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Laboratory studies on performance of positive feed metering devices for band placement of fertilizers

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ABSTRACT

The effect of shape, number of grooves and speed of fluted roller metering device was studied on metering characteristics of urea for intermittent and continuous band placements. For intermittent band placement, 6 groove rollers of U-shape, J-shape and eccentric–circular shape were used whereas 12 groove rollers of U-shape and eccentric circular shape were selected for continuous band placement. The principle of two stage metering of fertilizer was employed using a star type agitator running at a constant speed of 0.26 m/s and a fixed circular opening of 13.5 mm diameter in the hopper at the first stage and varying speeds of 28,42, 52, 68 and 85 rpm for positive feed fluted rollers at the second stage. The results showed higher percentage deposition of urea in 100 mm bands with J-shape fluted roller followed by eccentric circular and U-shape fluted rollers. In case of continuous band placement, the coefficient of variation ranged from 20.11 to 11.17% with eccentric circular shape and 15.79 to 9.45% with U-shape fluted roller with increase in speed from 28 to 85 rpm.

The traditional methods for application of fertilizers generally include either broadcasting over the surface of field or placement in the soil. The broadcasting is done mainly with centrifugal broadcasters which seldom give the coefficient of variations within 20 to 25% (Reed and Wacker 1970, Pingen and Brinkman 1980). The basal application of fertilizers at the time of sowing with planters and seed drills has, however, been found most effective. The localized placement of fertilizer bands near seeds at the time of planting favours early stimulation of seedlings and results in more effective utilization of plant nutrients (Bainer et al. 1972, Bulaev 1976 and Gills 1976). Various methods of placement of fertilizers around the seed which have been reported are ring, continuous and intermittent bands. The later two placements could be obtained with the fertilizer drills. The continuous band placement is required for crops having less than 150 mm plant to plant spacing whereas in crops with wider spacings such as cotton, castor, maize etc., the aim is to apply the fertilizer near seeds in intermittent bands which give better results in terms of higher fertilizer use efficiency by plants.

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Most of the commercially available fertilizer applicators in India use gravity feed with adjustable openings and agitators. These machines are relatively easy to manufacture and simple to operate but give uneven application of fertilizers primarily because of physical properties of fertilizers and vibration of machines in the field. The use of positive feed fertilizer metering device has been suggested to reduce unevenness in application rate of fertilizers (Dehpour, 1986). Fluted roller type metering devices are very common on Indian grain drills for sowing of seeds but these have also been tried for placement of fertilizers (Bansal et al., 1983). Therefore, considering the commercial use of fluted roller type metering device on ferti-seed drills, the present study was undertaken to observe the effects of shape, number of grooves and speed of metering rollers on metering characteristics of fertilizer for intermittent and continuous band placements. Urea was selected in this study because of uniform size of granules.

MATERIALS AND METHODS

The experimental set-up

The experimental set-up consisted of two stage metering of fertilizers (Fig.1). The first stage consisted of a frame, a hopper with adjustable circular openings and a star type agitator as suggested by Dehpour et al. (1988). The agitator shaft was driven at two speeds of 0.261 m/s for urea and 0.052 m/s for di-ammonium phosphate and super phosphate with the help of sprockets and chains. The second stage metering system was provided with a housing for mounting different types of positive feed metering roller. The rollers could be driven at five different speeds ranging from 28 to 85 rpm with the help of sprockets and a chain mounted on the metering shaft. The clearance between the first and second stage metering systems could be varied upto 150 mm

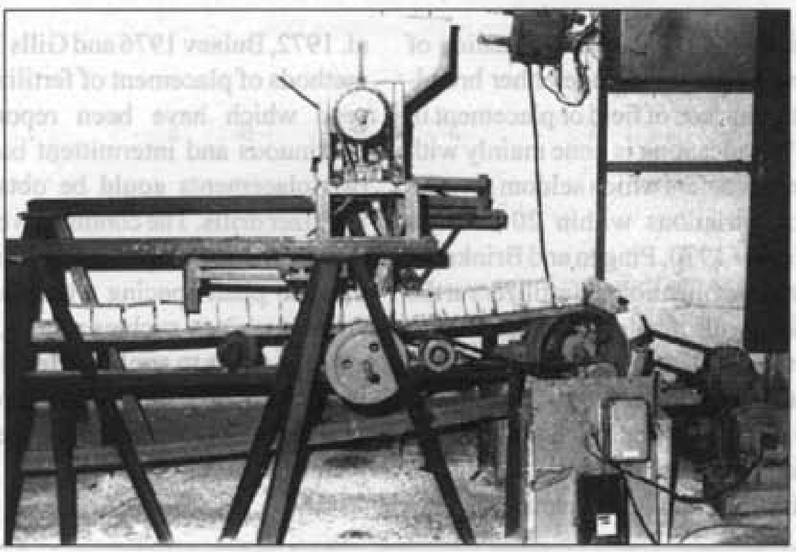


Fig. 1 A view of experimental set-up used in investigation

by adjusting the fertilizer hopper on adjustable screws. Provision was made to change the inclination of fertilizer delivery tube from 0° to ±60° from the vertical plane along the longitudinal direction in steps of 15°. The exposure length of metering rollers could be adjusted according to application rate of fertilizers. The complete set-up was mounted over an endless flat conveyor belt of 300 mm width and 11 m length as shown in Fig.1. The fertilizer samples from metering rollers were collected in 40 boxes of 50 x 100 x 40 mm size mounted on the conveyor belt. These boxes were fabricated from 22 gauge galvanized iron sheet. The inside of each box was coated with detachable polythene sheet to check bouncing and spill over of fertilizer granules. A 1.5 kW variable speed electric motor was used to drive the complete system. The motor drove the conveyor belt at a constant speed of 1.39 m/s which in turn transmitted power to the metering as well as agitator shafts through sprockets and chains.

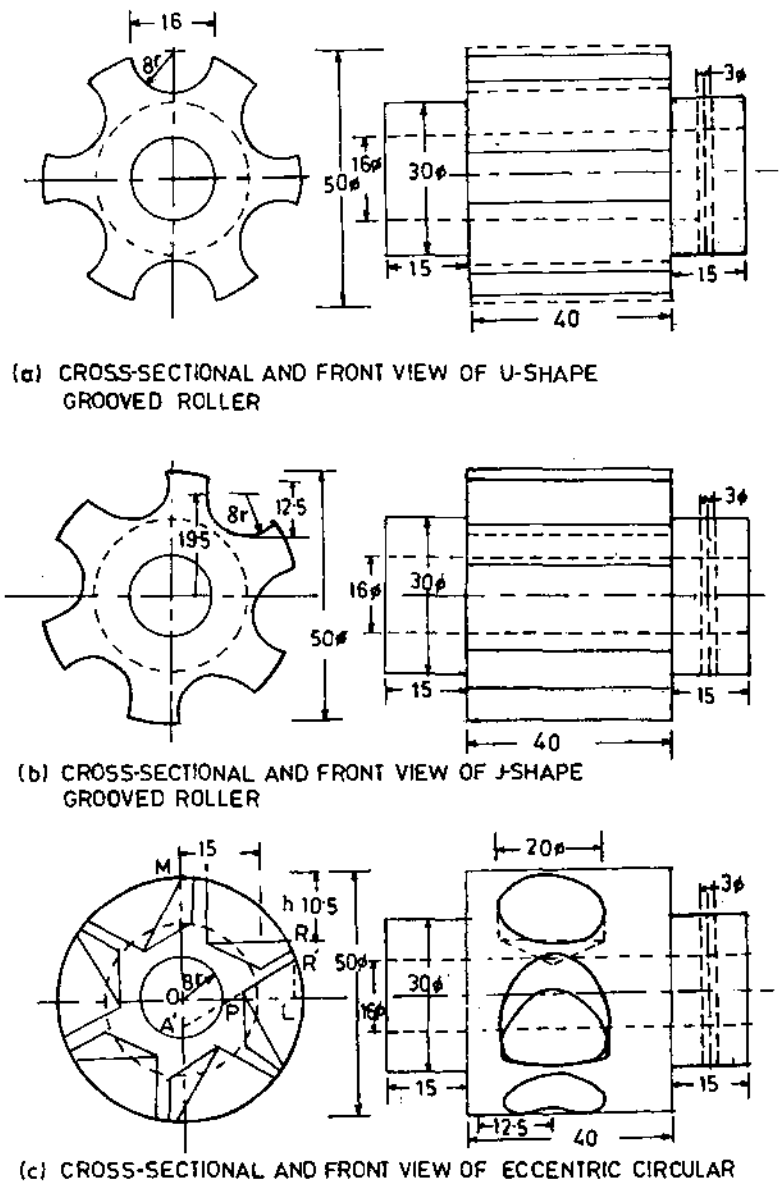
Two sets of metering rollers were fabricated. The first set consisted of 6-groove rollers having U-shape flutes, J-shape flutes and eccentric circular shape grooves and were used for intermittent band placement (Fig.2). The second set consisted of rollers of 12 grooves with U-shape fluted and eccentric circular shape, and used for continuous band placement (Fig.3).

Experimental technique

The performance of metering rollers was studied with urea having bulk density and moisture content of 0.714 g/cc and 5.85%, respectively. The angle of intergranular friction, particle mean-weight-diameter and fineness modulus were determined as 36.5°, 1.48 mm and 4.72, respectively. Prior to conducting the main experiment, preliminary investigations were carried out to determine the clearance between the metering roller and the fertilizer hopper as well as the inclination of fertilizer tube for intermittent and continuous band placements. The height of hopper above the metering roller within the range of 50 to 150 mm showed no significant effect on the distribution pattern of urea and therefore, a clearance of 100 mm was selected. Similarly, the studies on inclination of delivery tube from 0° to ±60° from the vertical plane along the direction of motion of the belt gave best results at 0° and 45° backward for intermittent and continuous bands, respectively. The agitator speed of 0.26 m/s (35 rpm) and the hopper opening of 13.5 mm were kept constant. The speed of metering rollers was varied from 28, 42, 52, 68 and 85 rpm corresponding to 0.073, 0.110, 0.136, 0.178 and 0.223 m/s, respectively.

The distribution pattern of urea was first observed visually by dropping the fertilizer over the conveyor belt greased to a length of 4 m and then measuring the total length of bands and hill spacing for comparison. The fertilizer was also collected in 40 sample boxes mounted on the conveyor belt for the analysis of discharge rate and uniformity of distribution pattern.

The pattern obtained in case of intermittent band placement was cyclic and the number of peaks were dependent on the speed of the metering rollers. Since the basic concept of applying the fertilizer in intermittent bands is to place it close to the seed, therefore, the percentage of material dropped in a specified band to that of total material dropped at each

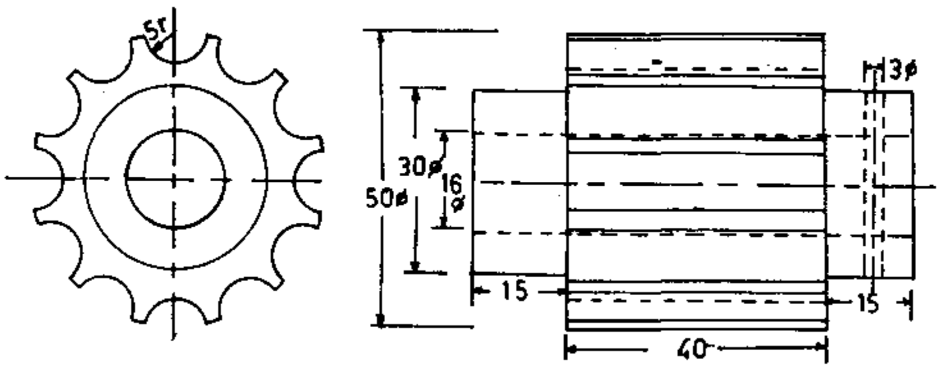


(a) CROSS-SECTIONAL AND FRONT VIEW OF U-SHAPE GROOVED ROLLER

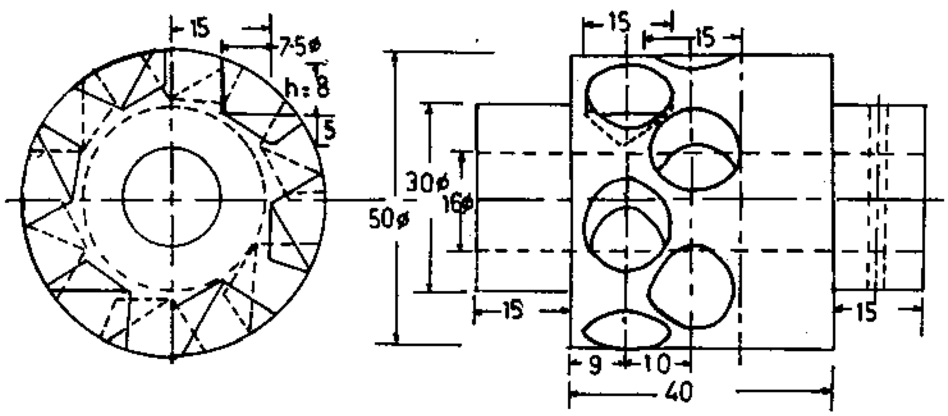
(b) CROSS-SECTIONAL AND FRONT VIEW OF J-SHAPE GROOVED ROLLER

(c) CROSS-SECTIONAL AND FRONT VIEW OF ECCENTRIC CIRCULAR GROOVED ROLLER

Fig. 2 Six groove rollers for intermittent band placement



(a) CROSS-SECTIONAL AND FRONT VIEW OF U-SHAPE GROOVED ROLLER



(b) CROSS SECTIONAL AND FRONT VIEWS OF ECCENTRIC CIRCULAR GROOVED ROLLER

Fig. 3 Twelve grooved rollers for continuous band placement hill was determined for comparison. The length of the specific band for analysis was chosen as 100 mm as recommended by Bainer et al. (1972). They suggested that the lateral placement of fertilizers should be at a distance of 37 to 100 mm from the seed row. As the length of each sample box was 50 mm, therefore, the amount of material dropped in two central boxes of a hill was summed-up to determine the amount in a 100 mm band and compared to ascertain the best shape of metering roller.

The uniformity of placement of dry fertilizer with spreaders has been tested mainly by using the coefficient of variation for distribution pattern (Reed and Wacker, 1970), Bansal and Leeuwestein, 1989). Davis (1966), presented the analysis of parameters for describing the uniformity of water distribution from a sprinkler by using the indices such as Christiansen's coefficient of uniformity, statistical coefficient of uniformity and pattern efficiency. The uniformity of placement of urea in 40 sample boxes was, therefore, analyzed by determining the coefficient of variation as well as Christiansen's coefficient of uniformity which was determined by using the following relationship:

$$C_u = (1 - \frac{\Sigma |d|}{mn}) \times 100 \qquad ...(1)$$

where, C_u is Christiansen's coefficient of uniformity,%; $|d|$ is absolute value of the deviation of the individual observation of weight of fertilizer dropped in each box from the mean value, g; m is mean weight of material collected in 40 boxes, g and n is number of boxes.

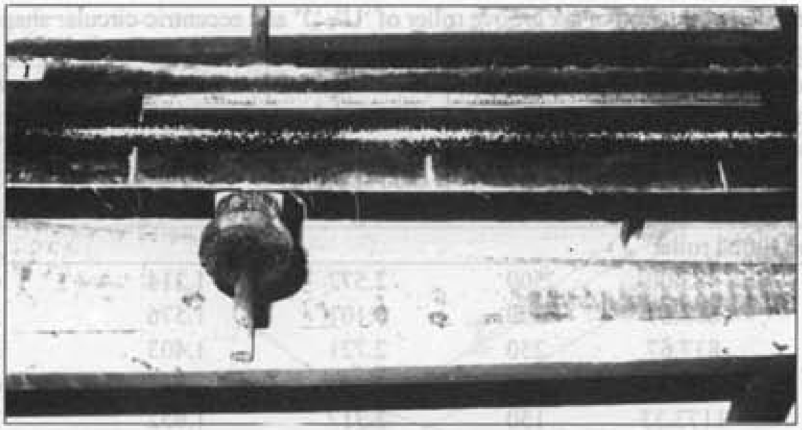
The Chi- square values for Bratlett's test were determined to test the homogeneity of variance of distribution patterns of urea at different speed of rollers.

RESULTS AND DISCUSSION

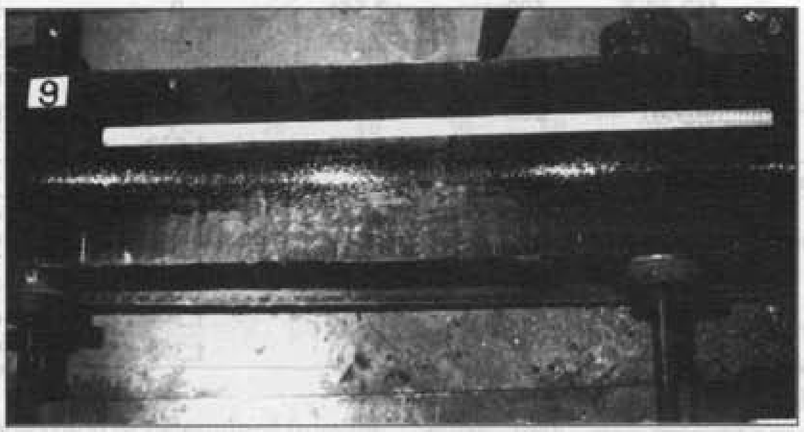
Metering characteristics of urea for intermittent band placement

The distribution pattern of urea with six groove metering rollers of U-shape, J-shape and eccentric circular shape as observed on a greased conveyor belt is illustrated in Fig.4. It was found that the size of band at each hill was largest for U-shape followed by eccentric circular and J-shape rollers. Maximum amount of urea was dropped in nearly 100 mm length at the center of a band which was well within the recommended range of application of fertilizers in reference to seeds (Bainer et al., 1972). The hill to hill spacings of bands were found to be 497, 346, 255, 203 and 115 mm corresponding to the metering roller speed of 28, 42, 52, 68 and 85 rpm, respectively. These spacings could cover the entire range of plant to plants spacing of crops such as cotton (350-450 mm), caster (450 mm), sugarcane (300 mm), maize (200-250 mm) and sunflower (200 mm).

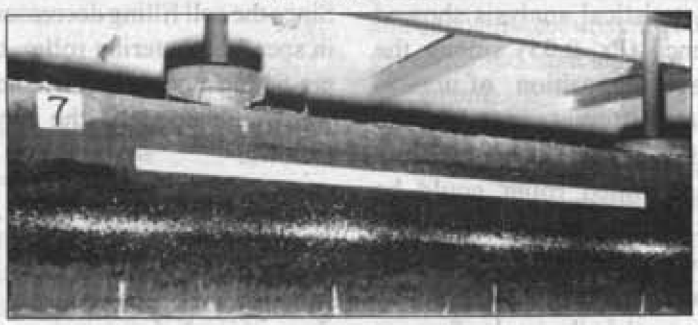
For the quantitative analysis of distribution pattern, the percentage distribution of urea in 100 mm bands at each hill was determined which showed maximum percentage deposition of urea with J-shape (Table 1). At the lowest speed of metering roller (28 rpm), the deposition of urea with J-shape roller was approximately 13% higher than other shapes. This difference was reduced to 4.80% and 0.46% at the maximum speed of 85 rpm with



A. U Shape roller



B. J Shape roller



C. Eccentric circular shape roller

Fig. 4 Distribution patterns of urea at 42 rpm of six groove rollers

Table 1 Performance evaluation of six groove roller of 'U', 'J' and eccentric-circular shapes at different metering speeds for intermittent band placement of fertilizer

Sl. No.	Speed of metering rollers, rpm	Discharge rate, g/min	Observed hill spacing, mm	Average material dropped at each spacing, g	Average material dropped in 100 mm band, g	Average percent material dropped in 100 mm range of band, %
i)	U-shape fluted roller					
1	28	483.00	500	2.572	1.214	47.20
2	42	698.67	350	3.101	1.576	50.82
3	52	837.67	250	2.721	1.403	57.55
4	68	1011.67	200	2.363	1.535	65.50
5	85	1173.33	150	2.717	1.652	74.45
ii)	J-shape fluted roller					
1	28	452.67	500	2.541	0	53.52
2	42	682.33	350	2.617	1.588	60.69
3	52	862.00	250	2.638	1.677	63.56
4	68	1069.67	200	2.396	1.597	66.67
5	85	1284.33	150	2.353	1.838	78.00
iii)	Eccentric-circular groove roller					
1	28	402.00	500	2.148	1.013	47.16
2	42	586.33	350	2.113	1.166	55.18
3	52	713.33	250	2.073	1.201	57.97
4	68	880.00	200	1.988	1.347	67.74
5	85	1105.00	150	1.793	1.392	77.64

U-shape and eccentric circular groove rollers, respectively. The statistical analysis showed significant difference ($P< 0.05$) among the means of percentage deposition of urea in bands obtained at different speeds. The maximum deposition of urea in the required bands with J-shape fluted roller could be attributed to quick delivery of material by the straight wall of the groove whose slope with respect to the horizontal plane at delivery position becomes more than the angle of repose of urea.

The relationship between the discharge rate and speed of metering rollers is illustrated in Fig.5. Since the cell filling decreases with the increase in speed of metering roller, the discharge rate prediction models for different speeds of rollers were developed of the form $Q = a N^b$ as follows:

$Q = 34.50 (N)^{0.80}$
for U-shape, $R^2 = 0.99$ ...(2)

$Q = 20.01 (N)^{0.94}$
for J-shape, $R^2 = 0.98$ ...(3)

$Q = 20.20 (N)^{0.90}$
for eccentric circular, $R^2 = 0.99$ ...(4)

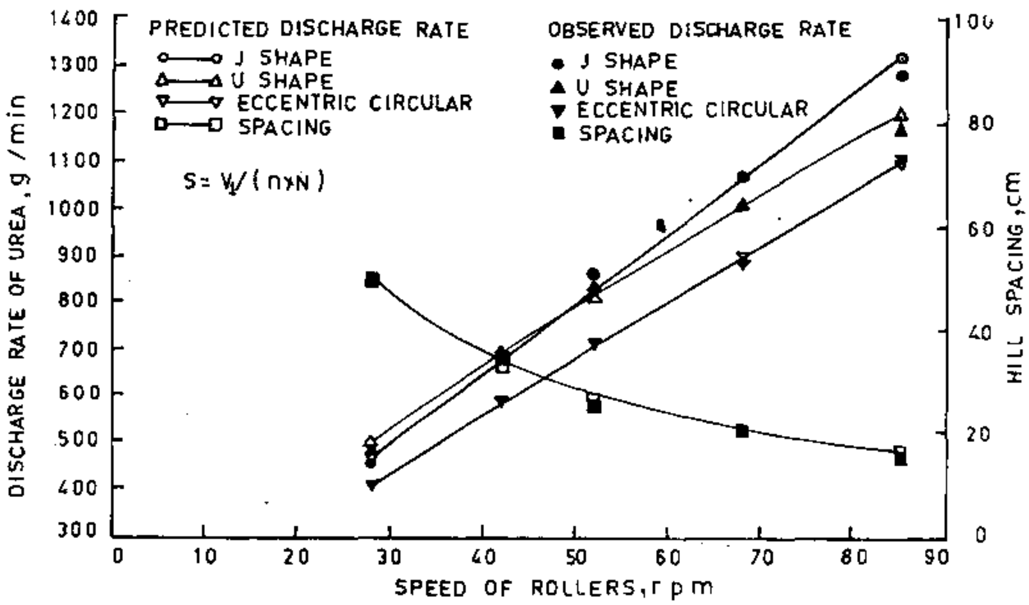


Fig.5 Effect of speed of six groove metering rollers of U-shape, J-shape and eccentric circular grooves on discharge rate of urea and hill spacing

Where,
Q = discharge rate of urea, g/min
N = speed of metering roller, rpm.

The hill spacing could be determined from the following relationship :

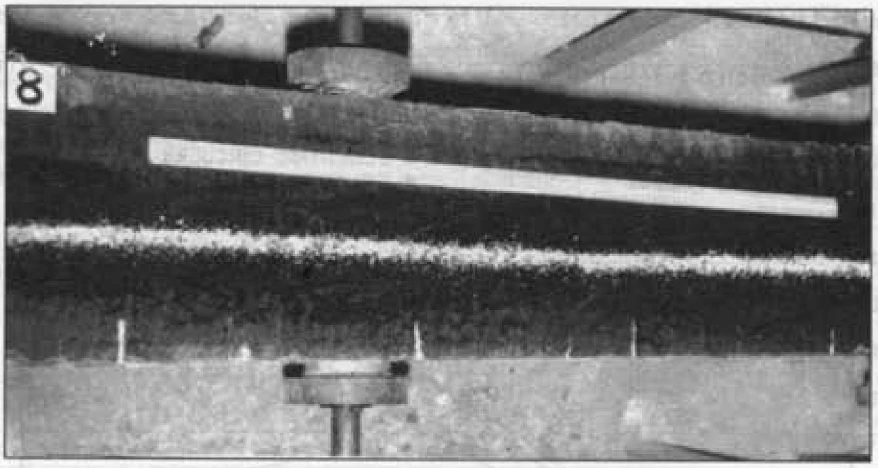
$$S = V_f / (N.n) \qquad \ldots(5)$$

Where,
S = hill spacing, cm;
V_f = forward speed of the machine, cm/min;
n = number of grooves on metering roller
N = speed of metering roller, rpm

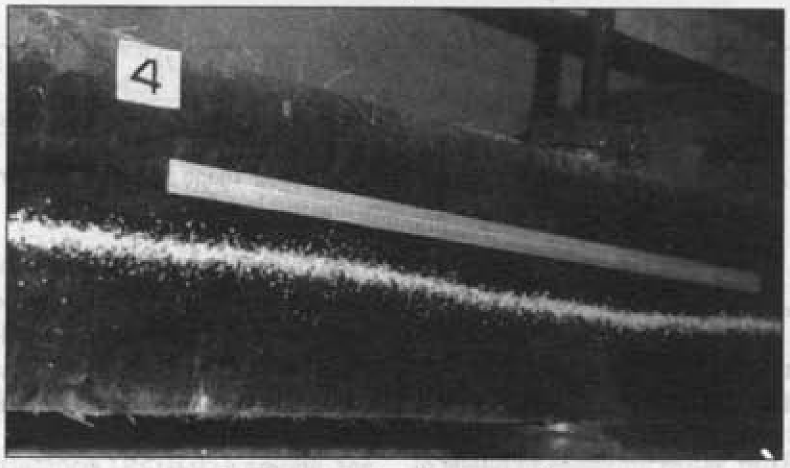
The values of constant 'b' for J-shape fluted and eccentric circular groove rollers was 0.94 and 0.90, respectively which revealed that increase in speed of the rollers did not affect the cell filling substantially. However, for U-shape fluted roller, the value of coefficient 'b' was 0.80 which showed a decrease in cell fill with increase in the speed of roller. It could, therefore, be postulated that the J-shape fluted roller with six grooves gave the best performance in terms of maximum cell filling and deposition of urea in 100 mm bands. It also gave desired spacings for intermittent band placement.

Metering characteristics of urea for continuous band placement

The distribution pattern of urea with U-shape fluted and eccentric circular shape rollers with twelve grooves at a speed of 85 rpm are shown in Fig.6. It was found that the distribution pattern was comparatively more uniform with U-shape fluted roller.



A. U Shape roller



B. Eccentric circular shape roller

Fig. 6 Continuous band placement of fertilizer with 12 grooves roller at 85 rpm

The average material dropped in each box, coefficient of variation and Christiansen's coefficient of uniformity are presented in Table 2 for different speeds of rollers. The average urea dropped in the sample boxes ranged from 0.18 to 0.480 g with U-shape fluted and 0.20 to 0.47 g with eccentric circular groove rollers with increase in speed from 28 to 85 rpm. The coefficient of variation ranged from 11.17 to 20.11% and 9.45 to 15.79% with eccentric circular groove and U-shape rollers, respectively. The Christiansen's coefficient of uniformity increased from 82.16 to 90.27% with eccentric circular groove and 86.43 to 91.45%

Table 2 Performance evaluation of twelve groove rollers of U-shape and eccentric circular shape for continuous band placement of fertilizer

Sl. No.	Speed of metering rollers, rpm	Discharge rate, g/min	Average of material dropped in each box, g	Standard deviation, g	Coefficient of variation, %	Christiansen's coefficient of uniformity, %
i) U-shape fluted roller						
1	28	317.17	0.178	0.0281	15.79	86.43
2	42	424.00	0.227	0.0344	15.16	87.78
3	52	517.00	0.303	0.3890	12.84	89.65
4	68	692.00	0.374	0.0367	9.82	91.58
5	85	815.00	0.480	0.4540	9.45	91.54
ii) Eccentric-circular groove roller						
1	28	375.66	0.195	0.0392	20.11	82.16
2	42	492.66	0.277	0.0565	20.41	82.94
3	52	564.33	0.305	0.0476	15.61	87.25
4	68	685.00	0.366	0.0528	14.43	88.51
5	85	833.33	0.472	0.0528	11.17	90.27

with U-shape rollers with increase in speed. The statistical analysis showed significant difference ($P< 0.05$) among variances in distribution of urea by the rollers. The analysis showed that U-shape fluted groove roller gave better results in terms of higher uniformity of distribution. However, the distribution of urea in 40 sample boxes and Chi-square values (Table 3) as determined from Bartlett's test of homogeneity of variances for different speeds of rollers, showed no significant difference. This indicated that both the rollers could deliver uniform and continuous band of urea in the speed range of 28 to 85 rpm and the speed of metering rollers could be varied to obtain different application rate of urea. The discharge rate prediction models for different speeds of rollers were found as follows:

(i) U-shape fluted 12 groove roller

$$Q = 16.886 N^{0.87} \quad R^2 = 0.993 \qquad ...(6)$$

(ii) Eccentric circular shape 12 groove roller

$$Q = 34.99 N^{0.71} \quad R^2 = 0.997 \qquad ...(7)$$

Where,
Q is discharge rate of urea, g/min
N is speed of metering roller, rpm.

The problem of sticking of urea was, however, observed with U-shape fluted groove roller which required frequent cleaning after each set of experiment. This would necessitate the use of a cleaning device either in the form of a brush or other similar kind when recommended to be used on ferti-drills. Contrary to this, the eccentric circular groove has got self-cleaning characteristics.

CONCLUSIONS

From the present study the following conclusions have emerged:

a) J-shape fluted roller with six grooves gave best performance as compared to U-shape

Table 3. Distribution of urea in 40 collection boxes and their Chi-square values for U-shape fluted and eccentric circular shape 12-groove rollers at different speeds

Box No.	Distance of each box from reference point, cm	Distribution of urea in boxes, g									
		Speed of metering roller, rpm									
		28		42		52		68		85	
1	2	3	4	5	6	7	8	9	10	11	12
1	5	0.163	(0.197)*	0.224	(0.349)	0.387	(0.281)	0.330	(0.306)	0.525	(0.513)
2	10	0.122	(0.239)	0.245	(0.332)	0.218	(0.319)	0.416	(0.348)	0.450	(0.404)
3	15	0.223	(0.165)	0.202	(0.314)	0.328	(0.295)	0.420	(0.365)	0.490	(0.524)
4	20	0.129	(0.172)	0.218	(0.304)	0.219	(0.205)	0.382	(0.307)	0.428	(0.508)
5	25	0.151	(0.245)	0.211	(0.278)	0.291	(0.341)	0.358	(0.412)	0.423	(0.515)
6	30	0.155	(0.213)	0.193	(0.213)	0.334	(0.286)	0.382	(0.401)	0.438	(0.505)
7	35	0.144	(0.181)	0.205	(0.313)	0.332	(0.356)	0.356	(0.307)	0.446	(0.405)
8	40	0.173	(0.164)	0.258	(0.370)	0.353	(0.323)	0.357	(0.403)	0.515	(0.541)
9	45	0.156	(0.145)	0.203	(0.231)	0.290	(0.222)	0.292	(0.314)	0.500	(0.427)
10	50	0.139	(0.162)	0.205	(0.365)	0.302	(0.227)	0.322	(0.334)	0.448	(0.538)
11	55	0.195	(0.242)	0.225	(0.279)	0.315	(0.294)	0.366	(0.393)	0.450	(0.449)
12	60	0.139	(0.235)	0.272	(0.182)	0.305	(0.247)	0.390	(0.409)	0.423	(0.420)
13	65	0.208	(0.175)	0.196	(0.281)	0.250	(0.284)	0.383	(0.435)	0.400	(0.429)
14	70	0.180	(0.165)	0.181	(0.286)	0.300	(0.263)	0.304	(0.346)	0.454	(0.449)
15	75	0.201	(0.217)	0.192	(0.207)	0.280	(0.322)	0.406	(0.350)	0.449	(0.402)
16	80	0.217	(0.245)	0.184	(0.227)	0.370	(0.319)	0.432	(0.461)	0.521	(0.536)
17	85	0.154	(0.139)	0.179	(0.284)	0.316	(0.377)	0.413	(0.358)	0.531	(0.420)
18	90	0.216	(0.150)	0.227	(0.269)	0.335	(0.354)	0.373	(0.328)	0.557	(0.528)
19	95	0.206	(0.260)	0.217	(0.278)	0.289	(0.405)	0.409	(0.296)	0.528	(0.514)

Contd....

1	2	3	4	5	6	7	8	9	10	11	12
20	100	0.215	(0.264)	0.205	(0.368)	0.322	(0.406)	0.411	(0.379)	0.530	(0.489)
21	105	0.166	(0.138)	0.191	(0.272)	0.283	(0.327)	0.380	(0.328)	0.510	(0.418)
22	110	0.197	(0.185)	0.189	(0.220)	0.278	(0.348)	0.330	(0.321)	0.456	(0.500)
23	115	0.194	(0.144)	0.194	(0.179)	0.324	(0.257)	0.340	(0.343)	0.401	(0.471)
24	120	0.135	(0.139)	0.265	(0.188)	0.305	(0.377)	0.352	(0.419)	0.410	(0.465)
25	125	0.205	(0.201)	0.205	(0.215)	0.321	(0.301)	0.332	(0.483)	0.522	(0.509)
26	130	0.166	(0.206)	0.257	(0.224)	0.342	(0.361)	0.386	(0.342)	0.524	(0.571)
27	135	0.165	(0.203)	0.310	(0.302)	0.347	(0.271)	0.400	(0.324)	0.500	(0.432)
28	140	0.213	(0.170)	0.208	(0.299)	0.286	(0.259)	0.353	(0.357)	0.422	(0.487)
29	145	0.193	(0.160)	0.307	(0.304)	0.256	(0.326)	0.385	(0.246)	0.499	(0.437)
30	150	0.170	(0.215)	0.228	(0.206)	0.265	(0.294)	0.338	(0.327)	0.481	(0.444)
31	155	0.163	(0.226)	0.256	(0.224)	0.240	(0.258)	0.405	(0.453)	0.422	(0.382)
32	160	0.180	(0.180)	0.223	(0.236)	0.320	(0.311)	0.343	(0.356)	0.528	(0.507)
33	165	0.171	(0.149)	0.230	(0.322)	0.295	(0.247)	0.333	(0.342)	0.479	(0.343)
34	170	0.183	(0.171)	0.220	(0.231)	0.237	(0.298)	0.389	(0.362)	0.434	(0.424)
35	175	0.148	(0.257)	0.276	(0.244)	0.284	(0.338)	0.325	(0.400)	0.476	(0.470)
36	180	0.164	(0.227)	.237	(0.364)	0.314	(0.319)	0.413	(0.490)	0.536	(0.541)
37	185	0.205	(0.168)	0.301	(0.324)	0.262	(0.308)	0.384	(0.380)	0.545	(0.535)
38	190	0.231	(0.253)	0.256	(0.272)	0.326	(0.335)	0.415	(0.373)	0.501	(0.532)
39	195	0.194	(0.255)	0.226	(0.379)	0.339	(0.274)	0.425	(0.439)	0.540	(0.457)
40	200	0.182	(0.177)	0.264	(0.343)	0.346	(0.255	0.435	(0.370)	0.510	(0.452)

*Figures in the brackets are for eccentric circular shape roller.

Analysis :

(i) U-shape fluted roller: Chi-square for 5 speeds from Bartlett's test = 9.291;
Chi-square tabulated (4,0.05) = 9.488

b) Eccentric circular shape roller: Chi-square for 5 speeds = 5.88
Chi-square tabulated (4,0.05) = 9.488

fluted and eccentric-circular shape six groove rollers for intermittent band placement. The percentage deposition of fertilizer in 100 mm bands was found maximum with J-shape which varied from 54 to 78% with increase in speed of roller from 28 to 85 rpm.

b) For maximum uniformity in continuous band placement, U-shape fluted roller with 12-grooves gave better performance in comparison to eccentric circular shape roller. The speed of rollers from 28 to 85 rpm had no significant effect on distribution pattern indicating that the discharge rate of fertilizer could be changed by varying the speed of roller. The U-shape roller, however, required frequent cleaning of grooves to avoid chocking while the eccentric circular groove roller had a self-cleaning characteristics.

c) The cell fill of rollers decreased with increase in speed with least variation in case of J-shape fluted and eccentric circular groove rollers.

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