Indian Journal of Agricultural Sciences **86** (5): 598–604, May 2016/Article
https://doi.org/10.56093/ijas.v86i5.58255

Development and evaluation of electronically controlled precision seed-metering device for direct-seeded paddy planter

P RAJAIAH[1], INDRA MANI[2], ADARSH KUMAR[3], SATISH D LANDE[4], ASHOK KUMAR SINGH[5] and CINI VERGESE[6]

ICAR - Indian Agricultural Research Institute, New Delhi 110 012

Received: 13 November 2015; Accepted: 17 December 2015

ABSTRACT

An electronic experimental set-up was developed to evaluate three seed-metering mechanisms, viz. slanting, semi-circular and rectangular shape for three paddy varieties and to investigate the influence of the selected levels of variables, viz. forward speed, cell shape and inclination of seed-metering plate on performance parameters of seed-metering. Mean seed spacing, miss index and seed damage were found to increase with increase in forward speed and angle of inclination while multiple index decreased with increase in forward speed and angle of inclination for all metering plates tested. Precision decreased with increase in forward speed and with increase in angle of inclination, it increased initially up to optimum value and then decreased. The mean seed spacing of 14.8 cm close to theoretical seed spacing of 15 cm, highest quality feed index of 88.1%, lowest miss index of 6.1% and minimum seed damage of 0.38% were observed in slanting type metering plate at an angle of 35º with the horizontal and at a forward speed (belt speed) of 2 km/h. Hence, for design of precision paddy planter, the optimum parameters, like slanting type metering plate with angle of inclination 35º and forward speed of 2 km/h can be used to achieve best results.

Key words: Metering device, Miss index, Multiple index, Precision planter design, Quality feed index

Transplanting of seedlings into puddle soil is commonly practiced for rice growing in India. However, repeated puddling adversely affects soil physical properties by destroying soil aggregates, reducing permeability in subsurface layers, and forming hard-pans at shallow depths, all of which can negatively affect the following non-rice upland crop in rotation. Moreover, puddling and transplanting require large amount of water and labour (360 man-h/ha). Direct-seeding is a viable alternative to puddled transplanting to overcome the problem of labour and water shortage. Direct-seeding by manual methods requires high seed rate, consumes more time per unit area and could be overcome by using tractor drawn precision planters with well-designed metering plate mechanisms. At present, farmers are using multicrop seed drill fitted with fluted roller metering mechanism driven by ground wheel and having tyne furrow openers (Dutta 1974, Ryu and Kim 1998, Singh *et al*. 2011, Patil and Dhande 2015). However, the wheel bears high resistance and slips easily, heavily affecting the drilling quantity. The seed undropped variation is in the range of 10 to 20% (Singh *et al*. 2011 and Zeng *et al*. 2012). Problems identified with these seed drills are unequal seed placement in a row, excessive seed dropping, clogging of seed tubes due to soil intrusion, struck-up of ground wheel in sticky soils and ground wheel slip in loose soils. To improve the efficiency of crop stand, reduce the missing hills and to address the other existing problems in a seed drill, a precision planter for direct dry sowing of paddy is the need of the hour for small and medium scale farms. These types of precision seeding can save seeds and effectively control the sowing depth, sowing densities and sowing distance (Li *et al*. 2013, Li *et al*. 2015). In addition, the output of precision seeding increases by 10-30% compared with that of the conventional drill (Yao 2004).

The planter drive assembly and its operational mechanism should be given high consideration so as to achieve efficient performance. Today, adopting electronic controllers and circuits in planting machines facilitates the system tasks and simplifies their applications while increasing their functional precision. The necessity for high, accurate and high performance agricultural machines are the main reasons for incorporation of electronic systems in these equipments. Furthermore, the new planting units are more user-friendly. Using measuring systems and electronic controllers in planters reduces mechanical frictions in

[1]Research Scholar (e mail: rajaiah69@gmail.com), [2]Principal Scientist (e mail: maniindra99@gmail.com), [3]Principal Scientist (e mail: adarsh_iari@rediffmail.com), [4]Scientist (e mail: satishiari@gmail.com), Division of Agricultural Engineering, [5]Principal Scientist (e mail: aksingh@gmail.com), Division of Genetics. [6]Senior Scientist (e mail: cinivergese@gmail.com), ICAR - Indian Agricultural Statistics Research Institute, New Delhi 110 012.

conventional power transmission systems, resulting in decreasing wheel slippage and avoiding excessive miss index (Panning *et al*. 2000, Singh and Mane 2011, Sharma and Pannu 2014).

Keeping the above facts in view, the present study was devoted to develop electronic set-up of high accuracy for metering of paddy seeds in direct-seeding in upland condition. It was expected that such system could result in lower wheel slippage and therefore higher planting accuracy. The present study also aimed to develop an electronic precision metering device and evaluate the impact of precision seeding on rice to overcome the inability of mass flow seed meters for saving high quality seeds, reducing the labour force used for thinning out seedling and realizing a high productivity with the minimal seed rate for economic benefit.

MATERIALS AND METHODS

Metering device is the heart of any planter, which places single or group of seeds at a predetermined depth and the space interval. Thus, in planter, row-to-row and seed-to-seed distance are maintained, which provides sufficient space for proper growth of the individual plant and also helps in easy intercultural operations and hence, more production per unit area is ensured. The performance of a planter depends upon uniformity of seed distribution in furrows, which is difficult to measure in the field condition due to soil coverage after planting operation. Hence, proper design of metering device influences the performance of the planter. A laboratory experiment was conducted to evaluate the performance of developed seed-metering mechanisms namely, slanting, semi-circular and rectangular slot for three paddy varieties, viz. PUSA-1121 (long), PUSA-44 (medium) and BPT-5204 (short) in the lab using electronic sticky-belt set-up developed. In direct-seeding of rice, the seed is to be soaked in fungicide solution for 24 h to manage soil borne diseases and allowed for shade drying for 3 h to make it suitable for drilling with planter. Three metering plate cells were designed such that the cell diameter or length should be about 10% greater than the maximum seed dimension and cell depth should be equal to the average seed diameter or thickness (Kepner *et al*. 1978 and Sharma and Pannu 2014).

An electronic laboratory experimental set-up was developed based on the flow diagram furnished in Fig 1 to investigate the influence of the selected levels of variables, viz. peripheral speed of seed-metering disc, cell shape and inclination of seed-metering disc on seed spacing, quality feed index, miss index, multiple index, precision and seed damage (Table 1).

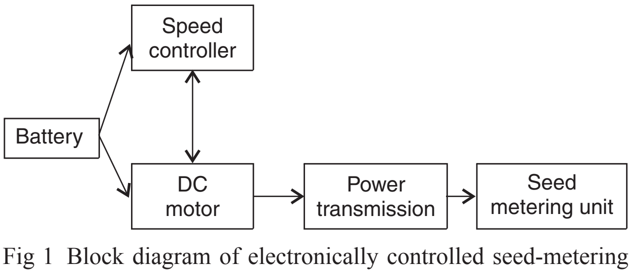

Fig 1 Block diagram of electronically controlled seed-metering device

The electronic sticky-belt metering mechanism comprises main frame, sub-frame for seed-metering box set-up, 2 m endless leather belt with 0.2 m width and 5 mm thickness, 0.75 kW AC motor with proximity sensor and variable frequency drive unit, DC motor (12 V, 150 W and 150 rpm) and speed controller.

The data obtained were statistically analyzed using SPSS software to determine the effect of forward speed, angle of inclination and shape of metering plate on the above mentioned variables. As stated by Singh and Saraswat (2005), the performance parameters for the pneumatic planter are as follows:

Table 1 Laboratory experimental plan in evaluation of metering devices

Variable	Levels
Variety	V_1- PUSA 1121, V_2- PUSA 44 and V_3- BPT 5204
Forward speed	S_1 - 1.5 km/h, S_2 - 2.0 km/h, S_3 - 2.5 km/h, S_4 - 3.0 km/h and S_5 - 3.5 km/h
Inclination of hopper	θ_1 - 25^0, θ_2 - 30^0, θ_3 - 35^0, θ_4 - 40^0 and θ_5 - 45^0
Metering cell shape	M_1 - Slanting, M_2- Semi-circular and M_3 - Rectangular slot

Multiple index: It is an indicator of more than one seed dropped within a desired spacing. It is the percentage of spacing's that are less than or equal to half of the theoretical spacing.

$$D = n_1/N \quad (1)$$

where, N = total number of observations, and n_1 = number of spacing in the region less than or equal to 0.5 time of the theoretical spacing.

Quality of feed index: It is the measure of how often the seed spacing was close to the theoretical spacing (Kachman and Smith 1995). It is the percentage of spacing's that are more than half, but not more than 1.5 times the theoretical spacing. The quality of feed index is mathematically expressed as follows:

$$A = n_2/N \quad (2)$$

where, N = total number of observations, and n_2 = number of spacing between 0.5 times of the theoretical spacing and 1.5 times of the theoretical spacing.

Miss index: It is an indicator of how often a seed skips the desired spacing. It is the percentage of spacing greater than 1.5 times the theoretical spacing, and is expressed as:

$$M = n_3/N \quad \ldots(3)$$

where, N = total number of observations, and n_3 = number of spacing in the region greater than 1.5 times of the theoretical spacing.

Precision: It is a measure of the variability in spacing after accounting for variability due to both multiples and skips. The degree of variation is the coefficient of variation of the spacing that are classified as singles, and is expressed as:

$$C = S_2/X_{ref} \quad \dots (4)$$

where, S_2 = sample standard deviation of the n_2 observations, and X_{ref} = theoretical spacing.

RESULTS AND DISCUSSION

Development of seed-metering device

Three metering plate cells were designed based on the physical and engineering properties of paddy seeds of three varieties selected (Table 2) such that the cell diameter or length should be 10% greater than the maximum seed dimension and cell depth should be equal to the average seed diameter or thickness (Kepner *et al*. 1978 and Sharma and Pannu 2014). The three seed-metering devices are given in Fig 2. The cell dimensions designed for the three seed-metering plates are furnished in Table 3.

Table 2 Physical and engineering properties of paddy seeds

Variety	Length (mm)	Width (mm)	Thickness (mm)	Mean diameter (mm)
Pusa-1121	12.12	2.38	1.79	3.75
PUSA-44	8.91	2.55	1.94	3.93
BPT-5204	7.83	2.22	1.73	3.11
Mean	9.62	2.4	1.82	3.60

Table 3 Cell dimensions of different seed-metering plates for one-day soaked seed

Cell dimension	Type of cell/groove		
	Slanting	Semi-circular	Rectangular
Length (mm)	11	11	11
Height (mm)	4	4	4
Thickness (mm)	3	3	3
Diameter (mm)	4	4	

Electronic experimental set-up

An electronic laboratory experimental set-up was developed to investigate the influence of the selected levels of variables, viz. peripheral speed of seed-metering disc, cell shape and inclination of seed-metering disc on seed spacing, quality feed index, miss index, multiple index, precision and seed damage (Panning *et al*. 2000, Jayan and Kumar 2003). The electronic sticky-belt metering mechanism comprises main frame, sub-frame for seed-metering box set-up, 2 m endless leather belt with 0.2 m width and 5 mm thickness, 1 hp AC motor with proximity sensor and variable frequency drive unit, DC motor (12 V, 150 W and 150 rpm) and speed controller. An endless 5 mm thick nylon conveyor belt of 2 000 mm length and 200 mm width rolled through a pair of roller of 130 mm diameter was designed and used for this study (Kachman and Smith 1995, Singh *et al*. 2005). The rollers were mounted on 0.25 mm dia. shaft at both ends of the rectangular section with self aligning bearings. The drive to the conveyor belt was obtained with the help of a 1hp AC motor with 100 mm dia. pulley and a V belt. The speed of AC motor was detected by using proximity sensor which was placed against the motor pulley and the other end was connected to the variable frequency drive unit to fix the forward speed of the belt. The DC motor speed was controlled by speed controller and measured by a non-contact tachometer. The forward speed of the belt and seed-metering device rotational speeds considered for study are furnished in the Table 4. Ten numbers of (1.2×0.15×0.02 m) bakelite sheets smeared with grease were fed on the moving conveyor belt to collect the seed for measuring seed spacing.

Laboratory evaluation

Mean spacing: The mean seed spacing was significantly influenced by all the variables under study. The forward speed influenced the mean spacing the most followed by metering system as indicated by the F-values (Table 6). The

a. Slanting shape b. Semi-circular shape c. Rectangular shape

Fig 2 Seed-metering plates developed for evaluation

Table 4 Forward speed and metering device speed calculations

Forward speed (km/h)	Forward speed (m/min)(A)	Number of seeds/min (B=A/0.15)	Roller/ motor (rpm) & frequency (Hz)(C= A/3.14*0.13)	Metering plate speed (rpm) (D=B/18)
1.0	17.0	113	41 (4.2)	6
1.5	25.0	166	61 (4.6)	9
2.0	33.3	222	82 (5.0)	12
2.5	41.7	278	102 (5.4)	15
3.0	50.0	333	123 (5.8)	19

Diameter of belt roller = 13 cm; Number of cells on metering plate = 18.

seed spacing varied from 9.2 to 25.8 cm with mean spacing 15.9 cm and standard error mean of 0.25 for all the metering devices. It was observed that the forward speed, angle of inclination and cell shape significantly influenced the seed spacing at 1% level of significance for three metering plates and all selected paddy varieties. The coefficient of variation for slanting type metering mechanism observed was 10.34% followed by 13.88% and 18.24% for semi-circular and rectangular mechanisms respectively. From the Table 5, it is clear that mean seed spacing increased with increase in forward speed and angle of inclination. This may be due to the reason that at higher speed and higher angle, the metering cell may not be able to carry the seed properly from the hopper (Panning *et al*. 2000, Staggenborg *et al*. 2004, Sahoo and Srivastava 2008 and Patil and Dhande 2015). The observed seed spacing of 14.8 cm close to that of theoretical seed spacing of 15 cm was observed for slanting type metering shape at 35º plate inclination and at a forward speed of 2.0 km/h followed by 14.4 cm and 14.1 cm for semi-circular and rectangular shape, respectively.

Quality of feed index: It is the measure of how often the spacing was close to the theoretical spacing. It decreased with the increase in miss index, multiple index or both. The average quality feed index ranged from 79.3 to 88.1% with average quality feed index of 83.2% and standard error of 0.138 for all three metering devices. The coefficient of variation for slanting type metering mechanism observed was 3.78% followed by 4.59% and 8.56% for semi-circular and rectangular mechanisms, respectively. Statistical analysis showed that the forward speed, angle of inclination and cell shape significantly influenced the feed index at 1% level of significance for selected paddy varieties (Table 5). It was observed that the quality of feed index increased with increase in forward speed from 1.0 km/h to 2.0 km/h and further increase of speed from 2.0 km/h to 3.0 km/h, it decreased. This may be due to the reason that at higher speed and angle of inclination, seed may not have enough time to occupy in the metering cell. Similar results were reported by Kachman and Smith (1995), Sahoo and Srivastava (2008), Bakhtiari and Loghavi (2009), Singh and Mane (2011), Sharma and Pannu (2014), Patil and Dhande (2015). Highest quality feed index of 88.1% was observed for slanting type metering shape at a metering plate inclination of 35º and at a forward speed of 2.0 km/h followed by 86.1% and 83.6% for semi-circular and rectangular shape, respectively.

Multiple index: It is an indicator of more than one seed dropped within a desired spacing. Multiple index was influenced highly by forward speed, metering system and cell shape at 1% level of significance. The multiple index was mostly influenced by forward speed followed by cell size as indicated by the F-values. The mean multiple index and standard error of mean was observed to be 8.96 and 0.136, respectively. The coefficient of variation for slanting type metering mechanism observed was 10.7% followed by 12.0% and 12.15% for semi-circular and rectangular mechanisms, respectively. It was observed that the multiple index decreased with increase in forward speed and angle of inclination for three metering plates. This was due to the difficulty in seed singulation at higher cell speed of the metering plate. At higher cell speed, the exposure time was low for removal of extra seed from the cell. Similar trend was observed by Sahoo and Srivastava (2008), Singh and Mane (2011) and Sharma and Pannu (2014). A multiple index of 6.2 was observed for slanting type metering shape at a metering plate inclination of 35º and at a forward speed of 2.0 km/h followed by 6.9% and 9% for semi-circular and rectangular shape, respectively.

Miss index: It is an indicator of the missing of seed-metering with in a desired spacing. It was influenced highly by all variables of the study. The forward speed influenced the miss index the most followed by angle of inclination as indicated by the F-values. The miss index values ranged from 3.8 to 11.7 with a respective standard mean and standard mean error of 7.68 and 0.125 for all metering devices. The coefficient of variation for slanting type metering mechanism observed was 7.65% followed by 11.54% and 12.18% for semi-circular and rectangular mechanisms, respectively. Statistical analysis showed that the forward speed, angle of inclination and cell shape significantly influenced the miss index at 1% level of significance for selected paddy varieties. It was observed that miss index increased with increase of forward speed and angle of inclination for three metering plates (Table 5). At higher speed, the cell exposure time was less for filling of seed in cell from the hopper. The miss index of 5.7 was observed at optimum forward speed 2.0 km/h and a plate inclination of 35º followed by 7% and 7.4% for semi-circular and rectangular shape, respectively (Panning *et al*. 2000, Singh and Mane 2011, Sharma and Pannu 2014, Patil and Dhande 2015).

Precision: The degree of variation is the coefficient of variation of the spacing, which is classified as singles. The variability due to multiples and skips are not accounted. Lower the value of coefficient of variation in singles better is the performance of the metering system. It was observed that precision was influenced highly by the forward speed at 1% level of significance. The precision values ranged from 4.9 to 22.1 with a general mean and standard error of 12.28 and 0.3 for three metering devices. The coefficient of variation for slanting type metering mechanism observed

Table 5 Performance parameters of seed-metering systems

	Spacing, cm					Quality of feed index					Multiple index					Miss index					Precision					Damage (%)				
	θ_1	θ_2	θ_3	θ_4	θ_5	θ_1	θ_2	θ_3	θ_4	θ_5	θ_1	θ_2	θ_3	θ_4	θ_5	θ_1	θ_2	θ_3	θ_4	θ_5	θ_1	θ_2	θ_3	θ_4	θ_5	θ_1	θ_2	θ_3	θ_4	θ_5
M_1S_1	9.4	10.1	11.2	11.4	13.9	83.5	84.8	86.5	85.8	84.9	12.7	11.4	9.2	7.6	7.6	3.8	3.8	4.3	6.6	7.5	6.8	6.9	11.1	9.0	9.1	0.43	0.45	0.40	0.50	0.74
M_1S_2	10.9	12.2	13.5	14.6	16.5	84.6	85.1	87	86	85.3	10.5	9.7	7.8	6.5	6.7	4.9	5.2	5.2	7.5	8.0	7.9	8.0	20.1	9.9	9.5	0.60	0.82	0.63	1.05	1.44
M_1S_3	12.1	14.2	14.8	16.6	16.6	85.2	85.7	88.1	86.7	85.1	9.2	8.3	6.2	6.3	6.1	5.6	6.0	5.7	7.0	8.8	9.8	11.6	22.0	11.0	10.4	0.62	0.44	0.38	1.42	2.63
M_1S_4	15.9	15.9	16.3	16.6	16.7	83	84.3	86.2	85.5	84.3	9.4	8.6	7.0	6.2	6.0	7.6	7.1	6.8	8.3	9.7	11.3	16.3	20.9	12.1	11.2	1.44	1.69	1.44	3.07	3.73
M_1S_5	17.4	18.9	19.2	22.5	25.0	82.2	83.8	85.6	84.6	83.8	9.1	8.4	6.5	6.3	6.0	8.7	7.8	7.9	9.1	10.2	13.8	20.4	21.4	13.5	12.4	3.08	4.18	3.02	4.31	4.39
M_2S_1	9.6	10.3	12.4	16.6	20.1	82.2	83.1	85	84.5	84.2	12.9	11.4	9.8	8.3	7.6	4.9	5.5	5.2	7.2	8.2	7.0	8.3	10.3	9.2	8.7	0.46	0.48	0.43	0.53	0.77
M_2S_2	11.1	11.4	12.7	16.7	17.3	83.3	84	84.4	84.6	83.9	11.4	10.4	9.4	7.3	7.3	5.3	5.6	6.2	8.1	8.8	9.1	9.2	18.3	13.1	12.7	0.63	0.85	0.66	1.08	1.47
M_2S_3	12.5	14.1	14.4	16.7	17.4	83.9	84.4	86.1	84.5	83.6	10.2	9.6	6.9	7.0	6.6	5.9	6.0	7.0	8.5	9.8	10.0	10.8	20.3	10.2	9.6	0.87	0.97	0.72	1.45	2.66
M_2S_4	16.4	16.6	17	17.4	19.2	81.7	83.6	84.3	84.2	83.2	10.3	8.3	7.7	6.8	6.4	8.0	8.1	8.0	9.0	10.4	10.8	17.7	19.7	16.3	15.0	1.47	1.72	1.47	3.10	3.76
M_2S_5	18.9	19.3	19.8	23.2	25.7	81	82.6	83.3	82.9	82.5	10.1	8.3	7.1	6.9	6.2	8.9	9.1	9.6	10.2	11.3	12.3	18.5	19.9	17.8	13.6	3.11	4.21	3.05	4.34	4.42
M_3S_1	12.1	13.5	13.1	14.2	15.7	79.3	80.9	82.6	81.7	80.4	14.7	13.1	11.6	10.3	9.6	6.0	6.0	5.9	8.0	10.0	4.9	5.0	9.2	7.2	7.3	0.84	0.86	0.81	0.91	1.15
M_3S_2	10.7	10.9	14.0	15.6	15.8	80.4	81.0	83.0	82.2	81.0	13.1	12.3	10.4	9.2	9.4	6.5	6.7	6.6	8.6	9.5	6.0	12.1	18.2	8.1	7.7	1.01	1.23	1.04	1.46	1.85
M_3S_3	13.5	13.7	14.1	15.9	16.1	81.0	81.5	83.6	82.6	81.8	11.9	11.1	9.0	8.2	8.4	7.1	7.4	7.4	9.2	9.8	7.9	12.7	18.1	9.1	8.6	1.25	1.35	1.10	1.83	3.04
M_3S_4	15.8	16.1	16.6	17.1	17.8	78.8	80.0	82.1	81.4	80.4	11.6	11.4	9.6	8.8	8.5	9.6	8.6	8.3	9.8	11.1	9.4	14.5	19.3	10.3	9.3	1.85	2.10	1.85	3.48	4.14
M_3S_5	19.7	21.1	22.6	23.6	25.5	78.0	80.4	81.5	80.5	79.9	11.0	10.6	9.1	8.9	8.4	11.0	9.0	9.4	10.6	11.7	11.9	18.6	19.5	11.7	10.5	3.49	4.59	3.43	4.72	4.80

Metering system (M_1-Slanting cell shape; M_2-Semi-circular cell shape; M_3-Rectangular cell shape); Metering plate inclination (θ_1-25°; θ_2-30°; θ_3-35°; θ_4-40°; θ_5-45°); Forward speed (S_1-1 km/h; S_2-1.5 km/h; S_3-2 km/h; S_4-2.5 km/h; S_5-3 km/h).

Table 6 F-values for mean performance parameters of seed-metering mechanisms

Source	F value				
	Mean spacing	Quality feed index	Multiple index	Miss index	Precision
R	0.415	0.005	0.690	0.641	0.423
M	58.15**	32161.52**	37586.32**	4602.68**	115.34**
θ	453.38**	4390.50**	32459.01**	9725.51**	692.03**
S	1343.79**	2061.87**	7169.23**	11019.8**	533.57**
M×θ	13.90**	62.32**	60.07**	45.57**	17.77**
M×S	18.65**	3.196**	7.40**	9.10**	6.67**
θ×S	17.68**	246.67**	342.74**	230.34**	42.99**

**Significant at 1% level, θ: Inclination of metering device, M: Metering shape of cell, S: Forward speed.

was 8.1% followed by 11.19% and 14.22% for semi-circular and rectangular mechanisms, respectively. The precision decreased with increase in forward speed and for plate inclination, it increased initially upto optimum value and later decreased as shown in Table 5 (Sharma and Pannu 2014, Raspinder Sing *et al*. 2015, Patil and Dhande 2015). The highest precision of 22.0 for slanting metering shape was observed at a plate inclination of 35^{o} and a forward speed of 2.0 km/h followed by 20.3 and 18.1 for semi-circular and rectangular shape, respectively.

Seed damage: It was influenced significantly by all the variables of the study at 1% level of significance. The metering system influenced seed damage the most by forward speed and angle of inclination as indicated by the F-values. The general mean and standard error of seed damage was 1.89% and 0.09, respectively. The coefficient of variation for slanting type metering mechanism observed was 8.88 % followed by 14.73% and 18.71% for semi-circular and rectangular mechanisms, respectively. It was also observed that the seed damage increased with increase in forward speed and angle of inclination as shown in Table 5. The lowest seed damage of 0.38% was observed at a forward speed of 2.0 km/h and plate inclination of 35^{o} followed by 0.72% and 1.1% for semi-circular and rectangular shape, respectively (Panning *et al*. 2000, Sharma and Pannu 2014, Patil and Dhande 2015).

Optimization of metering mechanism

The final selection of metering system of paddy planter was carried out on the basis of all the parameters, i.e. seed spacing, quality of feed index, multiple index, miss index, degree of variation and seed damage. The highest quality of feed index was observed to be 88.1% at a forward speed of 2 km/h for slanting cell shape compared to semi circular (86%) and rectangular slot shape (83.6%). The least multiple index and the least miss index was also observed to be 6.1% and 5.7% at a forward speed of 2 km/h in case of slanting cell shape metering plate. The mean spacing of 14.8 cm was observed for slanting shape cell metering plate at a forward speed of 2 km/h for theoretical spacing of 15 cm compared to semi circular (14.4 cm) and rectangular slot shape (14.1 cm). The highest precision was observed to be 22.0 for a forward speed of 2 km/h for slanting shape plate metering system. The metering system and cell speed influenced the seed damage the most. The least visible damage was observed 0.38% which is within 0.5% for slanting plate metering system compared to other metering plates as furnished in Table 5 (Panning *et al*. 2000, Singh and Mane 2011, Sharma and Pannu 2014, Patil and Dhande 2015). Hence, considering all the five parameters and the average spacing, the inclined plate metering system was selected for planting soaked paddy seed.

It may be concluded that mean seed spacing, miss index and seed damage were found to increase with increase in forward speed and angle of inclination while multiple index decreased with increase in forward speed and angle of inclination for all tested metering plates. The precision decreased with increase in forward speed while with increase in angle of inclination, it increased initially upto optimum value and later decreased. The mean seed spacing of 14.8 cm which is close to theoretical seed spacing of 15 cm, highest quality feed index of 88.1% , lowest miss index of 6.1% and minimum seed damage of 0.38% was observed in slanting type metering plate at an angle of 35^{0} with the horizontal and at a forward speed (belt speed) of 2 km/h. Summarizing, the slanting type metering system with angle of inclination 35^{0} and at a forward speed of 2 km/h could give best results in direct-seeding of paddy seeds with precision planter in uplands.

REFERENCES

Datta R K. 1974. Development of some seeders with particular reference to pneumatic seed drills. *The Harvester*, Indian Institute of Technology, Kharagpur, India **16**: 26–9.

Grewal Raspinder Singh, Khurana Rohinish, Manes G S, Dixit Anoop and Verma Aseem. 2015. Development and evaluation of tractor operated inclined plate metering device for onion seed planting. *Agriulture Engineering International* **17**(2): 31–7.

International Standardization Organization. 1984. Sowing equipment- Test methods- Part I: Single seed drills (Precision drills), 7256/1. Geneva, Switzerland.

Jayan P R and Kumar V J F. 2004. Planter design in relation to the physical properties of seeds. *Journal of Tropical Agriculture* **42** (1/2): 69–71.

Kachman S D and Smith J A. 1995. Alternative measures of accuracy in plant spacing for planters using single seed-metering. *Trans. ASAE* **38**(2): 379–87.

Kepner R A, Roy Bainer R and Barger E L. 1978. *Principles of Farm Machinery,* 3rd edition. AVI publishing company Inc., Westport, C T:

Li F H, Diao P S, Du R C, Cui Q, Zhang Y P and Li T. 2013. Development and test of no-tillage fertilization planter with embedded spoon disc helm wheel. *Trans. CSAE* **29**(19): 16–23.

Li Z Q, Yu J Q and Feng Z R. 2015. Simulation and performance analysis of a soybean seed-metering device using discrete element method. *Sensor letters* **11**(6): 1 217–22.

Patil A S and Dhande K G. 2015. Development of bullock drawn dry paddy seed cum fertilizer dril. *International Journal of Science and Applied Research* **2**(3): 14–21.

Panning J W, Kocher M F, Smith J A and Kachman S D. 2000. Laboratory and field testing of seed spacing uniformity for sugar-beat planters. *Applied Engineering in Agriculture* **16**(1): 7–13.

Ryu H I and Kim K U. 1998. Design of roller type metering device for precision planting. *Trans. ASAE* **41**(4): 923–30.

Singh R C, Singh G and Saraswat D C. 2005. Optimization of design and operational parameters of a pneumatic seed-metering device for planting cotton seeds. *Biosyst. Eng.* **92**(4): 429–38.

Sharma Sushil and Pannu C J S. 2014. Development and evaluation of seed-metering system for water soaked cotton seeds. *Agriculture Mechanization in Asia, Africa and Latin America* **45**(1): 41–7.

Singh T P and Mane D M. 2011. Development and laboratory performance of an electronically controlled metering mechanism for okra seed. *Agriculture Mechanization in Asia, Africa and Latin America* **42**(2): 63–69.

Yao J. 2004. Preliminary discussion the extension and developing prospect of corn precision metering technology. *Journal of Maize Science* **12**: 89–91.

Zeng S, Tang H T, Luo X W, Ma G H, Wang Z M and Zang Y. 2012. Design and experiment of precision rice hill-drop drilling machine for dry land with synchronous fertilizing. *Trans. ASAE* **28**(20): 12–19.