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Laboratory Assessment of Tractor Operated Fertilizer Broadcaster Based on Operational Parameters

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***Abstract*:** The production of the major crops increased many folds from last two decades. This tremendous increase in agriculture is attributed to factors such as high yield varieties of seed, more area allotted to the various crops, good quality of fertilizers and improved methods of cultivation etc. The consumption of fertilizers has also increased many folds. To meet this high demand of fertilizers, centrifugal spreaders become into existence and due to low cost of operation and simplicity of use, these centrifugal spreaders are very popular. Therefore, a setup was made to evaluate the performance of the machine in Indian conditions. The maximum uniformity of spread was at 0^0 angle of fins. The coefficient of variation with apparent swath width was varied from 32.18% to 92.92%. With overlapping, coefficient of variation was 7.05 at notch setting 4 (opening area 9.40cm^2), disc speed of 400 rpm and fin angle of -10^0. At setting N2S2A2, the effective swath width was 6.75 m with 5.4 m left turn and 8.1 m right turn. The fertilizer application rate was 1500.42 kg h^{-1} corresponding to this setting.

***Keywords*:** Angle of vanes, Centrifugal spreader, Orifice opening area, Skewness of spread

The tremendous increase in agriculture is attributed to factors such as high yield varieties of seed, more area allotted to the various crops, good quality of fertilizers and improved methods of cultivation. Solid chemical fertilizers are one of important sources for plant nutrition during its growing period, and works to improve the properties of soil (soil structure and the acidity degree)(Neina et al 2019). India is the second largest consumer of fertilizers in the world after China. In India, it is increased from 12.14 Mt in 1990-91 to 50 Mt in 2019-20 (Anonymous 2022). Increased inputs have played a pivoted role in augmenting production in India. Punjab, a leading agriculture state alone consumed 1.8 Mt of fertilizer during the year 2018-19 (Singh 2018). Efficient application with correct type and recommended dose of chemical fertilizer is important for achieving profitable yields (Singh 2018). The hand broadcasting is the most common method used for distribution of fertilizers. Besides being laborious and time consuming, its effectiveness depends on the skill and judgment of the farmer (Przywara et al 2020). Manually operated fertilizer spreaders can be used for applying recommended dose of fertilizer at different notch settings. Farmers of the region although shown interest in manual operated type fertilizer spreaders resulting in manufacturing of these spreaders. The popularity of this type of machine is due to its design characteristics, ease of handling and cleaning, economy and relatively small size for a given width of spread (Rahman et al 2018). However, has the disadvantage of low field capacity, producing an uneven distribution pattern and uneven application can lead to over dosage, causing material wastage, burnt crop and under application can leads to nutrient deficient plants and limited growth. The weight of the machine may cause stress on the neck of the operator. The mechanical broadcasters are better for fertilizer application but their performance depends on their design parameters as well as operational parameters (Villette et al 2012). The most famous mechanical broadcasters are the centrifugal distribution machine, and it was due to its low cost, low power requirement, simplicity of mechanical design and ease of maintenance.

There are many physical parameters which affect the performance of centrifugal broadcasters and every crop required different amount of fertilizer. Mass flow and rotational speed affect fertilizer centrifugal spreading is examined by Villette et al (2012) through potential interpretation in terms of the amount of fertilizer per vane. Kweon et al (2009) proposed a method which employed control of the drop location of fertilizer particles on the spinner disc to optimize the spread pattern uniformity. Research also been conducted on the simulation of particle motion to generate spread patterns for distributor worldwide. A tractor operated fertilizer broadcaster is commercially available and is being sold by manufacturers in the state to spread fertilizer with great ease and efficiency. There is no scientific data available regarding the performance of the machine. Hence, this study was carried out to evaluate tractor operated fertilizer broadcaster in Indian conditions and carry out necessary modifications based on the evaluation results.

MATERIAL AND METHODS

Description of tractor-operated fertilizer broadcaster: The tractor operated fertilizer broadcaster is a conical shaped broadcaster operated by the PTO (Fig. 1). The fertilizer-spreading disc consists of four metal vanes on its periphery for spreading the fertilizer (Table 1). Provision for adjustment of feed rate is present. In addition, slitter leavers have been provided to facilitate scattering at left or right side.

Experimental design and layout: Laboratory experiments were performed with Di-ammonium phosphate (DAP) as fertilizer to evaluate the selected broadcaster at Department of Farm Machinery & Power Engineering, PAU, Ludhiana to avoid any external disturbing factors such as wind speed. The broadcaster was attached with 36.76 kW tractors (Massey Ferguson 5245DI). A setup of 44 collecting channels (915 X 30 X 16.25 cm each) made up of iron bars and plastic sheets were fabricated and laid on the flat surface in a straight line perpendicular to the direction of fertilizer broadcaster (Fig. 2). The entire setup was able to cover the entire range of distributed fertilizer. The amount of fertilizer distributed from all the 44 channels was collected independently in separate plastic bags. Thereafter, the bags were weighed to analyse the effect of operational parameters on swath width and distribution pattern. Various parameters, such as notch setting, disc speed, angle of vanes, and type of fertilizer are known to affect the performance of broadcaster (Sharabasy and Afify 2007). In the study, 81 experiments in randomized block design encompassing 27 treatments were performed with three replications (9 treatments for each), comprising different combinations of independent parameters (disc speed, angle of vanes, and application rate). The data obtained for each dependent parameter (apparent swath width, fertilizer rate, and skewness of spread) with replications was analyzed using the statistical analysis software SAS 9.3 version.

Notch setting: Amount of fertilizer distribution was maintained through the metering device of the broadcaster. The application rate of granules was maintained by adjusting the size of an orifice to deliver the required amount of fertilizer. At level 1, the orifice was the smallest, which expelled the least amount of fertilizer. At level 8, the orifice area was maximum, which allowing the application of maximum amount of fertilizer to the field. The broadcaster was evaluated at three different notch settings (2, 4 and 6) based on recommended amount of fertilizer for crops and on preliminary trials.

Table 1. Brief specifications of fertilizer broadcaster

Parameters	Specification
Type of machine	PTO driven, mounted type
Source of power (hp)	Tractor, 35
Capacity (l)	361
Height (mm)	1130
Spreading width (m)	12-14
No. of vanes	4
Transmission ratio	1:1
Feed rate adjustments	8
Weight of the machine (kg)	63

Fig. 1. Stationary view of the fertilizer broadcaster

Fig. 2. Setup for evaluation of fertilizer broadcaster

Disc speed: Fertilizer broadcasting pattern and swath width of distribution varies according to the revolution speed of disc (rpm). Three levels of disc speed (300, 400 and 500 rpm) were selected by controlling the PTO rpm.

Angle of vanes: There are four C-shaped vanes (18 cm each) fastened to the circular disc of the broadcaster for providing the even distribution of fertilizer. Circular disc of this broadcaster equipped with five adjustments for angles of vanes, which allow the distribution pattern of spreading to be shifted towards right or left as per requirements. The ranges of vanes angle provided in the disc are +20°, +10°, 0°, -10° and -20°. Three different levels of vane angles (-10°, 0°, +10°) were selected.

Measurement of Parameters

Apparent swath width: Fertilizer broadcasters spread granular fertilizers and seed by centrifugal action. These fertilizers are spread to the certain width which is considered as apparent swath width.

Fertilizer rate (kgh^{-1}): The amount of fertilizer distributed by the broadcaster per unit time is called fertilizer application rate. It represents the quantity of fertilizer that flows out from the fertilizer broadcaster to the field.

$$\text{Fertilizer rate, (kg h}^{-1}) = \frac{W_t \times 60}{1000 \times T}$$

where, W_t= total fertilizer collected from channels in each treatment (g)

T = time taken in each treatment (min)

Skewness of spread:

$$\text{Skewness of spread} = \frac{\mu - v}{\sigma}$$

where, μ= mean of collected data

v = medium of collected data

σ = standard deviation

Evaluation for overlapping and without overlapping: The pattern acquire by fertilizer broadcasting was skewed. To get an even distribution, overlapping was done from each side of the pattern. A computer program was developed in PHP language. It has been found that there was a decrease in coefficient of variation after overlapping the swaths to certain spacing. To reduce the coefficient of variation three adjacent swaths were overlapped by computer program. Overlapping was done on both the side of pattern as left on left spacing and right on right spacing. After overlapping, the best result with maximum uniformity pattern was selected and corresponding spacing of maximum uniformity pattern was obtained from the computer program. It was observed that there was different spacing for left turn and right turn for maximum uniformity of spread.

RESULTS AND DISCUSSION

Effect of operational parameters on fertilizer rate: The fertilizer application rate displayed by the broadcaster increased with an increase in the level of notch setting (n = 2, 4, 6) at all disc speeds (300, 400 and 500 rpm) and angles of vanes (-10°, 0°, +10°). The mean values of fertilizer application rate were 91.01 kgh^{-1}, 595.50 kg h^{-1} and 1869.4 kgh^{-1} at notch setting levels 2, 4, and 6, respectively (Fig. 3). This increase was observed due to the increase in the size of orifice of the hopper with higher notch settings, leading to expulsion of higher amounts of fertilizer from the hopper to the circular disc. A similar trend of change in fertilizer application rate was recorded with varying disc speed of the broadcaster. As the disc speed was increased from 300 rpm to 400 rpm, the fertilizer application rate was increase from 851.90 kgh^{-1}to 966 kgh^{-1}. However, further increase in disc speed to 500 rpm lead to a decline in the fertilizer application rate to 738.02 kg h^{-1} (Fig. 3). This altering trend in fertilizer rate associated with disc speed maybe due to a change in the nature of vibrations. Sharabasy and Afify (2007) reported similar observation, stating that initial increase in disc speed led to a corresponding increase in the fertilizer application rate due to increase in vibration amplitude of the machine. Subsequently, fertilizer rate decreased as the amplitude decreased with further increase in disc speed.

The effects of notch setting and disc speed on fertilizer rate were statistically significant. However, no significant effect of angle of vanes was observed on fertilizer rate. The interactions between independent parameters, i.e. notch setting and disc speed, notch setting and angle of vanes, disc speed and angle of vanes were found significant (Fig. 4). Fertilizer rate were 856.68 kg h^{-1}, 848.82 kg h^{-1} and 850.41 kg h^{-1} at angle of fins -10°, 0° and +10° respectively.

Effect of operational parameters on apparent swath width: The apparent swath width exhibited variation with the notch setting of the fertilizer broadcaster (Fig. 5). As the notch setting level was increased from n=2 to n=4, the apparent

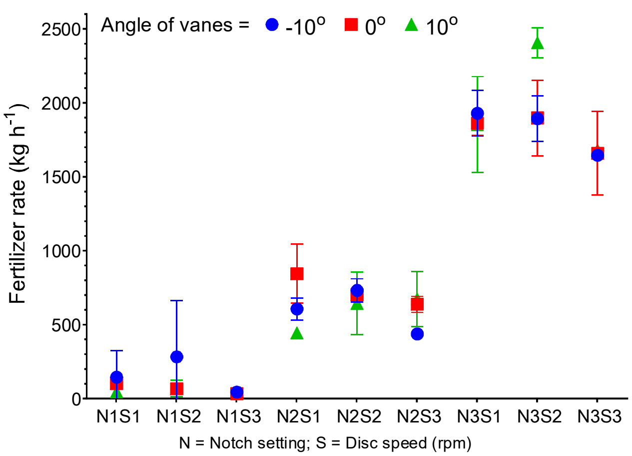
Table 2. Details of various independent parameters and their levels

Parameters	Levels	Remarks	Dependent parameters
Notch setting	3	To vary the application rate	• Apparent swath width (m)
Disc speed (rpm)	3	To vary the spread	• Fertilizer rate (kg/h)
Angle of vanes	3	To change the direction of flow	• Skewness of spread
Type of fertilizer	1	DAP	

swath width of distribution increased from 12.47 to 12.99 m, which further increased to 13.18 m at the notch setting level n = 6. This variation in apparent swath width is likely due to the increase in the amount of material present on the circular disc due to centrifugal action. Similar observations have been reported by Coetzee and Lombard (2011), wherein increase in fertilizer rate led to a concomitant increase in the apparent swath width. The overall trend of apparent swath width of the distributed fertilizer displayed a consistent increase with increase in the disc speed of the broadcaster. The mean of apparent swath width values recorded at various notch setting levels and angles of vanes were 12.01 m, 13.17 m, and 13.46 m at disc speeds of 300 rpm, 400 rpm and 500 rpm, respectively (Fig. 5). The observed increase in the apparent swath width may be explained by the increase in the angular speed of the disc, which provides higher terminal velocity to the fertilizer particles enabling them to travel a longer distance. The effect of disc speed on apparent swath width was more pronounced than that of the notch setting. mean values of swath width obtained from various experiments were 12.74 m, 12.93 m, and 12.96 m when the angles of vanes were-10°, 0°, +10°, respectively (Fig. 5).

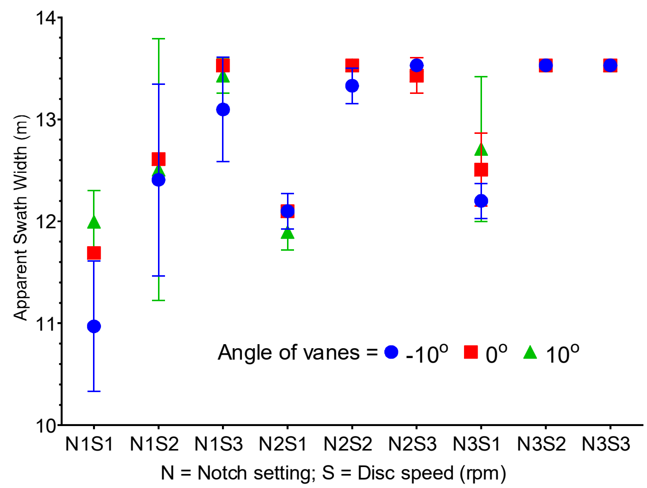
The effect of notch setting and disc speed on swath width were statistically significant, whereas that of the angle of vanes was not significant (Fig. 6). The interactions between disc speed and notch setting and that between notch setting and angle of vanes were also statistically significant. In contrast, the cumulative effect of disc speed and angle of vanes was non-significant. The combined interaction of these three parameters was also non-significant.

Effect of operational parameters on skewness of spread: The skewness of spread of the broadcaster varied with the



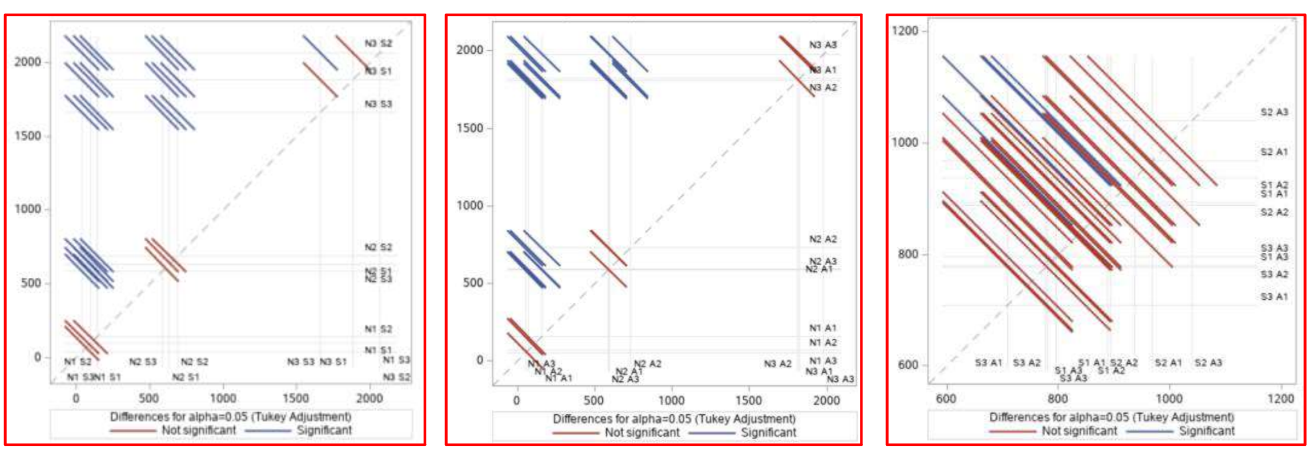
Error bars represent standard deviation about the mean in all graphs

Fig. 3. Effect of operational parameters on fertilizer rate (kg h^{-1})



Error bars represent standard deviation about the mean in all graphs

Fig. 5. Effect of operational parameters on apparent swath width (m)



a) Notch setting & Disc speed b) Notch setting and angle of vanes (c) Disc speed and angle of vanes

Fig. 4. Diffogram for the interaction of operational parameters on fertilizer rate (kg h^{-1})

level of notch setting (Fig. 7). As the notch settings were increased from n=2 to n=4, and thereafter to n=6, the mean skewness of spread values of the fertilizer broadcast were 0.29, 0.23, and 0.16, respectively. This decrease in the skewness of spread was noted irrespective of the angle of vanes and disc speed, and may be explained by the increased orifice size at every level, which enables a discrete flow, whereas a large expulsion area facilitates a uniform flow of the fertilizer. The skewness of spread of the tractor-operated fertilizer broadcaster also changes with the disc speed. The observed mean skewness of spread was 0.35, 0.11 and 0.22 at disc speeds of 300 rpm, 400 rpm, and 500 rpm, respectively (Fig. 7). However, the lowest coefficient of skewness of spread was at 400 rpm. Similar results have been reported by Sharabasy and Afify (2007) states that optimum value of disc speed at which the least value of skewness of spread was observed; and further increase or decrease in disc speed would distort the spread pattern of fertilizer. A slight variation was observed in the skewness of spread when the angle of vanes was altered. The observed mean skewness of spread was 0.23, 0.21, and 0.24 at angles of vanes -10°, 0° and +10°, respectively (Fig. 8). The most optimal distribution was at a 0° angle of fins. Similar has been observed by Yildirim (2006).

The effects of notch setting and disc speed on skewness of spread were significant, whereas that of angle of fins was non-significant (Fig. 8). The interactions between disc speed and notch setting, and angle of fins, and disc speed and angle of fins were also statistically significant. In addition, the cumulative interaction of the three parameters was significant. Kweon et al (2007) reported that increase in disc speed with higher quantity of fertilizer leads to reduced oscillation, since the particles are subjected to an increased force against the sidewalls of the vanes.

Coefficient of variation without overlapping: The least coefficient of variation without overlapping of swaths was 30.04% at N2S3A3 among all the combination of independent parameters (Fig. 9). The apparent swath width corresponding to this was13.53 m with fertilizer rate of 473.62 kg h^{-1}. At N1 notch setting (n = 2), the minimum value of coefficient of variation was 40.01% which comes at disc speed of 500 rpm and 0°angle of fins. The apparent swath width corresponding to variation was 13.53 m and fertilizer rate was 33.48 kg h^{-1}. At notch setting N3 (n=6), the minimum value of coefficient of variation was found to be 32.18% with disc speed of 500 rpm and +10° of angle of fins. The apparent swath width was calculated 13.53 with fertilizer rate of 1680 kg h^{-1}.

Coefficient of variation with overlapping: At notch setting 4 i.e., N2, the minimum value of coefficient of variation was

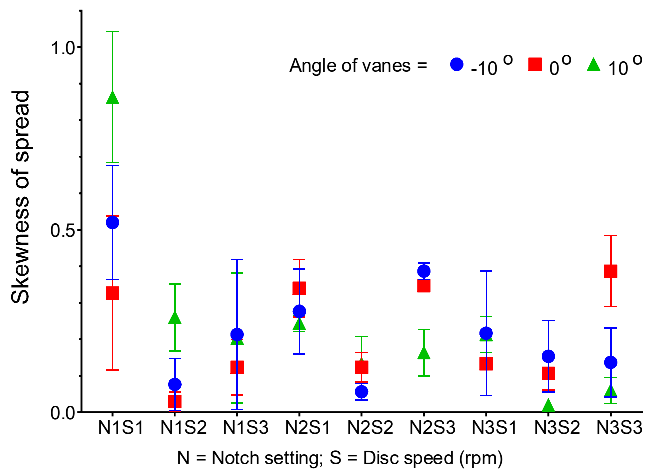
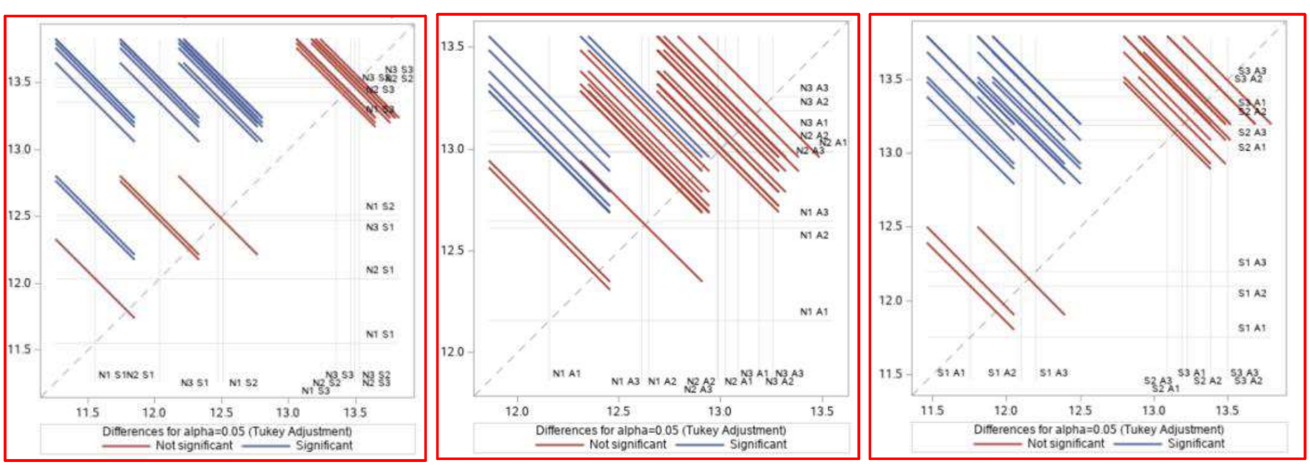


Fig. 7. Effect of operational parameters on skewness of spread

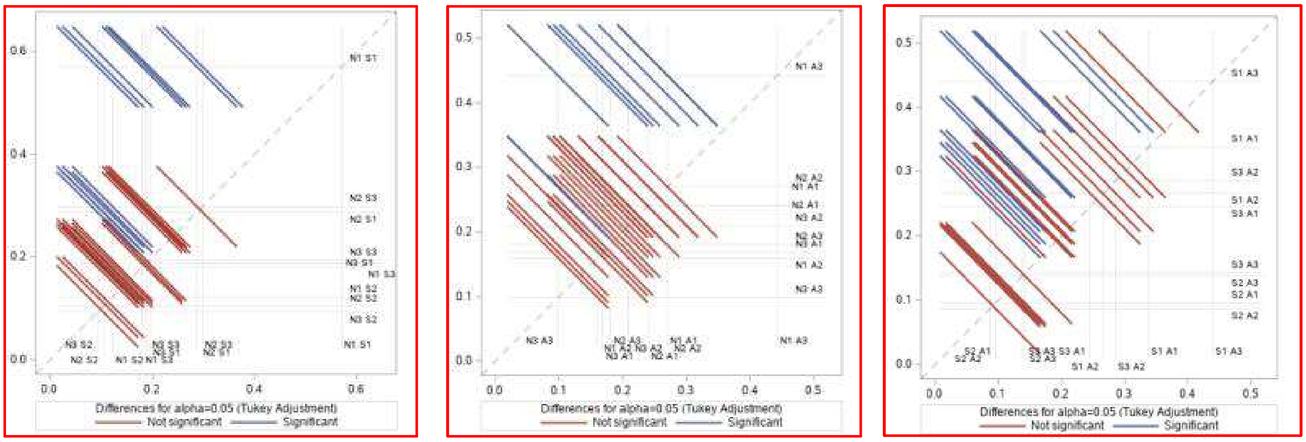


a) Notch setting & Disc speed

b) Notch setting and angle of vanes

(c) Disc speed and angle of vanes

Fig. 6. Diffogram for the interaction of operational parameters on apparent swath width



a) Notch setting & Disc speed b) Notch setting and angle of vanes (c) Disc speed and angle of vanes

Fig. 8. Diffogram for interaction of operational parameters on skewness of spread

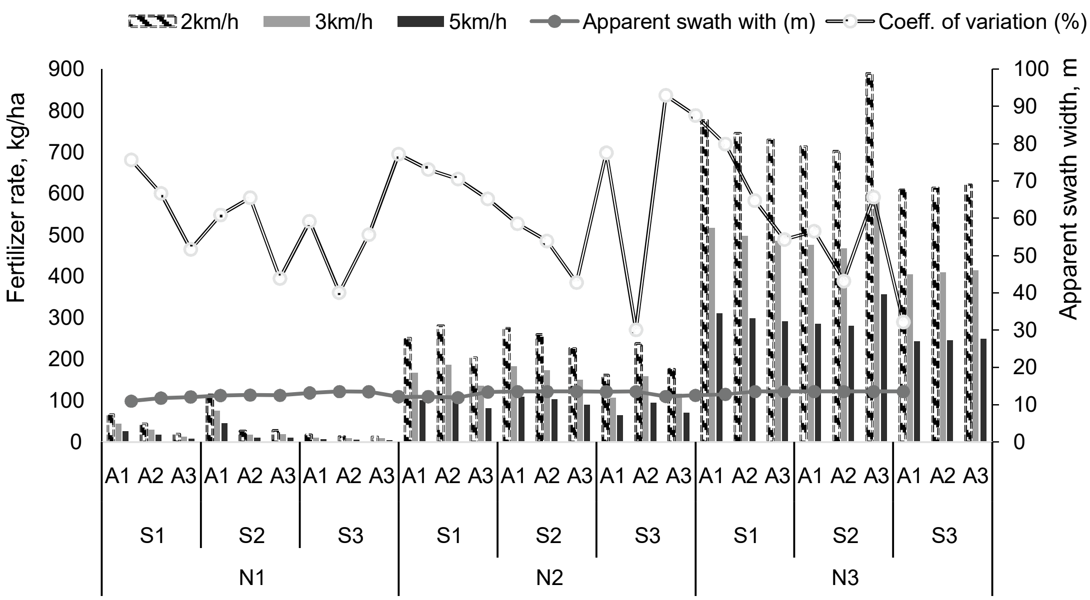


Fig. 9. Outcomes at different operational combinations without overlapping

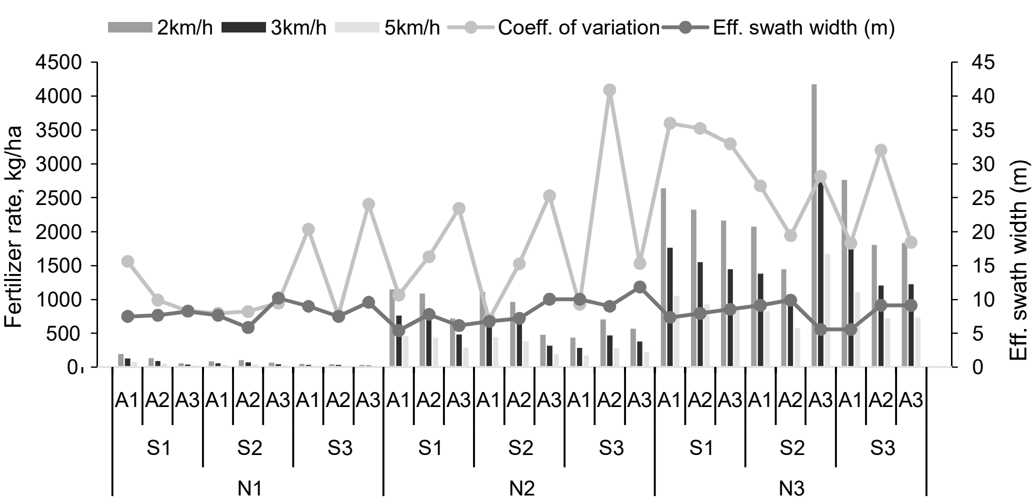


Fig. 10. Outcomes at different operational combinations with overlapping

7.05 at disc speed 400 rpm with -10° angle of vanes (Fig. 10). At notch setting 6 i.e., N3, the minimum coefficient of variation was 18.30 at disc speed 500 rpm with -10° angle of vanes. Overall, the minimum coefficient of variation was 7.05% at N2S2A1 after overlapping the swath width. At this setting, the fertilizer application rate was 25.01 kg/min and effective swath width was 6.75 m.

CONCLUSIONS

The fertilizer rate and apparent swath width increased with increase in level of notch setting (orifice opening area). The effect of notch setting and disc speed was statistically significant on fertilizer application rate. The skewness of variation decreased with increase in opening area of orifice. The maximum uniformity of spread was found at 0° angle of vanes. The coefficient of variation with apparent swath width varied from 32.18 to 92.92%. The best operational parameters from the study were notch setting 4 (opening area 9.40 cm^2), disc speed of 400 rpm and fin angle of -10^0.

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