kg). The average retention efficiency was found to be 92.91% and the average increase in weight was found to be 5.1 kg and moisture content 47.15% (SE: ±1.52%) (wb).

Table 1. Retention efficiency of paddy straw bale after spraying

Sr. No.	Weight of dry bale (kg)	Average liquid applied (l/bale)	Weight of sprayed bale (kg)	MC sprayed bale (%) (wb)	Average retention efficiency (%)
1	11.1	5.36	16.3	48.2	
2	10.9	5.36	15.3	45.89	
3	10.8	5.36	16.0	47.65	92.91
4	11.2	5.36	16.3	48.8	
5	10.9	5.36	15.9	45.23	
Average	10.98	5.36	15.9	47.15	
SE (±)	0.16		0.40	1.52	

MC = Moisture content

Evaluation of urea spraying system in paddy straw field: The UTS was fitted on baler and evaluated in paddy straw field. Some basic field observation data were recorded (Table 2). The average moisture content of paddy straw was 13.5% (wb). The weight of loose paddy straw was found to be 0.83 kg/m^2. The average time taken for one bale formation was found to be 30 sec for paddy straw. The average weight of twine was found to be 5.6 kg/ha for paddy straw. The working capacity of baler with UTS was 109 bales/h. The baling capacity of UTS system was slightly lower as compared to without UTS due to the non-productive time of tank filling. The moisture analysis of treated bales of paddy straw was carried out after 21 days of storage period. The straw samples were collected from different layers of urea treated bale.

Table 2. Field observation data of retrofitting urea solution spraying system

Parameters	Values
Crop straw	Paddy
Moisture content of straw (%, wb)	13.5
Weight of loose straw (kg/m^2)	0.83
Weight of untreated bale (kg)	12.5
Rectangular bale size (L×W×H), mm	600×470×360
Field capacity, ha/h	0.35
Working capacity of baler (bale/h)	120
Average time taken in one bale (s)	30
Working capacity of baler with spraying (bale/h)	109
Fuel consumption (l/h)	5.67
Average weight of twine, g/bale	8.5
Average weight of twine, kg/ha	5.6

The moisture content (MC) of individually treated bales was found to be vary from 44.33 to 46.38% (SE: ± 2.35%), 57.18 to 58.73% (SE: ± 2.16%) and 67.69 to 69.83% (SE: ± 1.94%) for moisture level of 50, 60, 70%, respectively in paddy straw bales (Table 3). This showed that the variation in MC in same treatment level was due to minor loss in weight of bale during curing period of 21 days.

Nutritional analysis of urea treated paddy straw bales: Nutritional analysis of baled paddy straw as influenced by different levels of UC and MC level was recorded (Fig 2). It was evident from the graph that due to treatment of urea solution at all levels, the crude protein (CP) content was increased in all the treatments. The variation in CP content was also found to be significantly (P<0.001) dependent on UC level. The CP content of untreated straw was the lowest at 6.61% (SE: ±0.24%), while CP content of urea treated straw was found to be in the range from 8.93% (T_1) to 13.41% (T_9). However, no extra benefit could be obtained beyond 8% of urea at 50% moisture level. When MC was increased from 50 to 70%, CP was found to be increased from 8.93% (SE: ±0.48%) to 11.82% (SE: ±0.64%) for 6% of urea. Similarly CP content was found to be 12.28 to 13.04% (SE: ±1.39%) for 8% of urea and from 12.94 (SE: ±1.29%) to 13.41% (SE: ±0.75%) for 10% of urea level for increase in MC level from 50 to 70%. The improvement in crude protein content due to urea treatment was also reported earlier (Agrawal *et al.*, 1989; Chandrasekharaiah *et al.,* 1996; 1997; Rehrahie and Ledin, 2001).

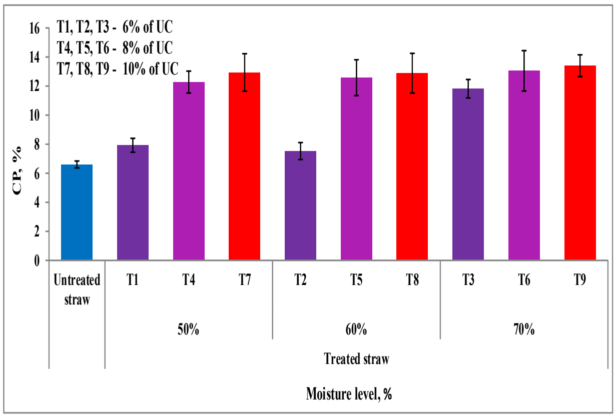

Fig 2. Effect of urea concentration and moisture level on CP content

IVDMD was found to be more in treatment T_4 and T_5 as compared to T_2 (Fig 3). In the case of T_5 treatment, IVOMD was more followed by T_7 and T_4 compared T_2. The IVOMD

Table 3. Moisture content of treated bales of paddy straw

UC	6 %			8 %			10 %		
MC	50%	60%	70%	50%	60%	70%	50%	60%	70%
Treated bale		MC % (wb)			MC % (wb)			MC % (wb)	
1	47.00	56.87	68.8	48.41	58.45	69.85	49.02	59.58	68.43
2	45.12	61.1	64.8	45.82	57.81	68.72	45.64	55.53	69.02
3	40.89	58.22	69.49	44.31	55.29	65.27	44.5	57.62	72.05
Average	44.33	58.73	67.69	46.18	57.18	67.94	46.38	57.57	69.83
SE(±)	1.12	2.16	2.53	2.07	1.67	2.38	2.35	2.02	1.94

UC = Urea concentration; MC = Moisture content; wb = Weight basis increased from 49.47 (SE: ±0.50) to 52.965% (SE: ±0.96) for increased in urea level from 6 to 8% at 50% MC. ME content (MJ/kg) was also found higher in treatment T_5 (7.41) followed by treatment T_4 (6.99) and T_9 (7.02). The ME was found to be 6.76 for untreated paddy straw and it was found to be varied from 6.62 for T_6 to 7.02 for T_9. Keeping in view the overall nutritional analysis, treating the straw at 8% urea and 50% moisture levels would be more economical. However, at higher level (T_5), additional benefit could be observed with better digestibility and ME content of the treated straw.

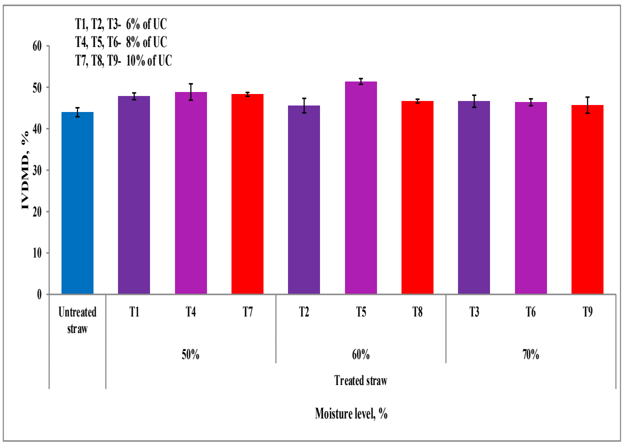

Fig 3. Effect of urea concentration and moisture level on IVDMD

In general, straw ammonification increased the digestibility of straw (Wanapat *et al.,* 1985; Chandrasekharaiah *et al.,* 1996; 1997). These effects might be due to improvement in rumen microbial degradation of rice straw by making the cellulose and hemicellulose more accessible for the rumen microbes (Shen *et al.,* 1999). The optimum moisture level (50%) observed in this study was close to that obtained by Cloete and Kritzinger (1985). Due to an optimum increase in CP, IVDMD and ME contents of treated straw at 8% urea with 50% moisture level, it was found good for baling of paddy straw. At higher level of 8% urea with 60% moisture, the additional benefit could be obtained in IVDMD and ME content of treated straw, but as we did not have any information on residual urea in treated straw, only 8% urea with 50% moisture level was recommended for the go-spraying of urea solution of the paddy straw baler.

Cost of developed system: The cost of urea spraying system was calculated in order to evaluate the economic feasibility of the system. The cost of construction of retrofitted urea spraying system on paddy straw baler was approximately Rs 0.30 lakh. The cost of urea treatment with developed spraying system is Rs 0.50/- per kg of straw. Thus treatment of straw with urea spraying system directly on baler was less expensive as compared to conventional methods like bale stack and manually urea treatment methods (Kumar *et al.,* 2010).

Conclusion

The go urea spraying system could be used in straw during baling. This system improved the nutritive quality of straws in terms of crude protein, IVDMD and metabolic energy content. But optimum increase in CP, IVDMD and ME was observed in treated straw by spraying 8% urea solution and increasing the bale weight to 50%. The weight of urea treated bales by the developed system varied from 18.14 to 20.95 kg for paddy straw compared to untreated bales. The moisture content of treated bales varied from 44.33 to 69.83% for paddy straw. The retention efficiency of the developed system was better when compared to the dripping method. Therefore, the developed go urea spraying system could be exploited in increasing the nutritive value of straws in large scale.

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