Development of a Low Volume Sprayer Nozzle for GA_3 Application: Enhancing Sustainability of F_1 Hybrid Rice Seed Production in the Philippines

Ricardo F. Orge [a]

[a] Rice Engineering and Mechanization Division, Philippine Rice Research Institute
Maligaya, Science City of Muňoz, Nueva Ecija, Philippines.
[a] Corresponding author: rforge@gmail.com

 ISSN 1923-6654 (print)
ISSN 1923-6662 (online). Available at http://www.ssrn.com/link/OIDA-Intl-Journal-Sustainable-Dev.html

Abstract: In hybrid rice seed production, Gibberellic acid (GA_3), a growth hormone, is normally applied to the mother rice plant (A-line) in order to facilitate panicle exertion and increase its chance to receive pollens from the father plant (R-line) thus enhancing seed setting. At present, the Filipino hybrid rice seed producers are using either the battery-operated ultra low volume (ULV) sprayer or the imported lever-operated knapsack (LOK) sprayer in the application of GA_3. The former is being recommended by agricultural technicians however it is relatively expensive hence not all of the farmers are using it. The latter, which most of the farmers are using, requires a lot of water to use (300-500 l/ha) hence taking a lot of time and effort in carrying out the operation. This knapsack sprayer however can be a low-cost alternative for applying GA_3 if only provided with a low volume (LV) nozzle. Unfortunately, no available sprayer nozzles could be found in the market that could satisfy the requirement. This study was conducted to develop a LV sprayer nozzle in order to provide Filipino hybrid rice seed producers a low cost but efficient alternative device for applying GA_3. The developed LV nozzle was fabricated mostly out from plastic pipe fittings and other commercially available materials. It could be fitted easily on the lance of farmers' sprayers. Field test results showed that the number of tank loads per hectare was reduced from 10-13 in the accompanying nozzle of a farmer's LOK knapsack sprayer to 2-4 in the developed LV nozzle. This resulted to savings in time and cost of the GA_3 application. Results of survey conducted after a pilot testing showed that all of the 21 farmer respondents preferred to use the developed nozzle over their existing nozzles.

Keywords: Gibberellic Acid; Hybrid Rice; Knapsack Sprayer; Low Volume Sprayer Nozzle; Rice Seed Production

Introduction

Hybrid rice is now becoming popular and is gaining acceptance in the Philippines. Aside from its good eating quality, hybrid rice is known for its high yielding characteristic over the ordinary (inbred) variety. Studies showed that it has a yield advantage of around 15% over the inbred varieties [1]. Hence, the government, through the Hybrid Rice Commercialization Program (HRCP), has been promoting for the planting of hybrid rice as a way of increasing rice production to attain rice self-sufficiency.

A sustainable production of hybrid seeds is an important factor that would ensure the success of the hybrid rice commercialization in the country. It is therefore important that practices involved in hybrid rice seed production needs to be continuously refined to ensure a more productive and cost efficient seed production system. One of these practices that need to be further improved is the application of gibberellic acid (GA_3).

In hybrid rice seed production, GA_3 (a growth hormone) is normally applied to the mother plant (A-line) in order to facilitate panicle exertion and increase its chances to receive pollens from the father plant (R-line) thus enhancing seed setting. At present, Filipino hybrid rice seed producers are using either the battery-operated ultra low volume (ULV) sprayer or the traditional LOK sprayer in the application of GA_3. The former is being recommended by technicians however it is relatively expensive hence not all of the farmers are using it. The latter, which most of the farmers are using, requires a lot of water to use (300-500 liters per hectare) hence taking a lot of time and effort in carrying out the operation. However, this knapsack sprayer can be a low-cost alternative for applying GA_3 if only provided with a LV nozzle. Unfortunately, no available knapsack sprayer nozzles could be found in the local market that could satisfy the requirement.

Developments in the science of sprayer nozzles, particularly the hollow cone types, were mainly due to Kutty *et al.* [2], Som [3, 4], Som and Mukherjee [5, 6], Datta and Som [7], Rizk and Lefebvre [8, 9], Suyari and Lefebvre [10], Yule and Chin [11], Jeng *et al.* [12], Liao *et al.* [13] and Sakman *et al.* [14]. Their works brought about an understanding of the swirling flow inside the nozzle and attempted to evaluate the liquid film thickness at the discharge orifice, the flow number and the spray cone angle of the nozzle either from empirical studies or from theoretical analyses. From the understanding gained from these works, the author attempted to develop a LV sprayer nozzle which could be attached to the existing knapsack sprayers of the farmers as a low cost and efficient alternative of applying GA_3 for use in hybrid rice seed production.

MATERIALS AND METHODS

Development of the nozzle

The idea of coming up with a low cost and efficient alternative to GA_3 application was focused on providing the farmers' knapsack sprayers with a LV nozzle. The design of the LV nozzle developed by the Cotton Research and Development Institute [15] was adopted as benchmark design with some modifications done so as to satisfy the following design criteria: (a) *low discharge*; capable of reducing the spray volume applied by at least 50% as compared to the nozzle used by the hybrid rice seed producers in applying the GA_3; (b) *fine mist* to ensure that more droplets are produced per unit volume of liquid to effect a more efficient GA_3 application; (c) *simple design* to ensure that it could easily and locally be fabricated as well as easily be operated and maintained by farmers; (d) *corrosion resistant*, to ensure that the parts would last longer even when used in applying corrosive chemicals such as insecticides and herbicides; (e) *low cost*, to ensure that it is affordable to farmers

Operating Principle

Basically, the designed nozzle operates in the same principle as that of a hollow cone type nozzle which accompanies most of the commercially available knapsack sprayers. As such, it operates by inducing a stream of liquid to rotate before it goes out of an opening (Fig. 1). Centrifugal force acts on the rotating mass of liquid which breaks the liquid into droplets as it goes out from the orifice. The difference between the designed nozzle and those accompanying the farmers' knapsack sprayers is that, in the designed nozzle, provisions are made such that the speed of rotation is increased. The higher the speed of rotation, the greater is the magnitude of centrifugal force acting on the rotating mass of liquid at the swirl chamber. As a result, more and finer droplets are produced as compared to that at lower speed

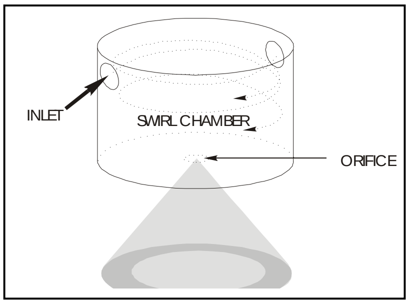
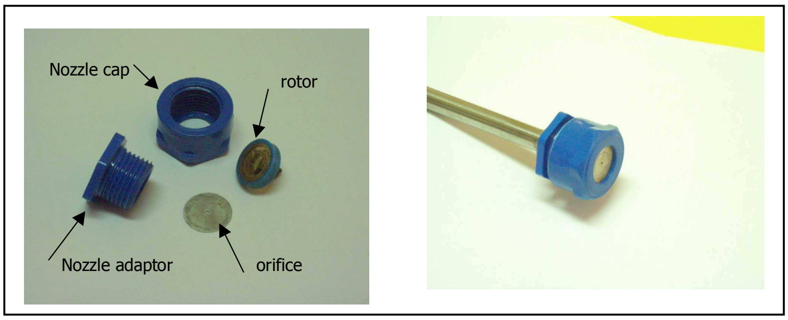


Figure 1: Operating mechanism of the LV nozzle.



a b

Figure 2: The prototype of LV nozzle : a - showing the disassembled parts; b - assembled and installed on the spray wand of the farmers' knapsack sprayer.

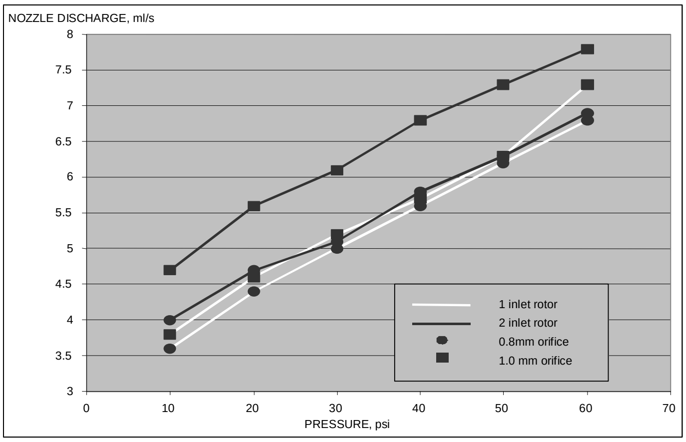


Figure 3: Nozzle discharge at varied operating pressures as influenced by rotor and orifice designs.

Table 1: Performance of the designed nozzle as compared to existing devices used in GA_3 application*.

Nozzle/ Sprayer	Nozzle Discharge* (ml/s)	Droplet Density (droplets/cm^2)	Angle of swath (^{o})
Prototype	5.2	337	100
Farmers' sprayer	11.78	188	109
ULV sprayer	2.4	302	164

* taken at 2.1 kg/cm^2 (30 psi) for the designed LV nozzle and the farmers' nozzle

Table 2: Volume of spray consumed in spraying both the A-lines and the R-lines for the three types of nozzles tested.

Nozzle/Sprayer Used	Tank capacity, L	Volume applied per hectare* (L)		No. of tank loads applied per ha	
		R-line only	Both A&R lines	R-line only	Both A&R lines
Prototype	16	42.2	42.7	2.6	2.7
ULV sprayer	10	30.3	32.6	3.0	3.3
Farmers' sprayer	16	97.5	98.2	6.1	6.1

* projected value based on data gathered from a 1300 m^2 test area.

Table 3: Time spent in applying the GA_3 using the three methods

Sprayer Used	Width covered per pass (m)	Speed of travel (km/h)	Labor requirement per hectare (m-h)		
			Actual spraying	Refilling of tank*	Total
Prototype	4.8	0.95	2.5	0.7	3.2
ULV sprayer	2.4	1.83	2.3	0.8	3.1
Farmers' Sprayer	4.8	0.95	2.5	1.5	4.0

* includes time of traveling to and from refilling station and time of preparing the GA_3 solution

Laboratory testing

Based from previous studies, the performance of a nozzle was significantly affected by the design of its two most important parts, namely, the orifice and the rotor [15]. When assembled, these two parts form the swirl chamber (Fig. 1) where liquid coming from the spray wand of the knapsack sprayer is induced to rotate before coming out from the orifice. To optimize the designed nozzle's performance, laboratory test was conducted using two rotor designs (with 1 and 2 inlets) and two sizes of the orifice (0.8 and 1.0mm). Testing was conducted at 5 operating pressures (0.7, 1.4, 2.1, 2.8, 3.5, 4.2 kg/cm^2). Data gathered were nozzle discharge, swath angle, and droplet density. Droplet density was determined by counting droplet samples from water sensitive papers (WSP) placed on the ground with nozzle (in horizontal position) passing 30 cm above them at a speed of 1 m/s. The performance of the designed nozzle, at its best (selected) combination of rotor and orifice, was also compared with that of the farmers' sprayer nozzle and the ULV sprayer.

Field performance testing

The designed nozzle was tested in a hybrid seed production area (AxR) at the PhilRice-Central Experiment Station. The test was conducted together with other sprayers/nozzles commonly used in applying GA_3 (ULV sprayer and farmers' sprayer nozzle).

Pilot testing

After being tested and found to work satisfactorily in the field, additional units of the designed nozzle were fabricated and distributed to selected hybrid rice seed producers for use in the application of GA_3 in their hybrid rice seed production areas. A simple one-page questionnaire was prepared and used as a guide to gather feedback from these farmers regarding the performance of the designed LV nozzle.

RESULTS AND DISCUSSION

The prototype LV nozzle

The designed LV nozzle was equipped with parts shown in Figure 2. The nozzle cap houses the rotor and the orifice and is fabricated from 12.5mm female threaded polyvinyl chloride (PVC) coupling. The nozzle adaptor connects the whole nozzle assembly to the lance of the farmers' knapsack sprayer and is also fabricated out from a 12.5-mm threaded male PVC coupling. The rotor, which is the heart of the nozzle, is equipped with small grooves that induce the liquid to rotate before it goes out of the orifice.

Laboratory test results

A summary of laboratory test results is presented in Appendix Tables 1 and 2. Except for the nozzle discharge, other performance parameters such as droplet density and angle of swath were not significantly influenced by the designs of the rotor and the orifice. Hence, selection of the best combination of the design of the rotor and the orifice was mainly based on their effect on nozzle discharge.

Effect on nozzle discharge

Generally, there was an increase in nozzle discharge when the number of inlet of the rotor was also increased from one to two (Fig. 3). This conforms to the findings of Hewitt [16]. As expected, there was also an increase in nozzle discharge when the orifice opening was increased from 0.8 to 1mm. A good combination is the one that gives the lowest nozzle discharge which is a 1-groove rotor combined with 0.8mm orifice. However, for the same rotor design combined with 1mm orifice, the nozzle discharge was just a little higher. Considering the ease of fabrication, fabricating a 1mm orifice is easier as compared to a 0.8mm orifice because the latter requires a much thinner drill bit which would easily break during the fabrication process. Hence, the 1mm orifice was selected. At this combination (1-inlet rotor, 1mm orifice) and at a normal operating pressure of 2.1 kg/cm^2 (30 psi), a minimal nozzle discharge of 5.2 m/s was attained.

Designed vs. existing methods

At 2.1 kg/cm^2 (30 psi) operating pressure, the discharge of the designed nozzle (at 1-inlet rotor and 1.0mm orifice) was compared with the nozzle of the farmers' knapsack sprayer. As shown in Table 1, the discharge of the designed nozzle is lower by 56% as compared to that of the farmers' sprayer. The ULV sprayer on the other hand has the lowest discharge rate which is 54% lower than the designed nozzle.

Field test results

The designed nozzle, together with the existing devices for GA_3 application (ULV sprayer and farmers' sprayer) was tested in a 1,300 m^2 hybrid seed production area (AxR) which was composed of 2 rows of R-line planted beside every 10 rows of the A-line.

As shown in Table 2, the designed nozzle yielded at least 50% lower volume applied as compared to the farmers' nozzle in either modes of application (R line only or both A and R lines). This resulted to savings in time of spraying since in the designed nozzle, a wider area is covered per tank load hence the tank does not have to be filled more often as compared to the one that makes use of the farmers' nozzle (Table 3).

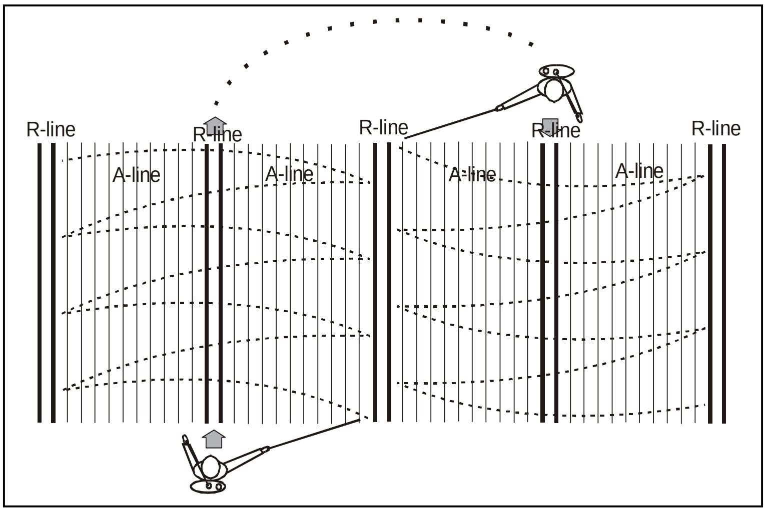


Figure 4: GA_3 application of A and R-lines using the farmers' sprayer nozzle or the designed nozzle.

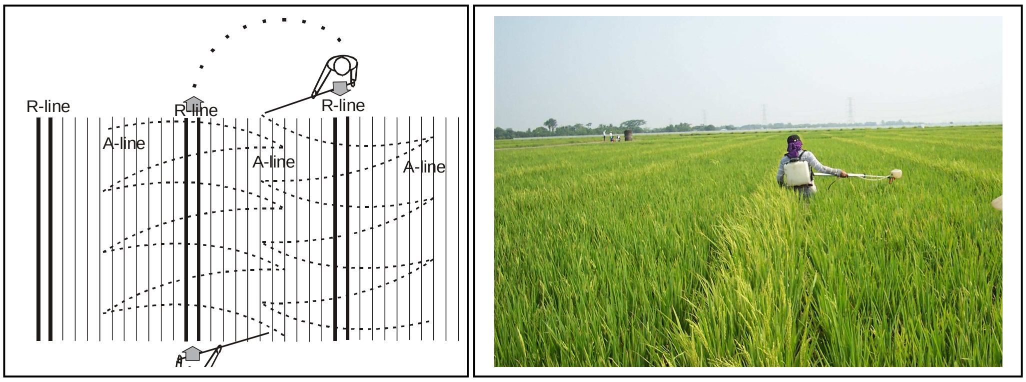


Figure 5: GA_3 application of A and R-lines using the ULV sprayer.

Table 4: Cost analysis of the three methods of applying GA_3.

PARAMETERS	ULV sprayer	Farmers' Nozzle	Designed LV nozzle
Acquisition cost, Php	4,000	80	100
Depreciation*, Php/h	2.0	0.04	.05
Labor requirement per hectare, man-h	3.1	5.5	3.2
Operating expenses, Php/h			
6 pcs size 'D' batteries @ Php19.85/pc to last 16h continuous operation	7.44	-	-
Operator (at Php250/8 hr)	31.25	31.25	31.25
Cost of operation, Php/h	40.69	31.29	31.30
Cost of operation, Php/ha/spraying	126.12	172.10	100.16

* computed using straight line method; assumes a lifespan of 2000 h and a salvage value = 0

This savings in number of tank loads largely influenced the amount of time saved in applying the GA_3 solution because every time the sprayer tank is refilled, considerable amount of time of at least 15 minutes was lost. Under actual situation, this amount varies from one field to another. If there is no clean source of water near the field and the water is to be sourced out from a distant place, then the time lost every time the tank is refilled would be higher. This is where low volume nozzle or the ULV sprayer is most advantageous.

In most cases, the application of GA_3 in hybrid rice seed production could either be in the R lines only or both in the A and R lines. Using the designed nozzle (as well as the farmers' nozzle), spraying both the A and R lines was done by letting the sprayer operator pass along the space between two R line rows with the sprayer lance swung in a rainbow-like pattern such that the next set of rows of the R lines are also covered (Fig. 4). For R line spraying, on the other hand, the operator has only to direct the nozzle on a fixed position while passing along the space between the R line rows. In terms of volume applied, there was no considerable difference observed when spraying was done on the R-line only or on both the A line and the R line. This is because even if a wider area is covered when spraying both the A line and the R line, the speed of travel was relatively lower (to ensure a more uniform coverage) as compared to that when only the R line rows are sprayed.

Using the ULV sprayer, because of limitations on the length of its boom (handle), only one set of R-lines and one set of the A-lines are covered in each pass (Fig. 5). Under actual situation, there are also instances that the application of GA_3 is repeated for the R-lines in order for the R-lines to grow taller than the A-lines and have a good chance of pollenating the A-lines. Hence, under this case, the designed LV nozzle is more advantageous to use than the ULV sprayer because the latter has a very wide swath and it is quite impossible to direct its spray towards the R-line only without contaminating the adjacent rows of the A-lines.

Farmers' feedback

Responses from 21 farmers who have tried using the designed nozzle were gathered and analyzed. These respondents were hybrid rice seed producers for 1 to 3 cropping seasons already. All of the them were users of the imported LOK sprayer. Only few, however, have experienced using the ULV hence no comparison between the LV and ULV application could be accurately made.

Results of survey showed that, using the farmers' nozzle, the number of tank loads consumed per hectare ranged from 8 to 13 or an average of 10.4 tank loads. On the other hand, using the designed LV nozzle, the number of tank loads used per hectare ranged from 2-4 or an average of 3.7 tank loads/ha. Seven out of the 21 respondents said that in using the LV nozzle, they could save time by at least 50%, the rest of the respondents were not able to determine how much. In terms of preferences, 18 out of the 21 respondents (86%) said that they prefer the LV nozzle over their existing nozzle. All of the respondents were willing to buy the designed LV nozzle once it will be commercialized.

Economics

With the designed LV nozzle, a farmer does not have to buy for a ULV sprayer, which costs around Php 5,000 (~$115)/unit, just to able to come up with an efficient method of applying GA_3. In terms of the cost of operation per hectare, the designed LV nozzle is the most economical to use as compared to the other methods of application (Table 4). The degree of advantage involved when using the designed LV nozzle varies from one field to another. The farther the source of clean water from the field, the more advantageous it is to use the designed LV nozzle.

SUMMARY AND CONCLUSION

A nozzle which could be attached to the lance of farmers' knapsack sprayers was designed for low volume application of GA_3, a growth regulator used to enhance seed setting in hybrid rice seed production. This nozzle was developed as a low cost alternative to the recommended battery-operated ULV sprayer because of the relatively low volume required in the application hence saving time and effort in carrying out the operation. Furthermore, it was also developed as a more efficient alternative to the existing sprayer nozzles which most hybrid rice seed producers use as substitute the ULV.

Testing of the prototype nozzle showed that it could approximate the performance of the ULV and provide greater advantage when compared with the traditional farmers' nozzle. The prototype, after undergoing some optimization tests in the laboratory, yielded an average nozzle discharge of 5.2 ml/s at 2.1 kg/cm^2 (30 psi) operating pressure. At the same operating pressure, the nozzle discharge of the farmers' nozzle was more than twice (11.78 ml/s). Field tests showed that, using the farmers' nozzle, around 6 tank loads were needed to cover a hectare whereas, with the designed nozzle, only around 2-3 tank loads were required.

Based on the response of 21 respondents who have tried using the designed LV nozzle, 18 of them (86%) favored the use of the designed nozzle over their existing nozzles. From the respondents' experience, an average of 3.7 tank loads were required to finish a hectare as against the 10.4 tankloads they normally consume per hectare. All of the respondents signified their willingness to buy the designed nozzle once it will be commercialized.

ACKNOWLEDGEMENT

This study was funded by the Department of Agriculture-Philippine Rice Research Institute (DA-PhilRice). The author would like to thank Engr. Noel Hamor for his assistance in the conduct of nozzle calibration tests and Engr. Leo Javier for facilitating the distribution of questionnaires to the farmer respondents.

REFERENCES

[1] Dela Cruz, I.A., S.M.F. Ablaza, S.A. Ordoňez Jr., A.T. Rigor, T.E. Mananghaya, I.G. Pacada, C. del Rosario, C.E. Arceo, L.S. Moreno, E.R. Corpuz, and E.D. Redoňa. 2001. Development of F1 hybrids at PhilRice. In Hybrid rice in the Philippines: Progress and New Horizons. Proceedings of the 2nd National Workshop on Hybrid Rice.

[2] Kutty, S. P., Narasimhan, M. and Narayanaswamy, K. 1978. Design and prediction of discharge rate, cone angle and air core diameter of swirl chamber atomizers. *In* Proceedings of the First International Conference on *Liquid Atomization and Spray Systems*, p. 93.

[3] Som, S. K. 1983. Theoretical and experimental investigations on the formation of air core in a swirl spray atomizing nozzle using power law non-Newtonian liquid. *Appl. Scient. Res.*, 40, 71.

[4] Som, S. K. 1983. Theoretical and experimental investigations on the coefficient of discharge and spray cone angle of a swirl spray atomizing nozzle using power law non-Newtonian fluid. *J. Non-Newtonian Fluid Mechanics*, 12, 36.

[5] Som, S. K. and Mukherjee, S. G. 1980. Theoretical and experimental investigations on the formation of air core in a swirl spray atomizing nozzle. *Appl. Scient. Res.*, 36, 173.

[6] Som, S. K. and Mukherjee, S. G. 1980. Theoretical and experimental investigations on the coefficient of discharge and spray cone angle of a swirl spray atomizing nozzle. *Acta Mechanica*, 36, 79.

[7] Datta, A. and Som, S. K. 2000. Numerical prediction of air core diameter, coef_cient of discharge and spray cone angle of a swirl spray pressure nozzle. *Int. J. Heat and Fluid Flow*, 21, 412.

[8] Rizk, N. K. and Lefebvre, A. H. 1985. Internal

flow characteristics of Simplex swirl atomizers. *Am. Inst. Aeronaut. Astronaut. J. Propulsion and Power*, 1(3), 193.

[9] Rizk, N. K. and Lefebvre, A. H. 1985. Prediction of velocity coeffcient and spray cone angle for Simplex swirl atomizers. In Proceedings of the Third International Conference on *Liquid Atomization and Spray Systems*, p. 111c/2/1.

[10] Suyari, M. and Lefebvre, A. H. 1986. Film thickness measurements in a Simplex swirl atomizer. *Am. Inst. Aeronaut. Astronaut. J. Propulsion and Power*, 2(6), 528.

[11] Yule, A. J. and Chin, J. J. 1997. Pressure swirl atomizer internal flow and performance. In Proceedings of 10th Annual Conference on *Liquid Atomization and Spray Systems*, p. 90 (Institute for Liquid Atomization and Spray Systems (ILASS-Americas), Irvine, California).

[12] Jeng, S. M., Jog, M. A. and Benjamin, M. A. 1998. Computational and experimental study of liquid sheet emanating from Simplex fuel nozzle. *Am. Inst. Aeronaut. Astronaut. J.*, 36(2), 201.

[13] Liao, Y., Sakman, A. T., Jeng, S. M., Jog, M. A. and Benjamin, M. A. 1999. A comprehensive model to predict Simplex atomizer performance. *Trans. ASME, J. Engg for Gas Turbine and Power*, 121, 285.

[14] Sakman, A. T., Jog, M. A., Jeng, S. M. and Benjamin, M. A. 2000. Parametric study of Simplex fuel nozzle internal flow and performance. *Am. Inst. Aeronaut. Astronaut. J.*, 38(7), 1214.

[15] Orge, R.F., L.T. Pascua and D. Castro. 1992. Design and development of a low-volume sprayer nozzle. Paper presented during the 42nd PSAE Annual National Convention held at MMSU, Batac, Ilocos Norte, April 22-24, 1992.

[16] Hewitt, L.M. 1984. Spray application technology. Mimeographed

APPENDIX

Table 1: Performance of the designed nozzle as affected by the design of the orifice and rotor

Operating pressure, psi	Orifice size (mm)	Number of rotor inlets	Nozzle discharge, ml/s	Angle of swath (deg)	No. of droplets per sq.cm.
10	0.8	1	3.6	96	253
		2	4	94	160
	1	1	3.8	91	272
		2	4.7	99	177
20	0.8	1	4.4	105	280
		2	4.7	98	145
	1	1	4.6	96	316
		2	5.6	101	199
30	0.8	1	5	108	277
		2	5.1	99	173
	1	1	5.2	100	337
		2	6.1	104	261
40	0.8	1	5.6	111	288
		2	5.8	100	161
	1	1	5.7	106	352
		2	6.8	111	293
50	0.8	1	6.2	115	247
		2	6.3	102	173
	1	1	6.3	111	407
		2	7.3	114	323
60	0.8	1	6.8	114	229
		2	6.9	106	207
	1	1	7.3	120	432
		2	7.8	119	339

Table 2: Performance of a typical farmers' knapsack sprayer nozzle

Operating pressure, psi	Nozzle discharge, ml/s	Angle of swath (deg)	No. of droplets per sq.cm.
10	8.84	104	116
20	10.61	103	137
30	11.78	109	188
40	13.13	109	108
50	14.06	110	164
60	15.11	104	157