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Development of liquid urea ammonium nitrate fertilizer foliar application system for enhanced nutrient use efficiency

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ABSTRACT

A tricycle type manually operated foliar applicator was developed with ground clearance of 74.15 cm that can be operated on standing wheat crop having row spacing of 20-22 cm. The physical properties of urea ammonium nitrate (UAN) with 3% N were found nearly equal to water with respect to dynamic viscosity, surface tension and specific gravity of UAN. Based on pressure, discharges requirement and corrosiveness of UAN, reciprocating type PVC pump (2 no.) with capacity of 4.53 l/min each was selected for the sprayer. Three type of nozzles, i.e. flat fan, stream jet SJ7 and stream jet SJ3 were evaluated in terms of discharge, spray pattern and spray angle at different heights and pressures. Spray pattern and uniformity of spray distribution of nozzles (flat fan, stream jet SJ3 and SJ7) were determined on patternator test rig. Flat fan nozzles showed most uniform pattern at 2 kg/cm^2 pressure and 500 mm nozzle height, whereas streamjet SJ7 showed maximum uniformity at 1.6 kg/cm^2 and 600 mm height. Streamjet SJ3 nozzles were found suitable for low boom height and directed application of fertilizer. Variation in discharge of nozzles among the boom was observed less than 10% while operated in field. Field capacity of the developed foliar applicator was found 0.3 ha/h. Operating pressure of 1.5 kg/cm^2 was found ergonomically suitable with an average heart rate and energy expenditure of 119 beats/min and 26.7 kJ/min, respectively for operating the prototype. The break-even point (BEP) and payback period (PBP) of developed foliar applicator were estimated as 113.43 h/year and 4 years at the operational cost of ₹ 94.68/ha.

Key words: Energy expenditure, Foliar applicator, Nozzle, Spray pattern, UAN

India is the second most populated country in the world with population of 1.21 billion people growing at 1.2% annually during 2011-15 (Census 2011; Anonymous 2015). To feed the growing population, agricultural productivity needs to be further increased. Fertilizer is one of the important inputs in crop production system. The excessive use of nitrogenous fertilizers has adversely affected soil health and also creates unfavorable conditions for microorganisms, i.e. bacteria and actinomycetes (Savci 2012). Nitrogen also reaches the water bodies by drainage, leaching and surface flow. The potential for ammonia volatilization is greatest when urea is applied on surface where soil conditions promote rapid granular dissolution, but restrict movement of urea into soil. Alternative mean of nitrogen supply to reduce volatilization and leaching is foliar application of fertilizers in liquid form. Urea-Ammonium Nitrate (UAN) is an important nitrogenous fertilizer widely used for foliar fertilization in the developed countries like USA (Leikam 2012). Foliar fertilization is a widely used supplement to improve the yield, protein content and quality of winter wheat crops (Woolfolk *et al.* 2002, Cahill *et al.* 2007, Totten *et al.*2008).

A tractor operated high clearance sprayer for spraying tall crops was developed with swath width of 20.9 m and height up to 3 m (Ahuja1979). A five-nozzle boom system was developed considering the canopy requirement of tall crops such as cotton and pigeon pea with effective field capacity of 0.146 ha/h in pigeonpea crop at forward speed of 1.31 km/h (Narang *et al.* 2013). Although tractor operated high clearance fertilizer sprayers have been developed for commercial crops, yet very less attempts have been taken for low cost foliar fertilizer application system for wheat crops suitable for marginal and small farmers. The aim of this study was to select suitable nozzles for foliar application at different heights and to develop a low cost high clearance foliar fertilizer applicator.

MATERIALS AND METHODS

The present study was undertaken to design and

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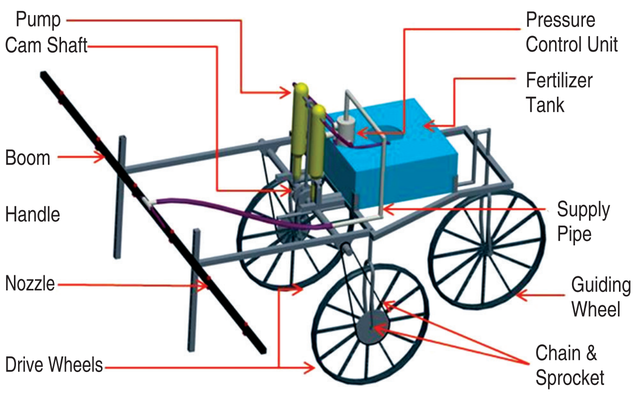

Fig 1 General view of prototype design.

develop technically feasible and economically viable foliar applicator for UAN application. The physical properties, i.e. specific gravity, viscosity and surface tension of UAN with 3% N solution were determined and compared with the properties of water to observe any significant difference in these properties from that of water. The fabrication and evaluation of the foliar applicator was done at Division of Agricultural Engineering, IARI, New Delhi.

Foliar applicator was designed and fabricated in divisional workshop according to drawing prepared using PTC Creo Parametric 2.0 shown in Fig. 1. The frame was made with square pipes and mild steel angle iron. Design and fabrication of different components according to requirements is described in Table 1.

The droplet sizes as well as uniformity of distribution are greatly affected by the type of the nozzle as well as nozzle size (Nuyttens *et al.* 2007). The correct nozzle tip size depends on application rate, forward speed and effective spray width of each nozzle. The individual nozzle discharge was determined with help of following equation considering the capacity of 400-1000 l/ha quantity of spray and average speed of about 2 km/h (IS 11429-1985).

Table 1 Specification of different components of foliar applicator

Particulars	Specification
Power source	Manually operated
Pump	Piston Pump Material = PVC Piston dia. = 4.3 cm Piston stroke = 8.75 cm Discharge per stroke = 127 l
Power transmission	Chain-sprocket Driver sprocket = 60 teeth Driven sprocket = 16 teeth Gear ratio = 3.75
Cam	Dia. = 14 cm Cam lift = 7.6 cm
Tank	Capacity = 100 l
Pressure relief valve	Piston-type , maximum capacity = 10.34 bars
Boom	3m, 6 nozzles having 50 cm spacing
Nozzles	flat fan FF110-02-VP, stream jet SJ3-02-VP and stream jet SJ7-02-VP
Ground clearance	74.15 cm

$$Q = \frac{V \times S \times W}{600}$$

where, Q = Discharge per nozzle, l/min; V = Total discharge, l/ha; S = Speed, km/h; W = Nozzle spacing (m) for broadcast spraying.

The nozzle tip giving the required amount of spray was selected for study. The nozzles selected were flat spray tip, stream jet (3-streams) tip and stream jet (7-streams) tip.

Developed foliar applicator was tested according to the BIS (IS:8548-1997) standards in laboratory conditions to ensure proper working of the components and to evaluate its performance in controlled environments. The uniformity of the spray distribution across the boom or within the spray swath is essential to achieve maximum chemical effectiveness with minimal cost and minimal non-target contamination. Nozzle type, Operating pressure, nozzle height and spray angle greatly influence the uniformity of the spray distribution (Hassen *et al.* 2013). The uniformity of spray distribution of the nozzles was calculated using a 2000×2000 mm patternator having inner dimensions of equal channels as 2000×25×100 mm at CIAE, Bhopal. Since boom height also changes for different crop heights, the nozzles were operated at different pressures (1.2, 1.6 and 2 kg/cm^2) and heights (300, 400, 500 and 600 mm) to check nozzle's uniformity of distribution at different heights. The coefficient of variation (CV) of the average data was calculated using MS Excel to find the uniformity of distribution. The treatment with least CV was considered the best. The effect of pressure and height on CV was studied. The effect of pressure on spray angle and nozzle discharge for each nozzle was calculated on the working pressure of 1.2, 1.6 and 2.0 kg/cm^2 and spray angle was determined using formula given in equation below (IS 11429-1985).

$$W = 2\,h \tan\frac{\theta}{2}$$

where, W is the width of spray cone, mm; h is the height of the spray, mm; θ is the spray angle in degrees.

Liquid fertilizer should be applied evenly and at the prescribed rate. Sprayers should be calibrated to determine the amount of mixture that is actually being applied per ha. The sprayer was operated at the average speed of 2 km/h for 30 m distance and the amount of water used to fill the tank was noted down. Spray volume required for 1 ha was calculated using formula (IS 11429-1985).

$$\text{Spray volume (l/ha)} = \frac{Q \times 600}{S \times W}$$

The experiments for ergonomic evaluation were carried out in ergonomics laboratory and field of Division of Agricultural Engineering, IARI, New Delhi. The ambient climatic conditions were measured as temperature 36°C and relative humidity 86%. First of all subjects were calibrated in terms of their physiological parameters. The postural and overall discomfort of the operators was also observed while operating the developed foliar applicator.

The cost of operation of the manual foliar applicator was computed according to IS: 9164-1979.The total cost of operation was determined as the sum of fixed and variable cost. The total cost of operation per hour of the applicator was computed. The break-even point (BEP) and payback period (PBP) were also computed using the formulae

$$BEP = \frac{FC}{CF - C}$$

where, BEP = Break-even point, h/year; FC = Annual fixed cost, ₹./year; CF = Custom hiring charges, ₹./h; C = Operating cost, ₹./h; CF = 1.25×(C+ 0.25C).

$$PBP = \frac{IC}{ANP}$$

where, PBP = Payback period, year; IC = Initial cost of machine, ₹; ANP = Annual net profit; ANP = (CF - C)×AU; AU = Annual utility, h/year; AU = AA × EC; AA = Average annual use, h/year; EC = Effective capacity of machine, ha/h.

RESULTS AND DISCUSSION

This study was performed to develop a foliar applicator for UAN for application in wheat crop. Physical properties of different nitrogen concentration solutions were determined and compared with that of water. On the basis of nozzle discharge and operating pressure nozzles selected were flat fan FF110-02-VP, stream jet SJ3-02-VP and stream jet SJ7-02-VP.

Uniformity of spray distribution

The discharge obtained from different channels of the patternator was measured for flat fan, Stream jet SJ3 and stream jet SJ7 nozzles. Readings were taken at the height range from 300 to 600 mm and pressure of 1.2 to 2 kg/cm^2. For all three nozzles, the discharge was maximum near the centre and it declined towards the ends as shown in Fig 2.

From the Analysis of Variance (ANOVA), it was observed that for all the three nozzle types, i.e. flat fan, SJ3 and SJ7 nozzles, the variation in discharge was significantly affected by pressure, height as well as their interaction (Table 2, 3 and 4). The minimum coefficient of variation of 1.12% was observed for SJ3 nozzle at 2 kg/cm^2 pressure and height of 300 mm. The maximum coefficient of variation 62.54% was observed for SJ7 nozzle at the pressure of 1.5 kg/cm^2 and height of 300 mm. From Duncan's t-test, it was observed that for all the three types of nozzles, the coefficient of variation of discharge (CV) was significantly increasing while increasing the pressure from 1.2 to 2 kg/cm^2. It was also observed that with increase in height from 300 to 600 mm the variation in discharge decreased significantly at 5% level of significance.

Table 2 ANOVA for effect of operating pressure and height on CV of flat fan nozzle. Dependent Variable: CV

Source	Type III sum of squares	Df	Mean square	F	Sig.
Corrected model	313.475[a]	11	28.498	11016.467	.000
Intercept	75113.397	1	75113.397	29036860.980	.000
Pressure	71.104	2	35.552	13743.406	.000
Height	220.163	3	73.388	28369.771	.000
Pressure* height	22.208	6	3.701	1430.835	.000
Error	.062	24	.003		
Total	75426.934	36			
Corrected total	313.537	35			

a. R Squared =1.000 (Adjusted R Squared = 1.000)

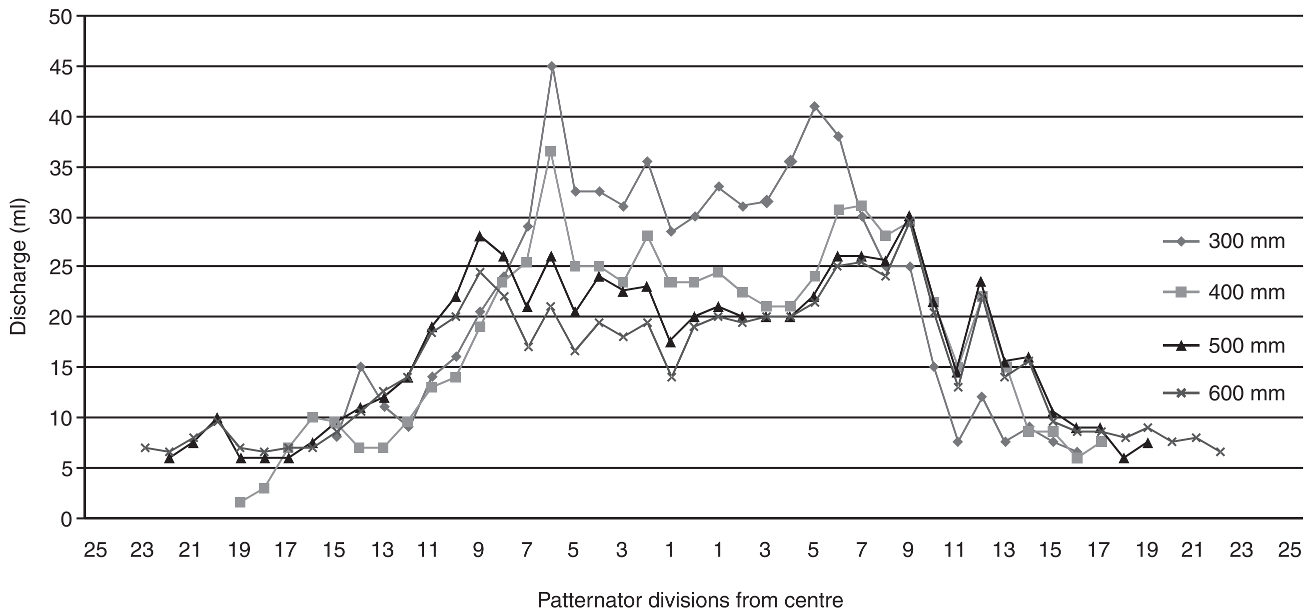

Fig 2 Effect of nozzle height on spray volumetric distribution of flat fan nozzle at 1.6 kg/cm^2 pressure.

Table 3 ANOVA for effect of operating pressure and height on CV of stream jet SJ3 nozzle. Dependent Variable: CV

Source	Type III sum of squares	Df	Mean square	F	Sig.
Corrected model	7672.470[a]	11	697.497	1261162.342	.000
Intercept	5369.236	1	5369.236	9708250.605	.000
Pressure	6.753	2	3.376	6105.109	.000
Height	7617.343	3	2539.114	4591036.864	.000
Pressure* height	48.373	6	8.062	14577.493	.000
Error	.013	24	.001		
Total	13041.719	36			
Corrected total	7672.483	35			

a. R Squared =1.000 (Adjusted R Squared = 1.000)

Table 4 ANOVA for effect of operating pressure and height on CV of stream jet SJ3 nozzle. Dependent Variable: CV

Source	Type III sum of squares	Df	Mean square	F	Sig.
Corrected model	208.144[a]	11	18.922	42262.105	.000
Intercept	123383.036	1	123383.036	275571635.000	.000
Pressure	55.474	2	27.737	61949.592	.000
Height	65.125	3	21.708	48484.947	.000
Pressure* height	87.545	6	14.591	32588.188	.000
Error	.011	24	.000		
Total	123591.191	36			
Corrected total	208.155	35			

R Squared =1.000 (Adjusted R Squared = 1.000)

Effect of pressure on the spray angle and discharge of all three type of nozzles was determined at a fixed height of 500 mm. For flat fan nozzle, spray angle increased from 90° to 106° when pressure was increased from 1.2 to 2 kg/ cm^2. Spray angle for SJ7 nozzle was 68° for 1.2 kg/cm^2 pressure and 79° for 2 kg/cm^2. Spray angle was minimum for SJ3 nozzle; it was 39° at 1.2 kg/cm^2 and was 48 at 2 kg/cm^2 (Fig 3). Discharge was observed as a function of working pressure. Discharge of flat fan, SJ7 and SJ3 nozzle at 1.2 kg/cm were found as 0.48, 0.50 and 0.49 l/min, respectively and it increased to 0.64, 0.63 and 0.62 l/min respectively at 2 kg/cm^2 pressure (Fig 4).

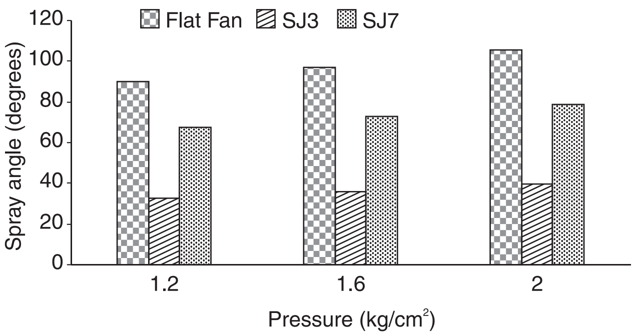

Fig 3 Effect of operating pressure on spray angle of nozzles.

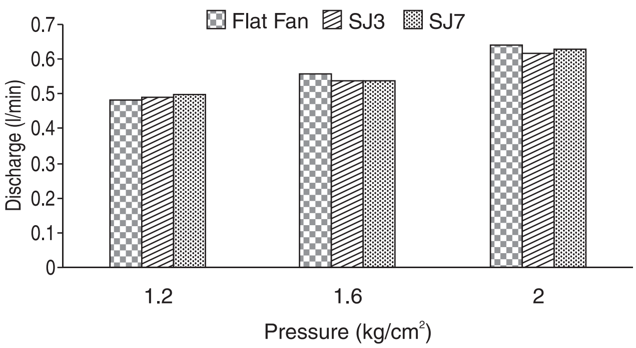

Fig 4 Effect of operating pressure on discharge of nozzle.

Table 5 Effect of nozzle distance and pressure on discharge in field

Pressure	Discharge rate of nozzles (l/min)					
	NL_3	NL_2	NL_1	NR_1	NR_2	NR_3
1.5 kg/cm^2	0.513	0.565	0.616	0.593	0.55	0.513
2 kg/cm^2	0.53	0.53	0.626	0.6623	0.62	0.516

The foliar applicator was calibrated in the field at average speed of 2 km/h. Discharge from each nozzle at two pressure levels was obtained (Table 5). Total discharge for 1.5 and 2 kg/cm^2 was 3.62 and 3.91 l/min respectively.

Ergonomic evaluation of the developed prototype

The developed prototype of foliar applicator was ergonomically evaluated in terms of heart rate, oxygen consumption and energy expenditure of the operators. Six subjects of different heights and age groups were selected. Calibration of selected subjects were carried out on the trade mill with the help of the K4b^2 instrument and calibration curves were obtained.

Average heart rate of subjects for 1.5 kg/cm^2 pressure was found as 120 beats/min and for 2 kg/cm^2 pressure it

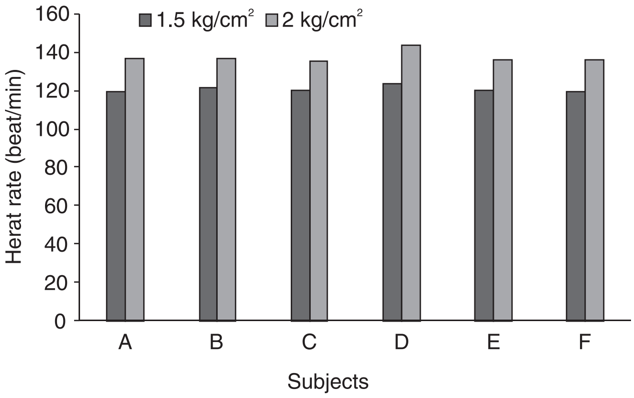

Fig 5 Heart rates of subjects at different operating pressures.

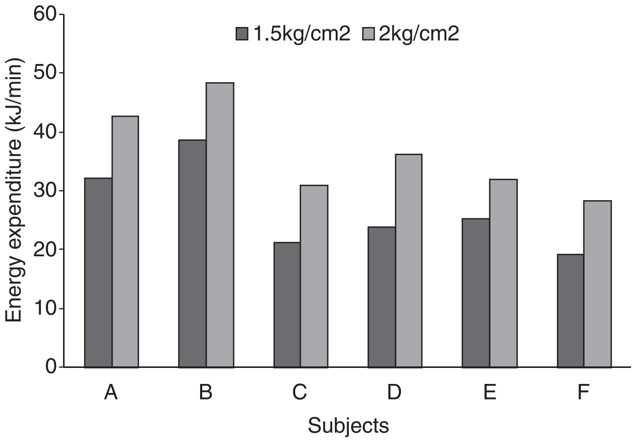

Fig 6 Energy expenditure of subjects for different operating pressures.

was recorded as 137.5 beats/min (Fig 5). Average energy expenditure of subjects at 1.5 and 2 kg/cm^2 was found to be 26.7 and 36.3 kJ/min respectively (Fig 6).

Cost economics

The final cost of the prototype, the total cost of operation per hour, break-even point (BEP) and payback period (PBP) of developed applicator were computed and obtained (Table 6).

The liquid UAN with 3% N is foliar fertilizer sprayed at different stage of wheat growth. The developed foliar applicator is to be operated in standing wheat crop hence it has ground clearance of 74.15 cm. The traction and steering wheels of tricycle type foliar applicator were selected to facilitate the ease of operation between rows of wheat having row spacing of 20-22 cm. As UAN is corrosive in nature therefore PVC tank and pump were selected instead of metallic. Cam lift was kept 7.5 cm lesser than pump stroke 8.6 cm to avoid possible leakage and damage of pump. For sufficient pressure generation by pump, gear ratio of 3.75 was maintained to get 50-55 strokes/min at average speed of 2 km/h. Combined effect of spray pressure and height of nozzle gave optimized conditions for a particular nozzle in terms of coefficient of variation. Spray angle was maximum for flat fan nozzles for a particular pressure because of fine atomization of spray droplets which make them less dependent on gravitational forces. Spray angle for stream jet SJ3 nozzle was least which made them suitable only for directed fertilizer application, not for broadcasting. Discharge among the boom nozzles during field calibration showed a decrease in nozzle discharge rate with increase of distance from central delivery pipe. It happened because of pressure loss in boom through the couplings and T sections. Ergonomic evaluation of developed prototype foliar applicator was performed to fit the task to the operator. The heart rate and energy expenditure observed during field operation of developed prototype were found ergonomically suitable at pressure of 1.5 kg/cm^2. When operating pressure was raised to 2 kg/cm^2, the operator found it difficult to run the prototype (American Industrial Hygiene Association 1971).

Table 6 Cost economics of developed prototype planter

Cost of prototype, ₹	13000
Hourly cost of operation, ₹/h	94.68
Break-even point (h/year)	113.43
Payback period, year	4

Conclusion

The result revealed that flat fan nozzle, stream jet SJ7 and stream jet SJ3 were suitable for application at height of 50 cm, 60 cm and 30 cm respectively at different operating pressure. The effect of pressure on spray angle was maximum for flat fan nozzle and was minimum for stream jet SJ3 nozzle. Discharge of flat fan, SJ3 and SJ7 nozzle was observed as 0.71, 0.73 and 0.71 l/min respectively at 1.6 kg/cm^2 pressure. Field capacity of the prototype applicator was found to be 0.3 ha/h.The average energy expenditure for operating the prototype was observed as 28 KJ/ min, the average heart rate was found 124 beats/ min at operating pressure of 1.5 kg/cm^2. The estimated cost of the research prototype foliar applicator was ₹ 13000. The operational cost of the equipment was ₹ 94.68/ha. The break-even point (BEP) and payback period (PBP) of developed foliar applicator were obtained as 113.43 h/year and 4 years respectively.

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