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AUTOMATIC SPRAY CONTROL SYSTEM FOR FOUR WHEEL DRIVE (4WD) SELF-PROPELLED HIGH CLEARANCE BOOM SPRAYER

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ABSTRACT

Crop sprayers help in attaining targeted application of chemical pesticides, which is necessary to reduce environmental degradation. As the overdose of chemical may lead to wastage and environmental pollution, performance of sprayers vastly depends on operator's skill. The use of advanced technologies and automation techniques shall aid in improving and optimizing the existing spray application techniques. An automated spray control system based on proximity or speed sensor, pressure and flow meter were installed and calibrated on high clearance boom sprayer. There was not much difference in actual discharge and actual speed as compared to discharge and speed observed by sensors. In manual mode, variation in the application rate ranged between 258.60 to 436.36 l/ha whereas in auto mode it varied between 250 to 268.42 l/ha which was approximately in the desired rate.

Keywords: Automatic spray controller, Boom sprayer, Flow meter, Proximity sensor, Sensors

Crop sprayers help in attaining targeted application of chemical pesticides, which is helpful in reducing environmental degradation, and also from an economic standpoint (Luck *et al.,* 2010). In Punjab, tractor-mounted sprayers equipped with guns are widely being preferred due to high field capacity (Narang *et al.,* 2015). However, during field application, the tractor operated gun sprayer technique requires four workers, two for handling the pipe and other two with tractor stationed outside the field. Besides, it often results in uneven distribution of pesticides (Wandkar, *et al.,* 2013). As the overdose of chemical/pesticide may lead to chemical wastage and environmental pollution from spray drift, performance of these techniques vastly depends on operator's skill. Furthermore, the tractor-operated boom sprayer with less ground clearance is not recommended as the yield is affected due to movement of tractor into the rows (Narang *et al.,* 2015).

An effective spraying technology is required to attain uniform distribution of chemical spray on the top, middle and bottom position of plants and also on the undersides of leave. A high-clearance drop-up boom sprayer developed by Punjab Agricultural University in collaboration with Industry has proven to be an effective machine for spraying in row crops. This machine reduced labour cost and provided better spray distribution on the top and lower crop canopy as compared to knapsack sprayers (Kumar *et al.,* 2020).

The use of advanced technologies and automation techniques shall further aid in improving and optimizing the existing spray application techniques. From this perspective, an automatic spraying control system with vertical spray booms is an alternative to the spray guns to reduce human intervention (Gonzalez *et al.,* 2012). Over the past few years, the automatic spray rate controller has gained popularity due to its ability to maintain desired application rates with ground speed changes during field operation (Cui *et al.,* 2019; Ayers *et al.,* 1990). Agricultural sprayers equipped with a rate controller provide adequate and consistent spray deposition compared to conventional sprayers (no rate controller) when ground speed changes occur during pesticide applications. While spray quality is also affected when using a rate controller, best management practices including proper nozzle selection and application at nominal ground speeds should be followed to minimize these effects and ensure effective technology utilization (Sapkota *et al., 2023*). Adoption of rate controllers with ability to maintain application provided clear advantages in lowering off-rate errors. The properly calibrated control system was able to maintain an application error of less than 5% with ground speeds varying from 3.2 to 9.7 km/h (Al-Gaadi *et al.,* 1994). The control systems are designed to be able to reduce off-rate errors that can minimize exposure of environment to chemicals/pesticides (Matthews*,* 2008).

Various commercial spray controllers use section control technology to auto-turn boom-section valves to ON/OFF (Winstead *et al.,* 2010). This technology has a potential to reduce overlapping application resulting in savings on inputs (Batte and Ehsani, 2006). There are two type of spray control technology available first is Automatic Section Control (ASC) and second

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Fig. 1. (a) Self-propelled 4-wheel-drive (4WD) high clearance boom sprayer

is Boom Section Control (BSC). The ASC technology has reduced over-application of pesticides to a large extent as compared to manual control system (Luck *et al.,* 2010). Over-application of some herbicides such as glyphosate has been shown to reduce plant growth during post-emergence applications (Reddy *et al.,* 2000; Reddy and Zablotowicz, 2003). Applying pesticides below a desired rate may lead to yield loss. Owing to its potential to save farm inputs, its ease of usage, and improved efficacy, the ASC technology has become increasingly popular among Indian farmers. At this rate, this technology will gradually become a part of sprayer control systems. Based on this background, it is imperative to integrate factors such as speed and flow rate with the functioning of self-propelled sprayer in order to prevent the hazards of non-uniform spraying. Hence, the current study has been undertaken to assess the feasibility of proximity and flow meter sensor based automatic spray controller for application rate variation in order to ensure uniform application of chemicals over a specific area. The application rate of high clearance sprayer with and without automatic control system has been compared.

MATERIALS AND METHODS

Self-propelled 4-wheel-drive (4WD) high clearance boom sprayer

The sprayer controller system used in this study was mounted on a self-propelled high clearance boom sprayer of 35 hp engine capacity (Fig. 1(a)). The sprayer had pesticide tank of 860 liters capacity, a piston pump, and ultra-low volume nozzles on the three boom sections. A total of 31 nozzles were fixed at an equal spacing on the three straight boom section (Fig. 1(b)). The nozzles were spaced at a distance of 0.34 m and total length of the spray boom was 10.54 m. Based on the crop stage, boom sections could be lifted or lowered with the help of a hydraulic lift system. A pump was used to develop pressure within the spray system for the application of chemicals. The pump could develop maximum pressure up to 35 kg/cm^2 at 800 rpm, and delivery output capacity was 30 l/min. All parts of the pump were made from heavy-duty brass forging.

Self-propelled high clearance boom sprayers are used for variety of crops and at any stage of the crop. It is critical to achieve effective crop protection using this type of machine. While most self−propelled sprayers use two-wheel steering, the use of 4WD may add vehicle manoeuvrability that may directly benefit the high clearance boom sprayer performance. In our study we used 4WD self-propelled high clearance boom sprayer. Field efficiency was improved by the changes in headland turns associated with 4WD.

Spray controller

The spray controller system consists of a manifold, electronic control unit (console), proximity sensor, pressure sensor, and water hose pipes (Fig 2). Manifold is composed of several components including flow meter, liquid strainer, electric regulating valve with bypass mode, and pressure relief valve (Fig. 2a). These components ultimately control the spray application rate by adjusting the liquid flow rate. Flow meter is used to measure the actual rate of flow in a system and the

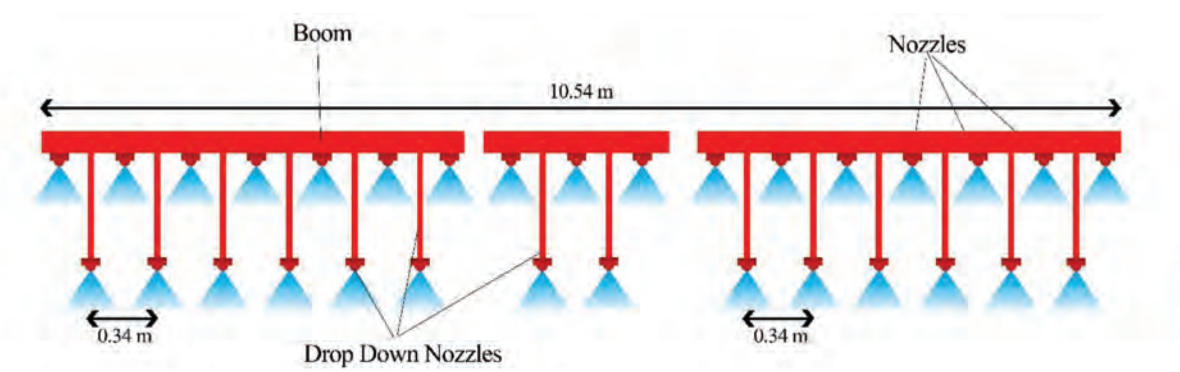

Fig. 1. (b) Schematic diagram of the spray boom section

value of system's real time flow rate is displayed on electronic control unit in a digital readout form. A liquid strainer is fitted to filter or separate out unwanted solid matter from the liquid stream. Regulating motor rated 3 rpm which is the most accepted motor used to regulate the liquid flow rate in automated systems was used. Motor opens the valve to the maximum flow in about 6 seconds and pressure relief valves in about 10 seconds. The pressure relief valve (PRV) is designed to open at a predetermined set pressure used to control or limit the pressure which otherwise may results in process upset or system failure. The pressure is relieved by allowing the pressurized liquid to flow from an auxiliary passage out of the system.

The function of the electronic control unit (ECU) was to control the spray boom sections during real-time applications and to switch on/off the spray. The selected ECU had a provision to control five boom sections in real-time. The number of active boom sections was set to three in ECU as only 3 boom sections were used. A small display provided on ECU delivered all real time information regarding sprayer. This system had a provision to run in auto and manual modes. The parameters like on-target application rate, number of tips on each boom sections, tip spacing, nozzle used were calibrated on ECU before the field operation (Fig. 2b).

A proximity transducer was fixed on rear tyre of high clearance boom sprayer to measure the forward speed. It works by sensing a metal object mounted in front of sensor face. The control system monitors the travelling speed and adjusts the amount of pesticide sprayed for a unit area accordingly for precise spraying applications (Fig. 2c). The analogue pressure transducer is mounted at valve manifold to monitor the overall liquid pressure. A pressure transducer generates an electrical signal which is displayed on electronic control unit (ECU) indicating the pressure imposed in the system. Pressure transducer used in this study is able to measure pressure up to 10 bar (Fig. 2d).

Installation and calibration of the automatic spray control system

A frame casing was fabricated using the angle-irons and G.I. sheet to house the manifold and sensors of the automatic spray control system. This complete unit was mounted on the high clearance sprayer such that the delicate parts were protected from the harsh operating conditions. The block diagram of the setup used to configure the automatic sprayer control system is shown in Fig. 3.

Once the system was successfully installed, calibration was necessary to ensure its effective operation. To this end, different sensors and other electronic parts of the system were optimally calibrated.

Calibration of proximity/speed sensor

The proximity/speed sensor installed near the rear wheel of high clearance sprayer counts the number of wheel rotations (Fig. 4a). It is calibrated by the spray controller (ECU) to provide the exact speed and spray area readings. For calibration, the tractor was made to run over a 100-meter distance i.e., point A to point B in the field after activating the calibration step of the automatic spray control system and pulses generated by the speed sensor were counted. Once the desired

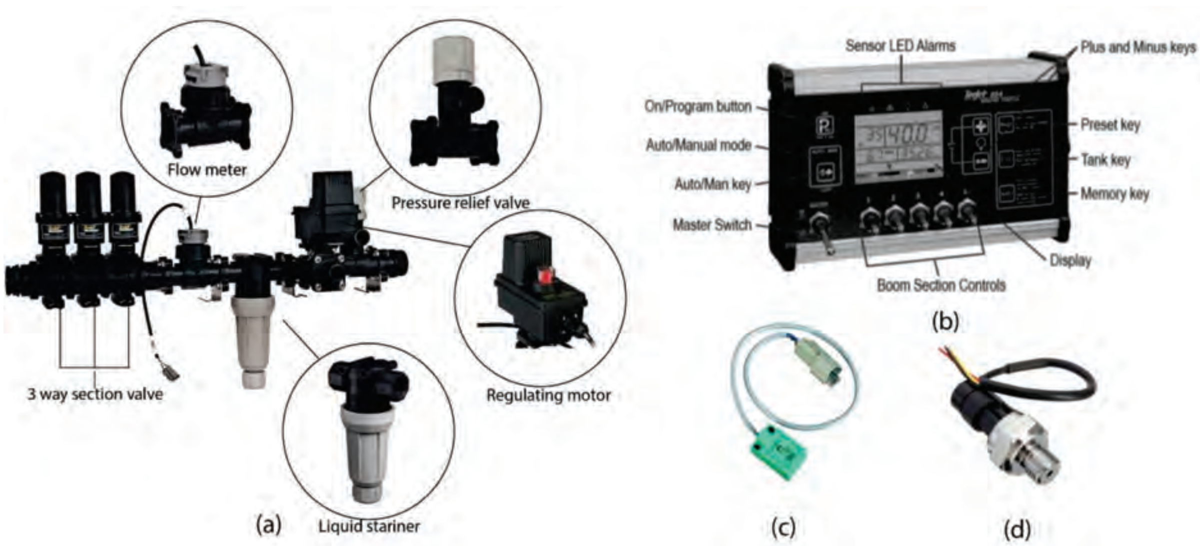

Fig. 2. (a) Manifold with 3-way section and its components (b) electric control unit (ECU) (c) Proximity sensor (d) Pressure transducer (10 bar)

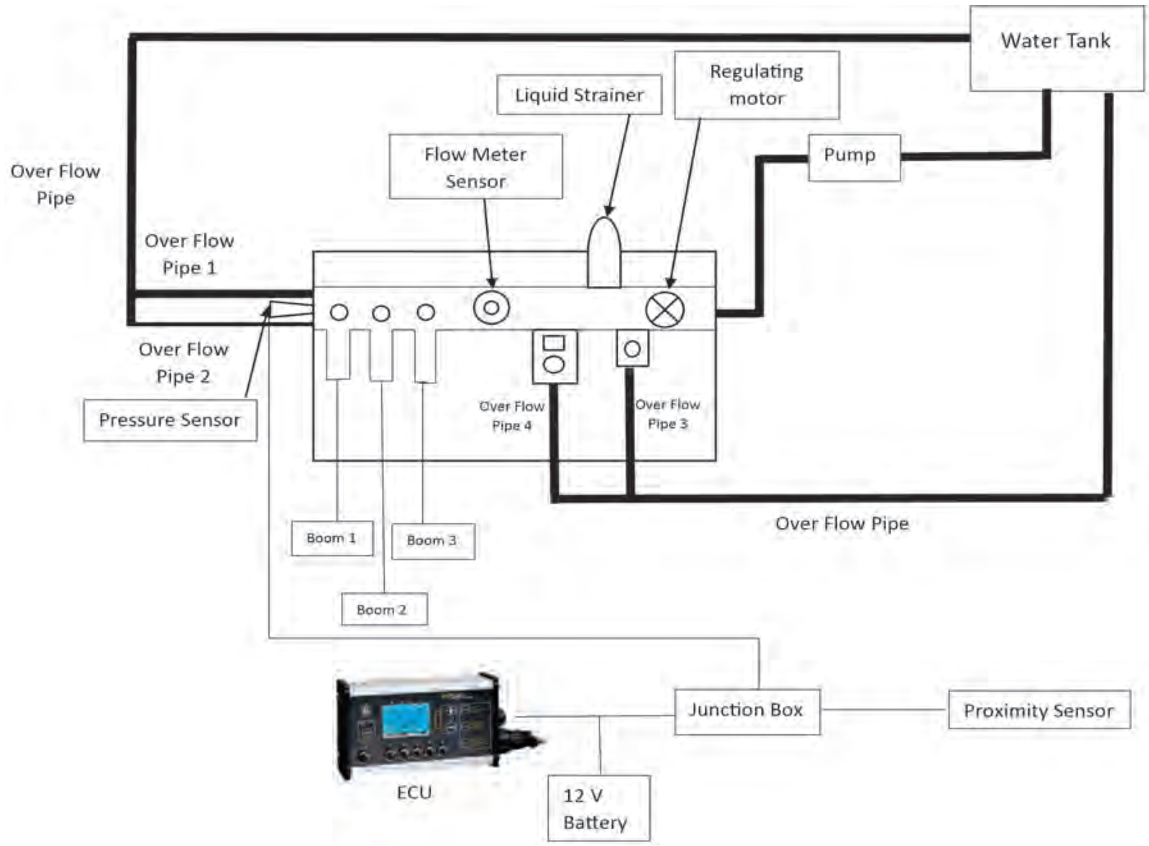

Fig. 3. Block diagram of an automatic spray control system

distance was covered, the speed calibration number was displayed on the screen (Fig. 4b). It was saved in console memory and calibration procedure was completed.

Calibration of pressure transducer

The pressure transducer was calibrated by adjusting the pressure displayed by the ECU to the actual pressure value. To this end, an accurate manual pressure gauge was placed in the spray line close to the spray nozzles to measure the actual pressure in the system. Then, in-auto mode calibration step was activated to calibrate the installed pressure transducer and the displayed pressure was adjusted. Once the actual pressure matched the displayed pressure, calibration was initiated. The newly recorded value of maximum rating of pressure transducer, which lies between "0-10", was displayed and saved in memory after calibration.

Calibration of flow meter

The calibration of flow meter sensor was performed by setting the console in auto mode and activating calibration step wherein the flow meter pulses are calculated on the basis of a known volume of fluid passing through the flow meter. To achieve this, calibration step was activated and the sprayer pump was started. During calibration, a known volume of fluid (360 litres) was sprayed and monitored. Once the entire volume had been sprayed, the ECU was instructed to stop counting pulses. Based on the pulse count obtained, the flow meter was calibrated.

Experimental procedure

Subsequent to calibration of automatic spray controller and its transducers, the validation of sensors was carried out on different spray quality parameters like discharge, pressure and application rate. Experiments were conducted and validated in the laboratory and field for discharge rate calculated by flow meter and observed at transducer. Similarly, experiments were conducted in the field for validation of forward speed by proximity sensor followed by measurement of application rate for automatic spray controller system and compared with manual mode. Spray tip calibrator was used to measure the discharge rate, in l/min (Fig. 5). The spray tip pressure tester was used to record pressure readings in kPa by installing on randomly selected nozzles. The sprayer was operated with target application rate of 250 litre/hectare, firstly in manual mode followed by auto mode and data was recorded. The performance of the installed spray controller was evaluated on a test plot.

(a) (b)

Fig. 4. A view of (a) Proximity sensor installed at rear wheel and (b) Calibration step screen on electronic control unit

Fig. 5. Discharge rate measurement and spray tip pressure tester

Each experiment was conducted with three replications at research farm of the Department of Farm Machinery & Power Engineering, Punjab Agricultural University, Ludhiana. The statistical analysis was done with the help of statistical analysis software (SAS 9.4). The t-test for two independent samples and CRD (complete randomized design) was adopted for the statistical analysis of different parameters.

RESULTS AND DISCUSSION

Variation in nozzle discharge rate

The sprayer was operated in laboratory and discharge was measured at different nozzles by spray tip calibrator for assessing the error in calibration. The automatic spray controller system was operated by turning ON the manual mode in ECU. In manual mode known discharge of 0.17 l/min was fixed for the nozzles followed by turning ON the automatic mode. Discharge was measured randomly at 6 nozzles (3 up and 3 bottom) each from left and right section of boom. Five nozzles from center boom section was considered for observing the discharge. As it can be observed from Fig. 6, increasing in pressure results in increasing in discharge in all three-boom sections. Also, it can be stated that there was no significant difference between upper side nozzles and downward nozzles that means similar trends was observed. The coefficient of variation for discharge of boom section 1, boom section 2 and boom section 3 were 9.94, 11.34 and 10.54%, respectively. However, there was no significant different in CV of discharge. The discharge rate ranged from 0.14 to 0.20 l/min which is non-significantly different from each other at 5% level of significance as depicted from diffogram where all the treatments mean is red in colour (Fig. 7).

Variation in nozzle pressure

Similarly, to ensure whether the system is properly calibrated or not with respect to actual pressure, the sprayer was operated in laboratory. The automatic spray controller system was operated by turning ON the manual mode in ECU where pressure of 240 kPa was fixed for the nozzles. Thereafter, automatic mode is turn ON, pressure was observed at randomly selected 6 nozzles (3 up and 3 bottom) of left and right boom each and five nozzles from center boom section and it was measured to be between 198 to 275 kPa which is non-significant different from each other at 5% level of significance as depicted from diffogram (Fig. 6 & 8).

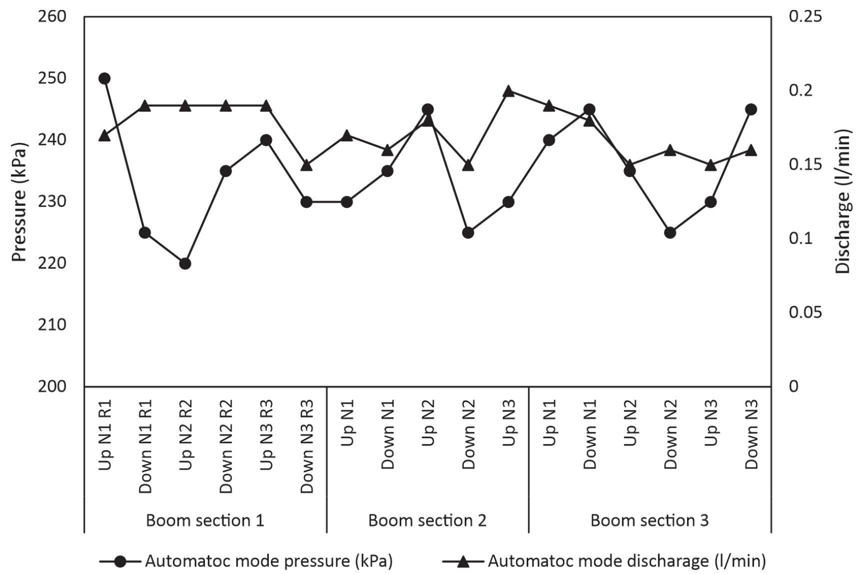

Fig. 6. Pressure (kPa) and discharge (l/min) at different boom sections

Hence, it was found that the automatic spray controller implemented on high clearance boom sprayer was able to provide the authentic discharge and pressure values by proximity sensor which can be used for future work.

Validation of discharge rate measured during field operation and observed at transducer

The automatic controller installed on high clearance sprayer was operated in the field after successful calibration. The actual discharge was measured with digital nozzle discharge meter and discharge observed by transducer displayed on the console unit. The experiment was conducted and observed at nine sample points. It has been observed that in manual mode (discharge without automatic system) was in the range between 5.27 to 5.89 l/min, while in auto mode (discharge with automatic system) was in the range of 5.3 to 5.9 l/min. It has been observed that trend for discharge rate measured during field operation and at transducer was almost same and superimposed with each other (Fig. 9).

It was evident from Table 1, that discharge rate measured during field operation and observed at transducer for different sample point were non-significantly different from each other at 5% level of significance. The box and whisker plot for discharge

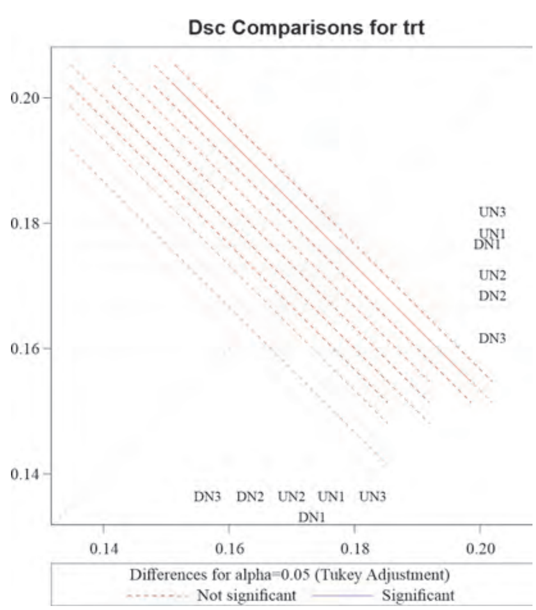

Fig. 7. Diffogram for discharge rate at different boom section

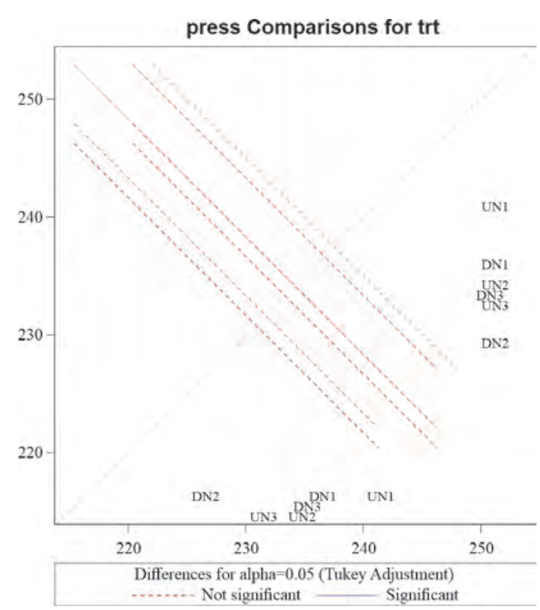

Fig. 8. Diffogram for pressure at different boom section

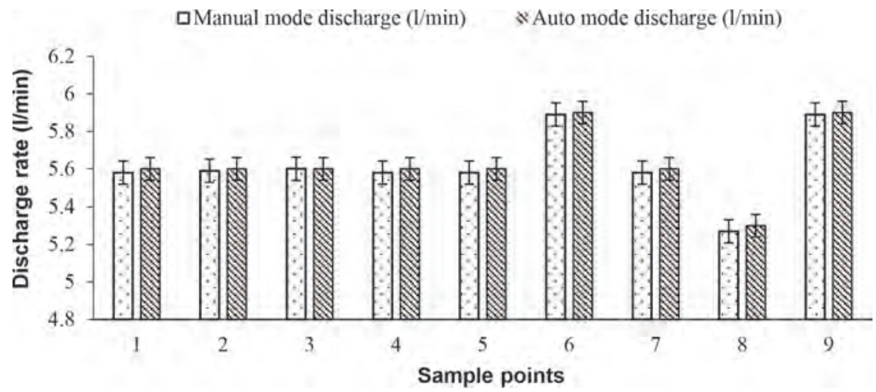

Fig. 9. Illustration of discharge rate measured during field operation and observed at transducer for different sample point

rate measured during field operation and observed at transducer/sensor is shown in Fig. 10. Hence, it was concluded that the automatic spray controller and transducers were appropriately calibrated and provided the valid results.

Field validation of forward speed by proximity sensor

The actual forward speed calculated using distance covered in specific time was compared with average speed displayed on ECU by proximity sensor (Fig. 11). There was not much variation in forward speed (kilometre per hour) compared to speed measured by proximity sensor. It was revealed from the Table 2, that actual speed of the sprayer (8.47 $\pm$ 0.41 km/h) and speed measured by proximity sensor (8.28 $\pm$ 0.79 km/h) were non-significantly different from each other at 5% level of significance. The box and whisker plots for actual and speed displayed on ECU is shown in Fig 12. Hence, the automatic spray controller implemented on high clearance boom sprayer was able to provide the authentic average speed by proximity sensor which can be used for future application satisfactorily.

Application rate variation in auto and manual mode

From Fig. 13, it is evident that in manual mode, application rates were in the range of 258.6 to 436.36 litre per hectare (CV=18.63 %) with the change in the forward speed of sprayer. This variation in the application rate was high, so excess amount of chemical was applied in target test plot resulting in wastage of chemical and water. In case of auto mode, the application rate was varied from 250 to 268.42 litre per hectare (CV= 2.47 %) irrespective of change in speed which is satisfactory and required. Also, from Table 3 it is clear that application rate variation in auto and manual mode were significantly different from each other at 5% level of significance. The box and whisker plots for application rate variation in auto and manual mode is shown in Fig. 14. Hence, it was observed from the data that automatic spray controller saved liquid, chemical and water on a large extent.

Different conclusions were drawn based upon the study and summarized. All components of spray controller were installed on self-propelled high clearance boom sprayer and worked satisfactorily.

Table 1. t-test for two independent samples of discharge

Method	Variances	DF	t Value	Pr > |t|
Pooled	Equal	16	-0.18	0.8592
Satterthwaite	Unequal	15.986	-0.18	0.8592

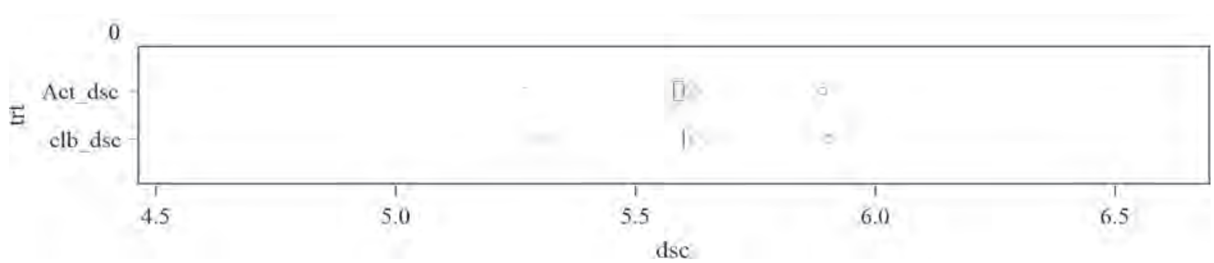

Fig. 10. Box and Whisker Plots for discharge rate measured during field operation and observed at transducer

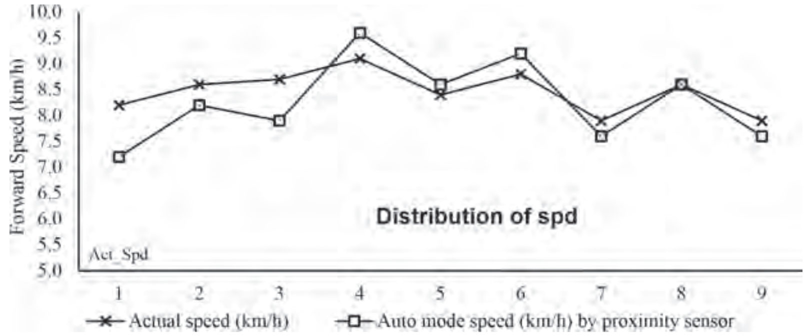

Fig. 11. Actual speed and speed measured by proximity sensor in auto mode

Table 2. t-test for two independent samples for speed

Method	Variances	DF	t Value	Pr > |t|
Pooled	Equal	16	0.64	0.5339
Satterthwaite	Unequal	11.925	0.64	0.5369

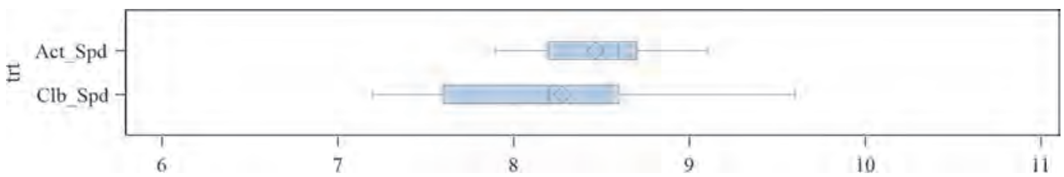

Fig. 12. Box and Whisker Plots for actual forward speed and calibrated forward speed

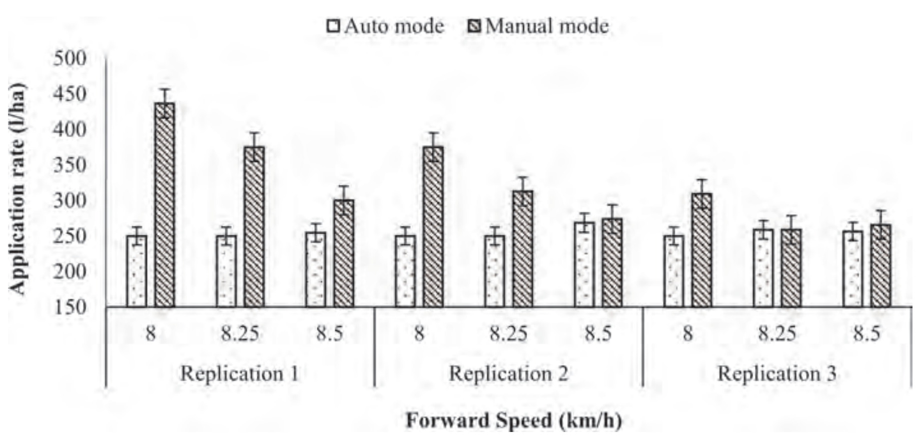

Fig. 13. Application rate (l/ha) comparison b/w auto mode and manual mode

Table 3. t-test for two independent samples for application rate

Method	Variances	DF	t Value	Pr > |t|
Pooled	Equal	16	-3.41	0.0036
Satterthwaite	Unequal	8.1736	-3.41	0.0090

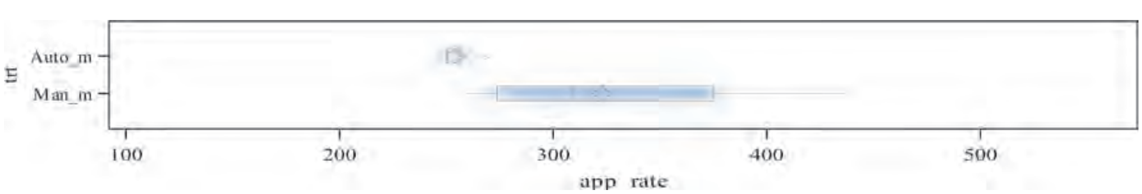

Fig. 14. Box and Whisker Plots for measurement of application rate variation in auto and manual mode

There is the need to calibrate different sensors/devices like proximity/speed sensor, pressure sensor and flow meter before the actual operation of the system. Automatic spray controller system mounted on high clearance boom sprayer was able to provide the exact discharge, pressure and forward speed of the system. In manual mode, application rate was in the range of 258.6 to 436.36 l/ha (CV=18.63 %) with the change in the forward speed of sprayer as compared to the application rate varied from 250 to 268.42 l/ha (CV=2.47 %) in auto mode. Application rate variation in auto and manual mode were significantly different from each other at 5% level of significance.

Authors' contribution

Conceptualization and designed the experiments (MS, LJ, AP, SK); Execution of experiments and data collection (PR, SS, HS, AP); Analyzed and interpretation of the data (PR, AP, SS, HS, MS, LJ); Manuscript draft and amendment (AP, MS, PR, LJ, SS, SK)

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