

## Evaluation of a Dual-Purpose Chemical Applicator for Paddy Fields

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**Abstract: Problem statement:** One of the major problems of rice production is the shortage of labor resulting from migration from rural to urban areas, making it very difficult to meet peak demands for paddy production. In most developing countries of Southeast Asia, agricultural mechanization of paddy field operation is mostly carried out using conventional machines. For example in rice production power-intensive operations such as water pumping, land preparations, transplanting seedlings, harvestings and threshing are being mechanized but other operations like fertilizer and chemical (pesticides) applications are not yet fully mechanized, rather they are performed manually with motorized backpack knapsack sprayers which have many disadvantages. The main objective of this study was to develop and evaluate a new concept dual-purpose chemical applicator for paddy fields farmers in order to complement the labor shortage during the peak period. **Approach:** A dual-purpose chemical applicator for flooded paddy field was evaluated using the S341.4 Standard in respect to the distribution patterns/droplet sizes and uniformity of spreading/spraying for the chemical application to boost agricultural mechanization in rice production and also to overcome the safety concern of hazardous spray drift during chemical application by the paddy farmers. The dual purpose applicator was mounted on a high clearance prime mover. The machine performances for both granular and liquid chemical application were reported. **Results:** Results for urea granular chemical indicate that at low ( $40 \text{ kg ha}^{-1}$ ) and high ( $120 \text{ kg ha}^{-1}$ ) rates and 550 rpm disc speed distribution pattern skewed to the left whereas the distribution pattern shape at medium ( $80 \text{ kg ha}^{-1}$ ) rates was good flattop. At high rate ( $120 \text{ kg ha}^{-1}$ ) and 1000 rpm disc speed, mean distribution pattern became poor (M-shape) and also at low and medium application rates the distribution pattern shapes lopsided to the left. For NASA glyphosate liquid chemical herbicide, the average values of (VDM) and (NMD) were 108 and  $79 \mu\text{m}$  at 80 lt/ha application rate and 5000 rpm rotary disc speed and 185 and  $119 \mu\text{m}$  at 80 lt/ha application rate 3000 rpm rotary disc speed. **Conclusion:** The experimental results from the experimental tests suggest that the average effective field capacity for the equipment with a prime mover was found to be  $0.89 \text{ ha h}^{-1}$  or 7.12 ha/man-day for an 8 h working day.

**Key words:** Dual-purpose, chemical application, paddy field, spinner spreaders, particle trajectories, particle dynamics, Analysis Of Variance (ANOVA), radial straight vanes, Coefficient of Variation (CV), calibrating granular broadcaster, power-intensive operations, knapsack sprayers, urban areas, analytical models

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### INTRODUCTION

Agriculture is one of the most important economic sectors for many developing countries of Southeast Asia. A large proportion of the population is involved in agriculture. However, this number has declined in the last ten years because of the rapid expansion in the

industrial, construction and tourism sectors. Consequently, labor has been drawn from the agricultural sector to others that resulted in labor shortages during the peak farming seasons. One of the major problems of rice production is the shortage of labor resulting from migration from rural to urban areas, making it very difficult to meet peak demands for

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paddy production (Kanetani and Fauzi, 1991; Cho, 2010). Meanwhile mechanization is needed to replace the labor which is not available or is very expensive (Mohod *et al.*, 2010; Kanetani and Fauzi, 1991). In Malaysia agricultural mechanization of paddy field operation is mostly carried out using conventional machines also in rice production power-intensive operations such as water pumping, land preparations, transplanting seedlings, harvestings and threshing are being mechanized but other operations like fertilizer and chemical (pesticides) applications are not yet fully mechanized, rather they are performed manually with motorized backpack knapsack sprayers which have many disadvantages. These include; lack of uniformity of input distribution applied to the crops, depending on high number of labor and drudgery in handling and loading of inputs on the field (Omar *et al.*, 2011; Razak *et al.*, 2011; Kanetani and Fauzi, 1991).

The performance of spinner spreaders has been widely investigated. Studies have typically focused on analytical models for particle trajectories on and off of the spinner (Liedekerke *et al.*, 2006; Liedekerke *et al.*, 2009; Dongbang *et al.*, 2010). Several authors have reported the problems of particle dynamics on a spinning disc in their studies of the impact of different parameters on the spreading and improvement on operation/control of centrifugal fertilizer spreaders in agriculture. Patterson and Reece examined the sliding motion and rolling motion of a single spherical granular material on a flat rotary disc equipped with radial straight vanes while neglecting particle bounce and assuming a near center feed. They developed models to describe particle motion on the spinner disc and found reasonable agreements between the model predictions and experimental results. They also reported that the particle's radial velocity depends on the shape and the friction coefficient between a granular material and a rotary disc. For the same disc configuration, Inns and Reece showed that if a granular material begins its motion at a certain distance from the center of the disc, friction between the granular material and rotary disc can be neglected because the vertical velocity of the granular material is not lost on impact. Therefore, the granular material is moving up or down the vane surface until it leaves the rotary disc. Due to the physical discomfort and awareness of health risk associated with granular fertilizer and pesticide application such as operators' hazard when having direct contact of chemicals during field operation (Juste *et al.*, 1990; Matthews, 2000). Nowadays, there has been a growing concern about the environmental problems (such as air and water pollution and decline in biodiversity) associated with the application of mineral

fertilizer and pesticides (Matthews, 2000; Yahya *et al.*, 2007; Snow and Ghaly 2008). For these reasons, accurate and uniform application of fertilizer/pesticides is absolutely important in minimizing environmental problems and costs. Over-doses can harm the environment seriously, as well as the crop itself. Consequently, the application methods of fertilizer/pesticides and the uniformity of the spread pattern have become important research topics in agricultural engineering (Yahya *et al.*, 2007; Mohammadi, 2006; Ramesh and Shanmugan, 2011). A lot of effort on the influence of machine characteristics on the spread pattern has been done by Olieslagers *et al.* (1996). Pearson found that spinning disc sprayers gave effective spray droplets with 250  $\mu\text{m}$  VMD than lower values of VMDs. Uremis *et al.* (2004) reported that 250-500  $\mu\text{m}$  drop diameters for herbicide applications which is easier to deliver to the target surfaces. The high volume application methods used by some farmers to apply chemicals could result in higher costs compared to using low volume method, hence the development of dual purpose equipment for granular fertilizer and pesticides application in the paddy field to address the problems of cost in paddy production and environmental pollution. Despite the fact that there are many equipment developed to distribute granular material, none has been developed to date which can effectively spread granular material such as granular fertilizer and as well as spray liquid materials such as, liquid herbicides in the rice crop production processes. Furthermore no equipment have been developed commercially which can distribute non- pressurized liquid on the crops. Most available liquid spreaders distribute liquid under pressure by nozzles and backpack with some type of pumping device which help to maintain enough pressure to push the liquid out of the nozzles on the crops. These pressurized devices make it very difficult to control the distribution, resulting inconvenient in backing heaving weight equipment, operator health hazard, spray drift hazard and consequently damaging the crop and the environment. This study presents the evaluation of a dual-purpose chemical applicator for paddy fields in respect to the distribution patterns/droplet sizes and uniformity of spreading/spraying for the chemical application.

**Description of the chemical applicator:** The chemical applicator consists of a hopper, orifices, rotary discs and electric motor Fig. 1. The applicator employs the use of two rotary discs rotating in an opposite direction driven by 0.204 hp electric motors (TM80-15150) and the rotational velocity can be varied continuously from

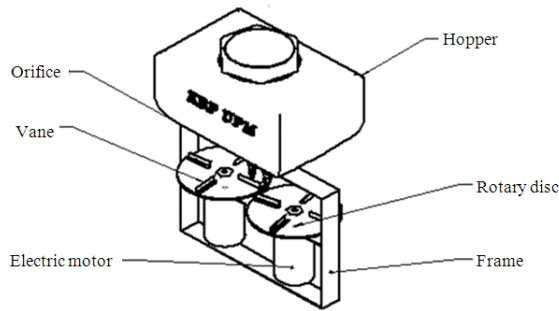


Fig. 1: 3D drawing of the dual-purpose rotary disc chemical applicator

almost zero to above 5000 rpm by means of a rheostat speed controller. Chemical materials (granular or liquid) inside the hopper fall freely by gravity through the orifices and drop directly on the rotating discs (impeller) subsequently are applied to the field. The disc is fitted with vanes for granular application and rotates at a speed of 550 and 1000 rpm while for liquid a plane flat disc rotates at a speed of 3000 and 5000 rpm to atomize liquid into fine spray. The centrifugal force of the rotary disc throws the material in an arc pattern over a distance to the right, front and to the left.

### MATERIALS AND METHODS

Rotary disc and chemical (granular and liquid) characteristics (such as cone angle, disc diameter, vane length, particle size, moisture content, density, viscosity, surface tension, coefficient of friction) were taken into considerations during the equipment development. The chemical applicator distribution tests Fig. 2 and 3 were conducted as recommended by ASAE Standard S341.4 Procedure for Measuring Distribution Uniformity and Calibrating Granular Broadcaster Spreaders in which array of collection trays were used for performing the tests (Uremis *et al.*, 2004). This is because outdoor testing is the most representative of what performance is achievable in the field. A total of 36 transverse tests were conducted. Six tests each for both urea granular chemical and NASA glyphosate liquid chemical were carried out. Each test was repeated three times and the mean values were reported. The Coefficient of Variation (CV) for the transverse spread pattern is commonly used to ascertain an acceptable working (swath) width for the chemical applicator. The CV is the measure of the overall uniformity of the chemical application distribution pattern and was determined by overlapping the transverse distribution pattern at meter intervals working widths, the sample mean and standard deviation of the overlapped application rate were



Fig. 2: Collection trays were removed on each of centerline to allow the prime mover wheels pass through

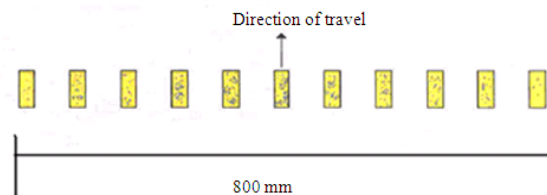


Fig. 3: Arrangement of water-sensitive paper for spray droplet collection

divided. The lower the CV, the more uniform the distribution pattern.

This study uses Water-Sensitive Paper (WSP) to evaluate the droplet sizes formed by the dual-purpose rotary disc chemical applicator. The water-sensitive paper images were captured using high resolution camera 1:1.4/12.5m (HF12.5HA-1B) after allowed to dry for 30 minutes and then scanned using Program FlexScan 2D. The percentage spray droplets cover, number of droplets per square centimeters, size distribution of droplets and volume/mass deposited, droplet density per unit area, the VMD and NMD of their spectrum on each study were estimated and

analyzed using MATLAB software program. The VMD and NMD of the spray droplet spectrum were determined to ascertain the spray characteristics. Before the experiment the applicator was calibrated into three different flow rates for both granular and liquid chemicals. The openings of the orifices for the applicator were set at position low (40 kg/ha), medium (80 kg/ha) and high (120 kg ha) for urea granular fertilizer and low (40 lt/ha), medium (60 lt/ha) and high (80 lt/ha) for NASA glyphosate liquid chemical herbicide. These application rates were obtained from the adjusting of the chemical flow onto rotary discs by manually operated valves to achieve constant application rate and were deemed as typical target operator of the equipment. The disc rotary speed was set at 550 and 1000 rpm and 3000 and 5000 rpm for urea granular chemical and NASA glyphosate liquid chemical respectively. Analysis Of Variance (ANOVA) was conducted for each of these uniformities using SAS 9.2 statistical software to identify statistical significant differences between the various combinations.

**RESULTS AND DISCUSSION**

Table 1 and 2 show the mean values of the Coefficient of Variation (CV) for the urea granular distribution uniformity and the volume median diameter for the liquid chemical. The CV of 16% was obtained at the overlapping transverse distance of 2 m and combinations of 550 rpm rotary disc speed and 80 kg ha<sup>-1</sup> application rate Table 1. The best liquid chemical Coefficient of Uniformity (CU) was obtained at the combinations of 5000 rpm rotary disc speed and 80 lt/ha application rate Table 2.

Results for the urea granular chemical showed that the mean values of distribution patterns varied in shape at three different application rates (Fig. 4 and 5). Increased in application rates and rotary disc speed caused the change in distribution patterns. Figure 5 shows that at low (40 kg ha<sup>-1</sup>) and high (120 kg ha<sup>-1</sup>) rates and 550 rpm disc speed distribution pattern skewed to the left whereas the distribution pattern shape at medium (80 kg ha<sup>-1</sup>) rates was good flattop. While at high rate (120 kg ha<sup>-1</sup>) and 1000 rpm disc speed, mean distribution pattern became poor (M-shape) and also at low and medium application rates the distribution pattern shapes lopsided to the left Fig. 5. It was observed that as the application rate increased from low through the medium to the high, the distribution pattern changed from low left sided to devastating peaks in the center pattern. Also experimental results revealed that when the application rate increased together with the increase of disc rotational speed the distribution pattern became

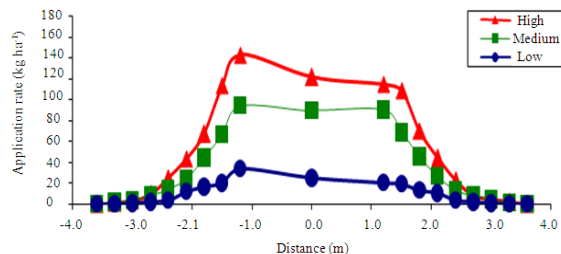


Fig. 4: Urea granular distribution patterns from 3 different application rates at 550 rpm disc rotary speed

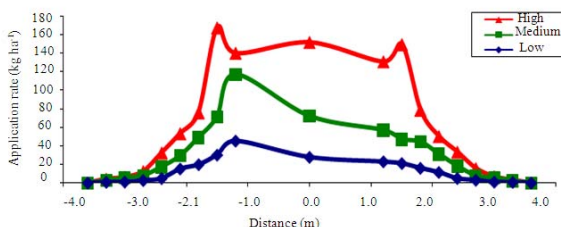


Fig. 5: Urea granular distribution patterns from 3 different application rates at 1000 rpm disc rotary speed

Table 1: Average values of coefficient of variation (CV) for the urea granular chemical

Rotary disc speed (rpm)	Application rate (kg/ha)	Coefficient of variation (CV) (%)	Distance (m)
550	40	22	3
	80	16	2
	120	42	5
1000	40	25	4
	80	38	4.5
	120	63	6.5

Table 2: Average values of VMD, NMD and ratio of VMD and NMD for NASA glyphosate liquid chemical

Rotary disc speed (rpm)	Application rate (lt/ha)	VMD (µm)	NMD (µm)	UC (VMD/NMD)
3000	40	272	180	1.51
	60	218	148	1.47
	80	185	119	1.55
5000	40	182	123	1.48
	60	134	92	1.46
	80	108	79	1.37

worst more and more. This agreed with the work of Aphale *et al.*, 2003 and Grift *et al.*, 2006, that reported that the mean distribution width increased with an increase in the disc rotational speed. They also reported that the distribution pattern uniformity is sensitive to some variations such as the increased in rotational speed of the disc.



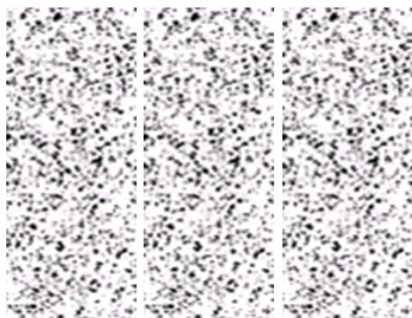


Fig. 6: Droplet size (VDM 108  $\mu\text{m}$ ) at 80 lt/ha rate and 5000 rpm rotary disc speed

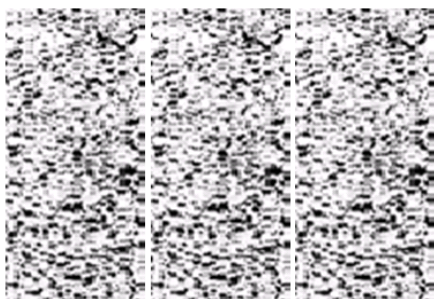


Fig. 7: Droplet size (VDM 185  $\mu\text{m}$ ) at 80 lt/ha rate 3000 rpm rotary disc speed

For NASA glyphosate liquid chemical herbicide, the average values of VDM and NMD were 108 and 79  $\mu\text{m}$  at 80 lt/ha application rate and 5000 rpm rotary disc speed and 185 and 119  $\mu\text{m}$  at 80 lt/ha application rate 3000 rpm rotary disc speed. Figure 6 shows that the droplet size with VDM of 108  $\mu\text{m}$  at 80lt/ha rate and 5000 rpm rotary disc speed. Figure 7 presents the droplet size with VDM of 185  $\mu\text{m}$  at 80 lt/ha rate 3000 rpm rotary disc speed. It was found that the Volume Median Diameter (VMD) of the spray droplet sizes decrease with increasing liquid flow rate and disc rotational speed. This shows that the dual-purpose rotary chemical applicator converts more liquid into fine droplets in comparison with that of reported results for motorized knapsack with flat fan pressure nozzles sprayers with 60-70% droplets larger than 250  $\mu\text{m}$ . Lefebvre found droplets size in the range of 120-300 micron in VMD be the most efficacious for chemical application. Also the new equipment average effective field capacity of the chemical application using high clearance prime mover was 7.12 ha/man-day for a 8 h working day, compare to the motorized knapsack sprayer in addition to cost of labor, covered only 1.2 ha/man-day which is 6 times lower than when the new equipment was used. Statistically, the effect of flow rate and disc speed was significant at  $P < 0.01$  level for all combinations.

## CONCLUSION

The study concluded that the distribution patterns of the dual-purpose rotary disc granular fertilizer do vary with change in application rate and rotary disc speed, also a spray of almost uniform drop size is formed when a liquid chemical is atomized under suitable conditions and the machine has the potential of addressing the risk to human health and the environment. It could be used for the application of both granular and liquid chemicals by the rice growers.

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