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Operational Efficiency and Safety Assessment of Agricultural Sprayers in Central India

AMBATI RAVINDER RAJU * AND POOJA VERMA
ICAR-Central Institute for Cotton Research, Nagpur, 440010
**Email : bumaraju@gmail.com*

Abstract : Agricultural sprayers *viz.*, Lever (LOK), Battery (BOK) and Motor (MOK) operated knapsack sprayers were tested at ICAR- Central Institute for Cotton Research, Nagpur, India, during 2017, to find out safer sprayer, optimum pressure and suitable nozzle for cotton at full bloom stage. Hollow cone (HC) and solid cone (SC) nozzles for the experiment were tested in hot humid October month at calm wind velocity on five variables *viz.*, nozzle pressure, angle of spray application, orifice number in the nozzle block, spray output on subject (henceforth, "output") /nozzle and output /orifice were tested and correlation, regression and principal component analysis were carried out. In LOK and BOK sprayers, pressure *vs* nozzle output regression statistics showed positive correlation (R^2=1.0*), while angle of spraying was non significant. In MOK sprayer, pressure had direct correlation on nozzle output on the subject (1.00**) and output/orifice (0.51*) as divided across number of orifices. The PCA showed highly significant Eigen correlation value for output/orifice and pressure (R^2=0.52**), nozzle output (R^2=0.76**) and output/orifice (R^2=0.70**). Eigen value were much higher in three variables only *i.e.*, pump pressure (3.03), followed by lever angle (1.17) and nozzle orifice number (0.77). Hence, MOK sprayer with different pressure and angles on output showed that pressure 2.5 kg/cm, angle of application 45°, 5 orifices in nozzle block, 36 lpm nozzle output should not exceed for minimisation of spray nozzle output on the subject. BOK sprayer was found to be most efficient, safest with least drudgery, hence it is popular in small holder farming. As the pressure induced drift hazard is established beyond 2.5 kg/cm in all the sprayers, pressure regulating valves with auto cut off switch must be mounted to reduce pesticide related poisonings along with all the mandatory safety accessories.

Keywords: Agricultural sprayers, *Bt* hybrid cotton, nozzle pressure, pesticide poisonings, spray angle

Medium to large cotton farmers of central India, having >2 ha land prefer to use a motorized knapsack sprayer (MOK) with hired labour at squaring to boll development stage covering maximum 2 ha/day (Table 1). Efficient coverage on underside of the leaves to kill hiding sucking pests and cost effectiveness at US $ 6.8/ha spray[-1] may be ensured if used with care and standard operating procedures (Nuyttens *et al.*, 2007, 2009; Dorr *et al.*, 2008). It can develop a pressure up to 6.0 kg/cm with 2 or 4 stroke cycle petrol engine with a centrifugal/diaphragm pump having a 18-25 L capacity of poly propylene pesticide tank with a pesticide delivery regulating valve at the elbow of the lever and a single orifice nozzle at the end (Felsot *et al.*, 2010). In *Bt* hybrid cotton, window based sprays, at least six to eight, consisting of herbicides, insecticides, fungicides, bio-stimulants, water soluble fertilizers (WSF) and growth retardants are being applied always in combinations. Moreover, sucking pests and bollworms protection costs alone in cotton is costing US $ 170/ha *i.e.* 23 per cent of the cost of *Bt* hybrid cotton cultivation (Table1).

MATERIALS AND METHODS:

Bt hybrid cotton environmental situation in 2017

Bt hybrid cotton, at peak bloom stage was severely damaged by sucking pests and young pink bollworm larvae in post monsoon hot humid weather condition (Fig.1), which required application of insecticides at every 12-15 days

interval (Table 1). Central Insecticide Board, Govt. of India (CIB, GOI, 2016, 2018, 2019) and FAO imposed tme to time restrictions and regulatory curbs on class Ia and Ib insecticides. However, they had limited penetration in creating awareness in adoption of the same by farmers. Non hazardous modern insecticides recommended by CIB, GOI and FAO cost 50 to 100 per cent more, therefore they are least penetrated into the rural markets (Kranthi, 2014; Srivastava and Kolady, 2016; Kranthi and Stone, 2020). Cotton farmers in Central India forced to manage their *Bt* hybrid cotton with monocrotophos and acephate; broad spectrum insecticides having oral LD_{50} 1-50 mg/kg body wt. Cotton farming community is least aware about the safety accessories and standard operating procedures (SOPs) of pesticide appliances (GOI, 2016, 2018, 2019). However, the much blamed knockdown effective difenthiuron during this time had oral LD_{50} 2200 mg/kg body weight (Anonymous, 2016, 2020). Majority of medical reports on pesticide poisonings involved organophosphate group of insecticides in India with a LD_{50} 1-50 mg/kg body wt (Gupta *et al.*, 2006; Muarali *et al.*, 2008; Banerjee *et al.*, 2012, PAN, 2017). Seven hundred farm laborers were reported to be affected by pesticide application poisonings in Yeotmal district of Maharashtra, India by September, 2017 and the deaths occurred due to excessive inhalation of pesticide nerve poison. Cotton crop pesticide application poisonings in Yeotmal (20.4° N, 78.1° E) and Amravati, (20.9° N, 77.8° E) districts of Maharashtra state, India's cotton belt, created huge uproar in press, state assembly and also in national parliament about the MOK sprayers and knockdown insecticides (difenthiuron) by the public representatives (PAN, 2017). The timings of poisoning reported in medico legal cases (MLCs) were between 12 to 14 hrs afternoon within first three rounds of the spray applications mostly by the aerosols produced by MKS sprayer (PAN, 2017). In hot 35°C, (Fig. 1) humid weather, when human skin pores are open for sweating, more than lethal dose of pesticide is absorbed through skin and nostrils from aerosols produced by MKS sprayer in the absence of protective body covering (apron, gloves, mask and goggles) by the pesticide application subjects. In order to find out the facts along with remedial measures on pesticide applicator's poisoning, MKS sprayer along with popular sprayers were tested using dummy sprays to simulate and validate various nozzle pressures and angles with protective clothing. A report was submitted to state and central government agriculture ministry's which formed a basis for both public and private sector agencies to create large scale awareness among cotton farmers across the country. They were trained, demonstrated, and provided with safety kits too.

Agricultural sprayers and accessories

Three commonly used sprayers by the Indian cotton farmers *viz.*, Lever operated knapsack (LOK) sprayer, battery operated knapsack (BOK) sprayer, motorized knapsack (MKS) sprayer were tested by professional agriculture engineers on trained subjects with commonly available and used nozzles such as hollow cone nozzle (HCN), solid cone nozzle (SCN) and flat fan (FFN). The testing was under variable pressure 1.0 to 4.5 kg/cm and number of delivery orifices at different angles (30-70°), output percentage of applied pesticide was expressed per unit nozzle and orifice at calm wind speed.

Testing protocol

Methylene blue dye 5.0 g/L was mixed with a pesticide (dummy) spray and the solution was sprayed on acrylic sheets (size 21 x 29.7 cm) to measure spray deposition on the subject and *kodak* photographic plates (5.0 x 7.5 cm) were kept at different locations in the cotton crop and non target areas, to estimate the dye. Transparent acrylic sheets were fixed on the

trained subject body parts such as fore limbs, chest, goggles and face mask. Methylene blue dye intensity was measured by colorimetry and used to standardize the protocol for test report of MKS sprayer. The age of the test *Bt* hybrid cotton Ankur 3028 crop was 105 to 120 days during test period with 1.4 m plant height. A working solution of 100 ppm KNO_3 pesticide (dummy) was also sprayed on rainfed cotton strip cropping with a two rows width (1.8m) and a length of 120m strip with average walking speed of 3.5 km/h to validate results from methylene blue dye results. We collected the recovered methylene blue dye and KNO_3 on the subject from various locations into 2.0 L glass beakers by repeated washings with double distilled water. The collected aliquot of samples was transferred to 500 ml volumetric flasks and only 50 ml of the sample was kept for estimation. The samples were repeated 4 times and average values were considered for estimation and interpretation. The quantitative analysis of the pesticide dummy at each location out of the total volume sprayed was calculated and expressed in ppm. Appropriate volume of deposition collected, made up for volumetric analysis and computed to required dilutions to estimate spray deposition at a specific location. The LD_{50} values were calculated from the quantity of pesticide dummies fallen on the subject in a given time with commonly used nozzle by the farmers on LOK, BOK and MKS sprayers at variable pressure 1.0-4.5 kg/cm and angle of application 30-75° ensuring wind speed near zero kmph with the help of hand held anemometer. Ambient temperature, humidity was measured from automatic weather station located at about 50 m away. Pesticide application subject's pulse and heart beat before and after application of the pesticide, required rest, protective aprons, goggles, masks and other standard operating procedures (SOP) for pesticide drift estimation (NIPHM, 2013; Anonymous, 2016, 2020) were followed. Double distilled water was used for spray application to avoid interference in estimation of the recovered dummy pesticide on the body of the subject. The testing was conducted at Field No A-34 of ICAR-Central Institute for Cotton Research Farm, Nagpur on 20th, October, 2017 with geospatial location 21.04° N, 79.06° E.

Statistical analysis

The sprayers were calibrated, tested at variable pressures, angles with single and multiple orifices nozzle blocks. The data was analyzed using correlation, regression and principal component analysis.

RESULTS AND DISCUSSION

Lever operated knapsack (LOK) sprayer

The conventional LOK sprayers are most preferred choice among the small and marginal cotton farmers utilizing the family labour. This sprayer is modestly priced at US $ 8 and used in cotton crop from vegetative growth to flowering stage using various types of nozzles. Drift hazard is minimal in the operational pressure range and almost zero accident prone, maintenance free except nozzle blockage by muddy water. SCN were used from vegetative growth to squaring and there after multiple orifice nozzle blocks, from flowering to the boll development stage. These pumps are either owned or borrowed from neighboring cotton farmers. Occasionally they are also available on rent in rural India. This is most suitable in the pressure range from 1 to 2 kg/cm beyond which the drift falls on the subject or excess pump pressure needs to be released through multiple orifices in the nozzle block. This is relatively safe sprayer without medico legal cases (MLCs), economic and affordable appliance for small and marginal cotton farmers in India. However, protective apron, gloves, goggles and shoes are essential part of SOPs for all plant protection appliances (NIPHM, 2013). The operating lever movement for full pump stroke

should not be more than ± 35° from horizontal for each upward and downward movement. The pump discharge rate should be minimum 500 ml/min at 16±1 stroke minute^{-1} at 2.80 kg/cm pressure (NIPHM, 2013). Continuous lever operation with one hand and operating the lancer trigger with the other, the operator is unable to concentrate on target of spraying, resulting in non uniform spray application due to fluctuations in pressure with a very low field capacity of 0.30 to 0.40 ha/day. The pump was tested with commonly used solid cone (SC) and flat fan (FF) nozzles. Drift at recommended pump pressure 1 to 2 kg/cmwas almost negligible. Flat fan nozzle did not produce any drift, due to their coarser particle size and spray angle direction. Although, it is difficult to generate higher pressure by manual lever operation, pressure directly corresponding to significant increase in output (R^2=1.0) on the subject. The output needs to be distributed atleast in 2 or 5 orifices to reduce the drift hazard on the subject. The results were in agreement with those advised by NIPHM, 2013.

Battery operated knapsack (BOK) sprayer

The weak points and drudgery of lever operation in LOK sprayer were removed in BOK sprayer, which was fitted at the bottom collar with a DC motor and diaphragm pump to develop 2.5 kg/cm pressure with auto cut off supported by a rechargeable Lithium battery, (12.0 V 8.0 AH) along with 1.0 AMP charger (NIPHM, 2013). Dropping pressure in LOK sprayer was resolved with a pressure chamber and a cut off valve to save battery. Tank weight was kept same as 16 L of high quality plastic material similar to LOK sprayer. Stainless steel extendable lancer with brass or plastic on off lock on the trigger. This can build pressure of 3-5 kg/cm. BOK sprayer was tested with SCN, HCN nozzles from 2.0 to 4.5 kg/cm with single, double, four and five orifices suitable for various stages of cotton crop. The ideal pressure remained between 2.0 to 3.8 with SCN, HCN nozzles with output 54 lpm with 2 orifices and with single orifice it reached 64 lpm at 4.5 kg/cm. The pump pressure generated *vs.* SCN nozzle output was significant at R^2 value 1.0 and spray angle (°) of operation. Solid cone nozzle (SCN) output remained non significantly influenced due to tail ended passive conduit lever steel rod with a nozzle block. Test results were in agreement with standard protocols recommended by NIPHM, 2013.

Comparison between LOK and BOK sprayer

Principal component analysis found pressure and angle of spraying were found significantly influenced on the output of orifice block even with the low pressure developing spray pumps like LOK and BOK sprayers (Table 6). Both pressure and angle of spraying are explaining the major source of drift in the absence of movement of air currents. They remain relatively safe within the pressure up to 2 to 3 kg/cm provided the increased pressure is distributed appropriately by number of orifices 2-5 as per the stage of demand.

Motorized knapsack (MK) sprayer

This sprayer received a lot of flak for pesticide poisoning related deaths of farmers and farm workers in central India during the year 2017 (PAN, 2017). The year saw a moderate to severe seedling drought during third week of July to mid August followed by rains which lead to excessive plant height (0.45m) by September end in bushy, well fertilized *Bt* cotton hybrids. When sprayed at greater than 45° angles, in excess of 4.0 kg/cm pressure and slightly higher than 5 kmph wind speed produced enough drift which fell directly on the unprotected face, chest, hands and limbs of the subject, especially with monocrotophos pesticide which was supplied at 50 per cent subsidy. In the hot humid weather at 12 to 14 hrs, unprotected, sweaty body absorbed beyond lethal dose, accompanied with head and stomach ache, giddiness with nausea symptoms

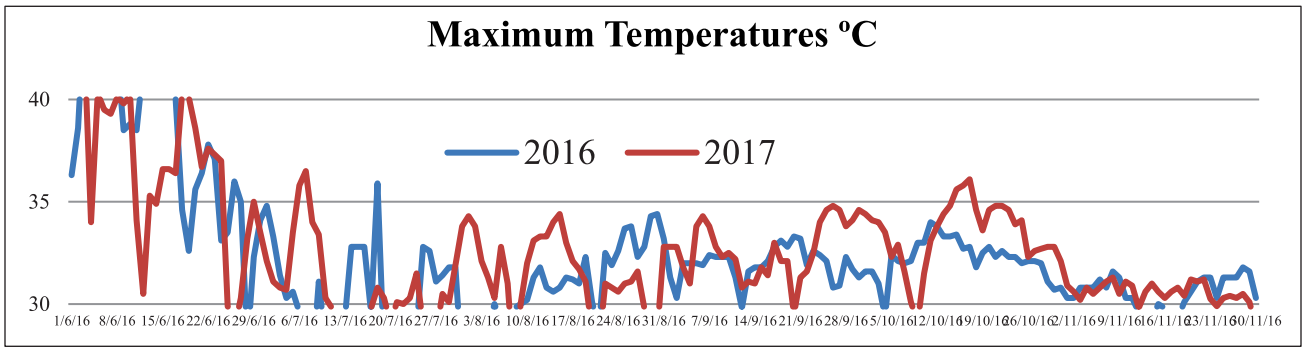

Fig. 1. Maximum temperatures (oC) during spray application in 2017 over previous year

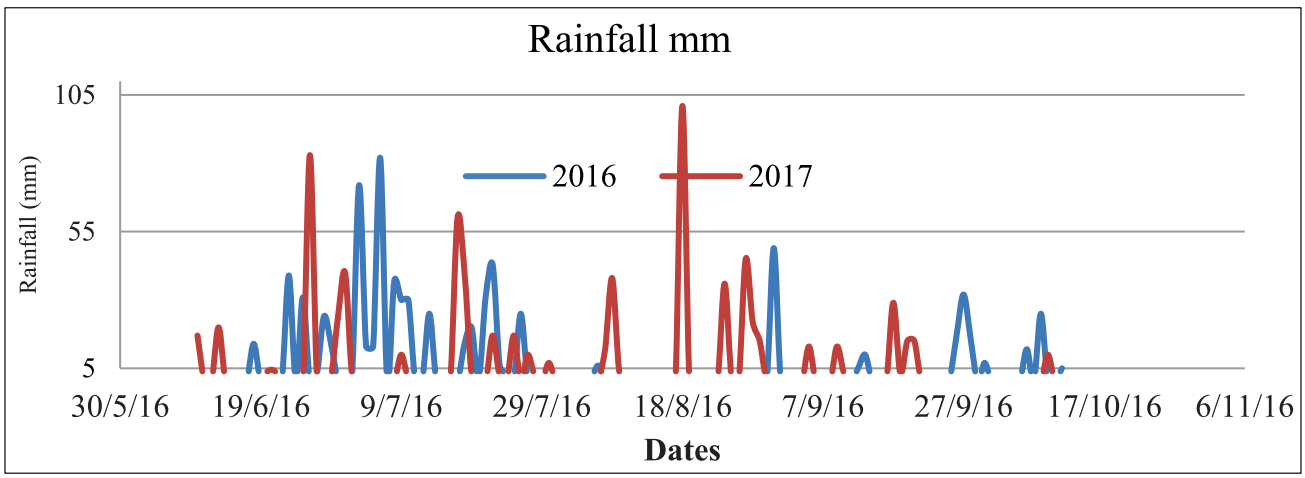

Fig. 2. Rainfall in the year 2017 after the seedling drought induced the excess plant height

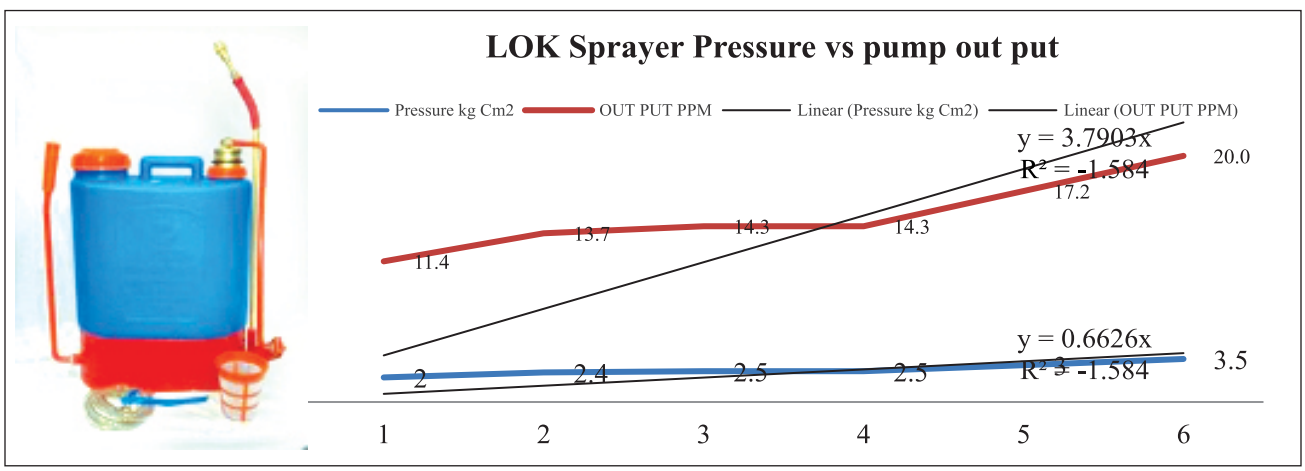

Fig. 3. LOK sprayer pressure vs SCN nozzle output on the subject regression analysis.

(Gupta *et al.*, 2006, Murali *et al.*, 2008). Pressure from 1.0 kg/cm produced minimum drift hazard with single orifice nozzle on the subject. Pressure 2.0 to 2.5 kg/cm was divided on 5 orifices with minimal drift induced hazard. However increasing angle of application from 35° to 70°increased the drift hazard from 28.4 to 35.6 ppm on the subject. Therefore, plant height induced angle and pressure produced drift which are the cause and effects of reported poisonings. The significant relationship was established on the pump pressure and angle and the output on

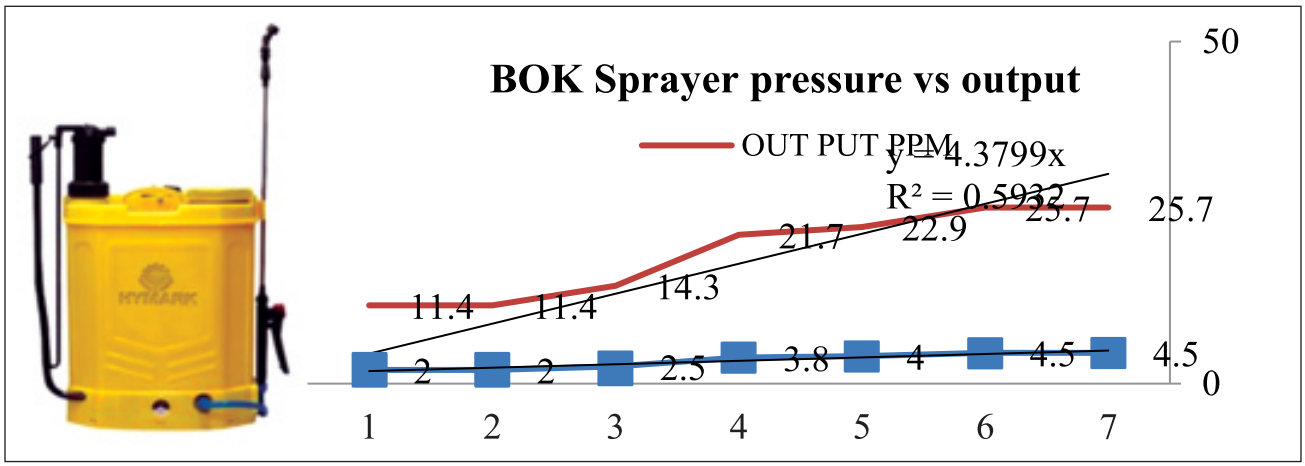

Fig. 4. BOK sprayer pressure vs SCN nozzle output on the subject regression analysis

the subject in PCA-1 and PCA-2.

CONCLUSIONS

The main problem of drift hazard lies with the high pressure of >3.0 kg/cm, followed by wind speed exceeding 5 kmph and by not using any safety accessories or precautions during high volume spraying. All the agricultural sprayers need to be fitted with pressure control auto cut off valves. It must be made mandatory for the manufacturers to pre fit the sprayers with pressure control auto cut off valves along with other spraying accessories and SOP instructions in local language to use, while field spraying of agrochemicals. Mass awareness must be created to restrict crop height upto one meter, restricted number of sprays after full bloom (80-110 days) and use of safe pesticides (yellow and blue colour), ISI marked appliances and necessary accessories with SOPs in local languages must be ensured.

MKS sprayer drifted 52 per cent of the spray aerosols on to the subject compared to LOK sprayer;

LOK sprayer is relatively safe, however, 3/4 th on stomach, gloves and right hind limb, which is often raised to direct nozzle and remaining 1/4 th on chest and remaining limbs. Therefore, Apron/ full sleeves cotton shirt and gloves are essential part of SOPs accessories besides, goggles and mask.

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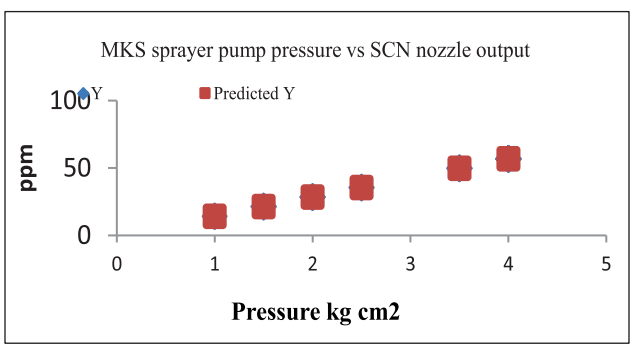

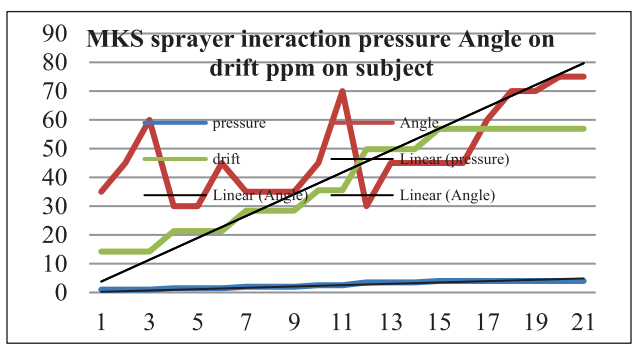

Fig. 5. MKS sprayer pressure vs SCN nozzle output on the subject regression analysis

sprayers, chemicals and other consumables. The authors duly acknowledge Director, ICAR CICR, Nagpur for providing this opportunity for testing of agricultural sprayers and extending institute facilities for this study.

Table 1. Validation of MKS sprayer based cost of cultivation of *Bt* hybrid cotton on raised beds

Operations	US $	Per cent cost of cultivation
Inputs	284.5	36.9
Bt hybrid cotton seed	41.7	5.4
Herbicides	27.9	3.6
Insecticide, fungicides, stimulants	135.7	17.6
Nutrients 83:85:65 kg/ha N:P_2O_5: K_2O	79.2	10.3
Labour	488.3	63.3
Planting	7.8	1.01
Manual weeding	100.6	13.0
Manual fertilizer application	14.3	1.9
Manual picking	272.7	35.3
Motorized knapsack spraying cost	40.9	5.3
Harrowing and raised bed forming	51.9	6.7
Lint yield kg/ha	960	100.0
Seed cotton value	1870	
C: B ratio	2.42	
Net returns/ha	1098	

Table 2. LOK sprayer testing with SCN, FFN nozzle on different parameters

Pressure kg/cm^2	Angle	Drift	Orifices	Output ppm	Output per orifice
2	45	0	1	11.4	11.4
2.4	30	1	5	13.7	2.7
2.5	30	1	1	14.3	14.3
2.5	30	1	2	14.3	7.2
3.0	45	0	1	17.2	17.2
3.5	30	1	5	20.0	4.0

Table 3. LOK sprayer testing SCN nozzle pressure vs output regression

	F calculated	*Sig F*	*P value*
Multiple R	1	2.57	
R Square	1		
Adjusted R Square	1		
Standard Error	1.32 E-15		
Observations	6		
	Coefficients	*T stat*	
Intercept	2.13E-14	1.75	0.15
X Variable 1	14.22	5.07E+15	9.05 E-63

Table 4. BOK sprayer pressure vs SCN nozzle output regression analysis

Pressure kg/Cm^2	Angle	Drift	Orifice	Output ppm	Output/orifice
2.0	45	1	2	12.5	6.3
2.0	45	0	5	12.5	2.5
2.5	45	0	4	17.1	4.3
3.8	50	1	2	29.0	14.5
4.0	30	0	1	30.8	30.8
4.5	45	0	1	35.4	35.4
4.5	50	0	1	35.4	35.4

Table 5. BOK sprayer pressure vs SCN nozzle output regression analysis

Multiple R	1.0	P value
R Square	1.0	
Adjusted R Square	1.0	
Standard Error	2.74 E-16	
Observations	7	
F	Sig F test	
	3.01E-83	1.0
	Coefficients	
Intercept	0.00	1.000
X Variable 1	5.72	3.01E-83

Table 6. LOK and BOK sprayer Eigen values of Covariance Matrix

	Pressure kg/cm	Angle	Drift	Orifice	Output ppm
Eigenvalues	83.916	61.617	2.439	0.197	0.000
Proportion	0.566	0.416	0.016	0.001	0.000
Cumulative Proportion	0.566	0.982	0.999	1.000	1.000

Table 7. MK sprayer testing with HCN nozzles

Pressure kg/cm	Angle°	Nozzle orifice number	Nozzle output ppm	Out put/orifice
1.0	60	2	14.2	7
2.0	35	5	28.4	6
2.5	45	5	35.6	7
2.5	70	5	35.6	7
3.5	45	2	49.8	25
4.0	60	2	56.9	28
4.0	70	2	56.9	28
4.0	75	5	56.9	11

Table 8. MK sprayer pressure V/s HCN nozzle output regression analysis

Nozzle pressure vs out put regression statistics		F cal	Sig F	
Multiple R	1.00	3.12E+32	8.06 E-32	
R Square	1.00			
Adjusted R Square	1.00		Coefficients	P-value
Standard Error	2.21 E-16	Intercept	0.631291	0.000
Observations	21	X Variable 1	0.109409	0.000

Table 9. MK sprayer descriptive statistics

	Pressure kg/cm	Angle o	Nozzle orifice number	Nozzle output ppm	Out put per orifice
Mean	**2.714**	**48.810**	**0.333**	**3.190**	**19.038**
Variance	1.414	244.762	0.233	2.662	118.192
S.D	1.189	15.645	0.483	1.632	10.872

Table 10. MK sprayer Eigen values of correlation matrix

	Pressure kg/Cm^2	Angle	Drift	Orifice	Output ppm
Eigenvalues	2.275	1.120	0.918	0.687	0.000
Proportion	0.455	0.224	0.184	0.137	0.000
Cumulative Proportion	0.455	0.679	0.863	1.000	1.000

Table 11. MK sprayer correlation matrix

	Pressure kg/cm	Angle o	Drift	Nozzle orifice number	Nozzle output ppm
Pressure kg/cm^2					
Angle o	0.370*				
Drift	0.080NS	0.218NS			
Nozzle orifice number	0.079NS	0.132NS	0.092NS		
Nozzle output ppm	1.000**	0.370*	0.080NS	0.079NS	
Out put/orifice	0.512**	-0.026NS	-0.158NS	-0.704**	0.512**

Table 12. MK sprayer analysis of variance

Source of Variation<="" th="">	DF th="">	Sum of Squares<="" th="">	Mean Squares<="" th="">	F-Calculated<="" th="">	Signficance<="" th="">
Regression	1	1,095.991	1,095.991	5.074	0.03127
Error	32	6,911.371	215.980		
Total	33	8,007.361			
R-square value : 0.1369					
Multiple R-value : 0.3700					

Table 13. MK sprayer regression coefficients, standard errors and t-values

Variables	Coefficients	Standard Error	t-value	Significance
Pressure kg/cm	0.415	0.184	2.253	0.026
Constant	21.387			

Table 14. Agricultural sprayer test report submitted to state and central governments ministry of agriculture, 2017

Date of test	20/10/2017		20/10/2017		
Time of test	15.00hrs		15.00hrs		
Cotton crop Ankur 3028 hybrid height	1.4m		1.4m		
Ambient temperature	350C		350C		
Weather	Hot humid over cast wind speed <5 KMPH or calm		Hot humid over cast wind speed <5 KMPH or calm		
Sprayers	MK sprayer		Conventional LOK sprayer		
Test chemical:	Methylene blue and KNO3				
Concentration	40% of recommended insecticide difenthiuron 500 g ha^{-1} chemical recovered on acrylic sheet 210 mm x 297mm fixed on following locations to catch spray droplets				
MKS sprayer	ug ml	Percent	LOK sprayer	ug ml	Percent
Chest	33.2	24	Chest	6.5	7.5
Hind limb right	15.9	12	Hind limb right	11.2	12.9
Hind limb left	13.6	10	Hind limb left	2.3	2.7
Fore limbs	5.6	4	Fore limbs	1.8	2.1
Stomach	30.3	22	Stomach	30.3	34.9
Gloves L R	37.2	27	Gloves L R	37.2	42.8
Total R2=0.99	136	100		89	
Percent recovered per tank	22			11	
Tanks to reach lethal concentration Ld_{50}	7			36	
Safer working hrs to reach lethal concentration LD_{50}	0.7			14.4	
Recommendations	Not recommended at this		Only against pink boll worm one or two spray with		

	height of crop even SOPs with this sprayer.	SOPs.
	Total face should be covered (Dupatta) at least Goggles+ cloth mask Rubber or PVC gloves Protective full sleeves cotton shirt. Gum boots and Regular washing hands and legs with fresh water. Avoid intoxication Wash clothes, gloves, mask, goggles and bath with soap after work.	Total face should be covered (Dupatta) at least Goggles + cloth mask Rubber or PVC gloves Protective full sleeves cotton shirt. Gum boots and Regular washing hands and legs with fresh water. Avoid intoxication Wash clothes, gloves, mask, goggles and bath with soap after work.

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