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Full Length Research Paper

Performance evaluation of tractor operated target actuated sprayer

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A tractor operated target actuated sprayer was developed and evaluated to reduce the off target application of chemical and thereby reduce soil and environmental pollution. From the observations, it is concluded that educator model IV was found to be the best connector with mixing chamber for the chemical and carrier liquid. The range of pressures adopted for chemical and carrier liquid produced droplets with volume median diameter (VMD) and numeric median diameter (NMD) ranging between 101 and 200 µ and VMD/NMD ratio of 1.09 and 1.29 which is classified as fine spray. The analysis of variance for optimum amount of chemical delivered as influenced by concentration of chemical, width of simulation plate, height of sensor above the plant canopy and forward speed of operation indicated that the selected variables and their interactions significantly affected the amount of chemical delivered. The mean comparison tests indicated that the minimum amount of chemical delivered (499 µl) was achieved at a chemical concentration of 25%, 100 mm width of simulation plate, 3.5 km h^{-1} forward speed and sensor height of 300 mm above the plant canopy.

Key words: Off target spraying, target actuated sprayer, spray droplet size, spray deposition.

INTRODUCTION

Chemical pesticides have played and will continue to play a major role in the rapid advancement of agricultural production. Crop quality and yields have been improved and the use of chemical herbicides has greatly reduced labor requirements for weed control. But the widespread use of pesticides has resulted in some serious environmental and health problems. These problems are of direct concern to both the user and the equipment designer. In crop spraying, off target application resulting in air and soil pollution has to be reduced. Off-target chemical application is a costly and time consuming problem for agricultural producers and turf grass managers. Reducing or eliminating off-target application is increasingly important in a society that places high value on environmental quality and in global markets that are extremely competitive. Targeted application of chemicals provides an economic benefit in that less material is applied and a corresponding environmental benefit with less chemical introduced to the environment. It is known that sprayer settings are important for spray distribution in crop canopy. Matching spray volume and direction to crop size and shape can reduce chemical application, thus reducing operational costs and environmental pollution. Manual or sensor actuated sprayers have shown potential reductions in agrochemical use of 30% and more. Hence, there is a need to develop technologies that automatically detect the presence of target plants and actuate the device to apply the pre-determined dose of pesticide.

LITERATURE REVIEW

Azimi et al. (1985) investigated the nozzle spray distribution for pesticide broadcast application, with

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spray table (patternator) having troughs to measure the distribution across the sprayed swath from single nozzle. They reported that the distribution pattern was dependent on the nozzle type, nozzle pressure, height of the nozzle above the target surface and the angle at which the nozzle was oriented with respect to the motion of the sprayer. Solie and Gerling (1985) reported that the nozzle height must be considered in order to achieve uniform coverage or distribution across the swath of the boom nozzle.

Wang et al. (1995) investigated the effect of nozzle height on uniformity of spray distribution. A laboratory set up including a simulated boom sprayer system and a spray deposition measuring system were used for this study. It was observed that the nozzle height had a strong effect on spray distribution uniformity. The width of plant canopy is the parameter that decides the width of spray to be applied on it such that the width of spray should go inside the average width of plant canopy to get maximum coverage (Speelman and Jansen, 1974; Giles and Comino, 1989). Whitney et al. (1989) examined the effect of ground speed (1.6, 2.8 and 4.0 km h^{-1}) on upper and lower leaf surface deposition using different air blast sprayers and spray volume and stated that the speed of operation significantly increased deposition on the upper leaf surface, but not on the lower leaf surface. Optical sensors can be used for recognition of plants and discrimination between plant species by utilizing image analysis methods and/or multi-spectra information. The reliability of crop and weed recognition under field conditions varied from 60 to 95% (Lee et al., 1999; Søgaard, 2005).

Teske et al. (2003) concluded that though the height and orientation of nozzle are directly proportional to the width of spray and it cannot be varied beyond the limits due to the negative effect of extraneous parameters like temperature and drifts hazards. Dhalin (2004) reported that the deposition efficiency was maximum (36.223%) Taylor et al., (2004) stated that the droplet size and velocity affected the structure of the spray deposits and the drift ability of the droplets.

Crowe et al. (2005) developed a sensor for detecting and quantifying spray deposition and evaluated. The sensor detects the presence of discrete fluid droplets on the sensor surface when droplets complete electrical circuit positioned in an array. Barawid et al. (2006) developed an automatic guidance system capable of navigating an autonomous vehicle travelling between tree rows in a real-time application. The investigation focused solely on straight line recognition of the tree rows using a laser scanner as a navigation sensor. Brown et al. (2007) developed target spray technology to reduce runoff from dormant orchards. The target-sensing sprayer produced a 40% reduction in the spray application rate and achieved a 41% reduction in ground deposition compared with the conventional air-blast sprayer. Pesticide concentration in surface water runoff was reduced by 44% with the target-sensing sprayer versus the conventional application. The results document the environmental and economic benefits provided by target-sensing spray technology in dormant orchards.

Chueca et al. (2008) developed a sensor controlled sprayer consisting of a hydraulic system that was fitted with air induction nozzles, an ultrasonic sensor and a control unit with display and navigator keys. The sensor recognized differences in crop canopy so could adapt the application to different citrus crop systems in commercial orchards. Fritz et al. (2009) developed a laboratory spray table for screening crop protection product and application parameters for efficacy and deposition. A database of spray volume deposition rates and droplet sizes with corresponding nozzle type, nozzle speed, and swath location was developed using water sensitive cards analyzed with the Droplet Scan software.

MATERIALS AND METHODS

The concentration of spray chemical is decided by the pressures at which the chemical and the carrier liquid are delivered to the mixing chamber and mixed. These pressures also decide the discharge rate of the spray and the distribution of droplet size. Hence the pressure in the chemical tank and pressure in the carrier liquid tank are to be optimized with respect to the discharge rate and the droplet size distribution at desired concentration level. The different parameters taken for this study are concentration of the spray, width of plant canopy, height of the sensor from the canopy and forward speed of operations.

Measurement of discharge rate

An experimental test rig was developed to measure the discharge rate at different pressure combinations of chemical and carrier liquid. The different levels of pressure adopted were 0.05, 0.1, 0.15, 0.2, 0.25, 0.3 and 0.35 MPa in both tanks. Different combinations of chemical and carrier liquid pressure were adopted to get pressure differences of 0.00, 0.05 and 0.10 MPa between chemical and carrier liquid. The discharge (v) for each pressure difference was collected for a known time (t) and the rate of discharge (q) was calculated as:

$$q = \frac{v}{t}, \text{ l s}^{-1} \quad (1)$$

From the discharge rate the application rate (Q) was calculated as:

$$Q = \frac{36000q}{S \times w} \times 10^4, \text{ l ha}^{-1} \quad (2)$$

where , Q = application rate, l ha^{-1}; q = discharge rate, l s^{-1}; S = speed of operation, km h^{-1}, and w = row to row spacing, m chemical in recommended proportion. Optimization test was conducted by using different connectors namely 'T' joint, 'Y' joint, non-return valves and educators of various models (I, II, III, IV) shown in Figure 1.

Optimization of spray concentration

Mixing ratio of chemical and water at different pressures will indicate the concentration of chemical achieved. Spraying

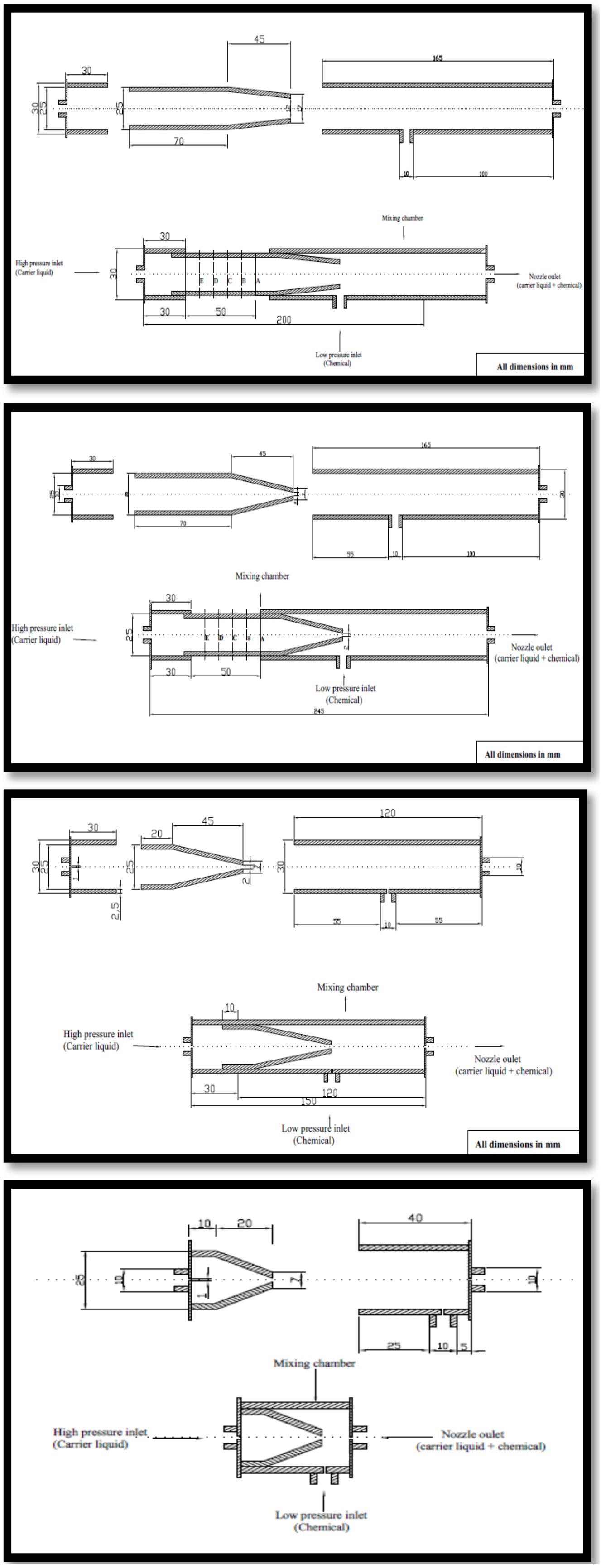

Figure 1. Different models of eductors (I, II, III, IV).

concentrated chemical without dilution is dangerous and it results in scorching of leaves. Pre dilution of chemical is based on stage of the crop and the recommended dosage. Pre diluted chemical is again mixed with carrier at the time of spraying. To achieve proper mixing of carrier and chemical with difference in pressure, connector was designed.

Droplet size determination

The size of spray droplet is the most important parameter that influences penetration and carrying ability of hydraulic sprayer. It also influences the efficiency of catch of sprays by plant surfaces and insects. Droplet size also affects the uniformity and completeness of coverage on plant surfaces and drift of the material from the treated area (Kepner et al., 2000; Farooq et al., 2001, Senthil Kumar, 1995). The uniformity of spray deposition was expressed as VMD (Volume Median Diameter), NMD (Numeric Median Diameter) and VMD/NMD ratio.

Width of plant canopy (W)

The width of plant canopy decides the actuation period of the sensor which in turn controls the duration of spray on that particular plant. The minimum width of plant canopy was 90 mm and the plant to plant spacing in a row was 300 mm. Hence the levels of variables is fixed between 100 and 250 mm with an increment of 50 mm. Artificial targets in the form of simulated green colored plates of width 100, 150, 200 and 250 mm corresponding to the width of plants were used in the lab set up for optimization.

Height of sensor from the canopy (H)

The infrared proximity sensor is used to sense the plant material which interferes with in its sensible range. Infrared proximity switches work by sending out beams of invisible infrared light. A photo detector on the proximity switch detects any reflections of this light. These reflections allow infrared proximity switches to determine whether there is an object nearby. Since the maximum range of the IR sensor used in this study is 350 mm, the levels of variable selected namely height of the sensor from the plant canopy are 100, 150, 200, 250 and 300 mm.

Forward speed of operation (S)

The variation in forward speed of operation influences the duration of sensor activation, the amount of spray and in turn the amount of chemical deposited on the plant. The minimum speed of tractor in the field can be 1.5 km h^{-1} while the maximum field speed of tractor can be 4 km h^{-1}. Hence the levels of forward speeds of operation were selected between 1.5 and 3.5 km h^{-1} with an increment of 1.0 km h^{-1}.

Development of prototype target actuated sprayer

The parameters such as travel speed, height of sensor and the pressure of carrier liquid and chemical were optimized based on the observations of the experimental set up to give desired chemical deposition on the plant canopy. These optimized values were used for the development of prototype target actuated sprayer. The schematic view of the developed prototype target actuated sprayer is shown in Figure 2. The rotary power to drive the hydraulic pumps of the prototype was taken from the PTO of

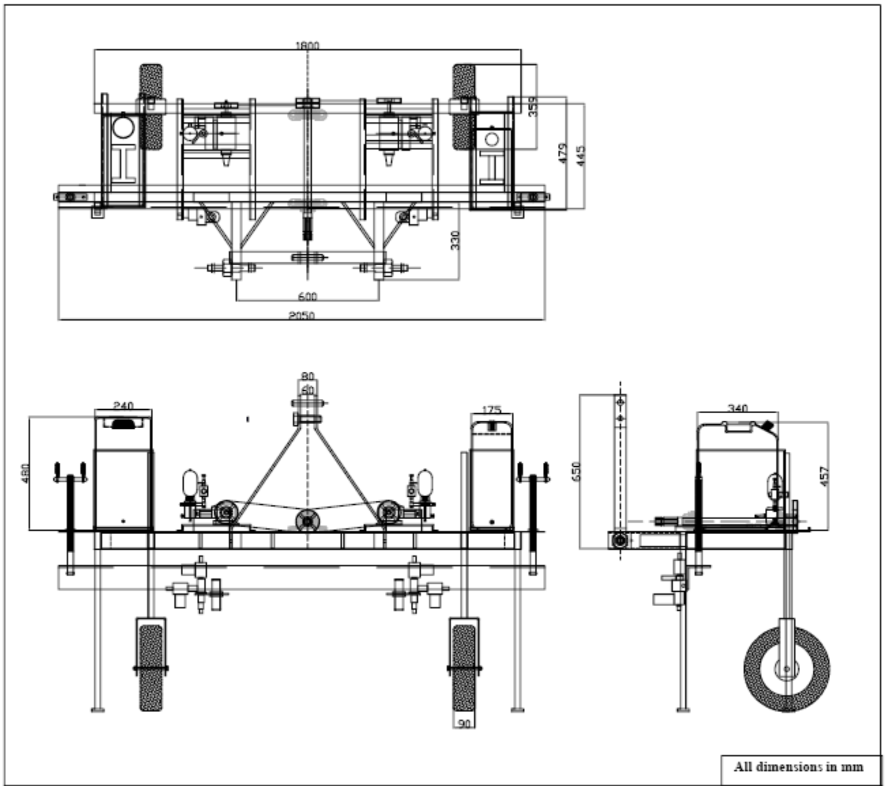

Figure 2. Schematic diagram of the target actuated sprayer.

the tractor while the electrical power required for operating the solenoid valve and the sensors was taken from the battery of the tractor. The prototype target actuated sprayer consists of the following major components like main frame, single acting pump, double acting pump, carrier liquid tank, chemical tank, sensor, solenoid valve, educator, nozzle, spray boom with height adjustment and power transmission system.

RESULTS AND DISCUSSION

The pressure of chemical and that of carrier liquid decides the concentration of spray. These pressures also decide the discharge rate and the droplet size distribution. The pressure in the chemical tank and the pressure in carrier liquid tank were optimized with respect to discharge rate and droplet size distribution. The outlets from the chemical and carrier liquid were connected using T joint, Non return valves, Y joint and the eductor and the discharge from both the tanks were measured.

The pressure of carrier and chemical liquid for getting maximum discharge using different connectors namely T joint, Non- return valves, Y joint and the eductor were varied for getting pressure difference of 0.00, 0.05 and 0.10 MPa and the corresponding total discharge and chemical contribution were measured. From the results it is observed that a higher chemical concentration of 49% at 0.00 MPa pressure difference, 39 to 40% at 0.05 MPa pressure difference and 23 to 25% at 0.10 MPa pressure difference was achieved with eductor model IV. Since the inner volume of the eductor was drastically reduced, there was no accumulation of the liquid in the eductor. Hence the discharge of chemical stopped instantaneously at the moment of cut off by the chemical solenoid. Hence eductor model IV has been selected as the connector and mixing chamber for the chemical and carrier liquid.

Effect of forward speed on quantity of chemical delivered

The effect of forward speed on the quantity of chemical delivered with respect to width of the simulation plate and height of sensor at 50, 40, and 25% concentration achieved by 0.00, 0.05 and 0.10 MPa pressure difference between the chemical and carrier liquid tanks is represented in Figure 3.

It was observed that the amount of chemical delivered was reduced to one third for all heights of sensor for 100 mm simulation plate width when the speed was increased from 1.5 to 3.5 km h^{-1}. For simulation plate width of 150 mm, it was reduced to about 50% for all concentrations and heights of sensor. For simulation plate width of 200 mm, it was reduced to about 58% for all concentrations and height of sensor. For simulation

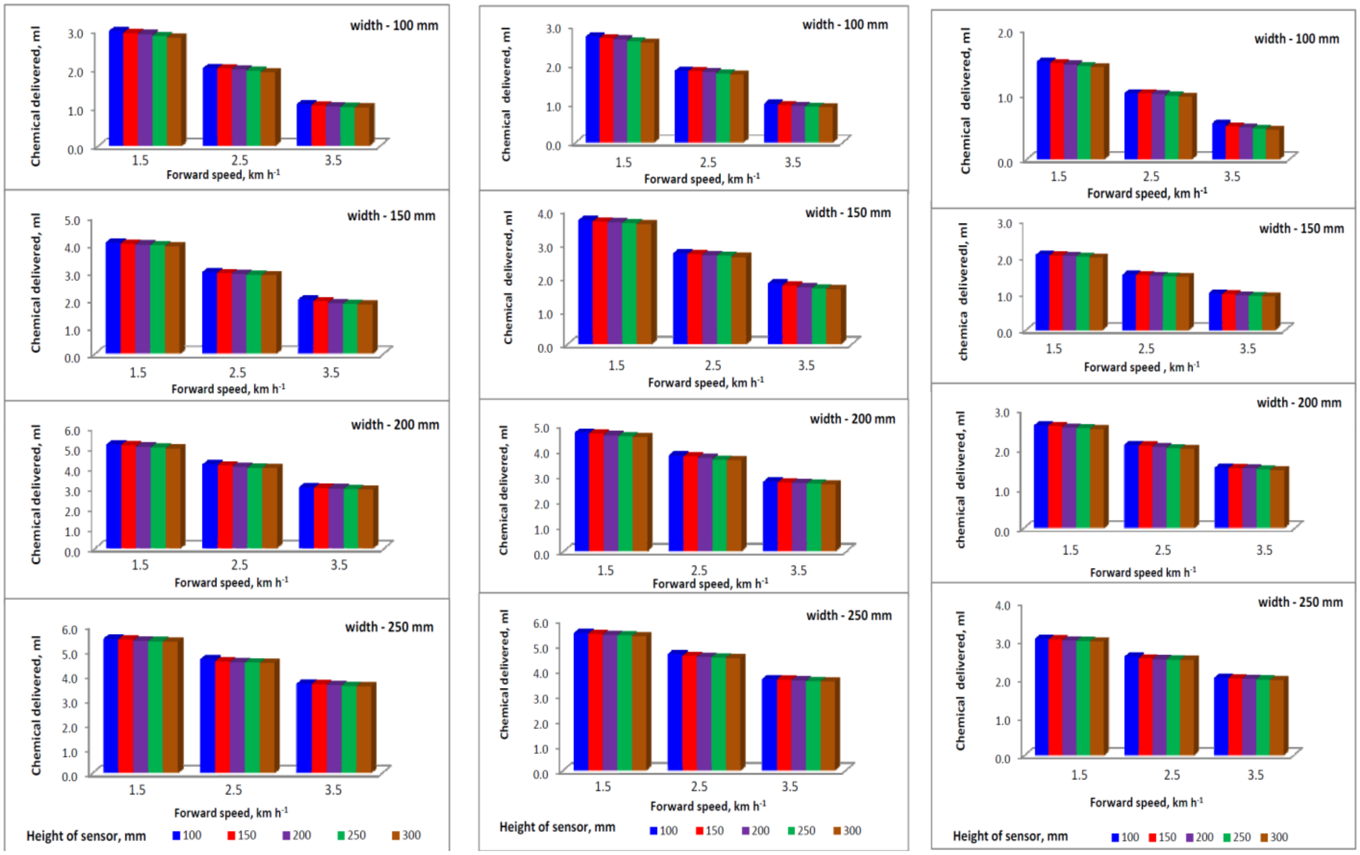

Figure 3. Effect of forward speed and height of sensor on quantity of chemical delivered for different simulation plate widths at 50, 40 and 25% chemical concentration.

plate width of 250 mm, it was reduced to about 34% for all concentrations and heights of sensor. The reduction in the amount of chemical delivered with increase in speed was due to the fact that the duration of exposure of the simulation plate to the sensor was reduced as the speed was increased.

Effect of simulation plate width on quantity of chemical delivered

The effect of width of the simulation plate on the quantity of chemical delivered at different heights of sensor and forward speed with 50, 40 and 25% chemical concentration achieved by a pressure difference of 0.00, 0.05 and 0.10 MPa between chemical and carrier liquid tanks is shown in Figure 4. It is observed that when the simulation plate width was increased from 100 to 250 mm the chemical delivered for all heights of sensors and at all concentrations for a travel speed of 1.5 km h^{-1} was almost doubled. Similarly it was increased by about 2.5 times for all heights of sensor and all concentrations when the forward speed was 2.5 kmh^{-1}. It was increased by 3.7 times for all the concentrations and heights of sensors when the forward speed was 3.5 km h^{-1}.The increase in the amount of chemical delivered with the increase in the width of the simulation plate was due to the increased activation time of the sensor. At the same time the reduction in the increase of the amount of chemical delivered with the increase in forward speed was due to reduction in exposure time to the sensor.

Effect of chemical concentration on quantity of chemical delivered

The effect of concentration on the chemical delivered at a forward speed of 1.5, 2.5 and 3.5 km h^{-1} for different simulation plate widths and different heights of sensors is presented in Figure 5. It was observed that when the chemical concentration was decreased from 50 to 25% the amount of chemical delivered was almost doubled for all combinations with different forward speed, different widths of simulation plates and different heights of sensors. The increase in the quantity of chemical delivered was due to the injection of higher volume of chemical when the pressure difference was

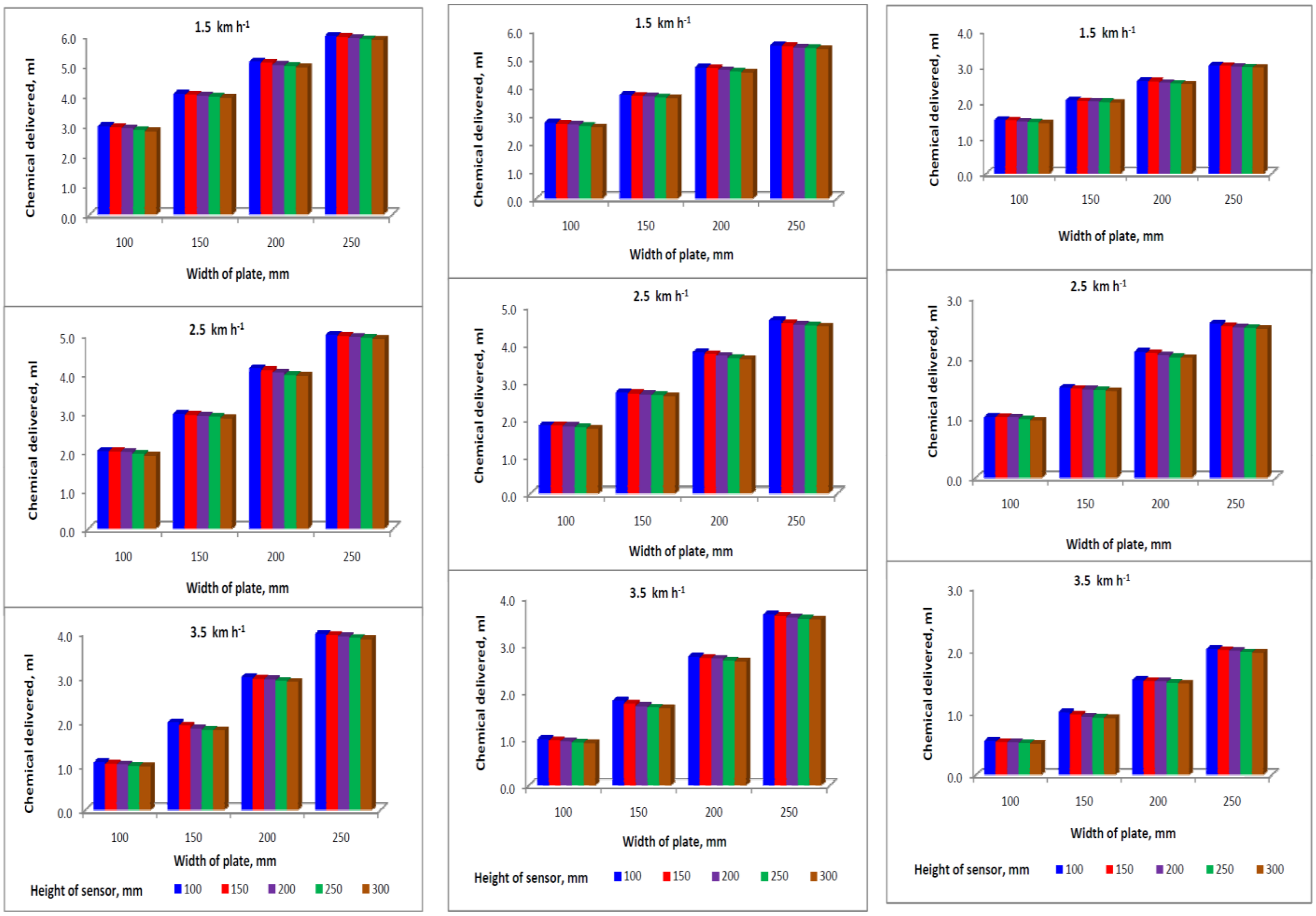

Figure 4. Effect of simulation plate width and height of sensor on quantity of chemical delivered for different forward speeds at 50, 40 and 25 % chemical concentration.

increased from 0.00, 0.05 and 0.10 MPa

Effect of height of sensor on quantity of chemical delivered

The effect of height of sensor on the amount of chemical delivered at different forward speed for different widths of simulation plats at a concentration of 50, 40 and 25% is presented in Figure 6. The decrease in amount of chemical delivered with increase in height of sensor with all combinations with different forward speeds, width of simulation plates and chemical concentration was due to the fact that the sensitivity of the sensor decreases with increase in the distance from the reflector namely the simulation plate.

Conclusion

The significance of spray fluid discharge rate, concentration of the spray, width of plant canopy, height of the sensor from the canopy and forward speed of operations was quantified. The range of pressures adopted for chemical and carrier liquid produced droplets with VMD and NMD ranging between 101 and 200 µ and VMD/NMD ratio of 1.09 and 1.29 which is classified as fine spray. The amount of chemical delivered decreased with the increase in forward speed and height of sensor and with decrease in chemical concentration while it increased with increase in simulation plate width. The Analysis of Variance for optimum amount of chemical delivered as influenced by concentration of chemical, width of simulation plate, height of sensor above the plant canopy and forward speed of operation indicated that the selected variables and their interactions significantly affected the amount of chemical delivered. The mean comparison tests indicated that the minimum amount of chemical delivered (499 µl) was achieved at a chemical concentration of 25%, 100 mm width of simulation plate, 3.5 km h^{-1} forward speed and sensor height of 300 mm above the plant canopy. A prediction model on the amount of chemical delivered was developed based on multiple linear regression analysis (q = - 707.1769461 +

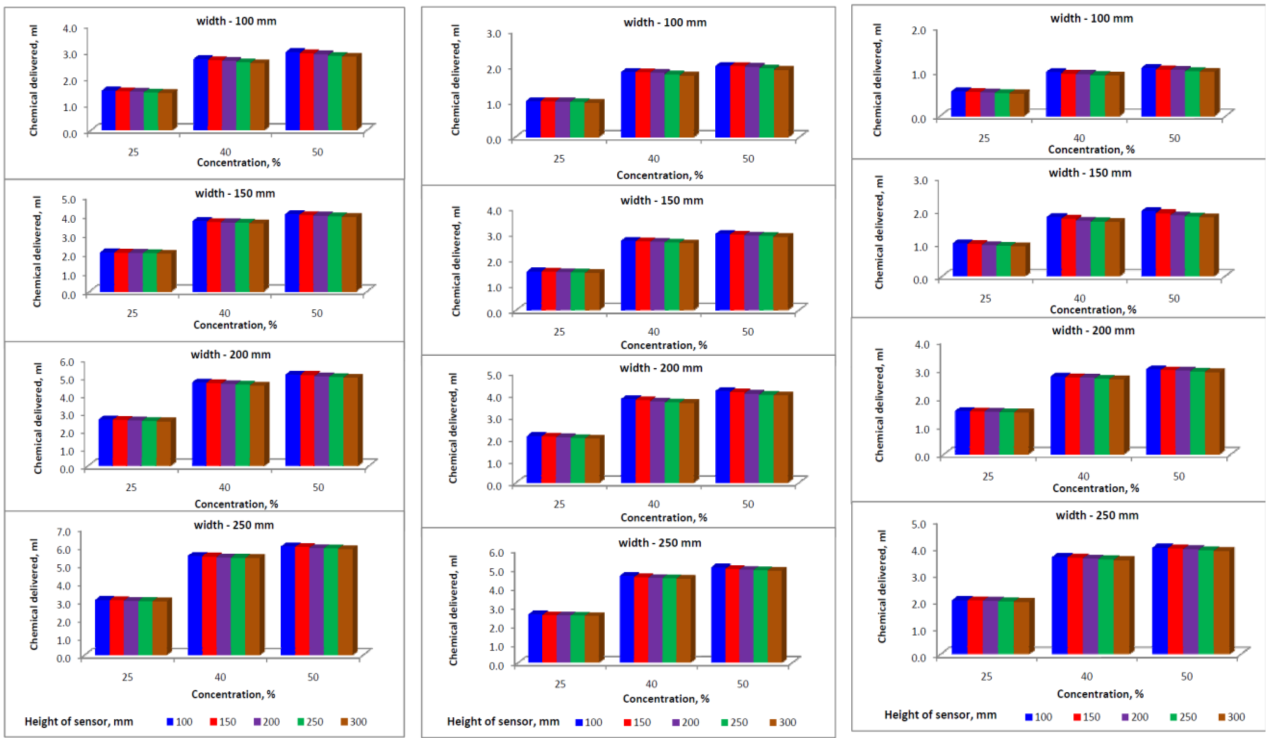

Figure 5. Effect of concentration and height of sensor on quantity of chemical delivered for different simulation plate widths at 1.5, 2.5 and 3.5 km h^{-1}.

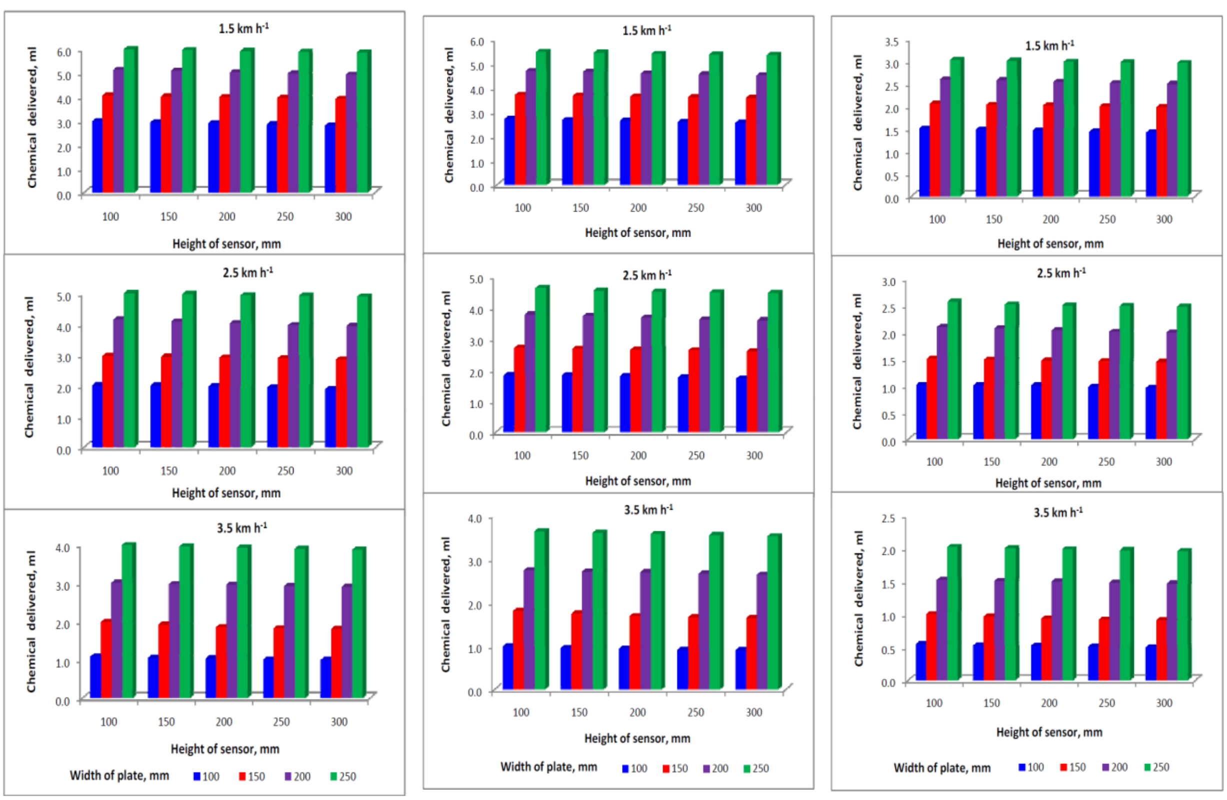

Figure 6. Effect of height of sensor and simulation plate width on quantity of chemical delivered for different forward speeds at 50, 40 and 25% concentration.

70.08855205C + 16.13430133W - 809.1538611S). The analysis of variance of lag time indicated that the selected variables and their interactions significantly affected the amount of chemical delivered at 1% level.

REFERENCES

Azimi AH, Carpenter TG, Reichard DL (1985). Nozzle sprays distribution for pesticide application, Trans. Am. Soc. Agric. Eng. 28(5):1482–1486.

Barawid OC, Mizushima A, Ishii K, Noguchi N (2006). Development of an autonomous navigation system using a two-dimensional laser scanner in an orchard application. Biosyst. Eng. 96 (2):139-149.

Brown DL, Giles DK, Oliver MN, Klassen P (2007). Targeted spray technology to reduce pesticide in runoff from dormant orchards. Crop Protect. 27:545-552.

Chueca P, Garcera C, Molto E, Gutierrez A (2008). Development of a sensor-controlled sprayer for applying low-volume bait treatments.Crop Protect. 27(10):1373-1379.

Crowe TG, Downey D, Giles KD (2005). Digital device and technique for sensing distribution of spray deposition. Am. Soc. Agric. Eng. 48(6):2058−2093.

Dhalin (2004). Investigation on development and evaluation of self-propelled air assisted boom sprayer for cotton as influenced by machine, crop and operational parameters. Unpublished Ph.D.Thesis. Tamil Nadu Agricultural University, Coimbatore.

Farooq M, Balachandar R, Wulfsohn D, Wolf TM (2001). Agricultural sprays in cross flow and drift. J. Agric. Eng. Res. 78(4):347-358.

Giles DK, CominoJA (1989). Droplet size and spray nozzles. J. Agric. Eng. Res. 47:249-267.

Kepner RA, Bainer R, Barger EL (2000). Principles of Farm Machinery, Third edition, CBS Publishers and Distributors. 13:282-312.

Fritz C, Parker JD, Lopez JR, Hoffmann WC, Schleider P (2009). Deposition and droplet sizing characterization of a laboratory spray table. Appl. Eng. Agric. 25(2):175-180.

Lee WS, Slaughter DC, Giles DK (1999). Robotic weed control system for tomatoes. Prec. Agric. 1:95-113.

Senthil Kumar T (1995). Studies on hydraulic energy nozzles for orchard spraying.M.E. thesis, Department of Farm Machinery, Tamil Nadu Agricultural University Coimbatore.

Solie JB, Gerling GF (1985). Spray pattern analysis system for pesticide application. Trans. Am. Soc. Agric. Eng. 18(3):439-443.

Speelman L, Jansen JW (1974).The effect of spray boom movement on the liquid distribution of field crop sprayers. J. Agric. Eng. Res. 19:117-129.

Søgaard HT (2005). Weed classification by active shape models. Biosyst. Eng. 91(3):271-181.

Taylor WA, WomacAR, Miller PCH, Taylor BP (2004). An attempt to relate drop size to drift risk. Proceedings of the International Conference on Pesticide Application for Drift Management. pp. 210-223.

Teske ME, Thistle HW, Ice GG (2003). Technical advances in modeling applied sprayers. Trans. Am. Soc. Agric. Eng. 46(4):985-996.

Wang L, Zhang N, Slocombe JW, Thierstein GE, Kuhlman DK (1995). Experimental analysis of spray distribution pattern uniformity for agricultural nozzles. Appl. Eng. Agric. 11(1):51-55.

Whitney JD, Salyani M, Churchill DB, Knapp JL, Whiteside JO, Little RC (1989).A field investigation to examine the effects of sprayer type, ground speed, and volume rate on spray deposition in Florida citrus. J. Agric. Eng. Res. 42:275-283.