DESIGN, DEVELOPMENT AND EVALUATION OF TRACTOR OPERATED AUTOMATIC GUN SPRAYER FOR FIELD CROPS

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CERTIFICATE

This is to certify that the thesis entitled **"Design, development and evaluation of tractor operated automatic gun sprayer for field crops"** submitted by **Mr. NAGESHKUMAR, T.** in partial fulfilment of the requirement for the degree of DOCTOR OF PHILOSOPHY (AGRICULTURAL ENGINEERING) in **FARM MACHINERY AND POWER ENGINEERING** of College of Agricultural Engineering, University of Agricultural Sciences, Raichur is a record of research work done by him during the period of his study in this University under my guidance and supervision and the thesis has not previously formed the basis of award of any degree, diploma, associate ship, fellowship or other similar titles.

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…any omission in this small manuscript does not mean lack of gratitude.

PLACE: RAICHUR

JULY, 2017 **(NAGESHKUMAR, T)**

Affectionately Dedicated

To

My Beloved Parents

CONTENTS

LIST OF ABBREVIATIONS

ANOVA	-	Analysis of variance
BIS	-	Bureau of Indian Standards
CAD	-	Computer aided design
CAE	-	College of Agricultural Engineering
cm	-	Centimetre
cm^2	-	Square centimetre
C.V.	-	Coefficient of variation
dc	-	Direct current
dpi	-	Dots per inch
et al.,	-	Others
Fig.	-	Figure
g	-	Gram
GDP	-	Gross Domestic Product
GI	-	Galvanized iron
h	-	Hour
hp	-	Horse power
IS	-	Indian Standards
kg	-	Kilogram
Kg cm^{-2}	-	Kilogram per square centimetre
Kg ha^{-1}	-	Kilogram per hectare
Km h^{-1}	-	Kilometre per hour
kPa	-	Kilopascal
kW	-	kilowatt
l	-	Litre
l min^{-1}	-	Litre per minute
l ha^{-1}	-	Litre per hectare

m	-	Metre
m ha	-	Million hectare
m s^{-1}	-	Meter per second
m^3 s^{-1}	-	Meter cube per second
min	-	Minute
mm	-	Millimetre
m m^{-1}	-	Meter per minute
Mpa	-	Mega Pascal
MS	-	Mild steel
N	-	Newton
NMD	-	Numerical mean diameter
N-mm	-	Newton millimeter
No’s.	-	Numbers
OECD	-	Organization for economic cooperation and development
P.T.O	-	Power take off
rpm	-	Revolution per Minute
Rs h^{-1}	-	Rupees per hour
s	-	Second
Std. Dev.	-	Standard deviation
VMD	-	Volume mean diameter
viz.,	-	Namely
UAS	-	University of Agricultural Sciences
UC	-	Uniformity coefficient
%	-	Percentage
°	-	Degree
°C	-	Degree centigrade

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Introduction

I. INTRODUCTION

Crop yield is reduced mainly due to attack of pests, diseases and weeds. In India, crops are affected by over 200 major pests, 100 plant diseases, hundreds of weeds and other pests like nematodes, harmful birds and rodents. Approximately, 18 per cent of Indian crop yield potential is being lost due to insects, diseases and weeds which in terms of quantity would mean 30 million tonnes of food grain. The value of total loss estimated at Rs 50,000 million, representing about 18 per cent of the gross national agriculture production (Manncsa, 2009).

Cotton crop is concentrated in semi-arid regions of the country and is one of the principal commercial crops in India with 9.5 million ha cultivated area which is largest in the world. Though, India is second largest producer of cotton in the world, the yield is only 440 kg ha^{-1} as against the world average of 667 kg ha^{-1} which is due poor control of insects, pests and dry land farming conditions (Gholap and Mathur (2013)). Cotton crop is infested by various pests. Among the pests of cotton, cotton bollworms *viz.*, American bollworm (*Helicoverpa armigera*), Pink bollworm (*Pectinophora gossypiella*) and spotted bollworms (*Earias vitella*) cause significant yield losses (Satyanarayan, 2016). Cotton is the highest pesticide consuming crop (36%) followed by rice (20%). About 10 per cent of insecticides on global basis and 45 per cent in India are being used for control of insects in cotton crop alone (Singh, 2004). It is found that, about 55 per cent of the total pesticide is being consumed on cotton in India against 5 per cent of total cultivable land accounting for 40 per cent of total production costs (Narang *et al*., 2015a). In Karnataka, cotton occupies an area of 4.66 lakh hectare with a production of 10.15 lakh bales and with a productivity of 370 kg lint per hectare (Anon., 2010).

Red gram (*Cajanus cajan millsp.*) is an important pulse crop in India. It is also known as Pigeonpea, Arhar and Tur. Red gram is mainly cultivated and consumed in developing countries of the world including India. India is the largest producer and consumer of Red gram in the world and produced 3.17 million tonne in the year 2014-15 under the area of 3.88 million hectare. Maharastra state is the largest producer of redgram accounting for 28.83 per cent of total production followed by Karnataka. In Karnataka state, area under redgram crop 6.81 lakh hectare with a production of 4.85 lakh tonnes and productivity of 712.19 kg ha^{-1}. The red gram crop is highly susceptible to insect attack. The pest and disease infection is a serious problem during the plant growth.

Among the many factors responsible for low yields of pigeonpea in India, insect, pests are the major ones. Though the pest spectrum of pigeonpea crop includes 200 insects and mites, the major insect causing heavy loss is the pod borer, *Helicoverpa armigera* (Hubner) (Kapasi *et al*., 2013). Pod borers caused 60 to 90 per cent loss in the grain yield under favourable conditions and damage of seed by pod fly ranged from 14.3 to 46.6 per cent (Jail *et al*., 2014).

1.1 Status of pesticide and insecticide

Agriculture plays an important role in Indian economy and contributes 18 per cent to the GDP, ensuring food security for more than 1.27 billion Indian population with diminishing cultivable land resource is a herculean task. In the process of achieving the target, pesticides play an important role in Indian agriculture. Pesticides, the agrochemicals are one of the invaluable inputs in sustaining the agricultural production as substantial food production is lost due to insect pests, plant pathogens, weeds *etc*.

India is second largest producer of pesticide in Asia and twelveth in world consisting 165 registered pesticides in the country. It accounts for less than 2.5 per cent of world market interms of value. There has been a steady growth in the production of technical grade pesticides in India, from 5,000 metric tons in 1958 to 85,000 metric tons in 2011 (Anon, 2011). Consumption is also less in India is low (around 500 g ha^{-1}) compared to other developing countries like Japan (12 kg ha^{-1}) and Germany (3 kg ha^{-1}) (Bhardwaj and Sharma, 2013). In the world, 44 per cent of the insecticides, 30 per cent of herbicides, 21 per cent of fungicides and others 5 per cent are used; while in India, 76 per cent of insecticides, 13 per cent of fungicides, 10 per cent of herbicides and 1 per cent others are used. Most pesticides used in agriculture today are synthetic organic chemicals that act by interfering with a vital metabolic process in the organisms to which they are targeted (Mathur *et al*., 2005).

Pesticides are the critical inputs for crop production world wide and are expected to continue to play a major role for the foreseeable future to protect most crop systems from the infestation of insect-pests and diseases. The main purpose of pesticide application technique is to cover the target with maximum efficiency and minimum efforts to keep the pest under control as well as minimum contamination of non-targets. A large volume of pesticides is used in crop protection, however, its application on different crops is highly inefficient. Misapplication, evaporation, leaf runoff and drift during the process of spraying results in loss of a major portion of these chemicals. According to the Central Cotton Research Institute, about half the applied chemical is lost during the spraying which not only add the cost of production but also pollutes air, water and soil. The major reason for this loss is due to inefficient spraying machine which are unable to maintain the specified nozzle pressure, uniform droplet size and even distribution with the result that dribbling or drift occurs during spraying. Dribbling can cause soil/water pollution while drift may cause air pollution in addition to wastage of costly pesticide (Ali *et al*., 2011). About 50 to 80 per cent of applied pesticides wasted due to adaption of poor spray machinery and inappropriate application methods (Khan *et al.*, 1997 and He and Escalada, 1997). Selection of suitable application methods and parameters are equally important for effectiveness of chemical sprayed.

Pesticide application is a complex process and the magnitude and uniformity of spray deposition is mainly influenced by target canopy characteristics, type of spray equipment and mode of operation and properties of spray chemicals. Uniform distribution and deposition of chemical spray from top to bottom of plant canopy and on the undersides of the leaves is of utmost importance for effective control of pests. Pesticide applied on the upper side of target in conventional method may be washed away by rains and overhead irrigation. Some studies have reported that over 80 per cent of the applied chemical reaches the soil (Ali *et al*., 2011). Non target pesticide application contaminates the soil in turn causes major changes in non target organism.

The pesticide needs to be applied to particular target areas occupied by insect, pest, disease or weed. Contamination to the environment by chemicals drifting out of the areas being treated has led to criticism for the use of pesticides. The studies indicated that pesticide contamination in the soil has caused changes in the population of earthworm to the extent of 60 per cent by the use of high volume of spray. Dosages are often increased to maintain control of a pest. Successful application means optimum quantity at right time with complete coverage to the target in an environmentally and hygienically safe way (Dahab and Eltahir, 2010).

Pesticide action on targeted insects and mites depends on pest's behavior *i.e*., mobility and pick up characteristic (Safari *et al*., 2013). A mobile pest has a higher probability of coming into contact with a given quantity of deposited pesticide than does a stationary one. There are cases where a cover density of only three or four droplets cm^{-2} is adequate for control of some leaf consuming larvae, but as many as 100 droplets are required for sucking insects or even 300 droplets for sessile armored scales ((Safari *et al*., 2013).

1.2 Pests and their control measures

An insect or micro organism or any other living being whose population increases to such an extent as to cause economic losses to crops or nuisance and health hazard to man and his livestock is declared as pest (Mathews, 1992a). Pests or insects are chief competitor of human being on the earth. They transmit diseases to him and his domesticated animals. About one third of the potential agricultural production in the world was annually lost due to the pest. Control of diseases can generally be achieved by natural control and control practices applied by man. Mathews (1992a) also reported following methods to control the pests.

i. Physical and mechanical control

This is one of the oldest methods and has been in use since time immemorial. It includes measures such as the collection of egg masses by hand picking or by dragging brushes, *etc*. This method can prove to be effective during the initial stages of pest incidences.

ii. Cultural control

The control of pest by means of cultural practice is preventive method. It is inexpensive and may prove effective and efficient if employed after acquiring a thorough knowledge of the life history and habits of pests. It is achieved by deep ploughing after harvesting a crop, removing and destroying of the stubble and other trash. It also includes adjusting the times of sowing, removal of alternative wild hosts and crop rotation, etc.

iii. Plant resistance

The resistance of plant to the pest can be achieved by plant breeding techniques. The developed crossed varieties have immunity, resistance, and tolerance to a disease or pests attack.

iv. Biological control

This can be achieved by introducing natural enemies of pests to reduce the population. The biological control agents are in the form of parasites, predators, and diseases causing organisms.

v. Chemical control

Chemical control is still only effective method of controlling most insects, pests, weeds and diseases. Thus, pesticide remains a powerful tool in pest management which is achieved with various chemicals used as insecticides, fungicide and herbicides.

vi. Integrated pest control

A single method may not be adequate in pest management programme, where several pests occur more than one control methods are often needed. Careful integration of several techniques is required so that they do not oppose each other but harmonize to provide optimal cost effective control over a long period rather than a short-term solution.

Among the various methods of pest control, chemical application is widely used for controlling disease, insects and weeds in the crops. They are able to save a crop from pest attack only when applied on time. They need to be applied on plants and soil in the form of spray, dust or mist and granule. Dusters and sprayers are used to apply the agro chemicals. But duster is less efficient than the spraying due to low retention of chemicals. Spraying is one of the most effective and efficient techniques for applying spray liquid to protect crops. Over 75 per cent of all pesticide applications are made as liquid sprays (Robert and Hipkins, 2012).

Sprayer is a machine to apply herbicides, fungicides and insecticides in the form of droplets. The primary aim of crop protection equipment (sprayers) is the reduction in the population of developmental stage of pest which is directly responsible for damage within individual fields and is most efficient when the chemical is applied economically on a scale dictated by the area occupied by the pest and the urgency with which the pest population has to be controlled taking the environment into consideration (Mathews, 1992a). The proper selection of a nozzle type and size is essential for proper pesticide application. The nozzle is a major component in determining the amount of spray applied to an area, the uniformity of application, the coverage obtained on the target surface and the amount of potential drift. The process of separating a liquid into many small droplets is called atomization. Nozzles break the liquid into droplets, form the spray pattern and propel the droplets in the proper direction. Atomization process is influenced by the nozzle design, configuration and by the physical properties of the sprayed liquid (Sun *et al*., 2015). They determine the amount of spray volume at a given operating pressure, travel speed, and spacing. Spray deposition on the plant canopy, soil surface or on flying insects takes place by gravitational sedimentation or inertial impact, or a combination of both processes (Rahman, 2010). The transport of the spray droplets to the target is affected strongly by weather conditions especially wind, low humidity and high temperatures, which generally reduce impaction efficiency and increase drift (Matthews, 1992a). Drift can be minimized by selecting nozzles that produce the largest droplet size while providing adequate coverage at the intended application rate and pressure (Safari *et al*., 2004).

The size of the spray particle plays an important role because it affects both efficacy and spray drift of the pesticide and can also influence the environmental impact of the spraying operations. Efficacy of spray particle is mainly influenced by the amount of chemical used per unit area, deposition of chemical and percentage of chemical received in a target area. Other important spray characteristics influencing the efficacy of spray particle is spray angle, spray shape and volume distribution pattern (Minov *et al*., 2014). Degree of coverage on the target with individual droplets determines biological efficacy. The more droplets per unit area, the better will be the efficacy of the spray. Nowadays trend has been towards low application rate through high ground speed and adequate pressure. Low application efficiency is not desirable due to reduced effectiveness of chemical, increased the cost of application, and results in risk of environmental pollution and killing of non-target organism.

Among others, lever operated or power operated knapsack sprayer, tractor drawn boom sprayer and bullock or tractor operated gun sprayer are commonly used by small to medium farmers for spraying of field crops. Spraying with knapsack sprayer is energy consuming operation because operator has to carry the weight of fluid throughout entire covering area. During spraying operation, the operator’s body assumes an awkward position giving severe discomfort to the body (Tamilselvi and Krishnan, 2016). There is a chance of overlap or missed areas during operation of lever operated knapsack sprayer and walking speed of the operator greatly influences on spray application quality (Piggin *et al.,* 2000). Varying the walking speed or distance between the nozzle and plant tops causes uneven distribution of spray material. Piggin *et al.* (2000) reported that there was a chance of overlap or missed areas during swing of lever operated knapsack sprayer lance operation and the nozzle height was changed by 10 per cent in each swing of lance. Performance depends on skill of operator; manual application often results in an uneven distribution of the pesticide. The height of crop and its density increases with the stage of growth of the crop and the effectiveness of manually operated sprayers decreases (Veerangouda *et al*., 2014).

Tractor drawn boom sprayer have longer boom which are generally trailed behind a tractor. Longer booms increases length of tractor-sprayer assembly resulting in increased turning radius (Nalavade *et al*., 2008) which may damage more crop. As the length of boom increases boom moment also increases. Horizontal and vertical movements of boom affect the uniformity of the spray. The excessive up and down swinging of this sprayer's booms results in uneven spray distribution (Nalavade *et al*., 2008).

1.3 Necessity of tractor operated automatic gun sprayer

In conventional method of gun spraying, two persons are required to swing the gun from side to side during operation behind the bullock cart or tractor. Most of the field crops in Raichur region are sprayed by animal drawn or tractor operated gun sprayer. It is fitted with two guns of 60 to 150 cm long lance. In field, tractor operated gun sprayer required three persons of which two persons are required for swinging the gun and one is for tractor driving. The gun spraying is becoming popular because of its multipurpose use for cotton, paddy and horticultural crops. Hand operated gun sprayer leads to excessive application of chemical and uniformity of application is less which leads to excessive operational cost and environmental pollution. Though this method gives good pest control, it consumes large volume of liquid per ha and required more amount of labour and time. Efficiency is depends on skill of operator; manual application often results in an uneven distribution of the pesticide. The spray swath depends on the movement of the lance's swing. Maintaining a constant swing speed and constant distance between nozzle and plant tops ensures uniform distribution of spray material per unit time. Uneven distribution is major drawback from conventional spraying due to varying swing speed and distance by operator. It is quite impossible to maintain a constant nozzle height during swing of the lance. Availability of labour for farm work is also decreasing day by day. Main drawback of this sprayer is fatigue to the operator hand because of continuous swinging of gun sprayer behind the tractor or bullock cart. On the other hand, operator is also affected by chemical being sprayed in front of his way. The low application efficiency of the existing mechanism also tends the farmers to apply frequently and more chemicals in the field thereby contaminating both soil and environment.

Therefore, there is an useful need to develop a tractor operated automatic gun sprayer for selected field crops which improves coverage, boosts chemical effectiveness, reduce labour, time and makes spraying operation easier and faster. Keeping the above factors in view, the present investigation is planned with the following objectives.

Objectives of investigation

1. To study the crop and machine parameters for the design and development of a tractor operated automatic gun sprayer for selected field crops
2. To design and develop a tractor operated automatic gun sprayer for selected field crops
3. To evaluate the performance of a tractor operated automatic gun sprayer for selected field crops
4. To work out the economics of a tractor operated automatic gun sprayer for selected field crops

Review of Literature

II. REVIEW OF LITERATURE

The world is seriously concerned about the increased consumption of the pesticide in the crop production. Pesticide application is a complex process and the magnitude and uniformity of spray deposition is mainly influenced by target canopy characteristics, properties of chemical and spraying equipment. In general, spraying equipment has an important role in distribution and deposition of pesticide on plant canopy.

Use of chemicals for plant protection started in first quarter of eighteenth century with introduction of new insecticide and fungicides. The liquid chemical solution were applied to plants with watering cans, syringe or with a heath brush in case of vineyard. The sprayers were probably first developed and used to apply fungicides for controlling diseases of grape in vineyards in the vicinity of Bordeaux, France (Thakare, 2004). The hand sprayer to control the insect was developed between 1850 and 1860 by John Bean of California. Gasoline engine power sprayers were developed in year 1900. Tractor mounted sprayers were not developed until several years after the introduction of the row crop tractor in 1925. Spray boom was first attached to airplane in early 1940s (Thakare, 2004).

Untill World War-II, pesticide application in India was almost non-existent. The Indian farmer used to practice the 'catch and kill’ methods on their farms. After World War-II, sprayers and dusters were gradually introduced (Thakare, 2004). Initially stirrup pumps were imported for spraying operation to control malaria mosquitoes. As the demand increased, the indigenous production of hand rotary duster was started which was used for dusting sulphur on crops and orchards. Since then, manufacturing of pesticide application equipment is ever progressing. During the green revolution, the high yielding varieties of wheat and rice were grown successfully under the protection umbrella of pesticide. The intensive use of pesticide during the recent years has cause great damage to the environment. In view of this, work has been started after 1970 to economize the pesticide application and improve the deposition efficiency besides protecting the environment. Since then, different types of sprayer have been developed and used. The earlier research findings and available information on design and development, crop and machine parameters affecting the sprayer performance were reviewed and presented under the following headings.

2.2 Design and development of power operated or tractor drawn sprayer

Black (1954) developed a self propelled high clearance sprayer to cover six rows of sweet corn crop. The boom of sprayer could be adjusted to a maximum height of 2 m. The sprayer was tested in the field and its performance was quite satisfactory.

Blatr *et al*. (1975) developed and evaluated a new small plot sprayer with two different sizes of nozzles *i.e*., 80067 to 8005. The results from the study showed that by increasing nozzle size, spray distribution was improved and was reflected in lower coefficient of variation.

Taylor *et al*. (1976) designed, fabricated and evaluated the performance of tractor mounted very low volume uniform drop size sprayer. The machine had five spray units, each with five rotating discs. Uniform sized drops in the range from 150 to 350 µm were produced with lipophilic, hydrophilic and emulsifiable formulations and spray volumes varied from 5 to 120 1 ha^{-1}.

Menzies (1978) designed an experimental sprayer for pesticide application in orchards. Its design features were three independently controlled vane-axial fans, vertically stacked and driven hydraulically, three pesticide nozzle manifolds and provision for altering the air outlet geometry.

Ahuja (1979) developed a tractor mounted high clearance spraying effective swath width of 20 m. The field performance of the sprayer was quite satisfactory except for time loss in filling the tank, limited speed of operation. Twenty metre wide boom posed an operational problem.

Cannon (1979) designed, developed and tested a wide boom ground sprayer. Various parameters *i.e*., effectiveness, field capacity and reliability were measured. The machine had a wide enough to cover 24 rows spaced 1.106 m part. The results showed that the actual field capacity of the sprayer was 23.8 ha h^{-1} at the ground speed of 16 km h^{-1}.

Verma and Singh (l979) developed a power tiller-operated sprayer for spraying of herbicides with swath width of 4 m. The sprayer was mounted on a power tiller of 7.5 hp.

Reichard *et al*. (1982) developed an experimental orchard sprayer that can surround a tree with spray using a self propelled base unit which could straddle trees that were about 2.6 m wide and 3.7 m high. The air delivery rate was 7.8 m^3 s^{-1} at an average velocity of 14 m s^{-1}.

Salyani *et al*. (1987) developed a methodology for fast and accurate assessment of deposition efficiency for foliar spray application. Two criteria used to evaluate deposition efficiency were per cent of material deposited on leaf surfaces and per cent coverage of water sensitive targets. Using this methodology, the highest deposition efficiency on washed citrus leaves was obtained when spray droplets were approximately 400 µm diameter.

Shukla *et al*. (1987) developed and evaluated the performance of wide swath tractor mounted sprayer for cotton crop. The sprayer boom has 13 triple action nozzles and two spray gun. It has a swath width of 12 m and covered 1.2 ha h^{-1} while operating at a speed of 3.5 km h^{-1}.

Kathirvel and Job (1989) developed a suitable tall tree spraying attachments to power tillers. The unit was equipped with a positive displacement pump which provides spraying up to a height of 7.5 m. The total discharge rate was 7.75 l m^{-1}.

Kasyap (1989) developed an orchard air carrier sprayer to spray on mango orchards. These sprayers were evaluated to provide the effective spraying technology to the farmers, which give good and economical pest control.

Jesudas *et al*. (1992) developed an orchard sprayer attachment to knapsack sack mist blower with a peristaltic pump and a spray lance of 63 cm long. A result showed that the average discharge of 60 ml spray fluid per minute was recorded with height of spray was about to 7 m.

Mathew *et al*. (1992b) developed a power tiller operated boom sprayer for spraying on groundnut and other crops. The sprayer had 7 hollow cone nozzles which were placed at 50 cm apart. The swath width of the sprayer was 3.5 m at a speed of 2.25 km h^{-1}. The results revealed that the 29 per cent reduction in cost compared with hand compression knapsack sprayer, the effective field capacity of the sprayer was 0.65 ha h^{-1}

for a power tiller speed of 2.25 km h^{-1}. The sprayer has worked satisfactorily at a pressure of 3 kg cm^{-2}.

Awadhwal *et al.* (1992) developed two devices for attachment to knapsack sprayers. The first was a closed chemical transfer system for handling pesticides consisting of a 1 litre container and a graduated pump. Tests indicated that it reduced contamination due to handling of pesticide by 60-80 per cent. The second was a mini-boom consisting of 4 spray nozzles which reduced operators' exposure to the chemical by approximately 68 per cent.

Hussain *et al.* (1993a) developed a tractor mounted PTO driven boom sprayer. They used a swirl grooved hydraulic nozzle and reported that pump pressure had significant effect on output of the nozzle and VMD within range of 100-200 µm.

Bindra and Singh (1997) developed a hydraulic sprayer and reported that increase in liquid pressure resulted in increased carry of droplets, spray angle, liquid flow and smaller spray droplets.

Bhargav (2001) developed and evaluated air sleeve boom sprayer for citrus. Results revealed that air velocity helped in penetration and breakup of liquid into droplets. Higher the velocity, more uniform was droplet spectrum. The VMD increased at centre of canopy with increase in air velocity. The smaller droplets were found to be advantageous in penetration in dense foliage.

Durairaj *et al.* (2002) developed and evaluated the down the row boom sprayer for power tiller. The length of trussed boom was 6 m with 3 m on either side of the tiller. The tread width of the system could be adjusted from 55 to 85 cm and could accommodate spraying of various crops ranging from ground nut to cotton.

Manian *et al*. (2002) developed a tractor operated tall tree sprayer for coconut. The unit consists of telescopic (60 mm and 37 mm) G.I. pipes which can extend from 8 m to 14 m high. The minimum height of the spray guns was 8 m. when telescopic pipes were moved up, the spray guns were at maximum height of 15 m. Results indicated that the best angle of inclination for maximum height of reach was optimized as 75 degrees to horizontal when height of reach was 6.92 m from the tip of the nozzle.

Kathirvel *et al*. (2002) developed and evaluated the power tiller operated orchard sprayer. The unit consisted of three aluminium hollow sections (50 × 25 mm) of 4 m length to which three spray lances of 1.8 m long each are fixed. The results revealed that about 10-15 trees can be covered per hour depending up on the tree density.

Manor and Gal (2002) developed an accurate vineyard sprayer. Four turbulent air nozzles fitted in each beam with relative angles adjusted to the cross section of the rows. Simple 600 litre tank with a fan and a diaphragm pump were mounted on the same structure. Two conejet nozzles were mounted alongside each air nozzle directed toward the turbulent air jets coming out. Results indicated that the all the nozzles had coverage efficiency of 80 per cent or better for application rates of 300 l ha^{-1} or greater, for the front of the leaves.

Safari *et al.* (2004) developed and evaluated the performance of a mounted spinning disk sprayer in comparison with the conventional tractor mounted boom sprayers. Results proved that there wasn't a significant different between spinning disk sprayer and conventional sprayer in order to weed removement at 1% level, but there was a significant different between spraying methods and no spraying treatment (after 20 and 25 days). Volume mean diameter (VMD) and number median diameter (NMD) was 242.6 and 116 µm, respectively with spraying quality coefficient of 2.08, respectively.

Iqbal *et al*. (2005a) designed, developed and fabricated university boom sprayer test bench to evaluate different types of nozzles for the measurement of discharge, swath width, cone angle, and spray pattern. Six nozzles had been provided, out of which five were fixed to spray top to bottom onto the corrugated sheet just below the boom pipe like a conventional boom sprayer and the sixth nozzle was directed towards the vertically moveable platform to spray at different angles (0°, 15°, 30° and 45°) with respect to horizontal on the underside of water sensitive papers. It appeared that the discharge of each type of nozzle increased with the increase in pressure.

Iqbal *et al*. (2005b) developed a drop-pipe tractor mounted university boom sprayer. This sprayer has upper and lower two booms to spray the cotton crop both from above and below the leaves. The lower boom has drop-pipes on the lower ends of which are mounted nozzles, which have the ability to be rotated and adjusted in 360° both in horizontal and vertical planes. The performance of newly developed drop-pipe boom sprayer was found best at 4 km h^{-1} field speed with 400 kPa pressure fluid pressure and 0 degree nozzle angle with respect to boom axis than those at other speeds, pressures, and nozzle angles.

Powar *et al*. (2006) designed and developed a power tiller operated sprayer. Spraying was carried out at three blower speeds (2250, 2500 and 2800 rpm) and three different liquid discharge rates for each blower speed. The best results were obtained at 2250 rpm blower speed and 600 cc min^{-1} liquid discharge rate.

Gite and Rahate (2007) developed and evaluated the performance of power tiller operated sprayer for grape vineyard. The performance of newly developed sprayer was evaluated for droplet size, droplet density and uniformity of spraying at various treatments. Effect of both, travel speed and the system pressure on spray deposition was found to be significant. Maximum droplet density (31 droplets cm^{-2}) was found for the travel speed of 1.0 km h^{-1} and system pressure of 9.0 kg cm^{-2}, which was most suitable for spraying in grape fields.

Mahal *et al*. (2007) developed a high clearance power sprayer for cotton. The sprayer is powered by a two cylinder 20 hp diesel engine and had a ground clearance of 1200 mm. The boom width of the sprayer was 8.87 m with 14 nozzles spaced at 67.5 cm. Boom height can be adjusted from 315 mm to 1685 mm to suit different crops heights.

Nuyttens *et al*. (2007) developed a test rig and protocol for the characterization of spray nozzles using a phase doppler particle analyzer (PDPA). Test rig was able to measure droplet sizes and velocities based on light-scattering principles. 32 nozzle pressure combinations were tested and classified based on droplet size spectra and the British Crop Protection Council (BCPC) classification scheme. The test results clearly showed that the effect of the nozzle type, size and pressure on the droplet size and velocity spectra.

Padmanathan and Kathirvel (2007) developed a power tiller operated rear mounted boom sprayer for row crops. The effective field capacity of the sprayer was 0.72 ha h^{-1} for the tiller speed of 2 km h^{-1} and the performance was satisfactory at a pressure of 3 kg cm^{-2}. The sprayer can be adopted for row crops as it saves the cost and time of operation per ha by 51 per cent over power operated knapsack sprayer.

Balloni *et al*. (2008) developed a self propelled sprayer for green house. The spray lance was 0.97 m long, with 4 steel nozzles 0.21 m spaced, suited to spray plants up to 3 m high. The prototype of sprayer consisted of a little tracked tractor powered by a gasoline engine with continuous power of 2.6 kW at 3000 rpm, carrying a 120 l main tank, a volumetric pump, and two vertical spray booms 1.5 m long, each with four nozzles.

Nalavade *et al*. (2008) developed a tractor mounted wide spray boom for increased efficiency. A 15 m tractor mounted spray boom was systematically developed considering the stresses acting on the boom structure. The developed spray boom's performance was compared with existing 9 m spray boom developed by a local manufacturer. A 15 m spray boom was found to be more economical than the existing 9 m spray boom.

Sirohi *et al*. (2008) developed a hydraulic sprayer for vegetable crops and tested with air assistance and without air assistance in the three crops, namely, brinjal, chilli and bittergourd. Field test showed that the droplet density and droplet size were more on the top surface of the canopy structure than on the bottom surface. Similarly, droplet density and droplet size obtained on underside of the canopy were found to be less than that obtained on the upper side. Leaf area density (LAD) and forward speed did not influence the volume median diameter of droplets significantly.

El-Ashry *et al*. (2009) developed and evaluated performance of a greenhouse pesticide sprayer and compared with a conventional disc sprayer and different pesticide applicator types, motorized knapsack sprayer and hydraulic sprayer (gun). The results showed that the modified disc sprayer performed the highest number of droplets (224 droplets). Meanwhile, lowest number of droplets (43 droplets) was gained using hydraulic sprayer (gun).

Tayel *et al*. (2009) developed and evaluated sprayer attachment to paddy transplanter for cotton crop. The sprayer was tested at four different spray heights, four different spray pressures, three different orifice diameter and four different nozzle spaces. The maximum values of coefficient of uniformity were 75.78, 78.60 and 77.22 per cent at orifice diameters of 0.50, 1.0 and 1.5 mm, respectively, with spray height of 700 mm and spray pressure of 500 kPa.

Singh *et al.* (2010) developed a tractor mounted air-assisted sprayer and compared with a conventional tractor mounted boom sprayer in cotton crop. Both the sprayers were operated at the forward speed of 4 km h^{-1} and working pressure of 3.5 kg cm^{-2}. Results showed that the deposition on the underside of the leaves of top, middle and lower portion of plants in case of conventional sprayer was negligible but in case of air-assisted sprayer deposition were 43, 23 and 14 drops cm^{-2}.

Gite and Deogirikar (2010) designed and tested a suitable boom for power tiller operated sprayer for bower type pattern of grape vineyard. Two booms of inverted L shape were designed and tested in the laboratory. Results showed that droplet density was decreased with increased in forward speed from 1 to 2.5 km h^{-1} and maximum uniformity coefficient (1.9) was obtained for 1 km h^{-1}.

Yasin (2012) designed and developed air sleeve boom sprayer. The sprayer required about 127-152 l ha^{-1} chemical to spray through hollow cone nozzles at 0.4 to 0.6 l min^{-1}. The boom width was 10.7 m with 20 nozzles fitted on the boom at the 510 mm spacing. The sprayer was tested in cotton field. Results showed that the field capacity of the sprayer was 2 ha h^{-1} and gave higher deposition on both sides of leaves as compared to conventional sprayer.

Raut *et al.* (2013) designed and developed a agricultural pesticides sprayer with weeder. The equipment is purposely designed for the farmers having small farming land say 5-6 acre. For 1 acre of land it consumed 75 liter of water and 250 ml of pesticide. In general, herbicides are most effective when applied as droplets of approximately 250 microns; fungicides are most effective at 100 to 150 microns and insecticides at about 100 microns. The pump selected was a reciprocating piston.

Suresh *et al.* (2013) developed a power tiller operated intra canopy sprayer for cotton and pigeon pea crops. A five nozzle boom system was developed considering the canopy requirement of tall crops such as cotton and pigeonpea. The effective field capacity was 0.146 ha h^{-1} in pigeon pea crop at forward speed of 1.31 km h^{-1}. The percentage area covered by the droplets on the front and back side of the leaves was almost equal *viz.,* 17.5-18 per cent. The mean droplet size varied from 120 to 124 microns with more than 90 per cent droplets was less than 300 micron size.

Safari *et al.* (2013) designed a tractor operated air assisted 8 meters boom sprayer equipped with nozzle of blower to work within 8 meters and compared with conventional sprayers to control Sunnpests in wheat production. Four sprayers namely turbo-liner, atomizer sprayers, Micron-air sprayer and boom sprayer were used to compare their performance. Results concluded that the maximum field efficiency was related to the tractor boom sprayers and the minimum was related to Atomizer sprayers. The highest solution was consumed by Turbo-liner and boom sprayers and lowest by Micron-air sprayer.

Amonye *et al*. (2014) designed and developed an animal drawn ground metered axle mechanism boom sprayer. The equipment consisted of a boom with multiple controlled droplet applicator (CDA) atomizer nozzles, a gear pump, a chemical tank, and chair for an operator; all attached to a framework bolted to a rear axle.

Gholap *et al.* (2014) developed and evaluated the performance of tractor operated boom type field sprayer for cotton crop. A 12 m tractor mounted boom sprayer was modified and developed considering the various components of the existing boom sprayer. The modifications were done in the boom sprayer for stability and new folding arrangement and further it was fabricated. The hydraulic boom sprayer was tested using the spray scanner and droplet analyzer in the laboratory for cotton crop to study effect of nozzle discharge rates (*viz*., 0.45, 0.70, 0.90 and 1.35 l min^{-1}) and nozzle pressures (*viz*., 275.8, 413.7, 551.6 and 689.5 kPa) on spray uniformity. From the study it was found that nozzle discharge rate of 0.9 l min^{-1} and nozzle pressure of 689.5 kPa produced more uniform spray. The liquid distribution under the boom sprayer was within the ±20 per cent of total mean value, which was within the limits as per standards. Droplet size (VMD), droplet density (DD) and uniformity coefficient (UC) of the boom sprayer ranged from 155.44 to 181.55 µm, 17 to 29 drops cm^{-2} and 0.99 to 1.23, respectively.

Azizpanah *et al*. (2015) designed and evaluated the sprayer drift measurement system. The sprayer was performed in wind speed of 12 km h^{-1}, three spraying pressure levels (3, 4 and 5 bar) and three nozzle heights (0.35, 0.5 and 0.6 m). The drift was increased with increase in operating pressure and height of the spray. The results showed that, largest droplet sizes were observed in the lowest spraying pressures and heights.

Kumar (2015) developed and evaluated the performance of single wheel driven boom sprayer compared with conventional knapsack sprayer. The application rate, swath width, discharge rate, nozzle angle at boom height of single wheel driven boom sprayer were found to be 106 l ha^{-1}, 95 m, 1.21 l min^{-1} and 43.5°, respectively which were optimum.

Reddy *et al*. (2015) designed and developed herbicide spraying technology while in sowing of groundnut. Power is transmitted from ground wheel to metering system through chain and sprockets for seed sowing and from P.T.O shaft to single axial piston type pump through belt drive for herbicide spraying. The results showed that, the field capacity of the machine was found to be 0.47 ha h^{-1} at an average operating speed of 3 km h^{-1} and herbicide application rate of 1100 l ha^{-1}.

Awgichew *et al*. (2016) developed and evaluated performance of agricultural chemical sprayer. The sprayer was capable to cover boom length of 7500 mm over which 14 hollow cone spray nozzles were fixed. The boom height was adjusted in accordance with height of different crop. Laboratory evaluation revealed that the nozzles average discharge was 4.33 l min^{-1} with standard deviation and coefficient of variation 0.34 and 7.85 per cent, respectively. Field performance test revealed that the slippage, theoretical field capacity, actual field capacity and efficiency were 1.01 per cent, 4.65 ha h^{-1}, 4.23 ha h^{-1} and 91 per cent, respectively.

Malonde *et al*. (2016) designed and developed multipurpose pesticides spraying machine consisting of 17 Volt, 0.58 amp solar panel was used as power source for sprayer. The developed sprayer performance was compared to manual operated sprayer. Results indicated that the flow rate is increased by 2.5 times the manually operated sprayer and area sprayed per hour was increased by 2.6 times of the manually operated sprayer and 1.5 times the knapsack power sprayer.

2.2 Performance evaluation of power operated/ tractor drawn sprayer

Frost and Ware (1970) compared different spraying equipment under similar environmental conditions. They found that the when sprayers were adjusted properly, the herbicide spray drift was greater from aerial and mist blower equipment than from a high clearance ground sprayer.

Smith *et al*. (1975) recommended that droplet size between 140 μm and 200 μm to be used for spraying most crops. They found that at 200 μm VMD, a droplet density of 20-25 droplets cm^{-2} was most effective for control of boll weevil in cotton.

Nordby and Skuterud (1975) studied the effect of boom height and working pressure on the deposition of spray droplets. Boom height of 40, 80 cm and operating pressure of 2.5 and 10 bar was maintained. The results found that the increasing the boom height, liquid deposition on the crop was reduced.

Reichard *et al.* (1977) studied the droplet sizes delivered by different atomizers on tree. All atomizers produced a wide range of droplet sizes, but which delivered a much greater proportion of large droplets than others. Nearly all of the droplet sizes distributed in either of two small size classes (7.5-22.5 μm and 22.5-37.5 μm).

Frangi (1982) evaluated the performance of self propelled high clearance sprayer. The sprayer fitted with an auxiliary pump which operates filling, agitation, washing and transfer of liquid with an input of 700 l min^{-1} and output of 500 l min^{-1}. The volume applied was 200 l and sprayer has 5000 l capacity. Area covered per tank was 25 hectares.

Azimi *et al*. (1985) investigated the nozzle spray distribution for pesticide broadcast application, with spray table (patternator) having troughs to measure the distribution across the sprayed swath from single nozzle. The results 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.

Franklin *et al*. (1986) evaluated the performance of two methods of boom spray application. One method used a standard system of hydraulic cone nozzles spaced along the boom. The other method used the same nozzles with the addition of a ducted air blast to each nozzle. The results show that the addition of an air blast to each nozzle is beneficial particularly when the crop grows large enough to form a complete canopy.

Travis (1987) studied the effects of travel speed, application volume and nozzle arrangement on deposition and distribution of pesticides in apple tress. The effect of sprayer travel speed was tested at 40, 54, 67 and 80 m min^{-1}, the effect of application rate tested at 374, 617, 935 and 3742 l ha^{-1} and nozzle arrangement. Under the conditions of this study, a travel speed of 54 m m^{-1} and volume of water of 61 l ha^{-1} with the nozzle arrangement has highest mean deposition.

Salyani (1988) conducted a study to identify the droplet size range for maximum spray deposition efficiency on citrus leaves using a vibrating orifice droplet generator, a wind tunnel and two spray fluids. Results showed that, the droplet size range of 240 to 340 µm gave the highest deposition efficiency.

Gilbert and Bell (1988) examined the spray drift from three different types of sprayers at two wind speeds and found that the type of sprayer was more important than the volume median diameter (VMD) of spray droplets in affecting spray drift. They showed that the air-assisted sprayer had greatest spray drift (VMD 150 ± 40 µm), followed by the hydraulic sprayer (VMD 100 ± 25 µm) and the rotary sprayer.

Young (1990) found with a Tee Jet 8002 nozzle that the number median diameter for droplets moving vertically down from the nozzle decreased by 10 per cent and the corresponding volume median diameter by 8 per cent with a doubling of pressure from 200 to 400 kPa.

Raisigl *et al.* (1991) stated that the spray volume between 300 and 500 lit ha^{-1} of insecticide in orchards was adequate for effective pest and disease control. It was further reported that spray volume of more than 600 l ha^{-1} resulted in losses through runoff.

Franz (1992) measured the spray coverage using hand held scanner. Measurement errors due to spot size, contrast, and method of selecting intensity threshold were evaluated. Measurements made using visual threshold selection were user dependent. Spot size and coverage errors were all greater than 5 per cent and count errors were less than 5 per cent.

Mathew *et al*. (1992b) studied power tiller operated boom sprayer for varying pressure with hollow cone nozzle. Results indicated that the higher pressure of 3 kg cm^{-2} showed more even distribution than that of 2 kg cm^{-2} pressure.

Nordbo (1992) conducted the study to examine the effects of nozzle size and travel speed on deposition on artificial vertical and horizontal targets in laboratory. Small horizontal and vertical targets were placed in the swath of a Hardi Twin air-assisted crop sprayer and sprayed indoors with a variety of conventional hydraulic nozzles with and without air assistance and at differing travel speeds. With conventional spraying, deposition was improved on vertical targets with high travel speed and small droplet-size spectra, whereas deposition on horizontal targets was relatively unaffected by the configuration used.

Yates and Smith (1992) reported that the spray deposition was not only a function of method of application of chemicals but also it depends on parameters like leaf surface area, forward velocity of sprayer and nozzle orientation.

Hussain *et al*. (1993b) conducted an experiment on the field performance of a tractor mounted boom sprayer and studied the effect of swath, nozzle height and nozzle position on spray deposit. Results showed that the spray deposition decreased with increasing tractor speed as well as wind speed.

Sarker (1993) conducted an experiment on performance studies of different sprayers available in Bangladesh and observed that deposition decreased when the horizontal distance and the height of target object from the nozzle of sprayer increased.

Womac *et al*. (1993) reported that the drop nozzle sprayers either with or without air assistance provided a high degree of nozzles orientation control, spray coverage and spray targeting to leaf underside.

Afshar and Fallah (1995) compared seven methods of spraying to control of Sunn pests of wheat crop. Results showed that there wasn’t any significant difference between treatments after 2, 5 and 10 days of spraying. The loss percentage was between 95-100 per cent among treatments. The conventional sprayers almost spray the chemical above of crop but most Sunn pests live in bottom of crop.

Celeste and Sandra (1995) tested hydraulic boom sprayer and compared with electrostatic sprayer and controlled droplet applicator (CDA) for the management of mustard aphid, *Myzus persicae* (Sulzer) by using contact insecticide melathion. Results showed that the maximum aphid control, good coverage of canopy and minimum drift was most consistently provided by hydraulic boom sprayer as compared with other two.

Patil *et al*. (1995) reported that high volume spray of 1000 l ha^{-1} gave the best results when compared to the sprayers of 750 l ha^{-1} and 500 l ha^{-1} both in achieving the pest control and in obtaining cotton yield. Spraying with 1000 l ha recorded 2.7, 8.6 and 0.9 jassids, aphids and white flies on the top three leaves as against 4.5, 22.8 and 1.2 per top three leaves using spray of 750 l ha^{-1} and 7.6, 30.1 and 1.6 per top three leaves using spray of 500 l ha^{-1} volume which indicated that high volume ground sprayers have lowest air borne drift followed by low volume and aerial sprays.

Wang *et al.* (1995) carried out a laboratory experiment on spray distribution pattern uniformity for agricultural nozzles and showed that nozzle height had a strong effect on spray distribution uniformity, but spray pressure had no significant effect on the uniformity.

Bjugstad and Torgrimsen (1996) studied the pesticide deposition in greenhouses using hand-held spraying equipment. A hot aerosol fogger and knapsack mistblower gave lower plant deposits than a high-pressure spray gun and knapsack sprayer.

Derksen and Sanderson (1996) found that in a mature poinsettia canopy, a handheld, low volume, air assist electrostatic sprayer produced significantly higher deposits on the underside of leaves at the bottom of the canopy compared to a high volume handgun treatment using only 1/25 the spray volume and treating the area three times more quickly. Also reported that, the treatment effects were not consistent on all leaf surfaces at different canopy elevations.

Grinstein *et al*. (1996) reported that the drop sprayer yielded a high cover density on both sides of the leaves on all parts of the plant and good control was obtained (85-95 per cent on both sides of leaf coverage). Use of drop-pipe sprayers resulted in leaf coverage of 200 droplets cm^{-2} of more than 80 per cent on both sides of the lower leaves of the plant and of close to 100 per cent on the higher leaves.

Guo *et al*. (1996) studied the deposition and distribution of droplets emitted by a low volume sprayer (LVS) and high volume sprayer (HVS) on cauliflower leaves. Results showed that both sprayers gave more deposition on middle layer leaves than leaves at the inner and outer layers.

Islam *et al*. (1996) carried out an experiment on performance of power tiller mounted boom sprayer. They varied nozzle pressure from 0.44 kg cm^{-2} to 0.80 kg cm^{-2} and found that the drift was 1.63 per cent and 7.45 per cent at wind speed of 2 m s^{-1} and 10 m s^{-1}, respectively.

Kaul *et al.* (1996) reported that the drift or loss of chemicals to the air was influenced by evaporation, drop size spectrum, wind speed, height of nozzles, forward speed, crop height, atmospheric stability, working width and boom height, in the order.

Khan *et al.* (1997) found through investigation on spray application and safety measures in Pakistan that poor pump pressure causes bigger droplet formation and excessive drift and ultimately adds to soil pollution. They also stated that non-uniform pesticide distribution results phytotoxicity (due to over dosing) and resistance (due to under dosing) of pests. Application of recommended pressure, flow rate, nozzle height, and spray swath are necessary for even spraying and getting maximum benefit from pesticides application.

Holterman *et al.* (1997) conducted an experiment on modelling spray drift from boom sprayers and showed that boom height, wind speed and nozzle size were the major factors affecting spray drift. Results indicated that liquid pressure did not affect downwind spray deposit at all.

Satyanarayana and Patil (1998) evaluated different types of nozzles used in cotton insect pest management. The nozzles used were hollow cone, deflector, flat fan and duromist nozzle. The results concluded that hollow cone nozzle was the best option with high volume knapsack type sprayers both in early and later stages.

One of the important indexes for evaluating pesticide application quality was the even distribution of chemicals on targets (He *et al.*, 1999). Good mixing of the spray in the tank before application is a prerequisite. The dynamic factors and the filling level of sprayer tanks influencing the efficacy of agitation was improved both by increase of flow rate and working pressure of back flow. The results showed that the increasing the flow rate appeared better than increasing the working pressure.

Bernard *et al*. (2000) evaluated air assisted sprayers in comparison with conventional sprayers in cabbage crop to control pests. Effects of air velocity, air flow and direction of the wind blowing with a standard boom was evaluated in the cabbage greenhouse. The results showed that the velocity of the air gets more coverage on the leafs. Higher air velocity (25 m s^{-1}) and smaller droplets in the coating are increased coverage on leaf surfaces. Results showed that air speed had the larger impact on leaf coverage.

Panneton *et al*. (2000) reported that the spray chamber evaluation of air assisted spraying where the effect of air speed, air flow rate and air jet orientation were isolated. The results showed that air speed had a larger impact on leaf coverage. Higher air speed (above 25 m s^{-1}*)* increased the coverage on the leaves at all levels within the canopy of the potato plants. It was also reported that the combine effect of higher air speed 25 m s^{-1} and 200 forward jet angles increased the spray penetration towards the bottom of canopy.

Piche *et al*. (2000) studied two different spraying technique *viz*., air assisted spraying and conventional spraying. The field trials showed that air assisted spraying provided a better overall spray penetration and coverage than conventional application. The application at lower volume (100 l ha^{-1}) using air assistance and application at higher volume (200 l ha^{-1}) without air assistance yielded comparable results.

El-Meseery and El-Fattah (2001) manufactured a local self-propelled sprayer with cured and local ability for spraying insects and disease pest control. It suits for spraying crop and orchard fields. Field efficiency and the field productivity for the self-propelled sprayer at spray swath 4.8 m and speed 2.5 km h^{-1} were 70 per cent and 2 fed h^{-1}, respectively.

Zhu *et al*. (2002) conducted on experiment to study the influence of plant structure, orifice size and nozzle incination on spray penetration into the peanut canopy. Spray was applied with flat fan pattern nozzles 8001VS, 8003VS, and 8005VS at 276 kPa pressure. Leaf area index, foliage density, and plant height and width were measured for each test and correlated with spray deposits at the bottom and middle of peanut canopies. The result showed that spray penetration into peanut canopies could be improved by increasing nozzle size from 8001VS to 8003VS but not beyond 8003VS to 8005VS. Spray deposits on the top of canopies from the 8003VS nozzle were 10.5 times higher than at the middle position and 62 times higher than at the bottom positions when plants were 109 days old.

Abdel-Fattah (2003) carried out a comparative study of different pest control machinery for cotton. Results showed that the smallest droplets were recorded with micron ULV sprayer (85.8 μm) followed by Mist blower (126 μm) then the Knapsack with hand lance (161 μm) and the biggest droplets were recorded with spray gun of motor spray (356 μm).

Bauer and Raetano (2003) evaluated the spray deposition on bean plants with different nozzles and volume rates by air-assisted and non-assisted sprayers. A completely randomized experiment was carried out using copper oxide as a tracer (50 per cent metalic copper) for deposit evaluation. The artificial targets were fixed on the upper and underside of the leaflets, at the top and lower third of the same plants under the spray boom. The tracer deposition on the artificial targets was quantified by atomic absorption spectrophotometry. The effects of air-assisted spray were not significant in relation to spray deposition 48 days after emergence of the bean plants.

Moustafa and Ismail (2003) studied the effect of the different fungicide applicator types on the efficacy of fungicides used to control late blight disease caused by phytophthora infestans on potato. They found that, using the ULV applicator caused a reduction in fungicide amount needed to perform appropriate control of this disease from 400 L fed^{-1}, (the recommend amount) to 50 L fed^{-1}.

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.

Ejaz *et al*. (2004) evaluated the performance of modified self levelling boom sprayer. The sprayer comprised of seven sections with a self-leveling mechanism. Its length was 16.42 m with 22 nozzles spaced 70.60 cm apart. The sprayer was tested at three different pump pressures (250, 300 and 350 kPa) for different height of cotton crop. The results showed that, variation in different operating parameters (discharge, spray angle, *etc*) was less along the boom at nozzle pressure of 350 kPa as compared to 250 and 300 kPa.

El-Khawaga (2004) performed laboratory tests to evaluate the static pattern uniformity for a spraying system at different values of spray pressure (1, 2, 3, 4 and 5 bar) and spray height (30, 50, 70 and 100 cm). The spray pattern uniformity increased with increasing spray pressure and boom height. A boom height of 70 cm was found to produce the lowest spray coverage CV, where it was 29 per cent and 25 per cent at a pressure of 3 bar and 5 bar, respectively.

Mahmood *et al*. (2004a) designed to evaluate the leaf surface coverage of spray by the drop pipe university boom sprayer and its impact on insect mortality of cotton crop.

Water Sensitive Papers were installed on three levels of plants (top, middle, and bottom) on both sides of the leaves to examine the spray coverage. The greatest spray coverage values on upper and lower leaf surfaces were 49.67 per cent and 65.87 per cent, respectively at $V_2P_20_2$ treatment, while for conventional system it was 35.6 per cent on upper sides of leaves and 12.4 per cent on lower sides of the cotton leaves. The relationship between spray coverage and bollworm mortality was established for drop-pipe university boom sprayer Hundred percent mortality of American and spotted bollworm occured after one week for a surface coverage of 52 per cent and 61.75 per cent, respectively.

Pankaj *et al.* (2004) studied the effect of air assistance, leaf area density and forward speed on spray deposition in simulated crop canopy. Results showed that droplet size and droplet density on under side of the canopy was less than that on the upper side. The leaf area density and forward speed significantly influenced the droplet density on the canopy.

Saha *et al.* (2004) evaluated the different spraying systems in mango orchard *viz*., tractor operated aero blast sprayer, power knapsack sprayer and manually operated rocker sprayer. The results showed that the tractor operated aero blast sprayer was found to produce smallest droplet size (254 µm) with better penetration of spray droplets into the canopy.

Faqiri and Krishnan (2005) analyzed the uniformity of distribution of different types of nozzles in both field and laboratory conditions. Different operating pressures, boom heights and travelling speed were used as main parameters in the tests. The variation coefficients were different for different testing conditions and the distribution was better at greater boom heights and operating pressures.

Panneton and Piche (2005) conducted experiment to determine the effect of spray quality and volume of application on potato under increasing air assistance. The use of very fine spray, air assistance tend to increase deposit uniformly along the vertical extent of the plants and to reduce coefficient of variation of the deposits.

Shashi *et al*. (2005) evaluated performance of different nozzles for tractor mounted sprayers nozzles *i.e*., Triple Action Nozzle (TAN), Bi-Action Nozzle (BAN) and Hollow Cone Nozzle (HCN) at four different pressures of 2.5, 3.0, 3.5 and 4.0 kg cm^{-2}, three spray heights of 40, 50 and 60 cm, and spacing of 40, 45 and 50 cm between nozzles. The results showed that the increase in pressure from 2.5 to 4.0 kg cm^{-2}, increased maximum swath, spray angle and discharge rate for all the three types of nozzles.

Fabio and Carlos (2006) evaluated the effect of air assistance combined with different boom angles of 0°, +30° and -30° were directed to a vertical position. Spray losses were measured by placing plastic measuring collectors between rows. After analysis found that the larger deposits were detected at both upper and lower positions of the plant when the spray boom was positioned at 0° and +30° in the presence of air assistance.

Sierra *et al*. (2006) evaluated the performance of pneumatic spraying with an over-the-row sprayer in high density apple tree orchards. Field tests were conducted in an artificial orchard made with wooden posts and in an orchard of high density apple trees. To evaluate the quality of distribution, colored water droplets were collected on white plastic cards, which were then photographed. Study showed that the best nozzle position to get a uniform coverage around wooden posts which simulate tree trunks is face to face.

Iqbal *et al*. (2006) evaluated the spray uniformity distribution of environmental friendly university boom sprayer test bench. Hollow cone nozzle was used for the controlling the pest/insects. Average uniformity of coverage found was 90.8, 73.7 and 32. 6 per cent at 30, 50 and 70 cm heights, respectively.

Jain *et al*. (2006) determined the effects of cone angle on the droplet spectrum of a hollow cone nozzle by keeping the constant operating pressure at 3 kg cm^{-2} and discharge of 473 ml min^{-1}. the results indicated that, hollow cone nozzle was more effective for spray angle 68.5° at a constant pressure and discharge rate.

Song *et al*. (2006) conducted the study on influence of nozzle orientation on spray deposit. Spray deposit tests were conducted with nine nozzle orientations ±40°, ± 30°,± 20°,± 10°, 0°to evaluate the influence of nozzle orientation on droplets deposition. Spray was applied with standard flat fan pattern nozzles ST120-015 at 0.25 MPa pressure and two spray volumes (150 l h^{-1} and 300 l h^{-1}). Results showed that the spray deposits at horizontal targets could be improved by (adjusting) the nozzle orientation and the increase at the bottom and middle horizontal targets was more than that at the top targets.

Khurana *et al*. (2007) conducted the study on nozzle spacing on sprayer boom. Nozzles are placed on sprayer boom in such a way that the chemical is spread evenly over the plant canopy. The nozzle was operated at working pressure of 4 kg cm^{-2} at a height of 40 cm moving at the forward speed of 2.5 km h^{-1}. The best spacing was found to be around 57 cm.

Lardoux *et al*. (2007) claimed that by making the right selection of nozzles with adequate calibration, good distribution uniformity can be achieved. Different operating pressures and types of nozzles give different distribution uniformity. The author tested different types of nozzles operating at different pressures and noticed changes in the variation coefficient.

Padmanathan and Kathirvel (2007) evaluated the performance of power tiller operated rear mounted boom sprayer for cotton crop. Test was carried out on the developed sprayer both in laboratory and in the field. The spray boom has sixteen hollow cone nozzles, placed 40 cm apart. It had a swath width of 3.2 m for a forward speed of 2 km h^{-1}. The effective field capacity of the sprayer was 0.72 ha h^{-1}.

Reginaldo *et al*. (2007) conducted an experiment to evaluate the leaf deposition and the efficiency of different drop pattern by spraying cotton plants at the end of the growing season, under adverse air temperature and humidity conditions. The sprays, applied at the same pressure, were made with a JACTO UNIPORT speed-sprayer equipped with the nozzles JA3 (hollow cone), AD-IA/D 11003 double flat fan), and AD-IA 11003 (flat fan) for 150 l ha^{-1} spray volume, and the nozzle AD-IA 11004 (flat fan) for 200 l ha^{-1} spray volume. The result showed that the nozzle AD-IA 11003 gave the highest leaf deposit in all plant parts.

Senthilkumar and kumar (2007) evaluated the hydraulic energy nozzles suitable for orchard spraying. In manually operated sprayers, generally hydraulic energy nozzles are used. Commercially available hydraulic energy nozzles (NMD/S, BAN, Broad cone, NMM, NTM) used for orchard spraying was selected for the study. The discharge rate of nozzles increased with increasing pressure.

Singh *et al.* (2007) studied in laboratory conditions at different combinations of forward speed and air velocity. It was observed that at each forward speed, air-assistance helped to put spray material on underside of the leaves whereas without air-assistance the spray deposition on underside of leaves was negligible at any forward speed.

Nanda *et al* (2008) conducted an experiment to study the efficacy of three sprayers, namely disc type low volume sprayer, hand compression sprayer and air assisted power sprayer. The efficacy of the power sprayer in controlling the stem borer (Dead Heart), stem borer (White Ear Head), Leaf folder damaged leaf (LFDL), Whorl maggot (WM), White back plant hopper (WBPH) and Brown plant hopper (BPH) was significantly ($P<0.05$) higher than low volume sprayer and hand compression sprayer with damage control of 82.90, 59.20, 88.25, 87.85 75.30 and 92.40 per cent, respectively. Damage control of gall midge (Silver Shoot) did not vary significantly between power sprayer (15.30 per cent) and hand compression sprayer (13.05 per cent). The low volume sprayer and hand compression sprayer were found equally good to control White ear head (53.76 per cent and 52.60 per cent) and Whorl maggot (72.45 per cent and 68.85 per cent).

Rengasamy (2008) evaluated the performance of tractor mounted hydraulic sprayer nozzle. The test nozzle was fitted in a compression sprayer and tests carried out with lindane wettable powder dispersion in tap water. The flow rate and swath width for 0.7- 5.6 kg cm^{-2} were 273 ± 35.4 to 1011.7 ± 93.5 ml min^{-1} and 85.6 ± 3.2 to 154.60 ± 11.2 cm, respectively.

Tekade *et al*. (2008) evaluated the performance of tractor mounted tall tree air carrier sprayer for spraying on mango orchard. The results showed that the VMD, NMD and UC values vary from 279.87 µm, 2.456 to 258.44 µm, 93.55 µm, 3.52 for 0.92 to 2 lit m^{-1} in discharge rate, respectively. The spray swath and horizontal throw of air carrier sprayer increases with increase of speed.

Zhu *et al*. (2008) demonstrated that an increase in the application rate when spraying nursery trees could greatly increase spray deposition but did not greatly increase spray coverage on targets inside canopies.

Braekman *et al*. (2009) found that a vertical spray boom performed better than the reference spray equipment in strawberries (spray gun) and in tomatoes (air-assisted sprayer) and that nozzle type and settings significantly affected spray deposition and crop penetration.

Foque *et al*. (2009) compared the performance between traditional hand gun and vertical spray boom. The sprayings with the spray gun were performed at an application rate of 850 l ha^{-1}. For the vertical spray boom system, two different reduced application rates (250 and 500 l ha^{-1}) with five different combinations of nozzle type, size, and pressure for each application rate were investigated. Nozzle type, size, and pressure on the vertical spray boom system only had a minor effect on the spray deposition. Although the spray gun performed well on the easily accessible crop zone with the runners, its performance in the denser main crop zone was inferior.

Safari (2009) compared conventional sprayers to control pests, weeds and fungus in wheat crop. Atomizer and micron-air had highest and lowest mortal pests in comparison with other treatments. They did not any significantly difference in aspect of field capacity. The boom sprayers had the highest field efficiency. The micron-air and atomizer sprayers had highest and lowest drift percentage respectively. The uniformity spraying in the micron-air sprayers was highest.VMD and NMD were 388 μm and 286 μm in Micron-air sprayer. Loss percentage was low in whole sprayers.

Sehsah and Kleisinger (2009) studied the some parameters affecting the spray distribution. The electrical axial fan of 2.2 kW was used to produce the cross wind speed of 1.2 and 3.1 m s^{-1}. The IDKN120-04, AD110-03, TT11003 Turbo Jet and ATR 208 (Albus) spray nozzles were used at different nozzle pressures. The results showed that the nozzle height and pressure has significant influence on spray distribution.

Alam & Husain (2010) showed that the change of spray width (w) in each swing of the lance when the operator was aware that his actions were being videoed. The average width of spraying was 298 cm with standard deviation of 31 cm and coefficient of variation of 11 per cent.

Al-Gaadi (2010) studied the effect of nozzle height and type on spray density and distribution for a ground field sprayer. Six nozzle types (four flat fan nozzles numbered from 1 to 4 and two hollow cone nozzles numbered 5 and 6) were tested at four nozzle heights (15, 30, 45 and 60 cm). The results revealed that the application rate error and uniformity of distribution (UD) of the spray liquid were proportional to nozzle heights. For instance, increasing the height of the hollow cone nozzle No. 5 from 15 to 60 cm caused an increase in the error in application rate from 10.9 to 47.6 and in the uniformity distribution from 36.2 to 92.5 per cent.

Dahab and Eltahir (2010) studied the spray droplet number and volume distribution as affected by pressure and forward speed. Sprayer was evaluated under the pressures of 4 and 2 bars and forward speeds of 5.4, 7.9 and 10.8 km h^{-1}. The results revealed that when pressure was increased from 2 bars to 4 bars, the average droplet density per square centimeter was increased by 52 per cent. Increasing the forward speed from 5.4 to 7.9 km h^{-1} increased the droplet density cm^{-2} by 18.28 per cent.

Deogirikar *et al*. (2010) evaluated the performance of rotary nozzles for air assisted sprayers for cotton crop. The major components of sprayer were spray pump, control panel assembly, pesticide tank, blower, impeller, casing, prime mover *etc*. Results concluded that showed the better penetration of spray on the upper surface of leaves with larger droplet and higher densities compared to lower surface of leaves in front of plant canopy and reverse phenomenon on the backside of plant canopy.

Derksen *et al*. (2010) evaluated the hand gun and broadcast spray system in greenhouse poinsettia canopies. Sprayer treatments were used to apply tank mixes of pesticides and fluorescent tracer. Nylon screen targets were secured to the abaxial surfaces of leaves in the upper and lower parts of the canopy. The results indicated that hand gun produced greatest variability across the target surface.

Johnson and Larry (2010) studied the different sprayer nozzles, selection and calibration. Study revealed that nozzle was a major factor in determining the amount of spray applied to an area, the uniformity of application, the coverage obtained on the target surface, and the amount of potential drift.

Khedkar and Shahare (2010) evaluated the three outlet type air assisted sprayer. Three nozzles were selected *i.e.*, HCN/PA, BCN, NMD/S. Sprayer was operated at 2 km h^{-1} tractor travel speed and at 1450 rpm blower speed. The three outlet type sprayer could cover a swath width of 7.5 m in brinjal field and actual field capacity was found to be 1.13 ha h^{-1} at 2 km h^{-1} travel speed. The field efficiency of the sprayer was found to be 75.4 per cent.

Prinzio *et al*. (2010) studied the effect of pressure on the quality of pesticide application in orchards. A fluorescent tracer was applied on fruit trees by an airblast sprayer, with two treatments: high pressure (1800 kPa) and low pressure (500 kPa). The results indicated that the there were no differences between the two treatments in the total quantity of deposits recovered from leaves.

Shahare *et al*. (2010) evaluated the performance of a tractor mounted sleeve boom sprayer for cotton. The developed sleeve boom sprayer was operated at four different sleeve angles and four nozzle angles in the laboratory. Result revealed that droplet density increased with increase in the nozzle angle.

Veerangouda *et al*. (2010) tested three types of sprayers namely bullock drawn traction sprayer, bullock drawn engine operated sprayer and local cart mounted engine operated sprayer were tested for cotton crop. The bullock drawn engine operated sprayer is capable to cover 6 rows at a stretch for cotton crop with an average quantity of 585.92 l ha^{-1} at an operating pressure of 20 kg cm^{-2}. The average travel speed of unit is 2.84 km h^{-1} with an average draft of 76.67 kg. The field capacity of bullock drawn engine sprayer is 1.19 ha h^{-1} with a power output of 0.60 kW.

Awulu *et al.* (2011) studied that ten-litre ultra-low volume (ULV) sprayer using locally available materials. The major components included the tank, spray head, battery case and extension pipe, delivery tube, and the strap (belt). The spray head was powered by 5 dry cell batteries which gave 7.5 Volts to actuate the electric motor for spinning the atomizer and found the convenience and ease with which the machine could be put to use to make it suitable for both rural and large scale farmers.

Bahadir and Saim (2011) investigated the spray distribution uniformity on sampling posts and spray deposition in potato plants with six different types of spray nozzles. Spray pressures were 4 bar for the hydraulic nozzles and 1.5 bar for the spinning disc nozzle and air assisted rotary atomizer. Results revealed that the hollow cone nozzle had the lowest mean in deposition at the bottom of the plants. The amount of dye deposited with the air assisted rotary atomizer transferring the top, middle and bottom of the plants was 35.2, 38.9 and 37.2 per cent, respectively found to be deposited on the underside of the leaves.

Bozdogan *et al*. (2011) studied the effect of different pesticide application methods on spray deposits, residues and biological efficacy on strawberries. Broadcast sprayings were applied via hollow cone nozzles (HC) and air-assisted spinning cage nozzles (ASC). Band spraying was applied via flat fan nozzles (FF). The results obtained showed that the highest pesticide deposits on leaf surfaces and also biological efficiency were obtained with FF.

Gupta *et al*. (2011) analyzed the influence of speed of air used for assistance, nozzle pressure, leaf area density and forward speed of the spraying system on spray deposition in a horizontal crop canopy under controlled conditions. Results of the study showed that droplet size and droplet density on under side of the canopy were less than that on the upper side. Droplet density on the crop canopy increased with increase in nozzle pressure.

Gurpreet *et al.* (2011) studied the spray distribution pattern of different sprayers on cotton using droplet analyzer. The spraying performance of commercial sprayers viz. knapsack sprayer, power operated sprayer, self propelled sprayer, aero blast sprayer and air assisted sprayer were compared based on droplet size (NMD, VMD, UC), density of droplets and volume of spray deposition. Spray deposition decreased from top portion to bottom portion of the plant for all types of sprayers. Uniformity coefficient (UC) was least for air assisted sprayer (1.8).

Hermosilla *et al*. (2011) evaluated the performance of a self-propelled sprayer and effects of the application rate on spray deposition and losses to the ground with vertical spray booms versus a gun sprayer. Three different spray volumes have been tested with a boom sprayer, and two with a spray gun. Results showed that the vehicle with the vertical spray boom gave similar depositions to those made with the gun, but at lower application volumes. Also, the distribution of the vertical spray boom was more uniform, with lower losses to the ground.

Sayinci and Bastaban (2011) studied the spray distribution uniformity of different types of nozzles and its spray deposition in potato plant were investigated with six different types of spray nozzles (standard flat fan, hollow cone, air induction and twin jet hydraulic nozzles, spinning disc nozzle and air assisted rotary atomizer). Spray pressures were 4 bar for the hydraulic nozzles and 1.5 bar for the spinning disc nozzle and air assisted rotary atomizer. All trials were conducted at 6.0 km h^{-1} travel speed. Results concluded that the air induction and twin jet nozzles had the lowest means in coefficient of variation (CV) at all sampling materials. The highest deposit at the middle of the plants was provided with the air induction and twin jet nozzles. The hollow cone nozzle had the lowest mean in deposition at the bottom of the plants.

Singla *et al*. (2011) studied on use of aero blast sprayer in Punjab. Swath width of aero blast sprayer varied from 14 to 24 m with the average of 17.7 m as observed and used by the farmers. Average area sprayed per day ranged from 12-40 ha day^{-1} with the mean value of 22.6 ha day^{-1}. Height of cotton varies from 0.9 to 2 m which was sprayed with the aero blast sprayer.

Zhu *et al*. (2011) evaluated the portable scanning system for spray deposition distribution. The system is integrated with a handheld business card scanner, deposit collectors, a laptop computer and a custom-designed software package entitled "DepositScan". The portable scanning system offers a convenient solution for on-the-spot evaluation of spray quality under various working conditions.

Cunha *et al*. (2012) assessed the ability of image processing software to analyze spray quality on water-sensitive papers used as artificial targets. The performance of several commercial and experimental software packages (Gotas, StainMaster, ImageTool, StainAnalysis, AgroScan, DropletScan and Spray_imageI and II) was compared against manual counting. These softwares give best accuracy for coverage and droplet spectrum as well as for droplet class distribution.

Foque *et al*. (2012) compared the performance of spray gun and spray boom applications in two ivy crops with different crop densities. The results of study illustrated that crop density affects spray deposition results. With a low crop density, the spray guns performed best. Despite some variation within the two types of application, the absolute deposition data reveal that the spray guns performed better than the spray boom applications.

Gholap *et al*. (2012) evaluated tractor mounted boom sprayer in the laboratory. Different tests were conducted such as liquid distribution under spray boom; pump testing, calibration of pressure gauge and droplet deposition on cotton crop. Liquid distribution under spray boom was scattered from average value, maximum pump discharge was 35.94 l min^{-1} at 950 rpm, and pressure gauge gave 520.6 kPa pressures for 600 kPa pressure of master gauge. The VMD, UC and droplet density for nozzle discharge 0.9 l min^{-1} and pressure 689.5 kPa was from 130.9-206.39 µm, 1.18-1.31 and 11-27 No. cm^{-2}, respectively.

Gimenes *et al*. (2012) evaluated the performance of air assistance in spray booms using different types of nozzles and spray volumes. Two spray nozzles (flat fan nozzle and hollow cone nozzle) were tested, combined with two air assistance levels in the spray boom (with and without air assistance). Results showed that the flat fan nozzle, combined with air assistance technology, was more effective for controlling fall armyworm.

Jayashree and Krishnan (2012) evaluated the performance of tractor operated target actuated sprayer. 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}. The mean comparison tests indicated that the minimum amount of chemical delivered (499 µl) was achieved at a chemical concentration of 25 per cent, 100 mm width of simulation plate, 3.5 km h^{-1} forward speed.

Wandkar and Mathur (2012) studied the effect of pump discharge on spray deposition. The performance of developed air sleeve boom was evaluated for different pump discharges, *viz.,* 2.5, 4.5, 7 and 9 l min^{-1} in the laboratory to assess the effect on spray deposition. Results of the study indicated that droplet size increased with decrease in pump discharge. Droplet size, droplet density and uniformity coefficient had a linear relationship with pump discharge.

Babashani *et al.* (2013) reported that a laboratory patternator was used to determine the spray volume distribution pattern of an improved animal drawn ground metered shrouded disc sprayer. The sprayer was mounted on a frame above the patternator at variable heights of up to 60 cm using nozzle spacing of 120 cm. The results revealed minimum distribution variation with coefficient of variation of 13.9 per cent at spray height of 60 cm.

Cunha *et al*. (2013) evaluated and compared the results obtained from four software programs for spray droplet analysis in different scanned images of water-sensitive papers. For the VMD, the program that provided the results closest to the manual reading in the four deposition patterns was Conta-Gotas. However, making the comparison by deposition pattern, DepositScan was the one closest to the manual reading.

Gholap and Mathur (2013) evaluated the performance of tractor operated boom sprayer of cotton crop. Hydraulic boom sprayer was tested in the field for cotton crop to study effect of nozzle discharge rates (*viz*., 0.45, 0.70, 0.90 and 1.35 l min^{-1}) and nozzle pressures (*viz*., 275.8, 413.7, 551.6 and 689.5 kPa) for spray uniformity. From the study it was found that nozzle discharge rate of 0.90 l min^{-1} and nozzle pressure of 689.5 kPa produced more uniform spray with droplet size of 125.55 to 287.50 μm, droplet density of 18 to 30 drops cm^{-2} and uniformity coefficient of 0.96 to 1.20.

Hassen *et al.* (2013) studied the effect of nozzle type, angle and pressure on spray volumetric distribution of broadcasting and banding application. A spray patternator was fabricated for the selection of a suitable nozzle to have uniform distribution of the spray liquid. Study conducted on a spray patternator through two types of spray nozzles (even flat fan nozzle TPE for banding application and standard flat fan nozzle TP for broadcasting application). The results revealed that increasing nozzle angle and pressure reduce the value of the coefficient of variation.

Hossain *et al*. (2013) evaluated the performance of two wheel tractor operated boom sprayer. The spray boom had 9 Tee jet nozzles, placed 50 cm apart. It had a width of 4 m for a forward speed of 5 km h^{-1}. The effective field capacity of the sprayer was 1.6 ha h^{-1}.

Mangado *et al*. (2013) conducted study to demonstrate accuracy of image analyzer to check the coverage percentage of a treated pesticide. Water sensitive papers were scanned and split in three levels of grey. After that, a binary image was obtained with only two values: droplet or no droplet. The results obtained proved the accuracy of this software to quickly determine the precision of the treatment applied.

Safari *et al*. (2013) compared tractor air assisted boom sprayer with conventional sprayers to control sunn pests in wheat production. They evaluated the turbo-liner sprayer, conventional boom sprayer, air assisted boom sprayer, micron-air sprayer and atomizer sprayer in randomized complete block design with four replication. The results showed that the maximum field efficiency was obtained the tractor boom sprayers and the minimum was related to atomizer sprayers. The highest solution consumption was belong to turbo-liner and boom sprayers and lowest was belong to Micron-air sprayer. The maximum and minimum percentage of dead pests was belonging to air-assisted tractor boom and turbo-liner sprayers, respectively.

Tamagnone *et al*. (2013) evaluated the performance of recycling sprayer. A comparison test was carried out in a barbera vineyard espalier trained, Guyot pruned, in order to assess the performance of a recycling sprayer with respect to a conventional air-assisted sprayer and to a multi-row sprayed. Spray deposition tests pointed out that when applying volumes between 200 and 400 l ha^{-1} the multi row sprayer and the recycling sprayer were able to reach a level of spray deposition on the target higher with respect to the conventional air-assisted sprayer.

Alheidary *et al.* (2014) studied the influence of spray characteristics on potential spray drift of field crop sprayers. Technological parameters such as nozzle height, spray angle, travel speed are then related to initial physical factors and their contribution was responsible for driftability of sprays.

Kharale *et al*. (2014) evaluated the performance of self propelled boom sprayer in cotton and chilli field. The average effective field capacity of self propelled boom sprayer in the field of cotton and chilli was found to be 1.28 and 1.69 ha h^{-1}, respectively. With an average field efficiency 62.74 per cent and 81.02 per cent, respectively.

Swiechowski *et al*. (2014) conducted a study to determine the influence of spray volume and the nozzle type on product deposition and distribution in apple tree canopies. The spray volumes 250, 500 and 750 l ha^{-1} were applied with fine spray and coarse spray nozzles generating droplets of VMD around 150 and 400 μm, respectively. Munckhof cross-flow sprayer was used at the driving velocity of 5.0 km h^{-1} to apply fluorescent dye as spray liquid. During flowering the greatest deposition was obtained at the spray volume of 250 l ha^{-1} applied with the coarse spray nozzles. The spray volume 750 l ha^{-1} resulted in the best coverage in the tree centre.

Cavalieri *et al*. (2015) conducted a study to evaluate the droplet spectrum, the deposition and uniformity of spray distribution with different spraying systems and traveling speeds of a self-propelled sprayer in two phonological stages of the cotton plant. Spraying deposition was evaluated for both leaf surfaces from the cotton plant apex and base (stage B9) and middle part of the plant (stage F13) with a cupric marker. Study states that the changes in the operational settings required for increased traveling speed negatively influence the droplet spectrum and its homogeneity, affecting the vertical distribution of the spraying deposits on cotton plants.

Creech *et al*. (2015) studied the effects of nozzle type, orifice size, and pressure and carrier volume on the droplet spectra of the herbicide spray. Droplet spectrum data were collected on 720 combinations of spray-application variables, which included six spray solutions (five herbicides and water alone), four carrier volumes, five nozzles, two orifice sizes, and three operating pressures. The effect on droplet size of the variables examined in this study from greatest effect to least effect were nozzle, operating pressure, herbicide, nozzle orifice size and carrier volume.

Dhande *et al*. (2015) estimated the air and spray volume requirement of mango tree for air carrier pesticide application. To find out the air volume and velocity of blower and discharge rate of the spray nozzle, canopy size, canopy height, leaf area, foliage density and canopy volume of mango tree, the measurement of data on the mango trees were carried out. The overall canopy height above ground level, height to the point of maximum canopy diameter, height from ground to canopy skirt and canopy diameter parallel to the row was measured. The average leaf area per cubic metre canopy volume found out by measuring leaf area by leaf area meter. An ideal spraying would result in deposition of 20-25 droplets of 100 micron size cm^{-2} of leaf area.

Gholap and Kushwah (2015) evaluated the performance of tractor operated boom type field sprayers on cotton crop. Two 12 meter tractor operated boom type field sprayers of the ASPEE make one of the existing design and other of new design (developed) having similar specifications were selected for the study. The discharge and pressure of the developed boom sprayer was nearly uniform for all nozzles. Droplet size (VMD), droplet density (DD) and uniformity co-efficient (UC) for the existing sprayer ranged from 130.9 to 206.39 μm, 11 to 27 drops cm^{-2} and 1.18 to 1.31, whereas for developed sprayer it ranged from 155.44 to 181.55 μm, 17 to 29 drops cm^{-2} and 0.99 to 1.23, respectively.

Narang *et al*. (2015a) evaluated the manual spraying technology against white flies on cotton crop in south-west Punjab. Three sprayers were selected for the experiments *i.e.*, battery operated knapsack, tractor operated gun type and electrostatic sprayers. VMD, NMD and UC of tractor operated gun sprayer were found to be 164.89 μm, 51.05 μm and 3.23, respectively.

Narang *et al*. (2015b) evaluated the performance of air assisted orchard sprayer at 800, 100, 1200, 1400, 1600 and 2000 engine rpm and pressure was set at three different levels of pressure at minimum (4 kg cm^{-2}), middle (10 kg cm^{-2}) and maximum (12,18,20,22 and 24 kg cm^{-2}). Results of the study showed that, the increasing engine rpm and pressure, swath width, height of spray and discharge rate increased for both the nozzles.

Narang *et al*. (2015c) evaluated the spraying technology in cotton belt of Punjab. Four sprayers were selected for the experiments *i.e*., battery operated Knapsack, boom type, tractor operated gun type and electrostatic sprayers. Results showed that field capacity was higher in the tractor operated gun sprayer because of large area coverage. The average volume median diameter (VMD) and average number median diameter (NMD) was 125.71 μm and 33.91 μm, respectively for gun type sprayer.

Sayinci (2015) studied the effects of spray pressure, and orifice size on the discharge coefficient of standard flat-fan nozzles. In the study, size, shape and area measurements concerned with nozzle geometry were performed and the differences between nozzles of different nominal sizes were revealed. Study revealed that the minimum flow rate required for complete atomization with regard to the nozzle orifice sizes linearly increased as the nozzle orifice size increased.

Sun *et al*. (2015) studied the effects of factors of spraying quality for boom sprayer. Uniformity of droplet distribution, drift and coverage rate to target are the main indexes of evaluation of spray quality. Study indicated that the wind speed was direct reason of droplet drift where environment temperature and relative humility are indirect reason of droplet drift.

Ferguson *et al*. (2016) study was conducted to examine the pressure, droplet size classification and nozzle arrangement on droplet density and droplet coverage. Spray coverage and droplet density was increased with increase in the pressure and nozzle type. The nozzle arrangement had significant effect on the coverage.

Jassowal *et al*. (2016) evaluated the performance of tractor operated trailed type boom sprayer in the cotton field at three forward speeds (2.5, 3.5 and 4 km h^{-1}) and at five fluid flow pressures (3.5, 4.0, 5.0, 6.0 and 7.0 kg cm^{-2}). The volume median diameter (VMD) was in the range of 300 to 452 μm. Smaller size droplets were obtained at higher pressure. The droplet density on leaves varied from 26 to 177 drops cm^{-2}.

Kharale *et al*. (2016) evaluated the performance of aeroblast sprayer in pigeon pea. The average effective field capacity of the aeroblast sprayer was found to be 2.5 ha h^{-1} and the fuel consumption of the tractor for the aeroblast sprayer were found to be 2.5 l h^{-1}.

Malekabadi *et al*. (2016) compared the quality of a telescopic boom sprayer with conventional orchard sprayers in Iran. A telescoping boom sprayer was designed and fabricated. The sprayer equipped with This Boom (TS) was evaluated in comparison with the conventional sprayers [Wheel Barrow (WBS), Electrostatic (ES) and side Pump (SPS) Sprayers] in terms of drift, spraying quality, solution consumption, fuel consumption, spray height, spraying time, and spray loss. Results showed that the spraying quality coefficient of ES was better than that of SPS. The maximum and minimum spraying times were recorded for WBS and SPS, respectively.

Visacki *et al*. (2016) studied the effects of spray boom height and operating pressure on the spray uniformity. Three types of nozzles (ST 120-04, IDK 120-04, and IDKT 120-04) were used for testing the uniformity of liquid distribution in laboratory conditions at three different operating heights, which are commonly adopted for pesticide treatments in Serbia (0.4, 0.5 and 0.6 m) and six different pressures within the range recommended by the manufacturer (200, 250, 300, 350, 400 and 450 kPa). The results of performed tests show significant differences between the set conditions. However, all nozzles had different coefficients of variation. The lowest coefficient was recorded with the air-injector nozzle, IDK 120-04. The flat spray nozzle ST 120-04 had the highest coefficient (from 8.545 to 7.226 per cent) and all the others were within the acceptable (10 per cent) limits for the distribution uniformity.

2.5 Bio efficacy of pesticide or Insectide against the insects and pests by sprayers

Santharam and Balasubramanian (1982) reported that high volume application of NPV was effective in controlling *Helicoverpa armigera* (Hubner) on chickpea and ULV spray was most effective on controlling Hubner.

Alms *et al*. (1987) studied the effect of actual ingredient, droplet size and distribution on egg deposition and control of adult mites. They found that 41 droplets/sq cm at 120 µm VMD or 18 droplets cm^{-2} at 200 µm VMD eliminated 80 per cent of egg deposition.

Pawar *et al.* (1987) compared the bio efficacy of HNPV with endosulfan against pod borer on chickpea and found that two sprays of NPV at 500 LE ha^{-1} were as effective as two sprays of 0.05 per cent endosulfan in reducing infestation by *H. armigera* (Hubner) larvae and pod damage and in increasing seed yield.

Singh and Chhuneja (1987) evaluated the performance of high-volume, low-volume and ultra-low-volume sprays for the control of Amrasca biguttula biguttula (Ishida) and Bemisia tabaci Genn infesting cotton. The EC formulation of endosulfan (0,875 kg ai ha^{-1}) in high-volume, low-volume and ultra-low-volume sprays and LVC in only ultra-low-volume spray were used to control the cotton jassid, Amrasca biguttula biguttula (Ishida) and whitefly (Bemisia tabaci Genn.) on upland cotton (Gossypium hirsutum Linn.). The reduction in the populations of cotton jassid and whitefly was lower in the ultra-low-volume (EC) sprays than in the high-volume, low-volume and ultra-low-volume (LVC) sprays. The seed-cotton yield was maximum of 1,563 kg ha^{-1} in high-volume and of 1,408 kg ha^{-1} in LVC formulation of the ultra-low-volume sprays. The ultra-low-volume (EC) gave a minimum yield of 1,211 kg ha^{-1} as compared with 726 kg ha^{-1} in the control.

Neupane and Sah (1988) studied the efficacy of some insecticides against the chickpea pod borer, *H. armigera* and concluded that 0.1 per cent endosulfan gave 20 per cent initial kill of larvae one day after spray, which made the insecticide suitable for the control of this pest.

Howard *et al*. (1994) reported that three air-assisted sprayers deposited more bifenthrin on both the upper and under-sides of leaves in the middle of the cotton canopy and had a higher percent coverage than conventional over-the-top hydraulic sprayers.

Dodia and Patel (1997) reported more or less equal larval population on pigeonpea after application of endosulfan with knapsack, barrel and Aspeebolo sprayers on active ingredient and concentration basis.

Mulrooney and Skjoldager (1997) found that air-assisted application of insecticides significantly enhanced the efficacy of boll weevil and beet armyworm control in cotton. Compared with over-the-top and drop-nozzle sprayers, the air assisted sprayer provided greater canopy penetration and deposit of fluorescent dyes/markers on mylar sheets and water sensitive papers in cotton.

Mulrooney *et al*. (1998) studied the efficacy of ultra low volume and high volume applications of fipronil against the bollweevil. Fipronil applied ultra low volume by aircraft at rates of 0.043 and 0.056 kg (a.i.) ha^{-1} were equally effective against boll weevils in bioassays of treated leaves.

Sumner and Herzog (2000) assessed the effectiveness of air-assisted and hydraulic sprayers in cotton via leaf bioassay. Three types of sprayer *viz*., conventional over-the-top sprayers, air-assisted and drop-nozzle sprayers were used. The results indicated that all three sprayers provided adequate coverage for good insect control in the top of the cotton canopy.

Satyanarayan and Patil (2000a) evaluated the different types of nozzles used in cotton insect pest management. Different nozzle namely hollow cone nozzle, deflector nozzles, flat fan nozzle and duromist nozzle using the high volume knapsack sprayer. The results indicated that the hollow cone nozzle was the best option with high volume knapsack sprayer both in early and later stage of cotton for the insect pest’s management.

Satyanarayan and Patil (2000b) evaluated the different spray volumes in the management of cotton bollworms under irrigated conditions. Four different volume viz., 750, 100, 1250 and 1500 liters per ha using the high volume knapsack sprayer and 125, 187, 250, 375 and 500 liters per hectare using low volume aspee bolo power sprayer against cotton bollworms at regional research station, Raichur. The results concluded that the high volume sprayer was second to none in curbing the early sucking pest in cotton.

Smith *et al*. (2000) conducted a study to determine the effects of droplet size on pesticide deposition. In this experiment five different droplet sizes were sprayed on leaf. The values showed that the deposition efficiencies decreased as droplet size increased.

Reed and Smith (2001) studied the effects of droplet size and volume on insecticide deposit and mortality of heliothine (Lepidoptera: Noctuidae) larvae in cotton. Results from this study do not support the recommendations of high volumetric application rates; and although droplet size was less influential than volumetric application rate in deposit and insect mortality, the data indicate a significant trend toward increased mid canopy larval mortality with smaller droplets.

Ahmed *et al*. (2003) studied the efficacy of high volume (hv) vs ultra low volume (ulv) spraying of Talstar 10ec (Bifenthrin), mustang 380 ec (Zetacypermethrin + Ethion) and novastar 56ec (Abamectin + Bifenthrin) against different larval stages of helicoverpa armigera (hub). On numerical basis, Novastar was found to be the most effective through ULV against I, II, and III larval instars of H. armigera and was followed by Novastar (HV), Mustang (HV), Talstar (HV), Mustang (ULV) and Talstar (ULV).

Mahmood *et al.* (2004b) found that the efficacy of environmentally effective university boom sprayer for bollworm mortality. At the time of first spray, the only bollworm seen was spotted, while at second spray Spotted as well as American bollworms were seen. At first spray, boll worm mortality was evaluated at three intervals after spraying (24, 48, and 72 h) while at second spray mortality rate measurements were made one day and one week after spraying. The mortality rate of spotted bollworms was found significantly affected by sprayer velocity, spraying pressure and spraying angle of drop nozzles. Greatest bollworm mortality was achieved 72 h after spraying in case of first spray and one week after in case of second spray at 4.0 km h^{-1} field speed, 400 kPa pressure and 30 ^{o} upward angle of drop nozzles *w.r.t.* horizontal.

Siddegowda *et al*. (2007) conducted a study for two years (2002-04) on evaluation of different sprayers revealed significant reduction in the larval population with high volume and low volume spray application as compared to ultra low volume spray, thus indicating their effectiveness. Results found that the ultra low volume sprayer, mist blower and Aspee back pack high volume sprayer did not influence the grain yield. Among the different formulations tested, indoxacarb 14.5 SC @ 25 g a.i./ha was highly effective as compared to chlorpyriphos 20 EC @ 250 g a.i./ha irrespective of spray equipment and gave maximum protection to pods which resulted in increased grain yield.

Nanda *et al*. (2008) conducted an experiment on efficacy of different sprayers *viz*., spinning disc sprayer, hand compression sprayer and air assisted power sprayer. The spray characteristics revealed that the ratio of VMD to NMD was near to unity in case of low volume sprayer followed by hand compression (1.33) and power sprayer (1.39). The efficacy of power sprayer was comparatively better than that of hand compression and low volume sprayer in controlling the pests studied.

Gopali *et al*. (2009) evaluated the different sprayers in the management of pod borer during khairf season of 2006-2008. The results over two years revealed lowest mean larval population (1.06 larvae plant^{-1}), pod damage (24.20 per cent), seed damage (15.78 per cent) and higher grain yield (10.82 q ha^{-1}) with high B:C ratio of 4.50 were recorded in the plot sprayed with tractor/cart mounted sprayers. Study revealed that that the performance of cart/tractor mounted sprayer was superior to other sprayers in terms of spray fluid requirement, time taken to cover unit area, suppression of larval population, reduction in pod damage and harnessing higher yield.

Babu *et al*. (2012) evaluated the different sprayers in the management of pod borer during khairf season of 2008-2010. The lowest mean larval population (1.06 larvae plant^{-1}), pod damage (24.20 per cent), seed damage (15.78 per cent) and higher grain yield (10.82 q ha^{-1}) with high B:C ratio of 4.50 were recorded in the plot sprayed with cart mounted sprayers.

Kapasi *et al*. (2013) evaluated of *Ha*NPV 100 LE in different sprayers for management of Pigeonpea pod borer. Commonly used spray equipments like knapsack sprayer, taiwan sprayer, tractor mounted sprayer, gator sprayer, air blast sprayer and ultra low volume sprayer (CDA) were evaluated for their effectiveness and uniform distribution of *Ha*NPV on plant surface. Among the three types of sprayers, high volume sprayers (Knapsack sprayers, Taiwan sprayer, tractor mounted sprayer and gator sprayer) were significantly superior to rest of the sprayers in reducing the larval population and produced higher grain yield.

Yousaf *et al*. (2014) studied the effect of field plot design on the efficacy of boom sprayer. Field performance of the boom sprayer was evaluated at three different plot sizes, three different operating pressures and at three different forward speeds of tractor. Four spraying operations were performed. The results indicated that increase in velocity decreases the mortality or sucking insects as well as bollworm insects. Best field speed for crop spraying operation was observed to be 4.0 km h^{-1}.

Simmons *et al*. (2015) compared of three single-nozzle operator-carried spray applicators for whitefly. Each knapsack spray equipment was evaluated with five biorational and conventional insecticides. Counts of whitefly nymphs (first, second, third and fourth instars) on leaf samples were taken on 3, 9, 15 and 21 days after treatments with the insecticides. Results showed that the economy micro ulva sprayer resulted in significantly more nymphal mortality as compared with the arimitsu sprayer and the CZP-3 sprayer, respectively.

2.6 Economics of power operated or tractor operated sprayer

Saha *et al.* (2004) calculated the cost of spraying for different sprayers. Three sprayer *viz*., tractor operated aero blast sprayer, power knapsack sprayer and manually operated rocker sprayer were used to calculated. The cost of operation of aero blast sprayer (Rs.197.19 ha^{-1}) was much higher than that of manual rocker sprayer (Rs. 42.26 ha^{-1}).

Nanda *et al.* (2008) conducted an experiment to study the efficacy of three sprayers, namely disc type low volume sprayer, hand compression sprayer and air assisted power sprayer. The field capacities of the sprayers were 0.08, 0.11 and 0.30 ha h^{-1} in low volume sprayer, hand compression sprayer and power sprayer respectively. The cost of spraying was found to be Rs. 65.00, Rs. 114.00 and. 134.00 ha^{-1} in low volume sprayer, hand compression sprayer and power sprayer, respectively.

Wachowiak and Kierzek (2009) studied the economics aspects of plant protection techniques. They reported that the developing methods and equipment to increase the pesticide application efficacy will result in less pesticide consumption, less pollution of the environment and reduced energy and cost requirements in the environmental friendly plant protection practice.

Yasin (2012) designed and developed a air sleeve boom sprayer for cotton crops. Results showed that the field capacity of developed machine was 2 ha h^{-1} with operational cost of the machine was 3.38 US dollar ha^{-1}.

Kharale *et al*. (2014) calculated the cost economics on self propelled boom sprayer in cotton and chilli fields. Spraying cost by using self propelled sprayer was found to be Rs. 359.27 ha^{-1} and Rs.283.87 ha^{-1} for cotton and chilli crop, respectively.

Narang *et al*. (2015a) compared the cost of spraying and labour requirement of aeroblast sprayer and tractor operated air assisted sprayer. The total cost per hour including fixed and variable was found to be minimum for tractor operated aero blast sprayer *i.e.*, Rs.324.96/-including tractor cost of Rs.167/- and for tractor operated air assisted sprayer, total cost per hour was found to be Rs.335/-.

Narang *et al*. (2015b) compared the cost of spraying for different spraying methods. Sprayers were selected for the experiments *i.e.*, Battery operated Knapsack, boom type, tractor operated gun type and electrostatic sprayers. The results revealed that the, for tractor operated gun sprayer was around Rs.381/- including tractor cost of Rs. 302/- and for boom sprayer the total cost ha-1 was 330/- including tractor cost of Rs. 302/-.

Kharale *et al*. (2016) evaluated the performance of aeroblast sprayer in pigeon pea. The average effective field capacity of the aeroblast sprayer was found to be 2.5 ha h^{-1}. The fuel consumption of the tractor for the aeroblast sprayer was found to be 2.5 l h^{-1}. the cost of operation of the machine were calculated and found to be 250 Rs. h^{-1} and 125 Rs. h^{-1}.

Materials and Methods

III. MATERIALS AND METHODS

Selection of right equipment or machine for pesticide application is very important from the point of the pest control. The correct usage of equipment and its proper maintenance are important factors which affect the ability to place pesticides on target more economically and effectively. The selection of equipment depends on many factors. Conventional tractor operated gun sprayer are commercially available. The main drawback is non uniformity and over application. Complete control on insects with this conventional method of spraying is very difficult because of poor penetration of spray and improper coverage. This method is beneficial provided that the recommended pesticide dose and volume are used. But, in practice actual dose requirement are more than theoretical values using this type of sprayer, operator comes in direct contact with toxic insecticides leading to health hazards. To overcome this drawback, strong need was felt to develop a tractor operated automatic gun sprayer for selected field crops to improve the spraying efficiency and achieve better droplet deposition on plants.

This chapter briefly describes the methodology followed for design and development of tractor operated automatic gun sprayer based on the crop and machine parameters. The standard method used for the measurements of crop and machine parameters was explained in this chapter. The evaluation techniques used to find the performance of the tractor operated automatic gun sprayer for the field conditions for the selected field crops of cotton and pigeon pea were enumerated under the following sub heading

3.1 Study of crop and machine parameters for the design and development of tractor operated automatic gun sprayer for selected field crops

3.2 Design and development of tractor operated automatic gun sprayer for selected field crops

3.3 Performance evaluation of tractor operated automatic gun sprayer for selected field crops

3.4 Economics of tractor operated automatic gun sprayer for selected field crops

3.5 **Study of crop and machine parameters for the design and development of tractor operated automatic gun sprayer for selected field crops**

3.5.1 Crop parameters

Before commencement of the experiments the data on targeted field crops were collected. Effectiveness of sprayer is mainly influenced by crop parameters. Different crops have different parameters. The biometric crop parameters *viz*., variety of crop, stage of crop, row spacing, height of crop and canopy of crop (leaf area index) were considered in design and development of the tractor operated gun sprayer in order to reduce the plant damage by sprayer and to increase the effectiveness of sprayer. These parameters were studied and considered while designing a sprayer.

i. Type of crops

The targeted field crops selected for this study were cotton and pigeon pea. Cotton crop consumes 40 per cent of the total pesticide used for effective control of pest and diseases on different crops and orchards. In general, cotton attains height of 120 cm giving dense foliage and in particular it is main cash crop in Raichur district of Karnataka. Cotton is a bushy crop leading to difficulties in distribution, coverage, and penetration of chemical. It is susceptible to large number of pests and diseases right from seedling stage to until harvest. The cotton (Hybrid: *Bt* cotton hybrid (MRC - 7351) grown in the farmers field was used for spraying.

Pigeonpea is one of the major pulse crops of the Raichur region of Karnataka. The red gram crop is highly susceptible to insect attacks. The pest and disease infestation is a serious problem during the plant growth. The crop yields are generally hampered by many pests, which are problem over the years. Pigeonpea is a tall growing, wide spaced crop. Pigeon pea (variety: Maruthi ICP 8863) grown in the research farm have been used for spraying operation.

ii. **Plant height**

Plant height is one of the key parameter to be considered in designing of sprayer. Height of boom or height of spray nozzle is adjusted based on the plant height. Plant height was measured from ground surface to height attained by leaf tip for randomly selected plants by using steel tape. Average plant height was calculated by averaging all plant heights measured in the field.

iii. Row spacing

Row spacing is very important parameter to be considered because it facilitates the movement of tractor in standing crop. Narrow spacing leads to damage to the crop by tractor wheels. Row to row spacing was measured as distance between two centers of crop by using the steel tape. According to the row spacing, wheel tread of tractor will be adjusted to avoid the damage of crops during spraying operation.

iv. Stage of crop

The spraying of chemicals mainly depends on the stage of the crop. Usually spraying is done at forty five days of crop and at the flowering stage. Pest incidence occurs at early stage of crop necessitating chemical crop protection. Number of spraying operation and quantity of spray solution required depends on the stage of crop. About 2 to 3 times spraying is needed at the flowering stage because at that time population of insects or pests are more. Stage of crop was noted down by considering the date of sowing.

v. Leaf area index

Leaf area index will influence the deposition of the spray material. It is an area of one side of the leaves divided by the corresponding ground area. It is dimensionless parameter and considered to be a gauge to assess the growth of plant. In order to calculate the leaf area index (LAI) of crop at a particular stage, leaf area of three plants were randomly selected. In that total three leaves were selected randomly per plant and area of each was calculated using a square method technique (Mathews, 1992a) from which the average leaf area of a plant at that stage of the crop grown was calculated. With the known area of the plot and with known number of plants in a plot, the leaf area index was calculated using the formula.

$$\text{LAI} = \frac{\text{Total leaf area}}{\text{Total ground area allotted for particular plant}} \quad \text{... (3.1)}$$

3.5.2 Machine parameters

Quality of spraying mainly depends on the machine parameter. Machine parameters considered in designing of sprayer is discussed below. Properly designed sprayer will increase the deposition, field efficiency and reduces the production cost. Some of parameters were measured during laboratory and field study.

i. Filling time for spray tank

Filling time is the time required to fill the spray tank. The fitted horizontal triplex pump was used to fill the tank from lakes or wells through a bypass valve. Connections to two ways clock was closed while filling. The pump was operated at maximum speed. The time taken to fill the spray tank was 35 minutes.

ii. Emptying time of spray tank

Empty time of spray tank depends on the discharge, pressure and speed of operation. Emptying time was noted during the spraying. This time provides the number of acres that can be sprayed when spray tank is full. Emptying time ranges between 30 to 45 minutes.

iii. Track width of tractor

Track width of tractor is the distance at the ground level between the median planes of the wheels on the same axle of the tractor when stationary and with the wheels in position for traveliing in a straight line. Crop damage by tractor wheels depends on the track width. Track width of tractor was changed based on the row spacing of the crop by changing or removing the complete wheel and assembling them in the new position.

iv. Speed of actuating mechanism

The speed of actuating mechanism was selected based on the trials conducted in the open field. In order to know the speed of actuating mechanism, two flag marks at a distance of 50 meter length were placed in the field. Sprayer along with actuating mechanism was started in advance so that actuating mechanism can run smoothly. Number of swings taken to cover 50 m length was recorded.

3.6 Design and development of tractor operated automatic gun sprayer for selected field crops

The main purpose of pesticide application technique is to increase the deposition of chemical on target surface with maximum efficiency and minimum effort to keep the insects or pests under control with non contamination to the off target organisms. All pesticides are toxic and if not applied properly and judicious, they can cause adverse effects to non target organism. So these must be used judiciously in order to avoid the ill effects to the environment. So application technique should be target oriented for the safety of non target organism and environment. Therefore, proper equipment, knowledge about pest behavior and skill of dispersal is very much important. The most susceptible stage of the pest for control measures will help to decide the time of application. The complete coverage and size of droplet depends on mobility and stage of pest. The complete knowledge of sprayer is needed to develop desired skill of operation, to select and estimate the time and number of times of spraying is needed to treat the crop in minimum time.

Pesticide is dispersed by many methods like spraying and dusting. For spraying chemical different nozzles such as hydraulic, gaseous and centrifugal nozzle are used. The liquid formulations of pesticide either diluted (with water, oil) or directly are applied in small drops to the crop by different types of sprayers. Usually the EC formulations, wettable powder formulations are diluted suitably with water which is a common carrier of pesticides. The volume of spray liquid required for certain area depends upon the spray type and coverage, total target area, size of spray droplet and number of spray droplets. It is obvious that if the spray droplets are coarse-size then the spray volume required will be larger than the small size spray droplets. Also if the thorough coverage (eg. both the sides of leaves) is necessary then the spray volume requirement has to be more.

In Raichur, most of the field crops are sprayed by using manually operated sprayers and tractor drawn boom sprayers. Manual spraying is time consuming; uneven distribution of pesticide occurs due to various parameters. In conventional sprayers, pesticide applied over top of the crop leads to more deposition in the upper surface, sometimes runoff of the pesticide occurs. Insects or pests hide in the lower position of the leaves, so efficacy of conventional sprayer is very less. Conventional tractor operated gun sprayer requires three persons, two of them for swinging guns behind the tractor and one for driving tractor. Due to acute shortage of labour, spraying operations are delayed which leads to crop losses due to pest and insect attack. In order to reduce the losses occurred by these, right time of application is necessary. Hence, there is an urgent need for developing the tractor operated automatic gun sprayer which gives more deposition both on top and bottom sides of leaves with less contamination to the environment and to reduce the dependence on the labour.

A prototype of tractor operated automatic gun sprayer for spraying of chemical for field crops has been developed and fabricated by considering crop and machine parameters. The development of tractor operated automatic gun sprayer was carried out in central workshop, Department of farm machinery and power engineering, CAE, UAS, Raichur. The essential components of sprayer are frame structure, spray tank, horizontal triplex pump, control valves, spray gun nozzle, pressure gauge, strainer, hydraulic agitator and actuating mechanism. The prototype of the automatic gun sprayer is shown in plate 1. The rear view and side view of the tractor operated automatic gun sprayer is shown in plate 2 and 3.

3.6.1 Design of power transmission system

The power transmission unit is the main component of the sprayer and it provides the power to the working components of the sprayer. The rotary power to drive the hydraulic pump of the sprayer was taken from the P.T.O shaft of tractor. Adjustable telescopic shaft is used to transmit the tractor P.T.O shaft power to 160 mm pulley which is mounted at the bottom of frame structure. From that pulley, power transmits to the pump shaft. V-belts and V-grooved pulleys are used to transmit power from one shaft to other parallel shaft. V- Belts are used because these will transmit a given amount of power with less overall shaft pull, do not require lubrication, tend to cushion shock loads, provide considerable freedom in orientation and arrangement of shafts and are less likely to be misaligned (Anon., 2016). Design procedure used for V-pulley and V-belts are summarized below.

3.6.1.1 Design of pulley

Pulleys are one of the oldest and most ubiquitous power transmission elements. Pulleys transmit power from one location to another and they can form a transmission ratio. The selection of required size of pulley for the bottom pulley to which universal

Plate 1 Prototype of the developed automatic gun sprayer

Plate 2 Rear view of the tractor operated automatic gun sprayer

Plate 3 Side view of the tractor operated automatic gun sprayer

propeller shaft is connected was made on the following criteria. A 100 mm pulley was selected at the pump shaft. The tractor P.T.O shaft speed and pump shaft speed were measured by non contact digital type tachometer.

- Required speed at pump shaft = 900 rpm
- Available speed at the tractor P.T.O = 540 rpm

a. Velocity ratio for horizontal triplex pump was calculated as following

$$\text{Velocity ratio} = \frac{\text{Speed of the pump, rpm}}{\text{Speed of P.T.O rpm}} \qquad \text{... (3.2)}$$

$$\text{Velocity ratio} = \frac{900}{540} = 1.6$$

100 mm pulley was selected on the pump shaft to adjust the velocity ratio. The diameter of the pulley (d_2) required for bottom pulley was determined as following,

$$d_2 = \text{velocity ratio} \times d_1$$

$$d_2 = 1.6 \times 100 = 160 \text{ mm}$$

Hence, a pulley of 160 mm size was selected and provided on bottom shaft.

b. Design of V- belt

The belts are used for transferring power from one shaft to other shaft. The belt relies on the frictional effects for efficient work. When the belt and pulley is stationary, the tension between slack side and tight side is equal. When belt passes over the pulley, one portion of belt stretched and other portion becomes slack.

Various parameters of V-belt of A-cross section were needed for design of the belt *viz*., density and allowable tensile strength. These were taken as 1000 kg m^{-3} and 2.5 MPa (Kurmi and Gupta, 2006). A groove angle of (2β) of 35° was taken.

Cross sectional area of belt = b × t = 120 × 80 = 9600 mm^2

The mass of belt per unit length was estimated as follows

m = Cross section area, m^2 × Length, m × Density, kg m^{-3}

m = 9600 ×10^{-6}× 1.06 × 1000 = 10.17 kg m^{-1}

V = Velocity of the belt, m s^{-1}

= (π× D× N)/60

= 3.14×0.16× 900/ 60

= 7.53 m s^{-1}

When the belt continuously runs over the pulley, some centrifugal forces are caused to increase the tension on both the tight side as well as slack sides. At lower belt speed (less than the 10 m s^{-1}), centrifugal tension is very small. The designed speed of the belt is 7.53 m s^{-1}, its centrifugal tension was not considered. Maximum tension in belts,

$$T = \sigma, \text{ N mm}^{-2} \times \text{section area of belt, mm}^2$$

Where,

σ = allowable tensile stress = 2.5 MPa

T = 2.5 ×1000 = 2500

Therefore, Tension in the tight side of the belt,

$$T_1 = T$$

$$= 2500 \text{ N}$$

The tension of slack side of open drive was calculated as follows,

$$\sin\alpha = \frac{O_2\ M}{O_1\ M_2} = \frac{r_2 - r_1}{x} = \frac{d_2 - d_1}{2x}$$

$$= \frac{160-100}{2\times 90} = 0.25$$

$$\alpha = 14.4$$

Angle of lap on a smaller pulley,

$$\theta = 93 - (2 \times 14.4)$$

$$= 65^{\circ}$$

$$= 65\times\pi/93 = 2.2 \text{ rad}$$

The tension at the slack side of the belt was calculated using following formula,

$$2.303 \log\left(\frac{T_1}{T_2}\right) = \mu\times\theta\times \text{Cosec}\left(\frac{\beta}{2}\right) \qquad \ldots (3.3)$$

$$2.303 \log\left(\frac{T1}{T2}\right) = 0.25 \times 2 \times \text{Cos}\left(\frac{12.60}{2}\right)$$

$$\text{Log}\left(\frac{T1}{T2}\right) = \frac{4.5}{2.30} = 1.9$$

$$\left(\frac{T1}{T2}\right) = 3.26$$

$$T_2 = 2500/3.26 = 766.87$$

The power transmitted by a belt was calculated using below formula

$$P = (T_1\text{-}T_2) \text{ x } V = (2500\text{-}766.87) \times 7.53 = 13.05$$

Therefore, number of V-belts required for the transfer of power to pump shaft from PTO shaft of tractor was calculated by using following formula,

$$n = \frac{\text{Total power transmitted}}{\text{Power transmitted by belt}}$$

$$n = 26.6/13.05 = 2.0$$

So, two numbers V-belts were selected for power transmission.

The length of the belt required was calculated based on the diameter of driven and driver pulley and distance between two pulley.

$$L = \frac{\pi}{2} \times (d_2 + d_1) + 2x + \frac{(d_2 - d_1)}{4x} \quad \text{... (3.4)}$$

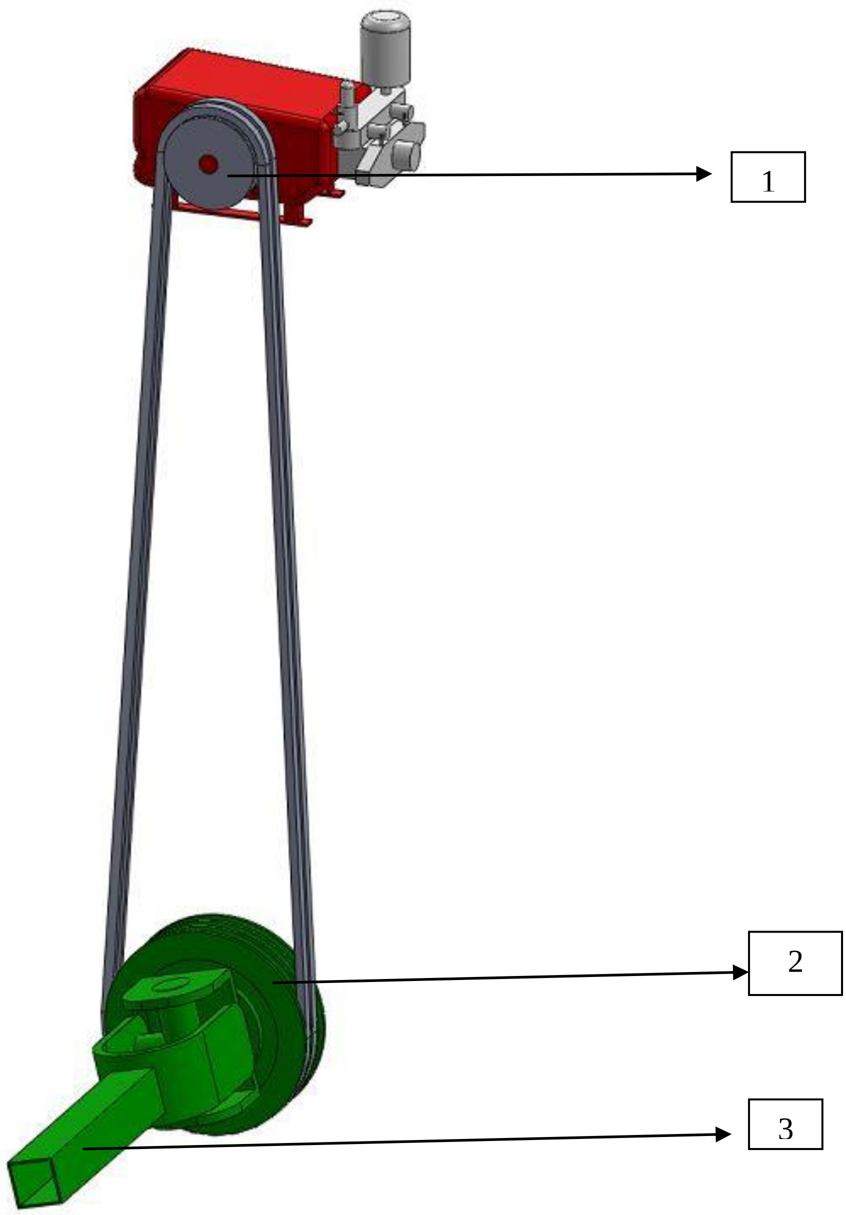
$$L = \frac{3.14}{2} \times (160 + 100) + 2 \times 90 + \frac{(160 - 100)^2}{4 \times 900}$$

$$L = 1.46 \text{ m}$$

The total length of belt was 1.46 m. The Type-B belts were selected for the power transmission. The power transmission system to horizontal triplex pump is shown in the Fig. 1.

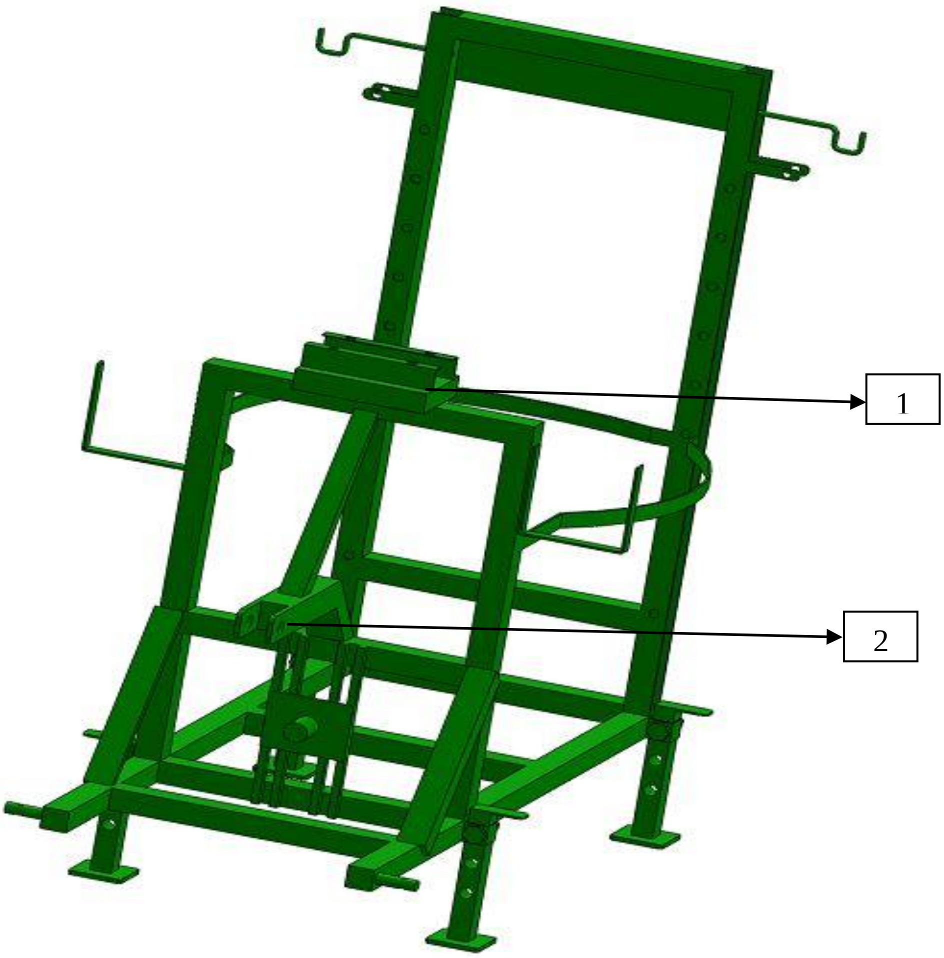
3.6.2 Development of frame structure

The frame has a box section at the bottom to hold the chemical tank. A frame of 1000 mm × 630 mm × 920 mm was fabricated by 50 mm × 50 mm hallow square MS. At the front end of the box, two hitches were provided for the attachment to tractor lower link. At the top of front portion of the box, rectangular frame is welded rigidly to serve as a support for pump. Just below the rectangular frame, top hitch was provided to attach the tractor top link. The inner section of the box could accommodate easily 500 litres chemical tank. Holes are provided at either side in rear frame to attach the boom. For support and to hold the delivery pipes hooks are provided at the top of rear frame. Isometric view of developed frame structure is shown in Fig. 2. The specification of the



1. Pulley on pump shaft	2. Pulley on bottom shaft	3. Telescopic shaft

Fig.1 Power transmission system to horizontal triplex pump



1. Supporting frame for pump	2. Lower hitch point

Fig. 2 Isometric view of developed frame structure for automatic gun sprayer

developed frame structure is shown in the Fig. 3. The prototype of developed frame structure is shown in plate 4.

3.6.3 Supporting frame for pump

The rectangular frame of 180 × 240 × 50 mm (W × L × T) was fabricated by using MS L-channel. Supporting frame was welded at the top of the frame structure. Pump was mounted on the supporting frame by using nuts and bolts.

3.2.4 Spray boom

The boom is a part of sprayer on which spray guns were mounted. The boom was attached to the rear portion of the frame structure. The boom was fabricated by using the 35 mm × 35 mm hallow square MS with thickens of 3 mm. One side of the boom has a locking arrangement. The boom of 1.7 m was provided either side of the frame separately. Actuating mechanism and spray guns were provided at the ends of boom. Height of boom can be adjusted to required height by attaching the boom to holes provided on the bottom frame structure. Holes are provided at every 15 cm interval. Boom height can be adjusted at an interval of 15 cm to 160 cm to suit different crop conditions. Distance between the spray guns can be adjusted based on the crop parameter. Provision was also made to fold the spray boom while in transport**.** Boom width of gun sprayer was calculated as suggested by Mathews (1999a). The area requiring treatment and time available was considered based on the time requiring for covering a unit area and time required for refilling of spray tank.

$$\text{Boom width (m)} = \frac{\text{area requring treatment (m}^2)}{\text{time available} \times \text{tractor speed (m h}^{-1})} \quad \text{... (3.5)}$$

$$= \frac{40000}{3 \times 2600}$$

$$= 5.12$$

Therefore, boom width of 1.7 m was mounted on either side of the frame, considering rest of the width is covered by spray guns.

The width of boom has significant effect on uniformity of spray. Boom moment of inertia increases as boom length increases and the vertical movement of the boom results in non-uniform spray coverage (Ghasemzadeh and Humbarg, 2016). When tractor is in motion, the different stresses (tension and compression) are developed in the boom as an

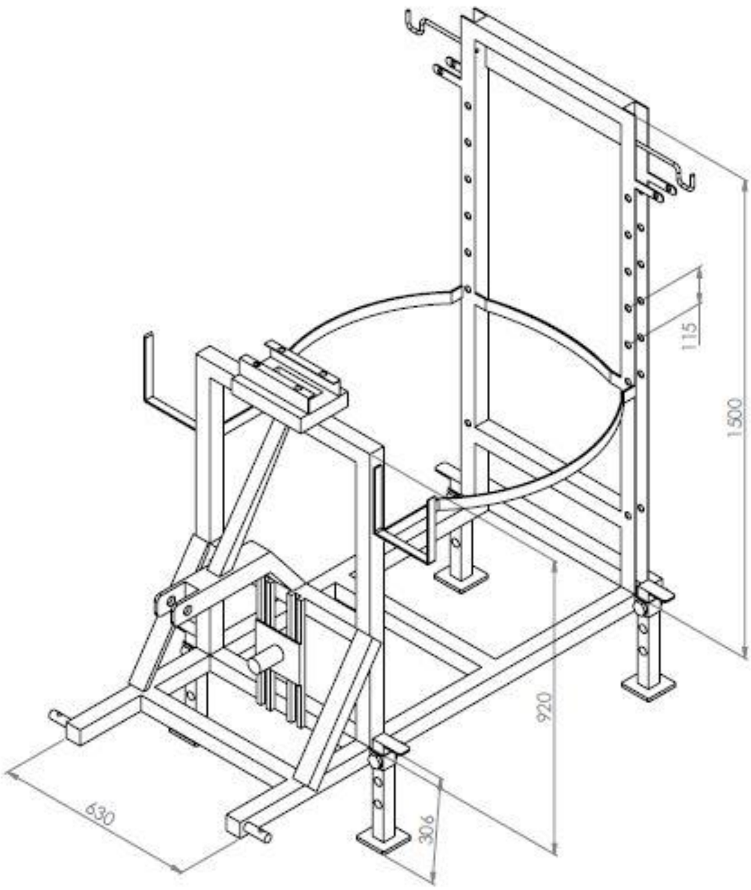


Fig. 3 Specifications of the developed frame structure for automatic gun sprayer (dimensions in mm)

Plate 4 Prototype of the developed frame structure for automatic gun sprayer

effect of its own load and the external load due to the jerks in the field. To overcome the distortions in the boom sections, to reduce the degree of freedom and reduce non uniformity, it was decided to fabricate the boom separately for either side. Schematic diagram of the spray boom is shown in the Fig. 4.

3.2.5 Selection of pump

A pump is the heart of the sprayer and key component to produce desired flow of spray. Various spraying situation requires different pressure and delivery rate, using correct sprayer pump is essential to achieve desired results. A pump must have sufficient capacity to operate a hydraulic agitation system, as well as supply the necessary volume to the nozzles. A pump should have a capacity of at least 25 per cent greater than the largest volume required by the nozzles. This will allow for agitation and loss of capacity due to pump wear. There are different types of pump *viz*., roller, centrifugal, diaphragm and piston pumps are available. Centrifugal and rollers are used for low pressure spraying (wolf, 2010). Piston type pump is most popular for high pressure spraying up to 40 bar (Manian *et al*., 2002) because these maintain flow output directly proportional to the speed. Pumps are typically either ground driven and auxiliary engine or tractor P.T.O. The choice of these is depends on the material to be pumped and capacity or volume needed. Now a days many pumps are driven by tractor P.T.O shaft because of mounting versatility and ease in maintenance (wolf, 2010). Pump was selected based on the required pressure and delivery rate.

a. Water horse power

Water horse power is the power required for pumping the water. In other words, it is the power that pumps would require if the pump were 100 per cent efficient. The water horse power can be determined by knowing flow rate of water and force required to produce that flow (Total head). Total head is the total height that a fluid is to be pumped, taking into account friction losses in the pipe. Sum of discharge head, suction lift and friction loss is total head. The water horse power requirement of pump was calculated by using the following formula

$$\text{Whp} = \frac{Q \times H}{75} \qquad \ldots (3.6)$$

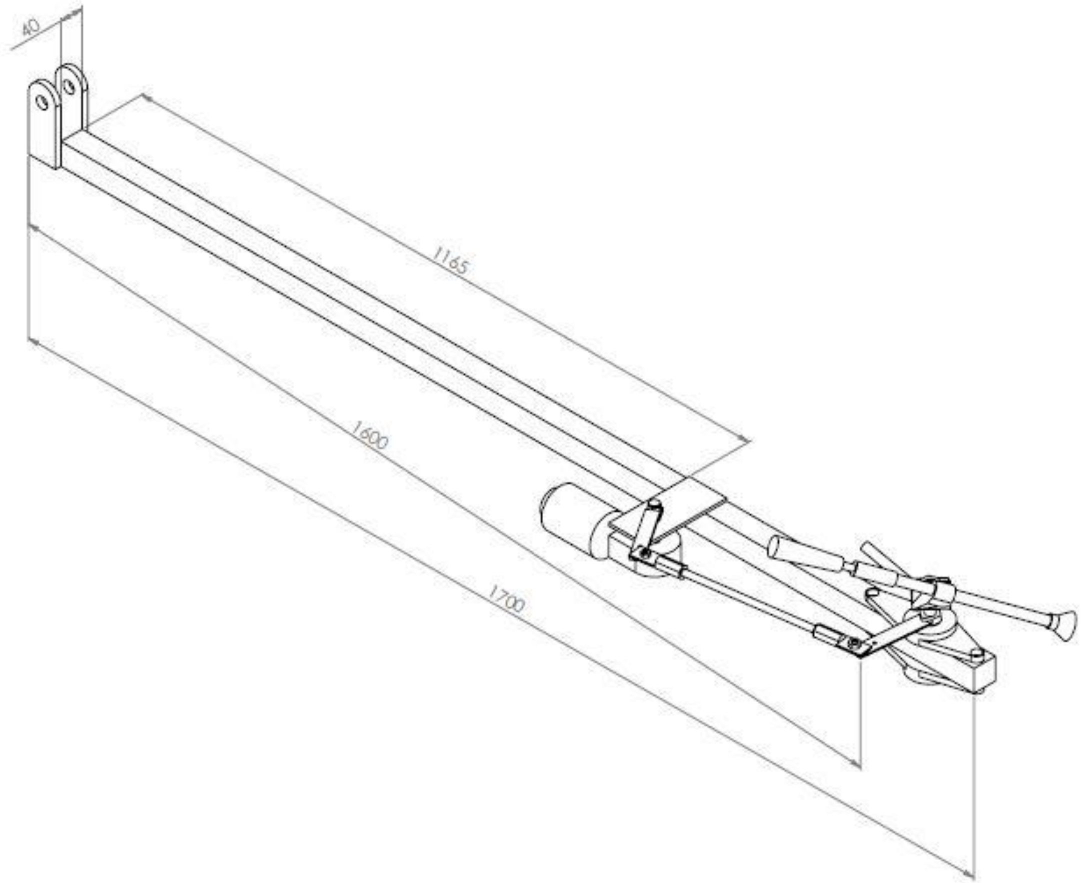


Fig. 4 Schematic diagram of the spray boom (all dimensions in mm)

Where,

Q= Discharge, l s^{-1}

H= Total head, m

$$\text{Whp} = \frac{0.60 \times 300}{75}$$

$$= 2.1 \text{ hp}$$

For the safer side of the pump, the factor of safety accounting 20 per cent has been considered. Hence, 2.1 + 0.42 = 2.52 hp is required for this experiment.

Hence, the commercial available 3 hp of horizontal triplex pump was selected for pumping of water for tractor operated automatic gun sprayer. The HTP pump is used for two purposes, one purpose is to lift water from lake, well to spray tank and other is to supply the required flow and pressure to the spray nozzles. Specifications of selected pump are presented in Table 1. The horizontal triplex pump was placed in the sprayer for the application of chemicals. The basic part of the pump was a chamber that was completely sealed at one end by pistons and other end an inlet and outlet valves. Liquid was drawn through inlet valve by movement of piston and on the return of the piston was forced out through the outlet valve.

b. Shaft horse power

It is the power available at the pump shaft. It is the ratio of water horse power and pump efficiency.

$$\text{Shp} = \frac{\text{Water horse power}}{\text{Pump efficiency}} \qquad \ldots (3.7)$$

The estimated value of water horse power as 3 hp and pump efficiency assumed as 60 per cent for estimation

$$\text{Shp} = \frac{3}{0.60} = 5 \text{ hp}$$

Table 1. Specifications of selected pump

Sl. no.	Particulars	Values
1	Type of pump	Horizontal triplex pump
2	Make and model	Usha
3	Pump capacity (hp)	3
4	Pump speed (rpm)	950
5	Pressure control valve	Pressure relief valve (by pass valve)
6	Discharge (l min^{-1})	34
7	Pressure range (kg cm^{-2})	20-35
8	L x W x H (mm)	430 x 430 x 300

3.2.6 Selection of spray tank

Spray tank is mounted inside the bottom frame structure. The tank acts as a reservoir for the supply of chemical solution during the spray. The chemical should be thoroughly mixed in the appropriate concentration with water and should be filled in the tank. The chemical solution is drawn from the tank through the suction hose pipe of the pump which is fitted with strainer to avoid the dirt and other foreign material entering the pump. The capacity of spray tank depends on location of source of water, type of agitation of chemical tank, area covered and hydraulic lift of the tractor. For cotton and red gram, application rate ranges from 125 to 350 l ha^{-1} depending on the equipment used (Shukla *et al*., 1987). A plastic chemical tank of 500 litres capacity was selected in order to avoid the frequent refilling. Plastic tank are chosen due to less expensive and they are extremely resistant to most of the agrochemicals used (Mathews, 1992a). Tank has 300 mm opening at the top for the filling of spray liquid and for cleaning. The pump is connected to the chemical tank by means of flexible hoses.

3.2.7 Design of hydraulic agitation unit

Agitation is essential to combine the components of the spray mixture uniformly and for some formulations, to keep the pesticide in suspension. If agitation is inadequate, the application rate of the pesticide may vary as the tank is emptied. The two common types of agitation are hydraulic and mechanical. But for most spraying situations, hydraulic agitation is sufficient (Sharma and Mukesh, 2010). For hydraulic agitation, small portion of water from the bypass is diverted to tank. The amount of flow for agitation depends on the chemical formulation, tank size and shape. Usually, use 5 to 10 per cent of tanks capacity for agitation flow (Sharma and Mukesh, 2010). The required flow for hydraulic agitation is calculated by using the following formula.

$$Q_a = (0.05 - 0.10) \times Q_t \qquad ...(3.8)$$

Where,

Q_a = Agitation requirements, l h^{-1}

Q_t = tank capacity, litres

$$Q_a = (0.05 - 0.10) \times 500$$

$$Q_a = 25 \text{ l h}^{-1}$$

A 20 mm bypass pipe was used to supply a 25 l h^{-1} of water to spray tank for hydraulic agitation.

3.2.8 Strainer

Proper filtering of the spray mixture not only protects the working parts of the spray system but also avoids misapplication due to nozzle tip clogging. Three types of strainers commonly used on sprayers are tank filler strainers, line strainers and nozzle strainers. It is positioned in between tank and pump. The 100 mm size of line filter was selected.

3.2.9 Control valves

The optimum operating discharge and pressure should be maintained for sprayer to produce desired droplets. The control valves basically controls the flow of liquid through pipe lines. The delivery from the pump is provided with two control valve *i.e.,* two way cock, pressure relief valve. A pressure regulator is provided in between pump and spray gun in order to control the discharge. Pressure regulator maintain working pressure on the discharge end of the system but move the overflow back into the tank at lower pressure, thus reducing strain on the engine and the pump. The excess chemical fluid pumped is returned to the spray tank through pressure relief valve. The chemical fluid is supplied to the two spray guns by two way cock. The bypass hose from the HTP pump was connected to the tank from the top through a hole provided at the upper side of the tank. The spray pressure was controlled by using bypass valve and the pump gauge. A relief valve is provided with the pump to limit the maximum pressure.

3.2.10 Pressure guage

A pressure gauge is essential in the sprayer system to correctly indicate the pressure at the nozzle. Pressure directly affects the application rate and spray distribution. A pressure gauge is provided on the pump to display the adjusted pressure of the fluid to be discharged. A glycerine-loaded diaphragm type pressure gauge was used because it dampens pressure pulsations and vibration resulting in a steadier reading. The pressure gauge display ranges from 0 to 100 kg cm^{-2} (10 Mpa). The sprayer pressure guage was calibrated prior to the test.

3.2.11 Hoses

The hose diameter of 25 mm of 3.5 m length of pipe was selected for the discharge hose from pump. The 4 m length suction pipe having diameter of 30 mm was selected for suction pipe. The arrow line power plus hoses having maximum pressure capacity of 160 bar (163 kg cm^{-2}) were used. The supply of water to each guns were individually controlled through control valve by means of flexible hoses so that guns function could be shutoff to meet field abstractions.

3.2.12 Actuating mechanism for spray guns

The actuating mechanism provides power to spray guns to move back and forth. Actuating mechanism consists of motor and worm gear reduction. A worm gear is attached to the output shaft of the motor having worm. This worm gear spins around as motor turns. The worm gear is connected to long rod, as the gear rotates, it moves the rod and inturn provides oscillation motion to the spray guns. The worm gear and rod converts rotational output of motor into back and forth motion to spray guns. A 0.5 kW of two motors (12 V dc) were selected based on the rated capacity of tractor battery. The rated capacity of tractor battery is 12 V. Motor gets power from the tractor battery. There is a provision to change the gear ratio for different speeds. These are mounted at 1.21 m from the frame. Complete motion of actuating mechanism is shown in the Fig 5**.** Mounting of the actuating mechanism on boom of the sprayer is shown in Fig. 6.

i. Design of worm and worm gear

The worm gears are widely used for transmitting power between two non intersecting shafts at high velocity. It can give velocity ratios as high as 300:1 (Khurmi and Gupta, 2006). The worm gearing is mostly used as a speed reducer, which consists of worm and worm wheel. The worm usually of a cylindrical form having threads similar shape as that of an involutes rack. The worm wheel or gear is similar to a helical gear with a face curved to

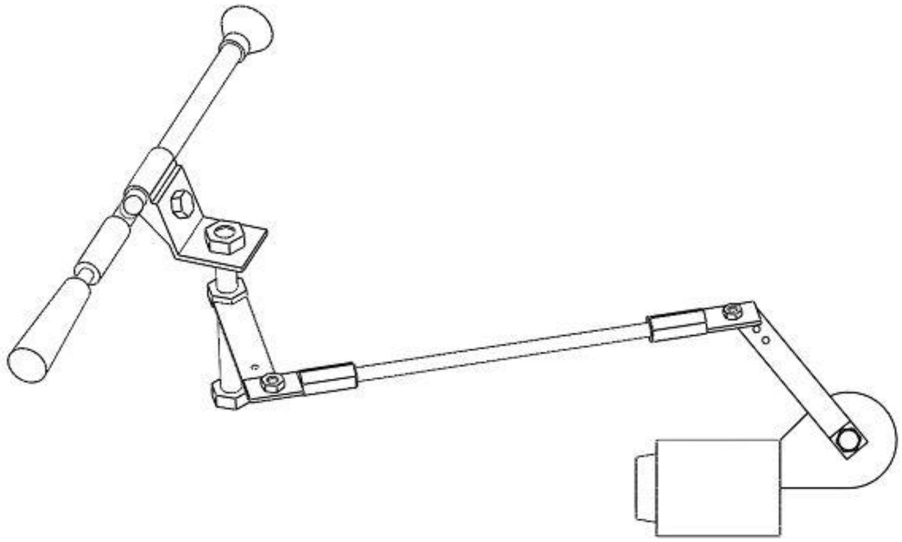
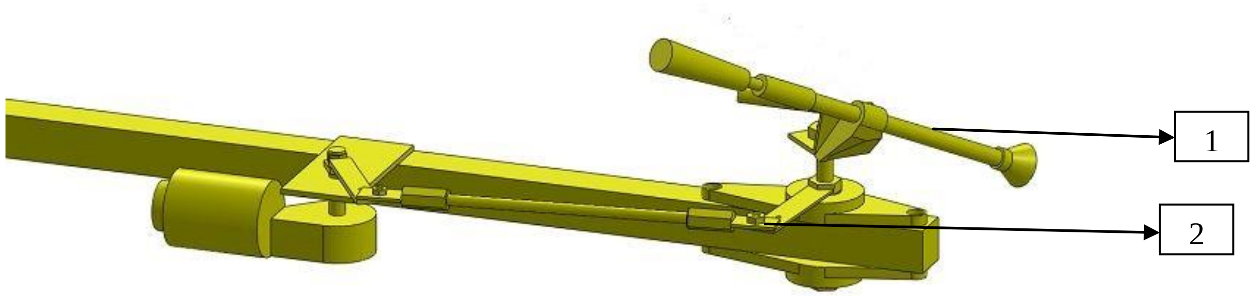


Fig. 5 Complete motion of actuating mechanism used for tractor operated automatic gun sprayer



1. Spray guns 2. Actuating mechanism

Fig. 6 Mounting of actuating mechanism on the boom of the sprayer

conform to the shape of worm. The required speed of the worm gear is 65 rpm. The diameter of the worm was 12 mm.

a. Velocity ratio for first speed reduction 65 cycles min^{-1} speed of actuating mechanism

Velocity ratio is the ratio of the speed of worm (N_w) in rpm to the speed of the worm gear (N_G) in rpm. Mathematically, velocity ratio,

$$\text{Velocity ratio} = \frac{N_W}{N_G} \quad \text{...(3.9)}$$

$$\text{Velocity ratio} = \frac{750}{65} = 11.5$$

According to Khurmi and Gupta (2006), for the velocity ratio of 12, the preferred worm gear is triple thread gear. The number of teeth on the worm gear was calculated by using following formula

T_G = Velocity ratio × n

Where,

T_G = number of teeth on the worm gear

n = number of starts of the worm

= 11.5 × 3 = 34.6

Hence, 76 mm diameter worm gear with 35 teeth available in the market was selected.

Peripheral velocity of worm gear was calculated as following

$$V = \frac{\pi \times 0.36 \times 63}{60} \quad \text{...(3.10)}$$

$= 1.2$ m s^{-1}

Centre distance: Centre distance between two shafts was calculated by using following formula.

$$x = \frac{D_W + D_G}{2} \quad \text{..(3.11)}$$

Where,

x= centre distance

D_W= Pitch circle of worm= 12 mm

D_G= Diameter of worm gear = m × T_G = 3 × 12= 36

$$x = \frac{12 + 36}{2} = 24\,\text{mm}$$

Torque transmitted by the worm was calculated as below

$$T = \frac{P \times 600}{2\pi\pi_G} = \frac{600 \times 60}{2 \times 3.14 \times 65}$$

= 88 N-mm

b. Velocity ratio for second speed reduction for 60 cycles min^{-1} speed of actuating mechanism

Velocity ratio is the ratio of the speed of worm (N_w) in rpm to the speed of the worm gear (N_G) in rpm. Mathematically, velocity ratio,

$$\text{Velocity ratio} = \frac{N_W}{N_G} \qquad \text{...(3.12)}$$

$$\text{Velocity ratio} = \frac{750}{60} = 12.5$$

According to Khurmi, for the velocity ratio of 12.5, the preferred worm gear is triple thread gear. The number of teeth on the worm gear was calculated by using following formula

T_G = Velocity ratio × n

Where,

T_G = number of teeth on the worm gear

n = number of starts of the worm

= 12.5 × 3 = 37.5

Hence, 100 mm diameter of worm gear with 40 teeth available in the market was selected.

Peripheral velocity of worm gear was calculated as following

$$V = \frac{\pi \times 0.37 \times 60}{60}$$

= 1.1 m s^{-1}

Centre distance: Centre distance between two shafts was calculated by using following formula.

$$x = \frac{D_W + D_G}{2}$$

Where,

x= centre distance

D_W= Pitch circle of worm= 12 mm

D_G= Diameter of worm gear = m × T_G = 3 × 12.5= 37.5

$$x = \frac{12.5 + 37.5}{2} = 25\,\text{mm}$$

Torque transmitted by the worm was calculated as below

$$T = \frac{P \times 600}{2\pi N_G} = \frac{600 \times 60}{2 \times 3.14 \times 60}$$

= 95 N-mm

c. Velocity ratio for third speed reduction 54 cycles min^{-1} speed of actuating mechanism

Velocity ratio is the ratio of the speed of worm (N_w) in rpm to the speed of the worm gear (N_G) in rpm. Mathematically, velocity ratio,

$$\text{Velocity ratio} = \frac{N_W}{N_G} \qquad \ldots (3.13)$$

$$\text{velocity ratio} = \frac{750}{54} = 13.6$$

According to Khurmi, for the velocity ratio of 12, the preferred worm gear is triple thread gear. The number of teeth on the worm gear was calculated by using following formula

T_G = Velocity ratio × n

Where,

T_G = number of teeth on the worm gear

n = number of starts of the worm

= 13.6 × 3 = 41

Hence, 115 mm diameter of worm gear with 45 teeth available in the market was selected.

Peripheral velocity of worm gear was calculated as following

$$V = \frac{\pi \times 0.41 \times 60}{60}$$

$$= 1.28 \text{ m s}^{-1}$$

Centre distance: Centre distance between two shafts was calculated by using following formula.

$$x = \frac{D_W + D_G}{2}$$

Where,

x= centre distance

D_W= Pitch circle of worm= 12 mm

D_G= Diameter of worm gear = m × T_G = 3 × 12.5= 37.5

$$x = \frac{13.6 + 41}{2} = 27.3 \text{mm}$$

Torque transmitted by the worm was calculated as below

$$T = \frac{P \times 600}{2\pi N_G} = \frac{600 \times 60}{2 \times 3.14 \times 55}$$

$$= 104.3 \text{ N-mm}$$

3.2.13 Spray guns

Two spray guns are mounted on the boom at either side of the frame structure. These gets swing action by actuating mechanism. Nozzles are mounted on the 45 cm lance. The spray pattern can be adjusted based on the requirement. There is a provision to change the orientation of spray. Spray guns are mounted on the boom at 1.60 m away from either side of the frame, though can change the distance of the guns based on the width of the spray. The angle of spray of each gun is 30 degree horizontally. Two spray guns are oscillating alternately from side to side. The length of lance is 45 cm and nozzle is mounted at one end of the lance, other end has controller for change of spray pattern. Pesticide was supplied to each gun separately to reduce the hydraulic losses.

3.2.14 Selection of power source

In modern agriculture, tractor has become one of the major sources of power which is used for majority of agricultural operations *i.e*., tillage, land preparation, sowing, spraying *etc*. It provides power in different outlets. Now a days most of the sprayer available in the market are P.T.O operated and three point hitch mounted sprayers. Power required to operate pump was calculated by using the following formula. The water horse power required for pump was calculated in the above section. The water horse power requirement for horizontal triplex pump was 3 hp.

a. Brake horse power

It is the actual horse power to be supplied by the engine to the pump for spraying operation. The brake horse power was calculated by the formula

$$\text{Bhp} = \frac{\text{Water horse power}}{\text{Pump efficiency} \times \text{Drive efficiency}} \quad \text{... (3.14)}$$

$$= \frac{5}{0.50} = 10 \text{ hp}$$

The factor of safety of 20 per cent was considered for calculation. Hence, 12 hp of brake horse power was required for the sprayer from the tractor P.T.O.

The total weight of tractor operated automatic gun sprayer is 750 kg when spray tank was full. According to BIS standard, the maximum lift capacity of 37.9 hp tractor is 1250 kg at the hitch points. Hence, the 37.9 hp tractor was selected as a power source for pump and for hydraulic mounting in order to avoid the overturning of the tractor. Specifications of selected tractor is presented in the Table 2.

3.2.15 Development of patternator for tractor operated automatic gun sprayer

The Patternator, a device used to measure spray distribution, is commonly used to study and correct the spray patterns of agricultural sprayers. Patternator are widely used to measure discharge, coefficient of uniformity of water distribution and volumetric distribution. It is also suitable for checking and recalibrating nozzles whose characteristics may have changed during use. Most of the patternator available in the market are used to measure the above for vertical nozzle sprayer. The width of the patternator available is very small. It is not suitable to check swing type of spray nozzle

Table 2. Specifications of selected tractor (As per test report no. 536/1023/12/OECD (2005))

Particulars		**Details**
Make		John Deere
Model		John Deere 5203
Type		Rear wheel drive (2WD)
Number of cylinders		Three
Rated engine speed (rpm)		2400
Drawbar power (Ps)		35.20
Type of wheel equipment		Pneumatic
PTO (rpm)		540
Maximum PTO power (kW)		37.9
Standard track width (mm)	Front	1540
	Rear	1460
Wheel base (mm)		2065
Total operational mass (kg)		2140

those cover large area at a single pass. There is no patternator for horizontal swing type sprayers. Hence, a strong need was felt to develop a horizontal patternator for gun sprayer.

Spray volume distribution determination was carried out on spray patternator of size 7.6 m × 3.7 m. The patternator was fabricated by using M.S channel for frame and galvanized iron sheet. The surface of the spray patternator was made of galvanized iron sheet of 0.2 cm thickness positioned horizontally over the frame. The patternator has 108 continuous U- type channels at equal spacing mounted on the rectangular frame. According to IS: 8548 -1977 Standard, channels should have 25± 0.25 mm width and depth of channel should be at least 100 mm. These restrictions make patternator difficult and expensive to construct. Selected U channels have 70 mm width is more than the recommended and 20 mm depth of channel to eliminate splash-back between the measurement grooves. The rectangular frame on which sheets are placed was made up of 5 mm × 5 mm L-shaped MS channel. Liquid from the channels was collected in measuring jar of 500 millilitre capacity mounted just below the channel through the transparent pipe. Patternator has 15 per cent slope for easy movement of water to the jar. The developed horizontal patternator is shown in the Fig. 7. The specifications of the galvanized sheet are presented in Fig. 8.

3.2.16 Geometric modelling of functional parts of tractor operated automatic gun sprayer using SolidWorks

SolidWorks is the leading 3D mechanical computer-aided design (CAD) program that runs on Microsoft Windows and is being developed by Dassault Systems. SolidWorks is a Parasolid-based solid modeller and utilizes a parametric feature-based approach to create models and assemblies. This means the solid is built by adding features (extrusion of the 2D sketches, etc) on the first or base feature. Building a model in SolidWorks usually starts with a 2D sketch. The sketch consists of geometry such as points, lines, arcs, conics and splines. Dimensions are added to the sketch to define the size and location of the geometry. Relations are used to define attributes such as tangency, parallelism, perpendicularity and concentricity. The parametric nature of SolidWorks means that the dimensions and relations drive the geometry, not the other way around. The dimensions in the sketch can be controlled independently or by relationships to other parameters inside or outside of the sketch.

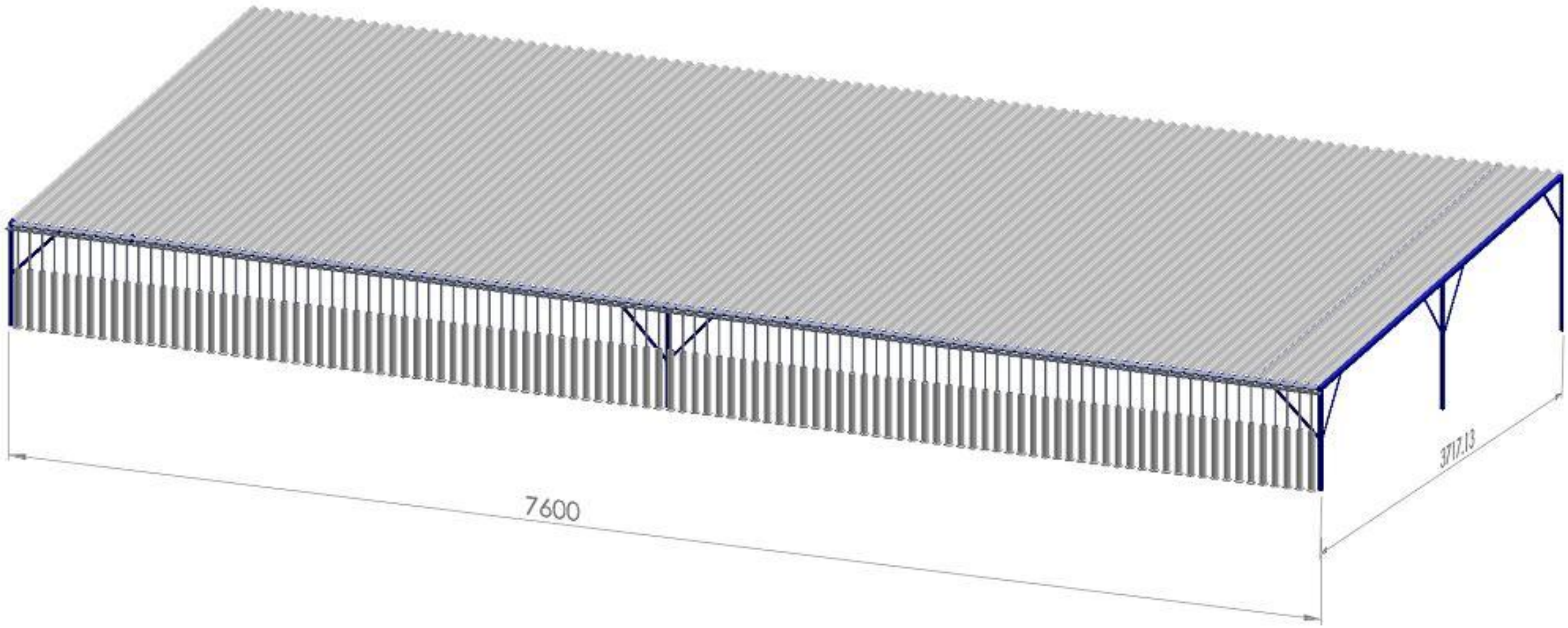


Fig. 7 Developed spray patternator

Fig. 8 Specifications of the patternator sheet

Finally, drawings were created from parts and assemblies. Views are automatically generated from the solid model and notes, dimensions and tolerances can then be easily added to the drawing as needed. The drawing module includes most paper sizes and standards. Isometric view of 3D model, 2D model and rear view of automatic gun sprayer is shown in Fig. 9, 10 and 11, respectively.

3.3 Laboratory evaluation of tractor operated automatic gun sprayer

The developed tractor operated automatic gun sprayer was evaluated under the laboratory to ascertain the performance under different variables. Its performance was evaluated in the Department of Farm Machinery and Power Engineering, plant protection laboratory under the controlled conditions to eliminate the effects caused by environmental parameters. Experiment was conducted under the different variables namely operating pressure, diameter of nozzle and orientation of nozzle to determine optimum value. The optimum values of those are important to ascertain the working of sprayer in the field condition. The laboratory calibration of sprayer was carried out in the same way as prescribed by the BIS code of IS: 11429 (1985): Methods for calibration of sprayers. The calibration of sprayer is the task of calculating and checking precisely, what output rate of sprayer is. It is not sufficient to assume that output printed on the nozzle pack, nozzle pressure reading over pressure gauge is correct. The variables selected for laboratory study is presented in Table 3.

Operating pressure and nozzle size affects the spray droplet size, discharge and length of throw of gun sprayer. Operating pressure of sprayer is the pressure required for atomization of the spray droplets. The spray droplet size, discharge and length of throw of gun sprayer are maximum if nozzle size and pressure is sufficient. A change of pressure and nozzle size affects all the above. The maximum operating pressure of gun sprayer is 30 kg cm^{-2}, but high pressure of spraying is not advisable as it affects application rate, discharge and droplet size. High pressure and small diameter may produce small droplets; small droplets are susceptible to weather conditions in field conditions. Nozzle orientation has major effects on spray deposition to targeted plant. In order to assess the performance of sprayer, three operating pressures, three diameter of nozzle and three nozzle orientations were selected.

The sprayer performance tests in the field conditions are labour intensive and depend on the weather conditions during the test along with terrain and vegetation *etc*.

1. Pump	2. Pressure chamber	3. Actuating mechanism	4. Telescopic shaft

Fig.9 Isometric view of 3D model of automatic gun sprayer

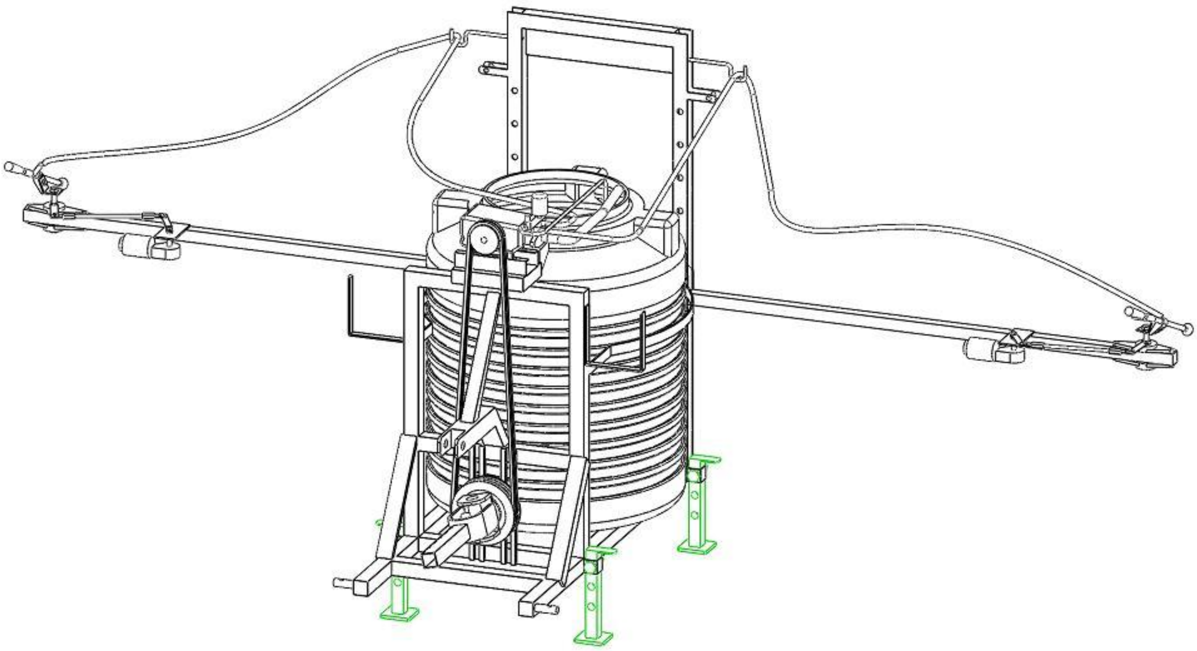


Fig. 10 Isometric view of 2D model of automatic gun sprayer

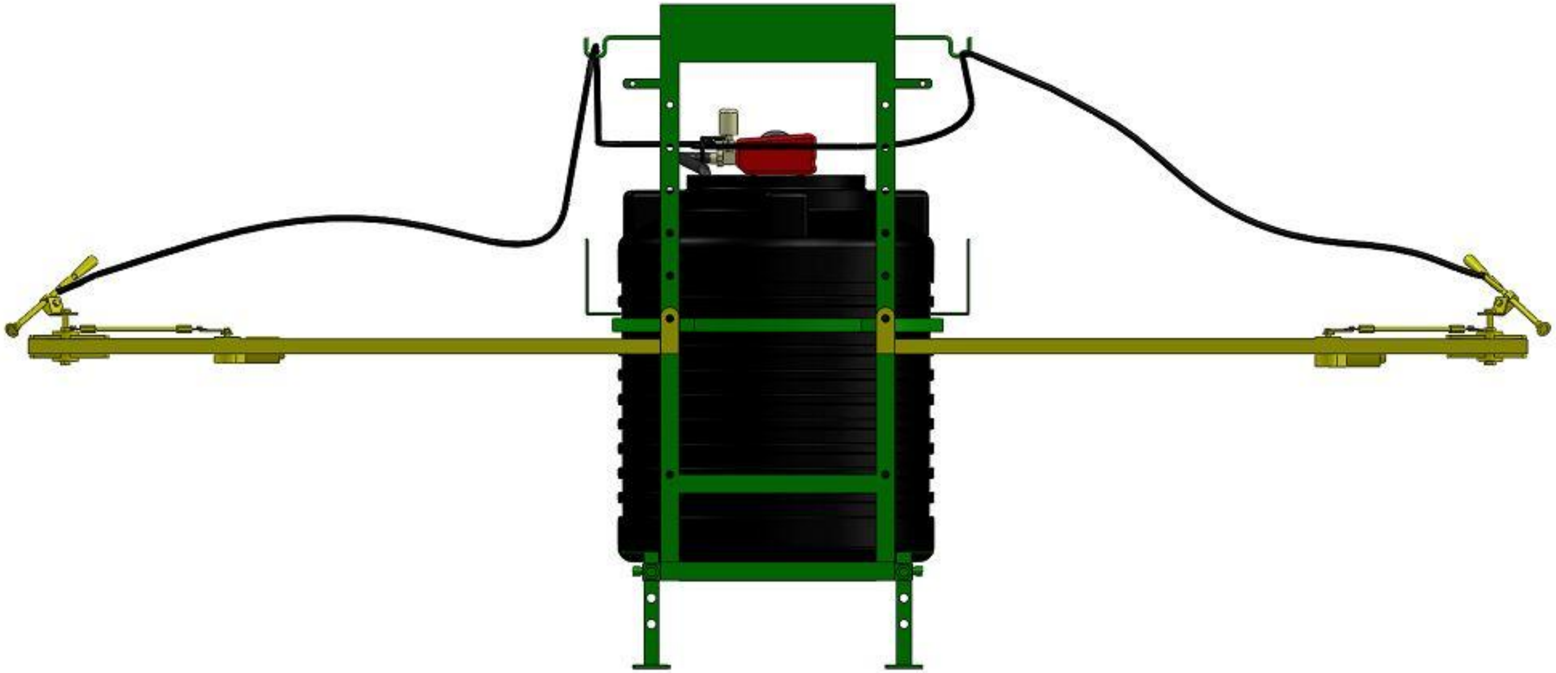


Fig. 11 Rear view of automatic gun sprayer

Table 3. Variables selected for laboratory study

Sl. no.	Parameters	Levels
Independent		
1	Operating pressure (kg cm^{-2})	20, 22 and 24
2	Nozzle size (mm)	2, 4 and 6
3	Orientation of spray nozzle (degree)	0, 15 and 30
Dependent		
1	Discharge (l m^{-1})	…
2	Length of throw (m)	…
3	Volumetric distribution (ml)	…
4	Droplet density (No’s cm^{-2})	…
5	Droplet size (µm)	…

Also it is very difficult to assess the influence of some variables individually. The major parameter influencing on the effectiveness of the spray is nozzle size, pressure and orientation of spray nozzle. The orientation of the spray nozzle was maintained by using the metal protractor. Actual plant was used to study effects of these parameters. The laboratory experiments were carried out by using the actual cotton and pigeonpea plant. The cotton and pigeonpea plants were raised in the polyethylene bags and after certain age placed in pot as same (Gholap *et al*., 2012). Instead of using false canopy, it was an attempt to establish actual plant canopy in the laboratory to get the correct results. In order to achieve uniform exposure to crop to the spraying, the sprayer was started 1m before canopy. One side of the gun sprayer was used to spray liquid, connections to other side of gun was disconnected for droplet size and droplet density measurement. Height of the spray nozzle was maintained at 30 cm above the plant canopy. The height of the crop was 450 mm and 650 mm for cotton and pigeon pea, respectively. Arrangement of actual plant for evaluation of the sprayer in laboratory is show in plate 5.

i. Discharge (l min^{-1})

Discharge of gun sprayer was measured by volume-time method. The spray volume was collected in measuring cylinder of 10 litre capacity for one minute duration for two spray guns at all levels of operating pressures and nozzle size. Discharge from individual spray gun was collected separately at a time. During discharge collection, actuating mechanism was not operated. The measuring was performed in three replicates at different pressures, nozzle size. Average of value of the discharge was considered as representative value. Fresh water was used to measure the nozzle flow rate.

ii. Length of throw (m)

The length of throw of gun sprayer was measured by using a tape**.** Length of throw was measured from the nozzle tip to last point where water reaches. Length of throw decides the starting point of spraying and height of spray nozzle in the field. Length of throw was measured at all the levels selected for laboratory study.

iii. Volumetric distribution (ml)

Spray patterns and distribution of agricultural sprayers depend on many factors such as: nozzle characteristics and orientation, amount of air assist, travel speed, spray bounce and micrometeorology during the applications. Accurate pesticide application

Plate 5 Arrangement of actual plant for evaluation of the sprayer in laboratory

from sprayers is essential in modern farming practice. The benefits of accurate application are increased pest control, reduced pesticide costs and wastage, and greater environmental safety. Evenness of lateral distribution of liquid from a sprayer is one of the requirements of accurate pesticide application. Lateral distribution of water from spray nozzles can be evaluated on a patternator or spray table, where spray from a nozzle is collected in many evenly spaced channels which make up the surface of the patternator.

The distribution was measured by directing the spray on to a channelled table with calibrated collecting tubes at the ends of the channels. Spray liquid was tap water. The spray was horizontally directed and landed on the equidistance grooves. When the fluid reaches the table, it will be separated into the different channels and flow down the incline. When the fluid reaches the base of the table, each channel flows into its own graduated cylinder. After completing the each experiment, height of water recorded in the measuring graduated cylinder was measured. Automatic gun sprayer was operated at 54 cycles per minute of actuating mechanism and height of spray nozzle was 30 cm above the spray patternator. The sprayer fitted with tractor was used for measurement. Sprayer was operated for 5 min. Evaluation of volumetric distrubution of sprayer in patternator and measurment of of volume of liquid collected in measuring jar is shown in plate 6 and 7.

iv. Droplet size (μm)

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*., 1987).

Spray contains a large number of very small spheres of liquid known as droplets. Droplet size is very important if pesticides are to be applied effectively with minimum contamination of environment. The droplet size requirement depends upon the pest, the pesticide, its mobility and mode of action. Size of spray droplet is represented as volume median diameter (VMD) and number median diameter (NMD). Volume median diameter (VMD) is a measure of the range of droplet size produced by the nozzle or it is an indication of the midpoint droplet size produced by the nozzle. One-half of the total output volume is contained in droplets larger than the volume median diameter and one-

Plate 6 Evaluation of volumetric distribution of sprayer in patternator

Plate 7 Measurement of volume of liquid collected in measuring jar

half of the volume is droplets smaller than the volume median diameter (Mehta *et al*., 2005). Number median diameter (NMD) is that diameter for which half of the drops in the sample are smaller in diameter and the other half is larger than the number mean diameter.

Numerous techniques had been developed to sample and measure droplet size of a spray. They ranged from simple collection technique to advanced nonintrusive technique. The most simple and inexpensive technique involved the measurement of droplet size by the capture of droplets in or on some form of medium. Once collected, droplet size was measured either by direct measurement, or by indirect measurement from stains or impressions.

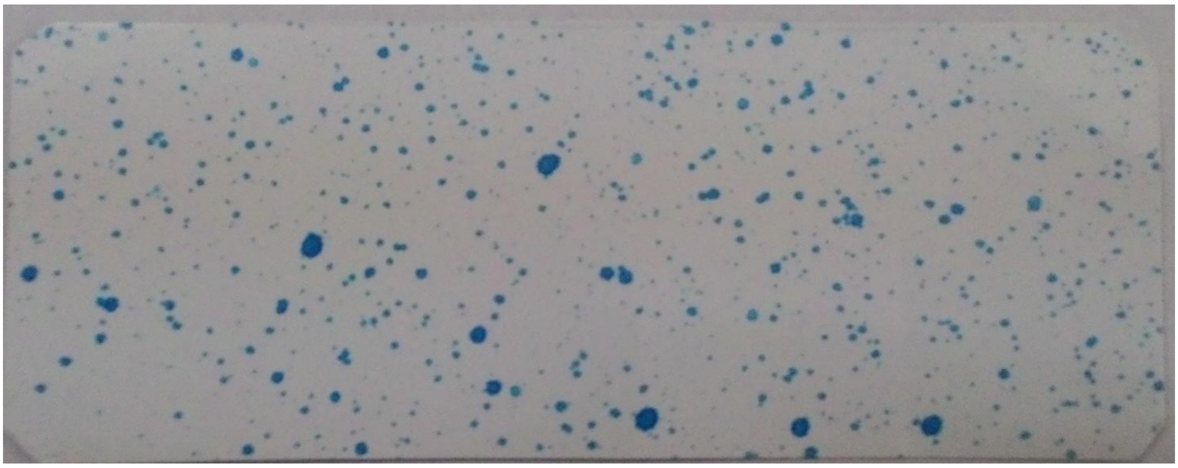
It is a proven fact that pest incidence mostly occurs on leaves. As such, it was decided to find out the droplet deposition on the leaves. To achieve this, use of glossy paper was made. For evaluating VMD and NMD, glossy photographic paper of size 7.5 × 2.5 cm selected because it has low spreading factor (Mathews, 1992a) and was placed on upper and underside of leaves at top, middle and bottom portion of plants. They are fixed to leaves at location horizontally. Placement of glossy photo paper on plant is show in plate 8. Methylene blue MS dye mixed @5 g l^{-1} in water and photographic paper were the same as that used by Jassowal *et al.* (2016). The dye mixed with water sprayed on the crop. When the sprayed material dried, the glossy paper strips were collected for analysis in the laboratory with DepositScan software. Glossy photographic paper before and after the spraying is shown in plate 9.

a. DepositScan software

DepositScan is a scanning program that can quickly evaluate spray deposit distribution on water sensitive paper or kromokote paper *etc*. The system was integrated with a table scanner, deposit collectors, a laptop computer and a custom-designed software package entitled "DepositScan". The program consists of a set of custom plugins that are used by an image processing program to produce a number of measurements useful for expressing spray deposit distribution. The DepositScan program offers a convenient solution for on-the-spot evaluation of spray quality even under field working conditions (Zhu *et al*., 2011). It takes less than 30 second to process the deposit analysis for a card. The program can be installed on a laptop computer and works with a table scanner to scan spray deposits on target cards. Any laptop or desktop computer with

Plate 8 Placement of glossy photo paper on plant canopy in laboratory

Glossy photographic paper before spraying operation



Glossy photographic paper after spraying operation

Plate 9 Glossy photographic paper before and after spraying

Java 1.4 or a later version along with any handheld or table scanner can operate the DepositScan program (Zhu *et al*., 2011).

DepositScan specifically quantifies spray deposit distributions on any paper type collector that could show visual differences between spray deposits and the background (Zhu *et al*., 2011). ImageJ is a Java-based image-processing program used for the acquisition and analysis of images. ImageJ can be used to measure an area and count number of spots in the user defined areas or throughout the entire image. The shape of selected areas could be rectangular, elliptical or irregular. The program supports any number of images simultaneously and is limited only by the available random access memory. The image processing speed of ImageJ is 40 million pixels per second. Any portable business card scanner with over 600 dpi can be used. A laptop computer with Windows 10 was used to operate the DepositScan program. The scanner was connected to the PC by USB port. In this program, the scanning resolution was chosen up to 2400 dots per inch (dpi) or 10.58 µm per pixel length.

When the DepositScan program was started, it opens an image-processing program, and prompts the user to scan the sample. The page heading of ImageJ program after DepositScan starts shown in Fig 12. The program then reports the individual droplet sizes, their distributions, the total number of droplets, and the percentage of area covered. The analysis of a spray deposition sample takes less than 30 seconds to complete. Finally, the program batch file calculates $DV_{0.1}$, $DV_{0.5}$ and $DV_{0.9}$ and displays the results from the area of the selected section, the total number of spots and the percentage area covered by the spots. $DV_{0.1}$, $DV_{0.5}$, and $DV_{0.9}$ represent the distribution of the droplet diameters such that droplets with a diameter smaller than $DV_{0.1}$, $DV_{0.5}$, and $DV_{0.9}$ compose 10 per cent, 50 per cent and 90 per cent of the total liquid volume, respectively. The program has two options for choosing thresholds to adjust image detection quality. The first option allows the system to automatically select a detection threshold based on the image contrast. The second option is a user defined threshold to select the image detection quality to match the actual deposit patterns. A sample of spray deposit on a glossy photographic paper for analysis with DepositScan is shown in Fig 13.

The program then searches for droplet diameters at the point where per cent cumulative volume = 10 for $DV_{0.1}$, per cent cumulative volume = 50 for $DV_{0.5}$, and per cent cumulative volume = 90 for $DV_{0.9}$. If no value of per cent cumulative volume exactly

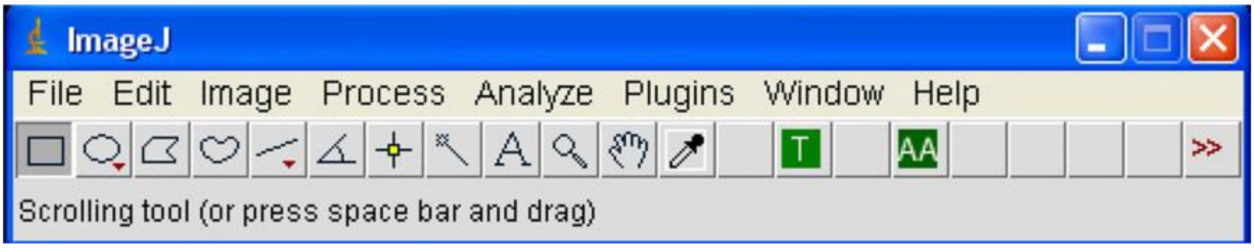


Fig. 12 The page heading of ImageJ program after DepositScan starts

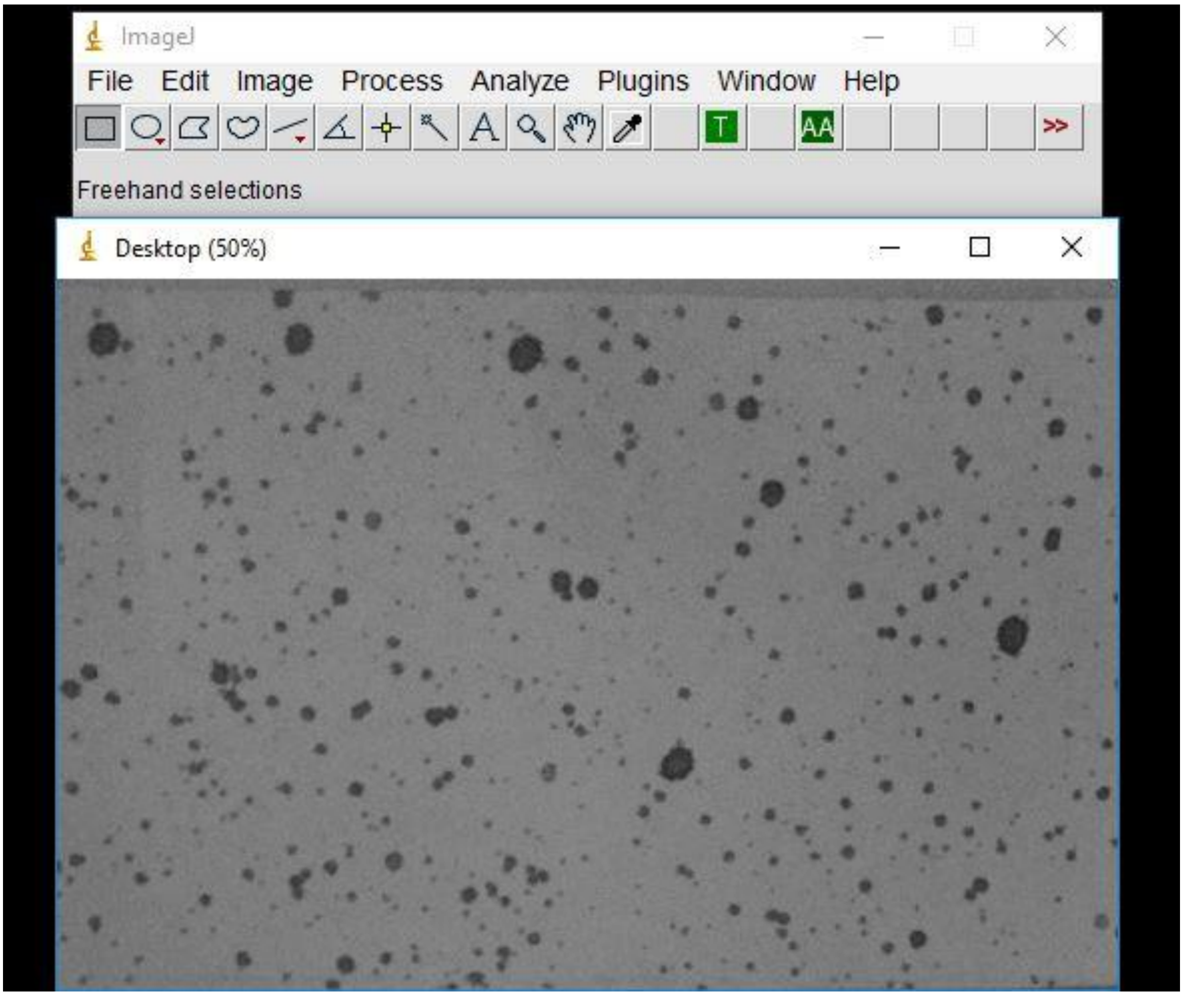


Fig. 13 A sample of spray deposit on a glossy photographic paper for analysis with DepositScan

matches the 10, 50, or 90 thresholds, the program will search for the closest higher and lower points to the value, and interpolate between the two closest points to obtain the per cent cumulative volume value. By dividing the area of the selected section, spray coverage is calculated from the total of the spot areas, the droplet density was calculated from total number of droplets, and the amount of spray deposits per unit area. The use of high resolution scanners can improve the accuracy of DepositScan. The accuracy of image measurements was also dependent on the calibration of scanners. Scanners are usually factory pre-calibrated or calibrated with standard size papers provided by scanner manufacturers. DepositScan will detect very small droplets.

In practice, some spots might be the result of overlapping deposits by several droplets and the resulting droplet diameter would then be a combination of several droplet diameters. Unfortunately, the program cannot distinguish a deposit originating from one droplet or from several overlapping droplets. The DepositScan program version used does not provide the NMD. DepositScan is the one closest to the manual reading. Visual analysis may be subject to errors in counting and measuring, mainly due to the difficulty of the process. Another possible source of error is the use of different spread factors in computer routines (Cunha *et al*., 2013).

V. Droplet density (No's cm^{-2})

The droplet density is also important along with droplet size for the quality of the spray since droplet density directly affects the volume of spray applied depending on the droplet size. By using imageJ, the number of droplet spots on one square centimeter area of photographic paper was obtained. The number of droplets per square centimeter area was termed as droplet density. The droplet density was measured in DepositScan software.

3.3.1 Statistical analysis

Three factorial designs were used to analysis the laboratory and field parameters. Some machine parameters were analyzed by using three factorial and some deposition parameters were analyzed by using four factorial of completely randomized design. The experimental data were processed using an analysis of variance (ANOVA) to determine the effects of the three independent variables of both laboratory and field parameters. The effect of interaction of these two independent variables was also studied through this analysis. The statistical software package "Design –Expert", [version 10.0.4 for windows, Stat-Ease, Inc.,] was used for statistical analysis.

3.3.2 Optimization of operational parameters of tractor operated automatic gun sprayer in laboratory conditions

Optimum process conditions are required to significantly enhance the performance of tractor operated automatic gun sprayer. Numerical optimization has been conducted to evaluate the optimum operating pressure, nozzle size and orientation of spray nozzle. In this study, different levels of each independent numerical variables of operating pressure, nozzle size and orientation of spray nozzle were used for the design of experiments to study the effects. Only best combination of different variables was taken for field test. The statistical software package "Design –Expert", [version 10.0.4 for windows, Stat-Ease, Inc.,] was used to organize the experimental design.

3.4 Performance evaluation of tractor operated automatic gun sprayer for selected field crops

The performance evaluation of tractor operated automatic gun sprayer for selected field crops *viz*., cotton (Bt) and pigeon pea (Maruthi) was carried out in the farmer's field and University Research Farm, Raichur. The performance was evaluated based on the standard procedure. Some parameter of the sprayer was measured in the field without having vegetation to get exact results and some of the parameters were measured in the standing crop. Before spraying operation, the wheel tread of tractor and spray boom height were adjusted according to row spacing and the height of crop. After making all the adjustments, set up was run for 15 min before actually starting the experiment. The performance of tractor operated automatic gun sprayer was carried out at the parameters which are optimized in the laboratory studies. The variables selected for field study is presented in the Table 4.

There are many factors which can affect the performance of sprayer *i.e.*, plant equipment, geometrical shape of the plant, weather *etc*. Some of the factors are uncontrollable. During spraying operation, the different meteorological parameters such as wind velocity, air temperature and humidity were measured by using different devices. A anemometer was used to measure the wind velocity over the target crop. A thermo hygrometer was used to measure the temperature and humidity. Meteorological

Table 4. Variables selected for field test

Sl. no.	Parameters	Levels
Independent		
1	Forward speed (km h^{-1})	2.2, 2.4 and 2.6
2	Speed of actuating mechanism (cycles min^{-1})	54, 60 and 65
3	Height of spray nozzle (cm)	30, 60 and 90
Dependent		
1	Swath width of spray (m)	…
2	Field capacity (ha h^{-1})	…
3	Application rate (l ha^{-1})	…
4	Difference of actual and theoretical application rate (Per cent)	…
5	Fuel consumption (l h^{-1})	…
6	Droplet density (No's cm^{-2})	…
7	Droplet size (µm)	…
8	Uniformity coefficient	…
9	Area covered by droplets (mm^2 cm^{-2})	…
10	Efficacy of sprayer	…

parameters at the time of spraying for both the crops were presented in the Table 5 and 6. Nordby and Skuterud (1975) suggested that field spraying should not be carried out in wind speeds of more than 3 m s^{-1}.

The most common error in spraying operation is operating the equipment at the wrong speed. Slow rate of travel will result in over spraying and waste of time, fuel, money and pesticide. The higher rate of travel will result in inadequate spray deposit and poor pest control. In order to know the forward speed of sprayer two flag marks at a distance of 50 meter length were placed in the field. The sprayer was started in advance so that sprayer runs constantly at reaching the first mark. The time taken by the sprayer to cover 50 meter length was recorded and travel speed was calculated. Throttle was so adjusted that tractor travel speed achieved within recommended range. The selection of forward speed is based on the recommended application rate and width of spray. The actual application rate of pesticide for cotton and pigeon pea is 350 to 400 l ha^{-1}. So, to find out forward speed, application rate of 400 was considered as suggested by Mathews (1999a). In general, a travel speed of 1.2 to 2.5 km h^{-1} proves to be satisfactory depending on the plant density (Singh, 2006). Deshmukh (1993) specified forward speed of 1.5 to 2.5 km h^{-1} for dense foliage crop (cotton). Therefore, in this experiment forward speed was kept less than 2.6 km h^{-1}.

$$\text{Application rate (L ha}^{-1}) = \frac{D\times 600}{S\times W}$$

Where

D= Discharge of guns (l min^{-1})

S= Speed of tractor (km h^{-1})

W= Width of sprayer

$$S = \frac{12.30\times 600}{7.2\times 400}$$

$$= 2.6 \text{ km h}^{-1}$$

So, three speeds of 2.2, 2.4 and 2.6 km h^{-1} of tractor were selected in this study to assess its effect on the performance of sprayer. Recommended application rate will get if sprayer is operated within these speeds. Unevenness of spray distribution usually increased at higher speeds of travel.

Table 5. Meteorological parameters at time of spraying in cotton crop

Sl. no	Parameters	Value		
		R1	R2	R3
1	Temperature (°C)	28	30	31.2
2	Humidity (per cent)	66	67	62
3	Wind speed (m s^{-1})	0.3	0.9	1.3

Table 6. Meteorological parameters at time of spraying in pigeon pea crop

Sl. no	Parameters	Value		
		R1	R2	R3
1	Temperature (°C)	32	34	29
2	Humidity (per cent)	61	63	68
3	Wind speed (m s^{-1})	0.5	0.4	0.9

The power to the drive actuating mechanism was taken from the tractor battery. The rated capacity of the tractor battery is 12 V dc. Motor above 12 V dc can be used but speed avaible at the actuating mechanism was less. There is no way to increase the speed of actuating mechanism. Hence, two motor of 12 V dc was used. The maximum speed of 65 cycles min^{-1} can be obtained. As per the trials conducted in the field, 65 cycles per minute of actuating mechanism was needed to cover field uniformly without overlap and miss application for 2.6 km h^{-1}. Therefore, three speeds of actuating mechanism *i.e.*, 55, 60 and 65 cycles per minute were selected to observe its effects on the performance of sprayer. Performance evolution of tractor operated automatic gun sprayer in cotton and pigeonpea is shown in Plate 10 and 11.

3.4.1 Swath width of spray (m)

Swath width is the effective width covered by the spray guns. Swath width of spray was measured by using tape. Sprayer was operated in the field having no vegetation for accurate reading. In case of vegetative field it can't be measure exactly the swath width. Measurements were made using pure water. The swath width at given height and actuating mechanism was determined by measuring the water distribution from edge to edge on the ground. Width of spraying operation was taken randomly in the field at the different locations.

3.4.2 Actual application (l ha^{-1})

Actual application is the amount of liquid consumed with respect to unit area. Measurements were made by using water in the plane field to get exact result. At same time, the uniformity of liquid application was observed visually. Field size of 100 × 100 m was selected for actual application rate measurement. Actual application is measured by filling known amount of liquid into the tank and time taken to spray was noted down by using stop watch. The actual application is average of thrice replications.

The theoretical application rate of sprayer was calculated by using following formula

$$\text{Theoretical application rate} = \frac{D \times 600}{S \times W} \qquad \text{... (3.15)}$$

Plate 10 Performance evaluation of tractor operated automatic gun sprayer in cotton crop

Plate 11 Performance evaluation of tractor operated automatic gun sprayer in pigeonpea crop

Where,

D = discharge of guns (l min^{-1})

S = Speed of tractor (km h^{-1})

W = width of sprayer (m)

The difference of actual and theoretical application rate was calculated as below

$$\text{Difference of actual and theoretical} = \frac{\text{actual rate - theoretical rate}}{\text{actual rate}} \qquad ...(3.16)$$

3.4.3 Actual field capacity (ha h^{-1})

The actual field capacity is calculated based on the time consumed for real work and that time lost for other activities such as turning (Sahay, 2008). The time required for actual work and time lost due to above factors measured by stopwatch. The time lost for refueling was not considered because filling up before starting test can make refueling unnecessary for specially large field, also time for adjusting or rectifying machine trouble and nozzles were not taken into consideration as it varies widely to various factors and its inclusion in time factor sometime unreasonably lower the actual field capacity.

$$\text{Actual field capacity (ha h}^{-1}) = \frac{\text{Actual area covered (ha)}}{\text{total time required to cover area (h)}} \qquad ...(3.17)$$

3.4.4 Fuel consumption (l h^{-1})

The method was used for measuring of fuel consumption as follows. The fuel consumption of tractor was carried out by filling up the fuel tank before starting each trial then after finishing the trial tank was refilled again. Amount of refueling after the operation was measured which was the fuel consumption of test.

3.4.5 Droplet size (µm)

Three plants were randomly selected, crop was divided into three positions based on height of crop and glossy paper was placed on upper and underside of leaves at top, middle and bottom portion of plants. Cards location in cotton plant is shown in Fig. 14. Methylene blue MS dye mixed @5 g l^{-1} in water was sprayed on cotton crop and pigeon pea. Sampling points for photographic paper placement is shown in Fig.15. Overall twelve glossy papers were placed on the each plant to get droplet spectrum. When the

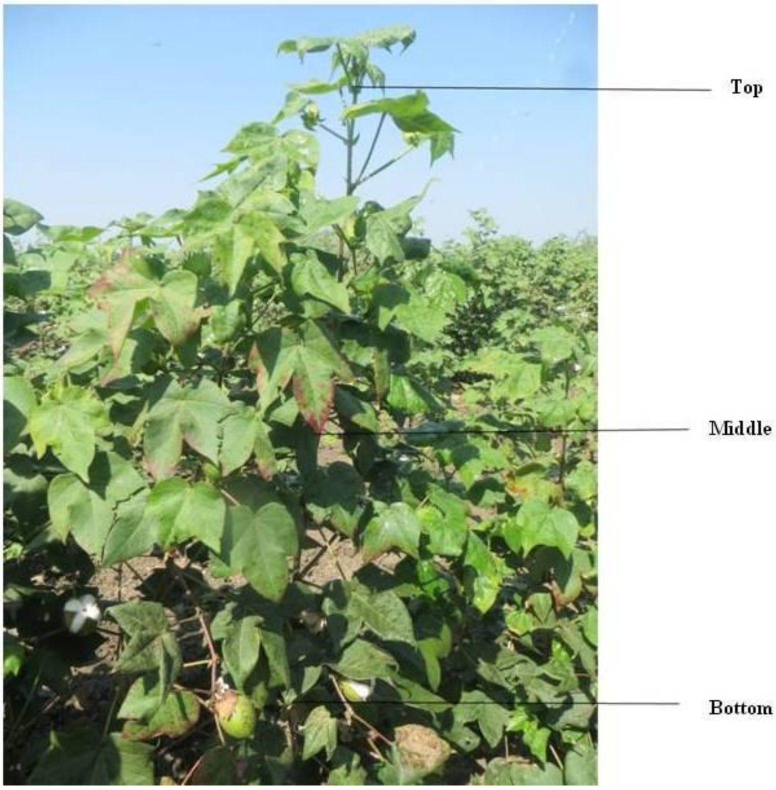


Fig.14 Cards location in cotton plant

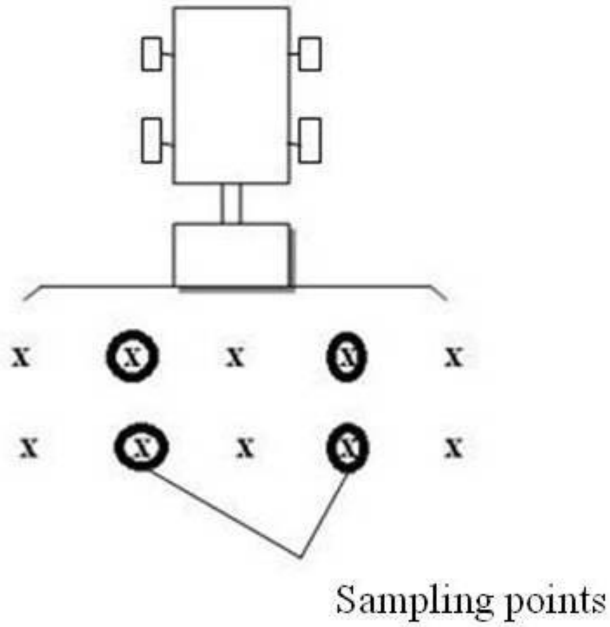


Fig. 15 Sampling point for photographic paper placement

sprayed material dried, the glossy paper strips were collected for analysis. A droplet on the glossy photographic paper on upper surface of the plant canopy is shown in plate 12. The procedure was repeated three times at all forward speed. The same method followed to calculate the droplet size in laboratory was used.

a. NMD (µm)

The DepositScan program version used does not provide the NMD. For calculation of NMD, the droplet size from the DepositScan has been taken to windows excel. The droplet spots diameters were separated into different ranges. From the total number of droplets, percentage of number of droplets and cumulative percentage number of droplets contributed by each range of droplet was calculated. Then from the plot of cumulative percentage number of droplets and actual droplet size, the droplet size at which cumulative percentage number of droplets reached 50 per cent was termed as number median diameter (NMD) of the sprayed particles.

3.4.6 Droplet density (No's cm^{-2})

The procedure followed in the laboratory to determine droplet size is discussed in above section. Same method is used to determine the droplet size in field condition.

3.4.7 Uniformity of coefficient

Uniformity Coefficient is the ratio of VMD and NMD, which gives the uniformity of the spray. Since the VMD and NMD are affected by the proportion of large and small droplets respectively, the ratio between these two parameters is often an indication of the range of sizes. Uniformity coefficient of spray droplets were determined by using following formula. The more the uniform the size of droplets the nearer is the ratio to 1.

$$UC = \frac{VMD}{NMD} \qquad \ldots(3.18)$$

3.4.8 Area covered by droplet spots (mm^2 cm^{-2})

Each range of droplet size on the glossy photographic paper was assigned a mean droplet diameter. With the number of droplets of each size in one square centimetre area and spotted diameter of those droplets, the area covered by droplets of a particular size was calculated as follows

Plate 12 Droplets on the glossy photographic paper on upper surface of the plant canopy

Area covered by droplets

$$= \left(\frac{\pi}{4}\right) \times (\text{spotted diameter of drops})^2 \times \text{number of drops} \qquad \ldots(3.19)$$

Similar method was used for the calculation of area covered by the drops of other ranges and the sum of the area covered by the drops of all ranges in one centimetre area of glossy paper gave the area of coverage per square centimetre (Singh *et al*., (2010) and Jassowal *et al*., (2016)).

3.4.9 Particle drift

The particle drift in the field was measured by collecting drift droplets at glossy photographic paper at the distances of 4.5 and 6.3 m away from the crop and cards were placed on top of the leaves of selected plant canopy perpendicular to row direction to record the chemical droplets in order to observe the particle drift (Yasin, 2012). The sample papers were collected carefully and analyzed by ImageJ to know the size of the droplets in the drift.

3.4.10 Plant damage (Per cent)

Plant damage was calculated by counting the number of plants in five meter row before spraying and number of the plant damaged in the same 5 m row length after spraying (El-Ashry *et al*., 2009).

$$\text{Plant damage (Per cent)} = \left(\frac{a}{b}\right) \times 100 \qquad \ldots(3.20)$$

Where,

a = Number of damaged plants

b = Total numbers of plants at the same deduced area

3.4.11 Optimization of operational parameters of tractor operated automatic gun sprayer in field condition

Optimum process conditions are required to significantly enhance the performance of tractor operated automatic gun sprayer. Numerical optimization has been conducted to evaluate the optimum forward speed, actuating mechanism and height of spray nozzle for cotton and pigeonpea. In this study, different levels of each independent numerical variables of forward speed, actuating mechanism and height of spray nozzle were used for the design of experiments to study the effects. The statistical software package “Design–Expert”, [version 10.0.4 for windows, Stat-Ease, Inc.,] was used to organize the experimental design.

3.5 Bio-efficacy of tractor operated automatic gun sprayer

The tractor operated automatic gun sprayer was evaluated its effectiveness against some of the insects and pests present in the cotton and pigeonpea. The efficacy of tractor operated automatic gun sprayer was carried out at the parameters which are optimized in the field studies.

3.5.1 Cotton

For calculation of bio-efficacy in the field, number of pests in the field was counted from 10 randomly selected plants. The pests were counted from a total of 3 leaves of a plant *i.e*. upper and lower side was recorded before and after the spray. The pests count was further recorded on 3^{rd} and 5^{th} day after spraying. The difference of number of pests before and after the spray was noted to calculate the percentage reduction of pests. The main sucking pests present in cotton were aphids and leaf hopper. The insecticide used (dinotefuran (osheen)) was solution with a recommended dose 150 g 500 l^{-1}.

3.5.2 Pigeonpea

The efficacy of pigeonpea crop was also measured during the field test. The chemical used for spraying the pigeonpea crop was emamectin benzoate (ASTRA). The chemical was mixed with water at a proportion of 100 g 500 l^{-1}. The major pest recorded was pod borer *Helicoverpa armigera*. The efficacy was measured by taking the number of larva present a day before spraying and number of larva present at 3 days and 5 days after spraying per plant. Later per cent pod damage was also calculated.

3.6 Economics of tractor operated automatic gun sprayer for selected field crops

The cost of operation of the sprayer was calculated based on the fixed and variable cost. The cost of operation for spraying and its labour requirement for cotton crop has been worked out based on the fixed cost, variable cost and labour charges. Fixed cost depends on the machine whether use or own. But variable cost directly depends on the amount of machine used in unit time. The cost of operation includes break- even point and payback period were calculated according to BIS standard IS: 9164-1979. The details of calculation are given in appendix I and II.

3.7 Comparison of developed tractor operated automatic gun sprayer with conventional tractor operated gun sprayer

i. Conventional tractor operated gun sprayer

Conventional gun sprayer consists of box type frame to hold the chemical tank. The inner section of box could hold 500 litre capacity of tank. At the front, two lower hitch pins and one upper hitch pin are provided to mount the frame to the tractor. Side chairs are provided at either side of the tank for the operator to sit. A three HTP pump was provided to get prerequisite pressure and discharge. Two persons are required to swing the guns side to side. Performance evaluation of conventional method of tractor operated gun sprayer in pigeonpea is shown in the plate 13.

i. Comparison between two sprayers

The developed tractor operated automatic gun sprayer was compared with conventional tractor operated gun sprayer. The same procedure was followed for evaluation of tractor operated automatic gun sprayer was used to evaluate the performance of conventional gun sprayer for two field crops. Tractor operated automatic gun sprayer was operated at the optimized parameters. The sprayer was operated in a straight path along with the row of the crop such that the distance between the nozzle and the surface of crop canopy was nearly 30 cm. In order to provide protection for driver and for two operators the protective clothes, hand gloves and face cover glass were utilized to avoid any harmful effects for the operator during the field trials.

Plate 13 Performance evaluation of conventional tractor operated gun sprayer in pigeonpea crop

Experimental Results

IV. EXPERIMENTAL RESULTS

In this chapter, the results pertaining to crop and machine parameters used in design, design and development of tractor operated automatic gun sprayer for selected field crops, performance evaluation of tractor operated automatic gun sprayer both in laboratory and field are presented and analyzed. Experiments were conducted under controlled conditions on actual plant canopy to determine optimum levels of machine and operating parameters of the sprayer. Based on these parameters, sprayer was tested on different field crops to evaluate the performance. The economic analysis of developed tractor operated automatic gun sprayer and comparison between newly developed and conventional tractor operated gun sprayer are also presented in this chapter. The results are described and discussed as follows

4.1 Crop and machine parameters for the design and development of tractor operated automatic gun sprayer for selected field crops

4.2 Design and development of tractor operated automatic gun sprayer for selected field crops

4.3 Performance evaluation of tractor operated automatic gun sprayer for selected field crops

4.4 Economics of tractor operated automatic gun sprayer for selected field crops

4.1 Crop and machine parameters for design and development of tractor operated automatic gun sprayer for selected field crops

4.1.1 Crop parameters

The targeted field crops for this study were cotton and pigeonpea. Cotton is dense foliage and in particular is the main cash crop in Raichur district of Karnataka. Cotton is a bushy crop leading to difficulties in distribution, coverage and penetration of chemical. It is susceptible to large number of pests and diseases right from seedling stage until harvest. The cotton (Hybrid: *Bt* cotton hybrid (MRC - 7351) were grown in the farmer field has been used for spraying operation.

Pigeonpea is one of the major pulse crops of the Raichur region of Karnataka. The red gram crop is highly susceptible to insect attack. The pest and disease infection is a serious problem during the plant growth. The crop yields are generally hampered by many pests, which are problem over the years. Pigeonpea is a tall growing, wide spaced crop. Pigeonpea (variety: Maruthi ICP 8863) grown in the research farm have been used for spraying operation.

i. **Plant height**

Plant height is one of the key parameter to be considered in designing of sprayer. Plant height was measured from ground surface to height attained by leaf tip for randomly selected plants by using steel tape. The average height of cotton crop at the time of spraying was 550 mm. The average height of the pigeonpea was found to be 900 mm.

ii. Row spacing

Row spacing is very important parameter to be considered because it facilitates the movement of tractor in standing crop. Narrow spacing leads to damage to the crop by tractor wheels. Row to row spacing was measured as distance between two centers of crop by using the steel tape. According to the row spacing, wheel tread of tractor was adjusted to avoid the damage of crops during spraying operation. Row spacing of cotton and pigeonpea was found to be 900 mm and 900 mm, respectively.

iii. Stage of crop

The spraying of chemicals mainly depends on the stage of the crop. Usually, spraying is done at forty five days of crop and at the flowering stage. Pest incidence occurs at early stage of crop necessitating chemical crop protection. Number of spraying operation depends on the stage of crop. About 2 to 3 times spraying is needed at the flowering stage because at that time populations of insects or pests are more. Stage of crop was noted down by considering the date of sowing. During spraying, the stage of cotton and pigeonpea were 110 days and 120 days, respectively from the date of sowing.

iv. Leaf area index

It is an area of one side of the leaves divided by the corresponding ground area. It is dimensionless parameter and considered to be a gauge to assess the growth of plant. The procedure as explained in the section 3.1 (V) was followed to calculate the leaf area index of the crop. Leaf area index of the crop at the time of spraying was 3.04. The leaf area index of the pigeonpea was 2.34 at 120 days of the crop. The biometric parameters of cotton and pigeon pea are presented in Table 7 and 8.

4.1.2 Machine parameters

Quality of spraying depends on the machine parameters. Machine parameters considered in designing of sprayer is discussed below. Properly designed sprayer will increase the deposition, field efficiency and reduces the production cost. Some of parameters were measured during laboratory and field study.

v. Filling time for spray tank

Filling time is the time required to fill the spray tank. The fitted horizontal triplex pump was used to fill the tank from lakes or wells through a bypass valve. Connections to two ways clock was closed while filling. The pump was operated at maximum speed. The time taken to fill the spray tank was 35 minutes.

vi. Emptying time of spray tank

Emptying time of spray tank depends on the discharge, pressure and speed of operation. Emptying time was noted during the spraying. This time provides the number of acres that can be sprayed when spray tank is full. Emptying time ranges between 30 to 45 minutes.

vii. Track width of tractor

Track width of tractor is the distance at the ground level between the median planes of the wheels on the same axle of the tractor when stationary and with the wheels in position for traveliing in a straight line. Crop damage by tractor wheels depends on the track width. Track width of tractor was changed based on the row spacing of the crop by changing removing the complete wheel and assembling them in the new position. The track width of the tractor at the front wheel is 1540 mm and at the rear wheel is 1460 mm.

viii. Speed of actuating mechanism

The speed of actuating mechanism was selected based on the trials conducted in the open field. In order to know the speed of actuating mechanism, two flag marks at a distance of 50 meter length were placed in the field. Sprayer along with actuating mechanism was started in advance so that actuating mechanism can run smoothly. Number

Table 7. Biometric parameters of cotton crop

Sl. no	Particulars	Details
1	Variety	*Bt* MRC 7351
2	Average height of crop, mm	550
3	Stage of crop, days	110
4	Row to row spacing, mm	900
5	Plant to plant spacing, mm	450
6	Leaf area index	3.04

Table 8. Biometric parameters of pigeonpea crop

Sl. no	Particulars	Details
1	Variety	Maruthi ICP 8863
2	Average height of crop, mm	900
3	Stage of crop, days	120
4	Row to row spacing, mm	900
5	Plant to plant spacing, mm	600
6	Leaf area index	2.34

of oscillation taken to cover 2.2, 2.4 and 2.6 km h^{-1} were 54, 60 and 65 cycles min^{-1}, respectively.

4.4 Design and development of tractor operated automatic gun sprayer for selected field crops

In Raichur, most of the field crops are sprayed by using manual sprayers and tractor drawn boom sprayers. Manual spraying is time consuming; uneven distribution of pesticide is also occurs due to various parameters. In conventional sprayers, apply the pesticide over top of the crop leads to more deposition in the upper surface, sometimes runoff of the pesticide occurs. Insects or pests hide in the lower position of the leaves, so efficacy of conventional sprayer is very less. Conventional tractor operated gun sprayer requires three persons, two is for swinging guns behind the tractor and one for driving tractor. Due to acute shortage of labour, spraying operations are delayed which leads to crop losses due to pest and disease attack. In order to reduce the losses occurred by these, right time of application is necessary. Hence, there is an urgent need for developing the tractor operated automatic gun sprayer which gives more deposition both under side and upper side with less contamination to the environment and to reduce the dependence on the labour.

A prototype of tractor operated automatic gun sprayer for spraying of chemical for field crops has been developed and fabricated by using crop and machine parameters. The development of tractor operated automatic gun sprayer was carried out in central workshop, Department of Farm Machinery and Power Engineering, CAE, UAS, Raichur. The essential components of sprayer are frame structure, spray tank, horizontal triplex pump, control valves, gun nozzle, pressure gauge, strainer, hydraulic agitator and actuating mechanism

4.4.1 Design of power transmission system

The power transmission unit is the main component of the sprayer and it provides the power to the working components of the sprayer. The rotary power to drive the hydraulic pump of the sprayer was taken from the P.T.O of tractor. Adjustable telescopic shaft is used to transmit the tractor P.T.O power to 160 mm pulley which was mounted at the bottom of frame structure. From that pulley, power transmitted to the pump shaft. V-belts and V-grooved pulleys are used to transmit power from one shaft to other parallel shaft. The design procedure used in section 3.2.2 was followed to design power transmission.

The velocity ratio of speed of pump and tractor P.T.O shaft was 1.6. The diameters of driving and driven pulley were 160 mm and 100 mm was provided on bottom pulley and pulley on pump shaft, respectively.

The belts are used for transferring power from one shaft to other shaft. The belt relies on the frictional effects for efficient work. When the belt and pulley is stationary, the tension between slack side and tight side is equal. When belt passes over the pulley, one portion of belt stretched and other portion becomes slack. Various parameters of V-belt of A-cross section are needed for design of the belt *viz.*, density and allowable tensile strength. These were taken as 1000 kg m^{-3} and 2.5 Mpa. A groove angle of (2β) of 35° was taken for design of belt. The method followed in section 3.2.2 (b) was used to calculate belt length.

The number of belt required to transfer the power from tractor P.T.O shaft to pump shaft has been calculated by using the formula. The total numbers of belt required were two. The total length of belt required to connect from driving pulley to driven pulley was 1.46 m and B77 belt was selected for power transmission.

4.4.2 Development of frame structure

The frame has a box section at the bottom to hold the chemical tank. A frame of 1000 mm × 630 mm × 920 mm was fabricated by 50 mm × 50 mm hallow square MS. At the front end of the box, two hitches were provided for attachment to tractor lower link. At the top of front portion of the box, rectangular frame was welded rigidly to serve as a support for pump. Just below the rectangular frame, top hitch was provided to attach the tractor top link. The inner section of the box could accommodate easily 500 litres chemical tank. Holes are provided at either side in rear frame to attach the spray boom. For support and to hold the delivery pipes hooks are provided at the top of rear frame.

4.4.3 Supporting frame for pump

The rectangular frame of 180 × 240 × 50 mm (W× L× T) was fabricated by using MS L-channel. Supporting frame was welded at the top of the frame structure across the frame. Pump was mounted on the supporting frame by using nuts and bolts.

4.4.4 Spray boom

The boom is a part of sprayer on which spray guns were mounted. The boom was attached to the rear portion of the frame structure. The spray boom was fabricated by using the 35 mm × 35 mm hallow square MS with thickness of 3 mm. One side of the boom has a locking arrangement. Actuating mechanism and spray guns are provided at the ends of boom. Height of boom can be adjusted to required height by attaching the boom to holes provided on the bottom frame structure. Holes are provided at every 15 cm interval. Boom height can be adjusted at an interval of 15 cm to 1.6 m to suit different crop conditions. Distances of the spray guns are also can be adjusted based on the crop parameter. Provision was also made to fold the spray boom while in transport**.** Sprayer in transport position is shown in the plate 14. The boom width of tractor operated automatic gun sprayer was calculated in the section 3.2.5. Total width of sprayer needed to cover an unit area was 5.1 m. Boom width has a major effect on uniformity of spray. Boom moment of inertia increases as boom length increases and the vertical movement of the boom results in non-uniform spray coverage. In order to reduce those effects, 1.7 m of two booms were fabricated and mounted on either side of the rear frame.

4.2.5 Selection of pump

A pump is the heart of the sprayer and key component to produce desired flow of spray. Various spraying situation requires different pressure and delivery rate, using correct sprayer pump is essential to achieve desired results. A pump must have sufficient capacity to operate a hydraulic agitation system, as well as to supply the necessary volume of spray liquid to the nozzles. The water horse power requirement of the pump was calculated in section 3.2.6. The water horse power requirement of pump was 2.52 hp. A commercially available 3 hp Usha horizontal triplex pump was selected to provide prerequisite discharge and pressure. The shaft horse power available at the pump shaft was 5 hp.

4.2.6 Selection of spray tank

Spray tank is mounted inside the bottom frame structure. The tank acts as a reservoir for the supply of chemical solution during the spray. The chemical solution is drawn from the tank through the suction hose pipe of the pump which is fitted with strainer to avoid the dirt and other foreign material entering the pump. For cotton and red

Plate 14 The sprayer in transport position

gram, application rate ranges from 125 to 350 l ha^{-1} depending on the equipment used. A plastic chemical tank of 500 litres capacity was selected in order to avoid the frequent refilling. Tank has 300 mm opening at the top of the tank for the filling of sprayer and for cleaning. The pump is connected to the chemical tank by means of flexible hose pipes.

4.2.7 Design of hydraulic agitation unit

Agitation is essential to combine the components of the spray mixture uniformly and for some formulations, to keep the pesticide in suspension. If agitation is inadequate, the application rate of the pesticide may vary as the tank is emptied. For hydraulic agitation, small portion of water from the bypass is diverted to tank. The amount of flow for agitation is depends on the chemical formulation, tank size and shape. Usually use 5 to 10 per cent of tanks capacity for agitation flow. The required flow for hydraulic agitation was 25 l h^{-1} was bypassed through 20 mm pipe.

4.2.8 Strainer

Proper filtering of the spray mixture not only protects the working parts of the spray system but also avoids misapplication due to nozzle tip clogging. Three types of strainers commonly used on sprayers are tank filler strainers, line strainers and nozzle strainers. It is positioned in between tank and pump. The 100 mm size of line filter was selected.

4.2.9 Control valves

The optimum operating discharge and pressure should be maintained for sprayer to produce desired droplets. The control valves basically controls the flow of liquid through pipe lines. The delivery from the pump is provided with two control valve *i.e.,* two way cock and pressure relief valve. A pressure regulator is provided in between pump and spray guns in order to control the discharge. Pressure regulator maintain working pressure on the discharge end of the system but move the overflow back into the tank at lower pressure, thus reducing strain on the engine and the pump. The excess chemical fluid pumped is returned to the spray tank through pressure relief valve. The chemical fluid is supplied to the two spray guns by two way cock. The bypass hose from the HTP pump was connected to the tank from the top through a hole provided at the upper side of the tank. The spray pressure was controlled by using bypass valve and the pressure gauge. A relief valve is provided with the pump to limit the maximum pressure.

4.2.10 Pressure guage

A pressure gauge is essential to the sprayer system to correctly indicate the pressure at the nozzle. Pressure directly affects the application rate and spray distribution. A pressure gauge is provided on the pump to display the adjusted pressure of the fluid to be discharged. The pressure gauge display ranges from 0 to 100 kg cm^{-2} (10 Mpa). The sprayer pressure guage was calibrated prior to the test.

4.2.11 Hoses

The hose diameter of 25 mm of 3.5 m length of pipe was selected for the discharge hose from pump. The 4 m length suction pipe having diameter of 30 mm was selected for suction pipe. The arrow line power plus hoses having maximum pressure capacity of 160 bar (163 kg cm^{-2}) were used.

4.2.12 Actuating mechanism for spray guns

The actuating mechanism provides power to spray guns for the oscillation. Actuating mechanism consists of motor and worm gear reduction. A worm gear is attached to the output shaft of the motor having worm. This worm gear spins around as motor turns. The worm gear is connected to long rod, as the gear rotates, it moves the rod and in turn provides oscillation motion to the spray guns. The worm gear and rod converts rotational output of motor into back and forth motion to spray guns. A 0.5 kW of two motors (12 V dc) were selected based on the rated capacity of tractor battery. The rated capacity of tractor is 12 V dc. Motor gets power from the tractor battery.

The design procedure for worm and worm gear for speed reduction between Dc motor and worm gear is explained in the section 3.2.10. The velocity ratio for first speed reduction was found to be 12. The driving worm was having 12 teeth and driven worm gear has 36 teeth. The peripheral velocity of worm gear was 12 m s^{-1}. The velocity required for second speed reduction was found to be 12.5. The number of teeth required for driven worm gear was 40 teeth. The torque transmitted by worm was 95 n-mm in second reduction unit. For third speed reduction, velocity ratio required was 13.6. The number teeth on driven pulley is 45 and torque transmitted by worm was 104 n-mm.

4.2.13 Spray guns

Two spray guns were mounted on the boom at either side of the frame structure. These get swinging action by actuating mechanism. Nozzles are mounted on the 45 cm lance. Spray guns are mounted on the boom at 1.6 m away from either side of the frame, though can change the distance of the guns based on the width of the spray. The angle of spray of each gun is 30 degree horizontally. Two spray guns are oscillating alternately from side to side. The length of lance was 45 cm and nozzle is mounted at one end of the lance, other end has controller for change of spray pattern.

4.2.14 Selection of power source

In modern agriculture, tractor has become one of the major sources of power which is used for majority of agricultural operations *i.e.*, tillage, land preparation, sowing and spraying *etc*. It provides power in different outlets. Now a days most of the sprayers available in the market are P.T.O shaft operated and three point hitch mounted sprayers. The procedure as explained in section 3.2.1 followed to calculate horsepower requirement for operating sprayer. A twelve horse power requirement is sufficient to operate the sprayer but total weight of the sprayer with tank full of water is 750 kg. The selected power source should be for both jobs *i.e.*, as power source to operate the sprayer and hydraulic system for lifting and holding the spray tank. By considering the above factors in addition with stability of tractor, 37.9 hp tractor was selected.

4.3 Laboratory evaluation of tractor operated automatic gun sprayer

The developed tractor operated automatic gun sprayer was evaluated under the laboratory to ascertain the performance under different variables. Its performance was evaluated in the Department of Farm Machinery and Power Engineering, Plant protection laboratory, CAE, UAS, Raichur under the controlled conditions to eliminate the effects caused by environmental parameters. Experiment was conducted under the different variables namely operating pressure, diameter of nozzle and orientation of spray nozzle to determine optimum value. The optimum values of those are important to ascertain the working of sprayer in the field condition. The laboratory calibration of sprayer was carried out in the same way as prescribed by the BIS code of IS: 11429 (1985): Methods for calibration of sprayers.

The laboratory experiments were carried out by using the actual cotton and pigeonpea plants. The cotton and pigeonpea plants were raised in the polyethylene bags and after certain age placed in pots as such (Gholap *et al*., 2012). The height of the crop was 450 cm and 650cm for cotton and pigeonpea, respectively. Instead of using false canopy, it was an attempt to establish actual plant canopy in the laboratory to get the correct results.

DepositScan is a scanning program that can quickly evaluate spray deposit distribution on water sensitive paper or kromokote *etc*. The system is integrated with a table scanner, deposit collectors, a laptop computer and a custom-designed software package entitled "DepositScan". It takes less than 30 second to process the deposit analysis for a card. DepositScan specifically quantifies spray deposit distributions on any paper type collector that could show visual differences between spray deposits and the background ImageJ is a Java-based image-processing program used for the acquisition and analysis of images. ImageJ can be used to measure an area and count number of spots in the user defined areas or throughout the entire image. The image processing speed of ImageJ is 40 million pixels s^{-1}. The DepositScan program version used does not provide the NMD. DepositScan is the one closest to the manual reading. The results obtained from the DepositScan software is shown in the Fig 16.

i. Effects of operating pressure, nozzle size and orientation of spray nozzle on discharge

The discharge of spray liquid delivered by different nozzle size at different operating pressure in the range of 20-24 kg cm^{-2} for different orientation of spray nozzle is presented in Table 9. The discharge of sprayer nozzle sizes of 2, 4 and 6 mm at operating pressure of 20 kg cm^{-2} were 8.40, 10.30 and 12.30 l min^{-1}, respectively for 0 degree orientation of nozzle. For 20 kg cm^{-2}, the maximum discharge of the sprayer was found to be 12.33 for 6 mm nozzle at 30 degree orientation of nozzle. The average discharge varied from 12.80 to 13.60 l min^{-1} as the pressure increased from 22 to 24 kg cm^{-2} for 2 mm nozzle size. The discharge (8.36 l min^{-1}) was observed minimum for 2 mm nozzle at 20 kg cm^{-2} for 30 degree orientation of nozzle. It was observed from the results, discharge of the sprayer was directly proportional to operating pressure and nozzle size. The orientation of nozzle had no effect on the discharge of the sprayer.

Table 9. Effect of operating pressure, nozzle size and orientation of nozzle on discharge of sprayer

Sl. no	Operating pressure ($kg\ cm^{-2}$)	Nozzle size (mm)	Discharge ($l\ min^{-1}$) Orientation of nozzle (Degree)		
			0	**15**	**30**
1	20	2	8.40	8.43	8.36
		4	10.30	10.28	10.32
		6	12.30	12.30	12.33
2	22	2	12.80	12.82	12.81
		4	13.90	13.70	13.92
		6	15.20	15.30	15.10
3	24	2	13.60	13.63	13.62
		4	15.40	15.41	15.38
		6	16.50	16.50	16.52

DepositScan Analysis Results -- USDA/ARS ATRU, WOOSTER, OHIO

DV 1 (µm)	DV 5 (µm)	DV 9 (µm)	% Coverage	Image Area (cm²)
106	167	280	6.25	0.65

Object	Image Spot Area (µm²)	Actual Diameter (µm)
1	5376.32	52.82
2	5376.32	52.82
3	5376.32	52.82
4	5376.32	52.82
5	5376.32	52.82
6	5376.32	52.82
7	5376.32	52.82
8	7168.43	60.21
9	7168.43	60.21
10	7168.43	60.21
11	7168.43	60.21
12	7168.43	60.21
13	7168.43	60.21
14	8960.54	66.65
15	8960.54	66.65
16	8960.54	66.65
17	8960.54	66.65
18	8960.54	66.65
19	8960.54	66.65
20	8960.54	66.65
21	10752.65	72.41
22	10752.65	72.41
23	10752.65	72.41

106 Total Deposits Counted   61.9 deposits/cm²   0.221 µL/cm²   Save...

Fig. 16 The results obtained from the DepositScan software (Sample: 20 kg/cm^2 operating pressure, middle position of the top surface)

The experimental results of discharge of sprayer were analyzed using Design-Expert software is shown in Table 10. To check the adequacy of the model, model sum of the squares, pure error and model summary statics were made. The results from the anova table indicated that, the main effect of each factor of operating pressure (A) and nozzle size (B) significantly influenced the discharge at 1 per cent level of significance but the main effect of orientation of spray nozzle has non significant as it did not had effect on the discharge. Among the two influenced variables, the operating pressures had highly significant followed by nozzle size. If the Prob > value of the model is considerably less than the 0.01, then the terms in the model have a significant effect on the model. The model F- value of 57.37 implies the model is significant. There is only 0.01 per cent chance for a model F-value of this large could occur due to noise. The interaction effect (A × B) has 1 per cent significant.

ii. Effects of operating pressure, nozzle size and orientation of spray nozzle on length of throw

The length of throw of the spray liquid for 2 mm nozzle size at different operating pressure in ranges from 20 to 24 kg cm^{-2} was found to be 2.10, 2.90 and 3.40 m at the 0 degree orientation of spray nozzle (Table 11). It was seen that the length of throw varied from 2.10 to 1.84 as the inclination varies from 0 to 30 degree orientation of spray nozzle for 2 mm nozzle at 20 kg cm^{-2} operating pressure. The average length of throw varied from 2.90, 3.10 and 3.90 m for 4 mm nozzle size at different operating pressure where as, for 6 mm nozzle size 3.20 to 4.20 m from 20 to 24 kg cm^{-2} operating pressure. Table indicates that change in orientation of spray nozzle changed the length of throw. The higher pressure (24 kg cm^{-2}) with three levels of nozzle size at 0 degree orientation of spray gave highest length of throw. Low pressure (20 kg cm^{-2}) with 30 degree orientation of spray nozzle produced a minimum length of throw.

Statistical analysis of length of throw is presented in Table 12. To check the adequacy of the model, model sum of the squares pure error and model summary statics were made. The results from the anova table, the main effect of each factor of operating pressure (A), nozzle size (B) and orientation of spray nozzle (C) significantly influenced the length of throw of sprayer. If the Prob > value of the model is considerably less than the 0.01, then the terms in the model have a significant effect on the model. The model F-value of 44.88 implies the model is significant. There is only 0.01 per cent chance for a

Table 10. Analysis of variance for discharge

Source	Sum of Squares	df	Mean Square	F Value
Model	474.68	26	18.26	57.37 **
A-Operating pressure	341.47	2	170.73	536.51**
B-Size of nozzle	126.80	2	63.40	199.23**
C-Orientation of nozzle	0.03	2	0.06	0.04 NS
AB	6.26	4	1.56	4.92**
AC	0.04	4	0.02	0.05 NS
BC	0.05	4	0.01	0.04 NS
ABC	0.10	8	0.01	0.04 NS
Pure Error	17.18	54	0.32	
Cor Total	491.86	80		

Std. Dev.	0.56	R-Squared	0.97
Mean	13.15	Adj R-Squared	0.95
C.V. (Per cent)	4.29	Pred R-Squared	0.92
PRESS	38.66	Adeq Precision	25.05

** = Significant at 1 per cent level, NS = Non significant

Table 11. Effect of operating pressure, nozzle size and orientation of nozzle on length of throw

Sl. no	Operating pressure ($kg\ cm^{-2}$)	Nozzle size (mm)	Length of throw (m) Orientation of nozzle (Degree)		
			0	**15**	**30**
1	20	2	2.10	1.94	1.84
		4	2.90	2.60	2.54
		6	3.20	3.00	2.85
2	22	2	2.90	2.70	2.63
		4	3.10	2.90	2.75
		6	3.70	3.50	3.20
3	24	2	3.40	3.20	3.00
		4	3.90	3.70	3.72
		6	4.20	4.10	3.80

Table 12. Analysis of variance for length of throw

Source	Sum of Squares	df	Mean Square	F Value
Model	33.93	26.00	1.30	44.88 **
A-Operating pressure	15.94	2.00	7.97	274.10 **
B-Size of nozzle	7.69	2.00	3.85	132.26 **
C-Orientation of nozzle	3.34	2.00	1.67	57.39 **
AB	2.43	4.00	0.61	20.86 **
AC	0.96	4.00	0.24	8.26 **
BC	1.38	4.00	0.35	11.90 **
ABC	2.19	8.00	0.27	9.43 **
Pure Error	1.57	54.00	0.03	
Cor Total	35.50	80.00		

Std. Dev.	0.17	R-Squared	0.96
Mean	3.04	Adj R-Squared	0.93
C.V. (Per cent)	5.61	Pred R-Squared	0.90
PRESS	3.53	Adeq Precision	23.97

** = Significant at 1 per cent level   NS = Non significant model F-value of this large could occur due to noise. The interaction effects (A × B), (B × C), (A × C) and (A × B × C) have 1 per cent significant.

iii. Effects of operating pressure and nozzle size on the volumetric distribution of water

The effects of operating pressure and nozzle size on the volumetric distribution of water is presented in the Table 13, 14 and 15. It can be observed that the volumetric distribution was more in the centre of the patternator. Volumetric distribution was less as the distance increased from the centre of the patternator. It can also be found that volumetric distribution was more as the pressure increased from the 20 to 24 kg cm^{-2}.

iv. Effects of operating pressure, nozzle size and orientation of spray nozzle on droplet density in cotton crop

The droplet density on upper side of top, middle and bottom position of leaves were 63.8, 58.4 and 15.2 no's cm^{-2} whereas, under side of leaves received a droplet density of 11.4, 8.3 and 0 drops cm^{-2}, respectively for 2 mm nozzle size at 0 degree orientation of nozzle (Table 16). The droplet density on upper side of top, middle and bottom position of leaves were varied 76.7, 73.9 and 19.2 no's cm^{-2} to 105.2, 96 and 26 no's cm^{-2} as the pressure was increased from 20 kg cm^{-2} to 24 kg cm^{-2} for 4 mm nozzle size where as droplets number at underside of top, middle and bottom was varied from 16.9, 10.2 and 0 to 26, 19.4 and 0 no's cm^{-2}. For 6 mm nozzle size, droplet densities on upper side of top, middle and bottom position varied from 95.8, 91.1 and 25 no's cm^{-2} to 125.8, 105.9 and 36.2 no's cm^{-2}. The highest droplet densities were observed on top positions of the plant, which was followed by middle and bottom plant.

The effect of operating pressure, nozzle size and 15 degree orientation of spray nozzle on droplet density for cotton crop is presented in Table 17. It can be seen that, droplet density at upper surface more than the underside position of leaves. The droplet density at different operating pressure in range of 20 to 24 kg cm^{-2} for 2 mm nozzle size varied from 65.9, 61 and 29.1 no's cm^{-2} to 76.9, 73.1 and 36 no's cm^{-2} for upper side of top, middle and bottom position of plant, respectively whereas for underside of top, middle and bottom position of plant was varied from 28.3, 21.1 and 5.2 to 35.4, 31.2 and 13.6 no's cm^{-2}, respectively. It can also be seen that the droplets covered all the parts of the plant canopy. Deposition of the spray droplets on both upper and underside of plant

Table 13. Effect of nozzle size on the volumetric distribution at operating pressure of 20 kg cm^{-2}

i.

Nozzle size (mm)	**Volumetric distribution (ml)**																					
	Channel number (right side of the patternator)																					
	33	32	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12
2	--	--	--	--	--	--	--	--	--	--	74	74.5	75	78	78.5	80.0	82.5	87.5	89.5	85.5	87	86
4	--	--	--	--	--	71.0	72.5	74	74.5	75.5	77.5	79.5	82	85	87.5	92.5	94.5	95.5	97.5	105.0	104.0	102.5
6	57.5	60.0	65.0	67.0	71.0	73.0	75.5	77	81.0	82.5	82.5	83.0	84	86	89.5	90.5	92.0	93.0	97.0	102.5	105.0	103.5

ii.

Nozzle size (mm)	**Volumetric distribution (ml)**																			
	Channel number (middle of the patternator)																			
	11	10	9	8	7	6	5	4	3	2	1	0	1	2	3	4	5	6	7	8
2	91	90.5	92.5	92	94.5	92	92.5	94.5	94.5	103	102.5	95.5	92	87.5	86	105	102.5	97.5	96	92.5
4	100.5	102.5	104.5	105	105	104.5	105	103	102	100.5	97	98.5	97.5	105	104.5	105	104.5	104	103.5	105

6	102.5	104.5	101.5	102	98.5	96	97	98	104.5	102.5	100.5	103	101.5	99.5	97.5	102.5	100.5	103	102	100.5

iii.

Nozzle size (mm)	**Volumetric distribution (ml)**																					
	Channel number (left of the patternator)																					
	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
2	93	94.5	95.5	87.5	86	89.5	82.5	81	79.5	77.5	76.5	70.5	73	74.5	--	--	--	--	--	--	--	--	--
4	104.5	103.5	100.5	97	97	94.5	93.5	90.5	88	85.5	84	82.5	81	82	77.5	77.5	71	71	--	--	--	--	--
6	97	96	97	96	97	97.5	95.5	96.5	95.5	96	92.5	90.5	88	86	80.5	79.5	77	75.5	74	71	73	97	96

Table 14. Effect of nozzle size on the lateral distribution of water at operating pressure of 22 kg cm^{-2}

i.

Nozzle size (mm)	**Volumetric distribution (ml)**																					
	Channel number (right side of the patternator)																					
	35	34	33	32	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14
2	--	--	--	--	--	--	--	--	--	--	87.5	89.5	93.5	95.5	93.5	96.5	100.5	102.5	106.5	108	109.5	113
4	--	--	--	--	70.5	71.5	73	81	80.5	81	87.5	93	98	100.5	103	105	106.5	109.5	110.5	111.5	113	118

6	77	79.5	84	84	87.5	87.5	85	91	90.5	89.5	91.5	91.5	90.5	91.5	97.5	98.5	99.5	100	103	105	109.5	112.5

ii.

Nozzle size (mm)	**Volumetric distribution (ml)**																		
	Channel number (middle of the patternator)																		
	12	11	10	9	8	7	6	5	4	3	2	1	0	1	2	3	4	5	6
2	120.5	125.5	138	138	145.5	158	167	165	166	150	147	145.5	155	152.5	163	160.5	159	154.5	151
4	120	128	130	132	135.5	136	139.5	146	148.5	150	150.5	152.5	154.5	154.5	145	150.5	152.5	152	154.5
6	117.5	121	126	134	136.5	139	145	152.5	156	158	150	148	150	154.5	157.5	143.5	138	135	136.5

iii.

Nozzle size (mm)	**Volumetric distribution (ml)**																		
	Channel number (left of the patternator)																		
	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
2	130	157.5	145	140.5	138	133.5	125	123	120.5	117	97	98	94.5	93	91	89.5	87.5	86.5	85.5
4	146.5	136	137.5	132	140	137.5	120	115	110	105	102.5	104.5	103	97.5	87.5	84	82.5	79.5	76

6	129	129.5	123.5	119	113	111	107.5	98	96	93	97.5	95.5	96	94.5	91	82	82.5	78	79.5

iv.

Nozzle size (mm)	**Volumetric distribution (ml)**																		
	Channel number (left of the patternator)																		
	26	27	28	29	30	31	32	33	34	35	26	27	28	29	30	31	32	33	34
2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
4	75	71.5	71.5	71	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
6	80.5	80.5	84	86	84	81	84.5	78	76.5	75.5	80.5	80.5	84	86	84	81	84.5	78	76.5

Table 15. Effect of nozzle size on the volumetric distribution at operating pressure of 24 kg cm^{-2}

i.

Nozzle size (mm)	Volumetric distribution (ml)																					
	Channel number (right side of the patternator)																					
	45	44	43	42	41	40	38	36	35	34	33	32	31	30	29	28	27	26	25	24	23	22
2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	72.5	74.5	75.5	76.5	84	89.5	92.5	95.5
4	--	--	--	--	--	--	70.5	73	75.5	84	84	86	87.5	85	90.5	87.5	89.5	91.5	91.5	89	92.5	96
6	57.5	60.5	62.5	66	69.5	71	73	75.5	78	79.5	86	86	88	84	79	79.5	82.5	84	85.5	91	97.5	104

ii.

Nozzle size (mm)	Volumetric distribution (ml)																	
	Channel number (middle of the patternator)																	
	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4
2	91	95.5	100.5	102.5	106.5	108	109.5	108	114	119	124.5	128.5	130.5	139.5	153.5	154	157.5	152.5
4	98.5	97.5	100	103	105	109.5	112.5	115.5	117.5	121	126	134	136.5	139	145	152.5	154.5	157
6	105	107.5	110.5	110.5	110.5	111.5	113	119.5	120.5	119	132	131	129.5	139.5	143	144	143	148

iii.

Nozzle size (mm)	Volumetric distribution (ml)																		
	Channel number (left side of the patternator)																		
	3	2	1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
2	147	141	145.5	151	152.5	154	150.5	152	154.5	151	130	150.5	145	138	138	133.5	125	123	120.5
4	150	148	150	154.5	151	141	141	134	132	124.5	123	119	121.5	110.5	113	106.5	98.5	90.5	90
6	146	148.5	145.5	140	140.5	143	146	148	141.5	144.5	141.5	140.5	135.5	137.5	130	130.5	120	115	110

iv.

Nozzle size (mm)	Volumetric distribution (ml)																		
	Channel number (left side of the patternator)																		
	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34
2	117	97	98	94.5	93	91	89.5	87.5	86.5	85.5	82.5	77	76	72.5	--	--	--	--	--
4	98.5	94.5	91	82	86	80	81	77.5	77.5	80	80.5	79.5	82.5	80.5	81	79	78	76.5	75.5
6	105	102.5	104.5	103	97.5	87.5	84	82.5	79.5	84	84	86	84	81	80.5	80	79.5	77	74.5

v.

Nozzle size (mm)	**Volumetric distribution (ml)**															
	Channel number (left side of the patternator)															
	35	36	40	41	42	43	44	45	35	36	40	41	42	43	44	45
2	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
4	71	70	--	--	--	--	--	--	--	--	--	--	--	--	--	--
6	72	70.5	67.5	65.5	62.5	60.5	57.5	56	72	70.5	67.5	65.5	62.5	60.5	57.5	26

Table 16. Effect of operating pressure and nozzle size on droplet density of sprayer at 0 degree orientation of nozzle for cotton crop

Sl. no	Operating pressure (kg cm^{-2})	Nozzle size (mm)	Droplet density (No's cm^{-2})					
			Position of leaves on plant canopy					
			Top		Middle		Bottom	
			Upper	Lower	Upper	Lower	Upper	Lower
1	20	2	63.8	11.4	58.4	8.3	15.2	0
		4	76.7	16.9	73.9	10.2	19.2	0
		6	95.8	25.4	91.1	12.1	25.0	0
2	22	2	65.8	15.0	59.3	10.0	19.0	0
		4	79.3	19.3	75.6	13.1	21.1	0
		6	105.3	26.3	96.4	15.1	29.9	0
3	24	2	73.0	16.2	69.9	12.0	21.1	0
		4	105.2	26.0	96.0	19.4	26.0	0
		6	125.8	31.0	105.9	23.0	36.2	0

Table 17. Effect of operating pressure and nozzle size on droplet density of sprayer at 15 degree orientation of nozzle for cotton crop

Sl. no	Operating pressure (kg cm^{-2})	Nozzle size (mm)	Droplet density (No's cm^{-2})					
			Position of leaves on plant canopy					
			Top		Middle		Bottom	
			Upper	Lower	Upper	Lower	Upper	Lower
1	20	2	65.9	28.3	61.0	21.1	29.1	5.2
		4	82.0	32.4	76.3	22.6	32.0	8.3
		6	92.9	33.2	85.4	23.6	42.1	11.9
2	22	2	68.7	32.1	64.0	26.4	31.3	9.0
		4	85.0	35.4	78.2	28.1	36.0	12.1
		6	96.3	36.1	92.0	31.2	46.9	16.1
3	24	2	76.9	35.4	73.1	31.2	36.0	13.6
		4	116.0	35.9	94.8	32.9	39.1	14.0
		6	121.7	43.1	115.0	41.0	51.1	19.8

leaves improved at 15 degree orientation of spray nozzle. The maximum mean droplet densities at almost all positions were observed with 15 degree orientation of nozzle

The droplet density at different operating pressure, nozzle size and at 30 degree orientation of spray nozzle is presented in Table 18. It was found that the upper side of top and lower surface did not receive droplets when the orientation of spray nozzle was 30 degree. Droplet density at top position of upper and lower of plant leaves were 0 no's cm^{-2} for all the treatments. The droplet density was more in the middle position followed by bottom position.

The maximum droplet density at the top position of upper surface (121.7) was obtained at higher pressure (24 kg cm^{-2}) for 6 mm nozzle and droplet density (65.9) was obtained lowest at lower pressure (20 kg cm^{-2}) for 2 mm nozzle size at orientation of nozzle was 15 degree.

Analysis of variance on droplet density both on upper and lower surface of the plant leaves (Table 19 and 20) showed that the operational parameter *viz*., operating pressure, nozzle size, orientation of nozzle and position of the plant had a significant effect at 1 per cent level of significance on droplet density at both upper and lower surface of plant. The interaction effects have 1 per cent level of significance. Among all main effects, operating pressure had highly significant effect on the droplet density followed by nozzle size and orientation of the spray nozzle.

v. Effects of operating pressure, nozzle size and orientation of spray nozzle on droplet size in cotton crop

The droplet size produced from the sprayer at different operating pressure and nozzle sizes for different orientation of nozzle is presented in the Table 21, 22 and 23. It was observed from the results that the droplet size decreased from top to bottom surface of the plant canopy. Droplet size was maximum on the upper surface of the plant than the underside of the leaves. Droplet size was found to be in the range of 183 to 135 µm on upper surface and 169 to 0 µm on lower surface of the leaves, respectively for 2 mm nozzle size at different operating pressure. Droplet size was decreased from 191 to 162 and 197 to 172 µm on upper surface when pressure increased from 20 to 24 kg cm^{-2} for 4 and 6 mm nozzle size. For all the treatment in the experiment at zero degree orientation of

Table 18. Effect of operating pressure and nozzle size on droplet density of sprayer at 30 degree orientation of nozzle for cotton crop

Sl. no	Operating pressure (kg cm^{-2})	Nozzle size (mm)	Droplet density (No's cm^{-2})					
			Position of leaves on plant canopy					
			Top		Middle		Bottom	
			Upper	Lower	Upper	Lower	Upper	Lower
1	20	2	0	0	61.9	31.3	36.6	14.0
		4	0	0	72.2	36.2	39.1	16.1
		6	0	0	85.9	45.1	51.4	19.4
2	22	2	0	0	71.0	34.0	39.4	17.0
		4	0	0	75.4	39.6	41.0	19.0
		6	0	0	87.2	52.5	56.4	23.0
3	24	2	0	0	73.0	39.4	46.8	19.0
		4	0	0	77.9	43.0	46.0	22.6
		6	0	0	91.8	62.9	61.0	26

Table 19. Analysis of variance for droplet density for upper surface of cotton crop

Source	Sum of Squares	df	Mean Square	F Value
Model	269196.41	80.00	3364.96	406.34 **
A-Operating pressure	6489.77	2.00	3244.88	391.84 **
B-Nozzle size	21482.57	2.00	10741.28	1297.08* *
C-Orientation of nozzle	34853.59	2.00	17426.80	2104.41 **
D-Position of crop	81099.67	2.00	40549.84	4896.67 **
AB	765.31	4.00	191.33	23.10 **
AC	1206.64	4.00	301.66	36.43 **
AD	1129.41	4.00	282.35	34.10 **
BC	2652.70	4.00	663.18	80.08 **
BD	1429.62	4.00	357.40	43.16 **
CD	111585.07	4.00	27896.27	3368.67 **
ABC	630.59	8.00	78.82	9.52 **
ABD	500.12	8.00	62.52	7.55 **
ACD	2057.43	8.00	257.18	31.06 **
BCD	2873.67	8.00	359.21	43.38 **
ABCD	440.24	16.00	27.51	3.32 **
Pure Error	1341.54	162.00	8.28	
Cor Total	270537.95	242.00		

Std. Dev.	2.88	R-Squared	1.00
Mean	57.92	Adj R-Squared	0.99
C.V. (Per cent)	4.97	Pred R-Squared	0.99
PRESS	3018.46	Adeq Precision	75.72

** = Significant at 1 per cent level, NS = Non significant

Table 20. Analysis of variance for droplet density for lower surface of cotton crop

Source	Sum of Squares	df	Mean Square	F Value
Model	46058.69	80.00	575.73	614.23 **
A-Operating pressure	1247.20	2.00	623.60	665.30 **
B-Nozzle size	2749.32	2.00	1374.66	1466.59 **
C-Orientation of nozzle	5236.18	2.00	2618.09	2793.17 **
D-Position of crop	10288.00	2.00	5144.00	5488.00 **
AB	73.82	4.00	18.45	19.69 **
AC	34.83	4.00	8.71	9.29 **
AD	102.09	4.00	25.52	27.23 **
BC	102.33	4.00	25.58	27.29 **
BD	324.11	4.00	81.03	86.45 **
CD	24054.91	4.00	6013.73	6415.88 **
ABC	112.79	8.00	14.10	15.04 **
ABD	96.44	8.00	12.06	12.86 **
ACD	272.69	8.00	34.09	36.37 **
BCD	1164.19	8.00	145.52	155.26 **
ABCD	199.78	16.00	12.49	13.32 **
Pure Error	151.85	162.00	0.94	
Cor Total	92269.22	80.00		

Std. Dev.	5.20	R-Squared	1.00
Mean	119.65	Adj R-Squared	0.99
C.V. (Per cent)	4.35	Pred R-Squared	0.99
PRESS	9873.27	Adeq Precision	60.90

** = Significant at 1 per cent level, NS = Non significant

Table 21. Effect of operating pressure and nozzle size on droplet size of sprayer at 0 degree orientation of nozzle for cotton crop

Sl. no	Operating pressure (kg cm^{-2})	Nozzle size (mm)	Droplet size (µm)					
			Position of leaves on plant canopy					
			Top		Middle		Bottom	
			Upper	Lower	Upper	Lower	Upper	Lower
1	20	2	183	169	171	148	151	0
		4	191	176	178	156	162	0
		6	197	182	185	162	172	0
2	22	2	165	158	165	143	146	0
		4	180	166	173	151	154	0
		6	189	172	181	159	161	0
3	24	2	156	141	146	134	135	0
		4	162	156	152	146	142	0
		6	172	164	166	152	146	0

Table 22. Effect of operating pressure and nozzle size on droplet size of sprayer at 15 degree orientation of nozzle for cotton crop

Sl. no	Operating pressure (kg cm^{-2})	Nozzle size (mm)	Droplet size (µm)					
			Position of leaves on plant canopy					
			Top		Middle		Bottom	
			Upper	Lower	Upper	Lower	Upper	Lower
1	20	2	171	155	162	145	149	128
		4	183	161	173	152	151	131
		6	191	169	183	161	163	138
2	22	2	163	146	146	134	139	121
		4	177	153	152	141	146	127
		6	186	160	163	152	149	133
3	24	2	152	138	142	131	133	115
		4	164	143	153	136	139	121
		6	175	154	158	140	143	128

Table 23. Effect of operating pressure and nozzle size on droplet size of sprayer at 30 degree orientation of nozzle for cotton crop

Sl. no	Operating pressure (kg cm^{-2})	Nozzle size (mm)	Droplet size (µm)					
			Position of leaves on plant canopy					
			Top		Middle		Bottom	
			Upper	Lower	Upper	Lower	Upper	Lower
1	20	2	0	0	167	159	154	142
		4	0	0	181	165	162	153
		6	0	0	194	173	171	159
2	22	2	0	0	162	143	146	136
		4	0	0	175	156	152	141
		6	0	0	183	167	164	153
3	24	2	0	0	159	136	139	129
		4	0	0	164	144	145	138
		6	0	0	170	154	151	141

nozzle, the bottom position of the lower side leave did not receive droplets. Hence, its droplet size was zero.

From the Table 22, it can be seen that as the nozzle size increases from 2 to 6 mm, the droplet size increased from 171 to 191 µm on the upper surface of top position. The droplet size was decreased from all the position as pressure increased from lower to higher pressure. The droplet size was maximum on the upper side of the top position followed by middle and bottom surface of leaves. The droplet size was obtained maximum at 20 kg cm^{-2} for 6 mm nozzle size and minimum droplet size was obtained at higher pressure (24 kg cm^{-2}) with lower nozzle size (2 mm) at upper surface of the plant canopy.

The droplet size of the sprayer by the different nozzle sizes at different operating pressure in the range of 20 to 24 kg cm^{-2} for 30 degree orientation of spray nozzle is presented in the Table 23**.** It was observed that the droplet size was zero at the top surface of the plant. The highest droplet size was obtained on the middle positions of the plant as spray was targeted to the middle and lower positions of the plant. The maximum droplet size on upper surface of the middle position was obtained at 20 kg cm^{-2} operating pressure for 6 mm nozzle size and the minimum droplet size was recorded at 24 kg cm^{-2} for the diameter of 2 mm nozzle size.

Statistical analysis of droplet size on both upper and lower position of the plant is presented in the Table 24 and 25. The results showed that the main effect of each factor of operating pressure (A), nozzle size (B), orientation of spray nozzle (C) and position of the plant canopy (D) significantly influenced on the droplet size both on upper and underside of the leaves at 1 per cent level of significance. The interaction effects have significant at 1 per cent level of significance.

vi. Effects of operating pressure, nozzle size and orientation of spray nozzle on droplet density in pigeonpea crop

The droplet density produced on upper and lower surface of the plant by different nozzle sizes at different operating pressure in ranges of 20 to 24 kg cm^{-2} for different orientation of spray nozzle is presented in the Table 26, 27 and 28**.** It was seen that the droplet size decreased from top to bottom surface of the plant. Deposition on the upper side of the leaves was greater than the underside of the leaves. The maximum droplet density was 119.5, 113.7 and 43.7 no's cm^{-2} on upper top, middle and bottom position of

Table 24. Analysis of variance for droplet size for upper surface of cotton crop

Source	Sum of Squares	df	Mean Square	F Value
Model	638518.27	80.00	7981.48	138.15 **
A-Operating pressure	25548.42	2.00	12774.21	221.11 *
B-Nozzle size	1116.18	2.00	558.09	9.66 **
C-Orientation of nozzle	143158.98	2.00	71579.49	1239.00 **
D-Position of crop	68394.37	2.00	34197.19	591.93 **
AB	2825.49	4.00	706.37	12.23 **
AC	1456.35	4.00	364.09	6.30 **
AD	4272.16	4.00	1068.04	18.49 **
BC	8645.06	4.00	2161.27	37.41 **
BD	3024.01	4.00	756.00	13.09 **
CD	334587.93	4.00	83646.98	1447.88 **
ABC	6437.22	8.00	804.65	13.93 **
ABD	6816.60	8.00	852.07	14.75 **
ACD	6321.05	8.00	790.13	13.68 **
BCD	10989.68	8.00	1373.71	23.78 **
ABCD	14924.77	16.00	932.80	16.15 **
Pure Error	9359.07	162.00	57.77	
Cor Total	647877.34	242.00		

Std. Dev.	7.60	R-Squared	0.99
Mean	145.73	Adj R-Squared	0.98
C.V. (Per cent)	5.22	Pred R-Squared	0.97
PRESS	21057.91	Adeq Precision	50.90

** = Significant at 1 per cent level, NS = Non significant

Table 25. Analysis of variance for droplet size for lower surface of cotton crop

Source	Sum of Squares	df	Mean Square	F Value
Model	967896.60	80.00	12098.71	446.66 **
A-Operating pressure	14104.06	2.00	7052.03	260.35 **
B-Nozzle size	1183.24	2.00	591.62	21.84 **
C-Orientation of nozzle	93397.17	2.00	46698.58	1724.01 **
D-Position of crop	155514.43	2.00	77757.21	2870.63 **
AB	3112.12	4.00	778.03	28.72 **
AC	2550.41	4.00	637.60	23.54 **
AD	6216.26	4.00	1554.07	57.37 **
BC	5521.45	4.00	1380.36	50.96 **
BD	2715.52	4.00	678.88	25.06 **
CD	644196.71	4.00	161049.18	5945.59 **
ABC	6436.60	8.00	804.58	29.70 **
ABD	6814.08	8.00	851.76	31.45 **
ACD	3019.34	8.00	377.42	13.93 **
BCD	8099.86	8.00	1012.48	37.38 **
ABCD	15015.35	16.00	938.46	34.65 **
Pure Error	4388.12	162.00	27.09	
Cor Total	972284.72	242.00		

Std. Dev.	5.20	R-Squared	1.00
Mean	119.65	Adj R-Squared	0.99
C.V. (Per cent)	4.35	Pred R-Squared	0.99
PRESS	9873.27	Adeq Precision	60.90

** = Significant at 1 per cent level, NS = Non significant

Table 26. Effect of operating pressure and nozzle size on droplet density at 0 degree orientation of nozzle for pigeonpea crop

Sl. no	Operating pressure (kg cm^{-2})	Nozzle size (mm)	Droplet density (No's cm^{-2})					
			Position of leaves on plant canopy					
			Top		Middle		Bottom	
			Upper	Lower	Upper	Lower	Upper	Lower
1	20	2	71.4	19.1	64.2	10.7	21.1	0
		4	82.1	26.7	73.4	15.4	26.7	0
		6	103.2	32.2	96.9	21.6	31.0	0
2	22	2	77.1	23.1	69.4	15.9	23.4	0
		4	86.6	29.7	76.7	19.2	28.0	0
		6	112.3	36.6	105.9	22.4	36.2	0
3	24	2	82.7	29.9	73.9	19.1	26.1	0
		4	97.3	31.2	82.7	26.8	31.6	0
		6	119.5	41.7	113.7	26.9	43.7	0

Table 27. Effect of operating pressure and nozzle size on droplet density at 15 degree orientation of nozzle for pigeonpea crop

Sl. no	Operating pressure (kg cm^{-2})	Nozzle size (mm)	Droplet density (No's cm^{-2})					
			Position of leaves on plant canopy					
			Top		Middle		Bottom	
			Upper	Lower	Upper	Lower	Upper	Lower
1	20	2	71.3	38.4	66.4	31.1	29.6	6.0
		4	76.7	42.1	71.8	33.2	31.1	10.1
		6	89.3	44.6	79.4	34.9	429	12.1
2	22	2	73.9	42.3	69.3	34.1	34.7	7.8
		4	79.8	46.1	71.6	39.1	39.0	11.1
		6	93.2	46.9	83.0	41.3	46.1	14.4
3	24	2	79.2	43.2	76.4	35.2	29.8	16.7
		4	86.0	46.3	83.5	40.5	36.7	16.9
		6	102.1	49.5	95.4	42.1	53.1	21.7

Table 28. Effect of operating pressure and nozzle size on droplet density at 30 degree orientation of nozzle for pigeonpea crop

Sl. no	Operating pressure (kg cm^{-2})	Nozzle size (mm)	Droplet density (No's cm^{-2})					
			Position of leaves on plant canopy					
			Top		Middle		Bottom	
			Upper	Lower	Upper	Lower	Upper	Lower
1	20	2	0	0	65.1	31.0	32.9	9.7
		4	0	0	69.6	36.0	35.2	12.2
		6	0	0	81.6	45.6	49.1	15.9
2	22	2	0	0	69.8	34.5	32.2	11.0
		4	0	0	72.9	39.0	36.1	14.2
		6	0	0	83.7	52.3	51.8	16.0
3	24	2	0	0	72.9	39.2	41.0	15.0
		4	0	0	76.0	36.7	39.1	17.8
		6	0	0	86.5	62.0	53.0	19.2

the plant where as, droplet density was 41.7, 26.9 and 0 no's cm^{-2} on lower top, middle and bottom position of the plant for 0 degree orientation of the spray nozzle for 6 mm nozzle size when operating pressure was 24 kg cm^{-2}. The minimum droplet density was recorded for 2 mm nozzle at operating pressure was 20 kg cm^{-2}.

The droplet density at different operating pressure and nozzle size at 15 degree orientation of the spray nozzle is presented in Table 27. It can be seen from the table, spray droplets were covered entire the plant canopy. The droplet density at under side of the leaves was also increased as orientation of spray nozzle changed from 0 to 15 degree. The maximum mean droplet densities at almost all the positions were observed with 15 degree orientation of spray nozzle. The droplet density produced by sprayer at 30 degree orientation of the spray nozzle is presented in the Table 28. It was observed from the table that the upper side of the plant position did not receive the droplets. The maximum droplet density was obtained at middle followed by bottom positions of the plant. The droplet density varied from 65.1 to 72.9 on upper surface of the middle position where as droplet density on underside varied from 31 to 39.2 for 2 mm nozzle size as the pressure increased from low to high. The maximum droplet density (86.5 no's cm^{-2}) was obtained on upper surface for 6 mm nozzle at operating pressure of 24 kg cm^{-2} where as minimum (65.1 no's cm^{-2}) was obtained for 2 mm nozzle on middle position of the plant at 20 kg cm^{-2}.

Effects of different variables on droplet density were summarized through analysis of variance for both upper and lower position of the plant is presented in the Table 29 and 30. The results showed that the main effect of each factor of operating pressure (A), nozzle size (B), orientation of spray nozzle (C) and position of the plant canopy (D) significantly influenced on the droplet density both on upper and underside of the leaves at 1 per cent level of significance. The interaction effects have 1 per cent significant.

vii. Effects of operating pressure, nozzle size and orientation of spray nozzle on droplet size in pigeonpea crop

The droplet size produced by different nozzle size at different operating pressure in the range of 20 to 24 kg cm^{-2} for various orientation of spray nozzle is presented in the Table 31, 32 and 33. The droplet size decreased from 190, 176 and 142 to 159, 141 and 122 µm as pressure increased from 20 to 24 kg cm^{-2} on upper surface of top, middle and bottom position, respectively whereas, the droplet size on underside leaves varied from

Table 29. Analysis of variance for droplet density for upper surface of pigeonpea crop

Source	Sum of Squares	df	Mean Square	F Value
Model	237346.54	80.00	2966.83	369.18 **
A-Operating pressure	2133.32	2.00	1066.66	132.73 **
B-Nozzle size	12892.53	2.00	6446.26	802.16 **
C-Orientation of nozzle	46039.01	2.00	23019.51	2864.49 **
D-Position of crop	67349.49	2.00	33674.75	4190.40 **
AB	565.95	4.00	141.49	17.61 **
AC	476.90	4.00	119.22	14.84 **
AD	600.38	4.00	150.09	18.68 **
BC	2583.43	4.00	645.86	80.37 **
BD	880.83	4.00	220.21	27.40 **
CD	98239.77	4.00	24559.94	3056.18 **
ABC	852.53	8.00	106.57	13.26 **
ABD	438.26	8.00	54.78	6.82 **
ACD	845.65	8.00	105.71	13.15 **
BCD	2509.26	8.00	313.66	39.03 **
ABCD	939.24	16.00	58.70	7.30 **
Pure Error	1301.86	162.00	8.04	
Cor Total	238648.40	242.00		

Std. Dev.	2.83	R-Squared	0.99
Mean	58.28	Adj R-Squared	0.99
C.V. (Per cent)	4.86	Pred R-Squared	0.99
PRESS	2929.18	Adeq Precision	73.01

** = Significant at 1 per cent level, NS = Non significant

Table 30. Analysis of variance for droplet density for lower surface of pigeonpea crop

Source	Sum of Squares	df	Mean Square	F Value
Model	52274.07	80.00	653.43	756.22 **
A-Operating pressure	1816.65	2.00	908.32	1051.22 **
B-Nozzle size	2584.38	2.00	1292.19	1495.46**
C-Orientation of nozzle	2146.45	2.00	1073.23	1242.06 **
D-Position of crop	14712.58	2.00	7356.29	8513.52 **
AB	58.37	4.00	14.59	16.89 **
AC	253.21	4.00	63.30	73.26 **
AD	368.26	4.00	92.07	106.55 **
BC	63.13	4.00	15.78	18.26 8**
BD	573.25	4.00	143.31	165.86 **
CD	28004.16	4.00	7001.04	8102.39 **
ABC	83.83	8.00	10.48	12.13 **
ABD	48.96	8.00	6.12	7.08 **
ACD	291.23	8.00	36.40	42.13 **
BCD	1062.82	8.00	132.85	153.75 **
ABCD	206.79	16.00	12.92	14.96 **
Pure Error	139.98	162.00	0.86	
Cor Total	52414.05	242.00		

Std. Dev.	0.93	R-Squared	1.00
Mean	19.70	Adj R-Squared	1.00
C.V. (Per cent)	4.72	Pred R-Squared	0.99
PRESS	314.95	Adeq Precision	115.53

** = Significant at 1 per cent level, NS = Non significant

Table 31. Effect of operating pressure and nozzle size on droplet size at 0 degree orientation of nozzle for pigeonpea crop

Sl. no	Operating pressure (kg cm^{-2})	Nozzle size (mm)	Droplet size (µm)					
			Position of leaves on plant canopy					
			Top		Middle		Bottom	
			Upper	Lower	Upper	Lower	Upper	Lower
1	20	2	190	162	176	143	142	0
		4	210	174	186	152	156	0
		6	220	181	195	158	161	0
2	22	2	170	151	168	138	135	0
		4	182	164	174	142	142	0
		6	195	172	182	150	153	0
3	24	2	159	146	141	129	122	0
		4	162	153	156	134	134	0
		6	171	160	161	141	142	0

Table 32. Effect of operating pressure and nozzle size on droplet size at 15 degree orientation of nozzle for pigeonpea crop

Sl. no	Operating pressure (kg cm^{-2})	Nozzle size (mm)	Droplet size (µm)					
			Position of leaves on plant canopy					
			Top		Middle		Bottom	
			Upper	Lower	Upper	Lower	Upper	Lower
1	20	2	185	162	171	154	136	125
		4	191	173	176	161	142	131
		6	201	180	183	164	153	139
2	22	2	169	151	153	146	129	119
		4	176	165	162	153	133	125
		6	183	172	171	162	146	132
3	24	2	141	132	134	125	115	105
		4	152	140	142	131	121	112
		6	164	151	152	140	132	126

Table 33. Effect of operating pressure and nozzle size on droplet size at 30 degree orientation of nozzle for pigeonpea crop

Sl. no	Operating pressure (kg cm^{-2})	Nozzle size (mm)	Droplet size (µm)					
			Position of leaves on plant canopy					
			Top		Middle		Bottom	
			Upper	Lower	Upper	Lower	Upper	Lower
1	20	2	0	0	185	162	169	141
		4	0	0	192	173	172	145
		6	0	0	201	180	181	151
2	22	2	0	0	171	151	152	129
		4	0	0	180	164	161	138
		6	0	0	192	172	173	143
3	24	2	0	0	156	142	144	121
		4	0	0	169	150	152	133
		6	0	0	171	162	161	139

162, 143 and 0 to 146, 129 and 0 µm for 2 mm nozzle size. The droplet size decreased from top upper surface 210, 186 and 156 µm to 162, 156 and 0 µm upper surface of the plant for 4 mm nozzle at 0 degree orientation of spray nozzle.

The droplet density on plant leaves at 15 degree orientation of nozzle for different nozzle size and operating pressure is presented in Table 32. It was observed that, droplet size was decreased as pressure increased and droplet size was increased as nozzle size increased from 2 to 6 mm. The maximum droplet size was observed for 6 mm nozzle size at lower operating pressure (20 kg cm^{-2}) on upper surface and minimum droplet size was found for 2 mm nozzle size at higher pressure (24 kg cm^{-2}). The droplet size observed at 30 degree orientation of spray nozzle is given in Table 33. It can be seen that the droplet size on the top position of the plant was zero. The droplet size was found maximum in middle position of the plant followed by bottom position.

The results pertaining to analysis of variance for droplet size for pigeon pea crop for upper and lower surface of the plant is presented in Table 34 and 35. It shows that the model is significant at 1 percent level of significance. The individual effect of the independent variables namely operating pressure, nozzle size, orientation of spray nozzle and position of the plant had influenced the droplet size and was significant at the 1 per cent level of significance.

4.3.1 Optimization of operational parameters of tractor operated automatic gun sprayer in laboratory conditions

Numerical optimization technique was followed to levels of independent and dependent variables for designed and developed model by using Design Expert. Numerical optimization constraints under laboratory condition are presented in Table 36 and optimized parameter under laboratory condition is presented in Table 37.

The desirability index of the discharge, length of throw, droplet density and droplet size were 0.41, 0.51, 0.78 and 1. The overall desirability index of the all the treatment combination was 0.60 for 22 kg cm^{-2} operating pressure, 2 mm nozzle size and 15 degree orientation of spray nozzle. These optimized parameters were considered for evaluating the tractor operated gun sprayer for field crops.

Table 34. Analysis of variance for droplet size for upper surface of pigeonpea crop

Source	Sum of Squares	df	Mean Square	F Value
Model	794507.54	80.00	9931.34	434.13 **
A-Operating pressure	43415.58	2.00	21707.79	948.92 **
B-Nozzle size	7098.29	2.00	3549.14	155.15 **
C-Orientation of nozzle	133903.69	2.00	66951.85	2926.69 **
D-Position of crop	135949.17	2.00	67974.58	2971.40 **
AB	851.44	4.00	212.86	9.30 **
AC	17081.02	4.00	4270.25	186.67 **
AD	2665.32	4.00	666.33	29.13 **
BC	4039.60	4.00	1009.90	44.15 **
BD	607.76	4.00	151.94	6.64 **
CD	439813.76	4.00	109953.44	4806.44 **
ABC	1614.89	8.00	201.86	8.82 **
ABD	893.49	8.00	111.69	4.88 **
ACD	2301.84	8.00	287.73	12.58 **
BCD	2075.87	8.00	259.48	11.34 **
ABCD	2195.84	16.00	137.24	6.00 **
Pure Error	3705.96	162.00	22.88	
Cor Total	798213.50	242.00		

Std. Dev.	4.78	R-Squared	1.00
Mean	147.52	Adj R-Squared	0.99
C.V. (Per cent)	3.24	Pred R-Squared	0.99
PRESS	8338.40	Adeq Precision	81.00

** = Significant at 1 per cent level, NS = Non significant

Table 35. Analysis of variance for droplet size for lower surface of pigeon pea crop

Source	Sum of Squares	df	Mean Square	F Value
Model	1059302.46	80.00	13241.28	469.44 **
A-Operating pressure	13891.59	2.00	6945.79	246.25 **
B-Nozzle size	2489.74	2.00	1244.87	44.13 8 **
C-Orientation of nozzle	107823.38	2.00	53911.69	1911.34 **
D-Position of crop	180951.63	2.00	90475.81	3207.65 **
AB	691.14	4.00	172.79	6.13 **
AC	7626.07	4.00	1906.52	67.59 **
AD	1696.78	4.00	424.19	15.04 **
BC	1610.73	4.00	402.68	14.28 **
BD	857.28	4.00	214.32	7.60 **
CD	734119.35	4.00	183529.84	6506.70 **
ABC	966.69	8.00	120.84	4.28 **
ABD	959.74	8.00	119.97	4.25 **
ACD	2069.66	8.00	258.71	9.17 **
BCD	1538.48	8.00	192.31	6.82 **
ABCD	2010.20	16.00	125.64	4.45 **
Pure Error	4569.41	162.00	28.21	
Cor Total	1063871.88	242.00		

Std. Dev.	5.31	R-Squared	1.00
Mean	119.50	Adj R-Squared	0.99
C.V. (Per cent)	4.44	Pred R-Squared	0.99
PRESS	10281.18	Adeq Precision	63.92

** = Significant at 1 per cent level, NS = Non significant

Table 36. Numerical optimization constraints under laboratory conditions

Name	Goal	Lower Limit	Upper Limit	Importance
Operating pressure ($kg\ cm^{-2}$)	is in range	Level 1 of A	Level 3 of A	3
Nozzle size (mm)	is in range	Level 1 of B	Level 3 of B	3
Orientation of spray nozzle (degree)	is in range	Level 1 of C	Level 3 of C	5
Discharge ($l\ min^{-1}$)	minimize	8.4	16.52	3
Length of throw (m)	maximize	1.84	4.2	3
Droplet density (No’s cm^{-2})	maximize	15.2	125.8	3
Droplet size (µm)	minimize	135	159	3

Table 37. Optimized parameters under laboratory condition

Name	Optimized value
Operating pressure ($kg\ cm^{-2}$)	22
Nozzle size (mm)	2
Orientation of spray nozzle (degree)	15
Discharge ($l\ min^{-1}$)	12.30
Length of throw (m)	3.05
Droplet density (No’s cm^{-2})	105.80
Droplet size (µm)	183.00
Desirability	0.60

4.4 Performance evaluation of tractor operated automatic gun sprayer for selected field crops

The performance evaluation of tractor operated automatic gun sprayer for selected field crops viz., Cotton (Bt) and Pigeonpea (Maruthi) was carried out in the farmer's field and University Research Farm, Raichur. The performance was evaluated based on the standard procedure. Some parameter of the sprayer was measured in the field without having vegetation to get exact results and some of the parameters were measured in the standing crop by maintain the same operational conditions. Before spraying operation, the wheel tread of tractor and spray boom height were adjusted according to row spacing and the height of crop. After making all the adjustments, set up was run for 15 min before actually starting the experiment. The performance of tractor operated automatic gun sprayer was carried out at the parameters which are optimized in the laboratory studies.

4.4.1 Performance evaluation of tractor operated automatic gun sprayer in cotton crop

The field trials were conducted by maintaining operating pressure of 22 kg cm^{-2}, nozzle size of 2 mm and 15 degree orientation of spray nozzle. The levels selected for performance evaluation of tractor operated automatic gun sprayer is presented in Table 4. The metrological at time of spraying in both the crops are presented in Table 5. Factorial completely randomized design was used to analysis the field experiments. The experimental data were processed using an analysis of variance (ANOVA) to determine the effects of the three independent variables of both laboratory and field parameters. The effect of interaction of these two independent variables was also studied through in this analysis. The statistical software package "Design –Expert", [version 10.0.4 for windows, Stat-Ease, Inc.,] was used for statistical analysis.

i. Effect of forward speed, speed of actuating mechanism and height of spray nozzle on swath width of spray

Swath width of spray at different forward speed ranging from 2.2 to 2.6 km h^{-1} for different speed of actuating mechanism at different height of spray nozzle is presented in Table 38. Swath width of spray indicates spread of spray and coverage of area. The results obtained showed that the swath width decreased as forward speed increased. The swath width increased as height of spray nozzle increased from 30 to 90 cm. For 2.2 km

Table 38. Effect of forward speed, speed of actuating mechanism and height of spray nozzle on swath width of spray

Sl. no	Forward speed (km h^{-1})	Speed of actuating mechanism (cycles min^{-1})	Swath width of spray (m)		
			Height of spray nozzle (cm)		
			30	**60**	**90**
1	2.2	54	7.60	8.20	8.34
		60	7.46	7.63	7.92
		65	7.20	7.42	7.64
2	2.4	54	7.51	7.62	8.23
		60	7.35	7.56	7.82
		65	6.91	7.24	7.54
3	2.6	54	7.42	7.51	8.11
		60	7.16	7.39	7.59
		65	6.80	6.92	7.21

forward speed, the maximum swath width was observed for 54 cycles min^{-1} actuating mechanism at 90 cm height of spray nozzle whereas the minimum swath width was obtained for 65 cycles min^{-1} actuating mechanism when height of spray nozzle was 30 cm.

The swath width was decreased from 7.46 to 7.16 as forward speed increased from 2.2 to 2.6 km h^{-1} for 60 cycles min^{-1} actuating mechanism. Swath width was increased from 7.46 to 7.92 m for 60 cycles min^{-1} actuating mechanism as height of spray nozzle increased from 30 to 90 cm. The maximum swath width (8.34 m) of spray was obtained for low speed of actuating mechanism (54 cycles min^{-1}) at low forward speed (2.2 km h^{-1}) when height of spray nozzle was 90 cm. The minimum swath width (6.80 m) was observed for high speed of actuating mechanism at high forward speed when height of spray nozzle was 30 cm.

Statistical analysis of swath width of spray is presented in the Table 39. It is clear that the main effect of each factor of forward speed (A), actuating mechanism (B) and height of spray nozzle has significantly influenced on swath width of spray at 5 per cent level of significance. The interaction effects have 5 per cent significant.

ii. Effect of forward speed, speed of actuating mechanism and height of spray nozzle on field capacity

The field capacity of the sprayer at different treatment combinations is shown in the Table 40. It can be seen that the field capacity of the sprayer decreased as the speed of actuating mechanism increased. The field capacity was increased as the height of spray nozzle was increased from 30 to 90 cm. It showed that the field capacity was decreased from 1.25 to 1.19 ha h^{-1} as speed of actuating mechanism increased for 2.2 km h^{-1} forward speed. The field capacity was increased from 1.25 to 1.68 ha h^{-1} as forward speed increased for 54 cycles min^{-1} actuating mechanism.

The maximum field capacity (1.84 ha h^{-1}) was obtained for 54 cycles min^{-1} speed of actuating mechanism at forward speed of 2.6 km h^{-1} when height of spray nozzle was 90 cm. The minimum field capacity (1.19 ha h^{-1}) was observed for 65 cycles min^{-1} speed of actuating mechanism at height of spray nozzle was 30 cm.

Statistical analysis of field capacity of sprayer is given in the Table 41. The results showed that the main effect of each factor of forward speed (A), actuating mechanism (B)

Table 39. Analysis of variance for swath width of spray

Source	Sum of Squares	df	Mean Square	F Value
Model	14.35	26.00	0.55	6.05 *
A-Forward speed	0.69	2.00	0.34	3.77 *
B- Speed of actuating mechanism	4.13	2.00	2.06	22.63 *
C-Height of spray nozzle	2.90	2.00	1.45	15.92 *
AB	1.06	4.00	0.27	2.91 *
AC	1.04	4.00	0.26	2.85 *
BC	1.44	4.00	0.36	3.93 *
ABC	3.09	8.00	0.39	4.23 *
Pure Error	4.93	54.00	0.09	
Cor Total	19.27	80.00		

Std. Dev.	0.30	R-Squared	0.74
Mean	7.71	Adj R-Squared	0.62
C.V. (Per cent)	3.92	Pred R-Squared	0.42
PRESS	11.09	Adeq Precision	9.69

** = Significant at 1 per cent level, * = Significant at 5 per cent level

NS = Non significant

Table 40. Effect of forward speed, speed of actuating mechanism and height of spray nozzle on field capacity

Sl. no	Forward speed (km h^{-1})	Speed of actuating mechanism (cycles min^{-1})	Field capacity (ha h^{-1})		
			Height of spray nozzle (cm)		
			30	**60**	**90**
1	2.2	54	1.25	1.35	1.38
		60	1.23	1.26	1.31
		65	1.19	1.22	1.26
2	2.4	54	1.44	1.46	1.58
		60	1.41	1.45	1.54
		65	1.33	1.39	1.48
3	2.6	54	1.68	1.79	1.84
		60	1.58	1.63	1.68
		65	1.50	1.53	1.59

Table 41. Analysis of variance for field capacity of sprayer

Source	Sum of Squares	df	Mean Square	F Value
Model	15.31	26.00	0.59	3.22 *
A-Forward speed	1.19	2.00	0.60	3.26 *
B- Speed of actuating mechanism	1.81	2.00	0.91	4.95 *
C-Height of spray nozzle	1.16	2.00	0.58	3.18 *
AB	3.75	4.00	0.94	5.12 *
AC	2.27	4.00	0.57	3.11 *
BC	1.99	4.00	0.50	2.71 *
ABC	3.14	8.00	0.39	2.15 *
Pure Error	9.88	54.00	0.18	
Cor Total	25.19	80.00		

Std. Dev.	0.43	R-Squared	0.61
Mean	1.80	Adj R-Squared	0.42
C.V. (Per cent)	23.82	Pred R-Squared	0.12
PRESS	22.22	Adeq Precision	7.69

* = Significant at 5 per cent level, NS = Non significant

and height of spray nozzle has significantly influenced on the field capacity at 5 per cent level of significance. The interaction effects have significant at 5 per cent level of significance. The model F value 3.22 implies that the model is significant at 5 per cent level of significance. The standard deviation and co-efficient of variation were found to be 0.43 and 23.82 per cent with a mean value of 1.80.

iii. Effect of forward speed, speed of actuating mechanism and height of spray nozzle on actual application rate

The application rate of the sprayer at different treatment combinations are given in the Table 42. The data presented in the table shows that application rate decreased with increase in the forward speed and height of spray nozzle. It was also found that the actual application rate was increased with increase in speed of actuating mechanism. The application rate was increased from 442.00 to 493.10 l ha^{-1} as speed of actuating mechanism increased from 54 to 65 cycles min^{-1}. The actual application rate was more than the theoretical application rate. The theoretical application rate was 428.92 l ha^{-1} but actual application rate was 442.00 l ha^{-1} for 54 cycles min^{-1} actuating mechanism at 30 cm height of spray nozzle.

Among all the treatments, the maximum actual application (493.10 l ha^{-1}) was obtained for 65 cycles min^{-1} at forward speed of 2.2 km h^{-1} when height of spray nozzle was 30 cm. The minimum actual application rate (314.30 l ha^{-1}) was observed for 54 cycles min^{-1} actuating mechanism at height of spray nozzle was 90 cm for 2.6 km h^{-1}.

The statistically analyzed data showed in Table 43, indicated that the main effect of each factor of forward speed (A) and actuating mechanism (B) has significantly influenced on the actual application rate at 5 per cent level of significance but main factor height of spray nozzle (C) has1 per cent level of significance. The interaction effects have 5 per cent significant. The model F value 4.51 implies that the model is significant at 5 per cent level of significance. The standard deviation and co-efficient of variation were found to be 14.33 and 3.36 per cent with a mean value of 426.08.

iv. Effect of forward speed, speed of actuating mechanism and height of spray nozzle on difference in actual and theoretical application rate

The difference in actual and theoretical application rate of the sprayer at different treatment combinations are given in the Table 44. The results showed that the difference

Table 42. Effect of forward speed, speed of actuating mechanism and height of spray nozzle on application rate of sprayer

Sl. no	Forward speed (km h^{-1})	Speed of actuating mechanism (cycles min^{-1})	Application rate (l ha^{-1}) (Theoretical application rate)		
			Height of spray nozzle (cm)		
			30	60	90
1	2.2	54	442.00 (428.92)	410.00 (399.11)	395.20 (386.12)
		60	468.20 (438.70)	455.78 (428.92)	433.40 (413.22)
		65	493.10 (454.54)	472.30 (441.06)	457.20 (428.36)
2	2.4	54	375.60 (399.46)	371.20 (393.70)	351.20 (364.52)
		60	422.20 (408.16)	408.50 (396.82)	385.20 (375.00)
		65	467.20 (434.15)	442.10 (414.36)	415.20 (390.11)
3	2.6	54	340.20 (363.41)	320.10 (341.03)	314.30 (333.24)
		60	372.10 (386.76)	361.20 (374.72)	352.10 (364.85)
		65	425.60 (407.23)	416.20 (400.17)	398.40 (384.08)

Table 43. Analysis of variance for application rate sprayer

Source	Sum of Squares	df	Mean Square	F Value
Model	485799.74	26.00	18684.61	4.51 *
A-Forward speed	32907.30	2.00	16453.65	3.98 *
B- Speed of actuating mechanism	26773.53	2.00	13386.76	3.23 *
C-Height of spray nozzle	109471.17	2.00	54735.58	13.23 **
AB	77194.12	4.00	19298.53	4.66 *
AC	44135.61	4.00	11033.90	2.67 *
BC	61587.89	4.00	15396.97	3.72 *
ABC	133730.12	8.00	16716.26	4.04 *
Pure Error	223487.37	54.00	4138.66	
Cor Total	709287.11	80.00		

Std. Dev.	14.33	R-Squared	0.68
Mean	426.08	Adj R-Squared	0.53
C.V. (Per cent)	3.36	Pred R-Squared	0.29
PRESS	502.84	Adeq Precision	9.24

** = Significant at 1 per cent level, * = Significant at 5 per cent level
NS = Non significant

Table 44. Effect of forward speed, speed of actuating mechanism and height of spray on difference in actual and theoretical application rate

Sl. no	Forward speed ($km\ h^{-1}$)	Speed of actuating mechanism ($cycles\ min^{-1}$)	Diff. of actual and theoretical application rate, (Per cent)		
			Height of spray nozzle (cm)		
			30	60	90
1	2.2	54	3.05	2.73	2.35
		60	6.72	6.26	4.88
		65	8.48	7.08	6.73
2	2.4	54	-5.97	-5.72	-3.65
		60	3.44	2.94	2.72
		65	7.61	6.69	6.43
3	2.6	54	-6.39	-6.14	-5.68
		60	-3.79	-3.61	-3.50
		65	4.51	4.00	3.73

was increased with increase in the speed of actuating mechanism for 2.2 km h^{-1}. The difference application rate was negative in 30 cm height of spray nozzle at 2.4 and 2.6 km h^{-1} forward speed of 30 cm. The negative sign indicates that actual application rate was less than that of the theoretical application rate. The actual application rate was -5.97 per cent less than the theoretical application rate. The difference was decreased from -5.97 to -6.39 as forward speed increased from low to high forward speed.

The maximum difference of application rate (8.48 per cent) was observed for 65 cycles min^{-1} at forward speed of 2.2 km h^{-1} when height of spray nozzle was 30 cm. The minimum difference of application rate (-6.39 per cent) was observed for 54 cycles min^{-1} actuating mechanism for forward speed of 2.6 km h^{-1}.

The statistically analyzed data on difference in actual and theoretical application rate showed in Table 45 indicated that the main effect of each factor of forward speed (A), actuating mechanism (B) and height of spray nozzle has significantly influenced on the difference in actual and theoretical application rate at 5 per cent level of significance. The interaction effects have 5 per cent level of significant but interaction of (A × B) has 5 per cent level of significance. The model F- value 26.02 implies that the model is significant at 5 per cent level of significance. The standard deviation and co-efficient of variation were found to be 0.75 and 13.10 per cent with a mean value of 3.05.

v. Effect of forward speed, speed of actuating mechanism and height of spray nozzle on fuel consumption of tractor

The fuel consumption of tractor at different forward speed, actuating mechanism and height of spray combinations is given in Table 46. The data presented in the table shows that the fuel consumption of sprayer did not affected by the speed of actuating mechanism as power to drive actuating mechanism was taken from the battery. Fuel consumption was not affected as height of nozzle height increased from 30 to 90 cm .The maximum fuel consumption of tractor was observed for highest forward (2.6 km h^{-1}) with 90 cm height of spray nozzle. The minimum fuel consumption of tractor was obtained at lower forward with 30 cm height of spray nozzle.

The statistically analyzed data showed in Table 47 indicated that the main effect of forward speed (A) has significantly influenced on the fuel consumption at 5 per cent level of significance. The interaction effects has non significant on the fuel consumption of

Table 45. Analysis of variance for difference of actual and theoretical application rate

Source	Sum of Squares	df	Mean Square	F Value
Model	2081.13	26.00	80.04	26.02 *
A-Forward speed	410.73	2.00	205.36	66.77 *
B- Speed of actuating mechanism	1337.84	2.00	668.92	217.47 *
C-Height of spray nozzle	41.74	2.00	20.87	6.78 *
AB	99.31	4.00	24.83	8.07 **
AC	92.07	4.00	23.02	7.48 *
BC	46.84	4.00	11.71	3.81 *
ABC	52.62	8.00	6.58	2.14 *
Pure Error	166.10	54.00	3.08	
Cor Total	2247.22	80.00		

Std. Dev.	0.75	R-Squared	0.93
Mean	4.07	Adj R-Squared	0.89
C.V. (Per cent)	3.0	Pred R-Squared	0.83
PRESS	373.72	Adeq Precision	20.60

** = Significant at 1 per cent level, * = Significant at 5 per cent level
NS = Non significant

Table 46. Effect of forward speed, speed of actuating mechanism and height of spray nozzle on fuel consumption of tractor

Sl. no	Forward speed (km h^{-1})	Speed of actuating mechanism (cycles min^{-1})	Fuel consumption (l h^{-1})		
			Height of spray nozzle (cm)		
			30	60	90
1	2.2	54	2.52	2.50	2.53
		60	2.50	2.53	2.55
		65	2.48	2.49	2.51
2	2.4	54	2.92	2.91	2.88
		60	2.90	2.88	2.94
		65	2.88	2.92	2.90
3	2.6	54	3.31	3.34	3.30
		60	3.30	3.38	3.32
		65	3.34	3.36	3.31

Table 47. Analysis of variance for fuel consumption of tractor

Source	Sum of Squares	df	Mean Square	F Value
Model	18.44	26.00	0.71	3.67 *
A-Forward speed	8.97	2.00	4.48	23.20 **
B- Speed of actuating mechanism	0.52	2.00	0.26	1.35 NS
C-Height of spray nozzle	1.26	2.00	0.63	3.26 NS
AB	1.28	4.00	0.32	1.65 NS
AC	2.14	4.00	0.53	2.77 NS
BC	2.04	4.00	0.51	2.63 NS
ABC	2.24	8.00	0.28	1.45 NS
Pure Error	10.44	54.00	0.19	
Cor Total	28.88	80.00		

Std. Dev.	0.44	R-Squared	0.64
Mean	3.04	Adj R-Squared	0.46
C.V. (Per cent)	14.45	Pred R-Squared	0.19
PRESS	23.49	Adeq Precision	7.30

** = Significant at 1 per cent level, * = Significant at 5 per cent level
NS = Non significant

tractor. The model F value 3.67 implies that the model is significant at 5 per cent level of significance. The standard deviation and co-efficient of variation were found to be 0.44 and 14.45 per cent with a mean value of 3.04.

vi. Effect of forward speed, speed of actuating mechanism and height of spray nozzle on droplet density

The effect of different forward speed, actuating mechanism and height of spray nozzle combinations on the droplet density is given in the Table 48, 49 and 50. The forward speed and actuating mechanism affected the droplet density at different crop positions both upper surface and lower surface of crop leaves. The 2.2 km h^{-1} forward speed gave maximum droplet density as compared to other speeds for 65 cycles min^{-1} actuating mechanism. The maximum droplet density was deposited on the upper surface of the top position of the plant followed by middle and bottom position. Droplet density was decreased from top position of upper surface 71.3 no's cm^{-2} to 42.6 no's cm^{-2} for lower surface of the top position for 2 mm nozzle at 2.2 km h^{-1} forward speed. Droplet density on top, middle and bottom surface for upper was 76.1, 75.2 and 15.6 no's cm^{-2} whereas for lower surface of leaves received low droplet density *i.e.*, 46, 26.1 and 0 no's cm^{-2} for 30 cm height of spray nozzle for 4 mm nozzle size.

The maximum droplet density was observed for low height of spray nozzle (30 cm) at actuating mechanism of 65 cycles min^{-1}. The minimum droplet density was observed for 90 cm height of spray at high forward speed. It was observed for the sprayer that, droplet density was 9.1 at bottom upper position of the leaves while no spray was found on the underside of the leave for all the treatments at 30 cm height of nozzle. When the height of spray nozzle changed from 30 to 90 cm, no spray was found at the bottom position of the leaves.

The statistically analyzed data for droplet density both for upper and lower surface of the plant leaves are showed in Table 51 and 52. Table indicated that the main effect of each factor of forward speed (A), actuating mechanism (B), height of spray nozzle (C) and position of the leaves has significantly influenced on droplet density both for upper and lower surface of the leaves at 5 per cent level of significance. The interaction effects have significant at 5 per cent level of significance for both the surfaces. The model F value for upper surface 366.64 implies that the model is significant at 5 per cent level of

Table 48. Effect of forward speed and speed of actuating mechanism on droplet density at 30 cm height of spray nozzle

Sl. no	Forward speed (km h^{-1})	Speed of actuating mechanism (cycles min^{-1})	Droplet density (No's cm^{-2})					
			Position of leaves on plant canopy					
			Top		Middle		Bottom	
			Upper	Lower	Upper	Lower	Upper	Lower
1	2.2	54	71.3	42.6	39.1	22.6	9.1	0
		60	76.1	46.0	75.2	26.1	15.6	0
		65	86.4	52.6	76.4	29.7	17.4	0
2	2.4	54	65.4	41.6	32.6	19.9	7.1	0
		60	72.6	46.4	42.9	23.7	12.3	0
		65	82.2	51.4	56.1	26.4	16.7	0
3	2.6	54	61.2	36.7	29.7	12.7	6.1	0
		60	64.5	41.6	33.9	19.4	9.4	0
		65	71.6	43.9	36.3	26.2	12.3	0

Table 49. Effect of forward speed and speed of actuating mechanism on droplet density at 60 cm height of spray nozzle

Sl. no	Forward speed (km h^{-1})	Speed of actuating mechanism (cycles min^{-1})	Droplet density (No's cm^{-2})					
			Position of leaves on plant canopy					
			Top		Middle		Bottom	
			Upper	Lower	Upper	Lower	Upper	Lower
1	2.2	54	65.3	36.1	25.6	12.4	0	0
		60	66.2	39.4	29.3	19.8	0	0
		65	72.1	45.5	45.4	22.5	0	0
2	2.4	54	62.6	31.4	22.7	8.6	0	0
		60	64.2	36.7	26.9	11.2	0	0
		65	69.9	43.9	29.4	16.4	0	0
3	2.6	54	42.9	29.0	19.7	6.3	0	0
		60	53.4	31.4	24.7	10.5	0	0
		65	59.7	46.9	31.7	15.7	0	0

Table 50. Effect of forward speed and speed of actuating mechanism on droplet density at 90 cm height of spray nozzle

Sl. no	Forward speed (km h^{-1})	Speed of actuating mechanism (cycles min^{-1})	Droplet density (No's cm^{-2})					
			Position of leaves on plant canopy					
			Top		Middle		Bottom	
			Upper	Lower	Upper	Lower	Upper	Lower
1	2.2	54	52.3	36.2	16.1	12.5	0	0
		60	56.1	39.1	22.3	17.6	0	0
		65	61.2	42.6	29.4	25.2	0	0
2	2.4	54	46.2	34.1	12.4	9.4	0	0
		60	49.9	36.0	19.6	12.3	0	0
		65	51.7	41.1	23.1	16.4	0	0
3	2.6	54	32.6	25.7	9.7	6.8	0	0
		60	36.4	29.9	11.9	7.9	0	0
		65	43.9	35.1	13.2	12.8	0	0

Table 51. Analysis of variance for droplet density for upper surface of cotton crop

Source	Sum of Squares	df	Mean Square	F Value
Model	80841.64	80.00	1010.52	366.64 *
A-Forward speed	1214.83	2.00	607.42	220.38 *
B- Speed of actuating mechanism	1090.44	2.00	545.22	197.82 *
C-Height of spray nozzle	1363.89	2.00	681.94	247.42 *
D-Position of crop	73105.51	2.00	36552.76	13262.05 *
AB	59.57	4.00	14.89	5.40 *
AC	86.11	4.00	21.53	7.81 *
AD	635.87	4.00	158.97	57.68 *
BC	123.59	4.00	30.90	11.21 *
BD	644.73	4.00	161.18	58.48 *
CD	1195.72	4.00	298.93	108.46 *
ABC	381.65	8.00	47.71	17.31 *
ABD	171.17	8.00	21.40	7.76 *
ACD	93.18	8.00	11.65	4.23 *
BCD	211.37	8.00	26.42	9.59 *
ABCD	464.01	16.00	29.00	10.52 *
Pure Error	446.50	162.00	2.76	
Cor Total	81288.14	242.00		

Std. Dev.	1.66	R-Squared	0.99
Mean	19.42	Adj R-Squared	0.99
C.V. (Per cent)	8.55	Pred R-Squared	0.99
PRESS	1004.63	Adeq Precision	55.06

** = Significant at 1 per cent level, * = Significant at 5 per cent level
NS = Non significant

Table 52. Analysis of variance for droplet density for lower surface of cotton crop

Source	Sum of Squares	df	Mean Square	F Value
Model	922173.77	80.00	11527.17	112.02 *
A-Forward speed	3988.22	2.00	1994.11	19.38 *
B- Speed of actuating mechanism	1072.81	2.00	536.40	5.21 *
C-Height of spray nozzle	196579.33	2.00	98289.67	955.20 *
D-Position of crop	549841.41	2.00	274920.70	2671.75 *
AB	1552.71	4.00	388.18	3.77 *
AC	1689.31	4.00	422.33	4.10 *
AD	424.42	4.00	106.11	1.03 *
BC	1715.43	4.00	428.86	4.17 *
BD	5383.23	4.00	1345.81	13.08 *
CD	144039.00	4.00	36009.75	349.95 *
ABC	1785.15	8.00	223.14	2.17 *
ABD	2374.46	8.00	296.81	2.88 *
ACD	1903.14	8.00	237.89	2.31 *
BCD	5171.82	8.00	646.48	6.28 *
ABCD	4653.34	16.00	290.83	2.83 *
Pure Error	16669.67	162.00	102.90	
Cor Total	938843.44	242.00		

Std. Dev.	10.14	R-Squared	0.98
Mean	116.59	Adj R-Squared	0.97
C.V. (Per cent)	8.70	Pred R-Squared	0.96
PRESS	37506.75	Adeq Precision	32.14

** = Significant at 1 per cent level, * = Significant at 5 per cent level
NS = Non significant

significance. The standard deviation and co-efficient of variation were found to be 1.66 and 8.55 per cent with a mean value of 19.42.

The model F value (Table 52) for lower surface 112.02 implies that the model is significant at 5 per cent level of significance. The standard deviation and co-efficient of variation were found to be 10.14 and 8.70 per cent.

vii. Effect of forward speed, speed of actuating mechanism and height of spray nozzle on droplet size (VMD)

The droplet sizes produced by sprayer at number of different treatments are given in the Table 53, 54 and 55. The droplet size decreased with increase in the forward speed and height of spray nozzle. It can also be seen that, droplet size was increased with increase in the speed of actuating mechanism. The droplet density was decreased from 169, 159 and 131 to 151, 142 and 119 µm for 54 cycles min^{-1} speed of actuating mechanism as forward speed changed from 2.2 to 2.6 km h^{-1} for top upper position of the plant. The droplet density on the top surface of the crop was decreased from 169 to 142 µm as the height of spray nozzle was increased from 30 to 90 cm for 54 cycles min^{-1} speed of actuating mechanism.

The maximum droplet size was obtained at low forward speed (2.2 km h^{-1}) with high speed of actuating mechanism for 30 cm height of spray nozzle. The minimum droplet size was observed for high forward speed (2.6 km h^{-1}) with low speed of actuating mechanism
(54 cycles min^{-1}) at 90 cm height of spray nozzle. When the height of spray nozzle changed from 30 to 90 cm, no spray was found at the bottom position of the leaves, hence, zero droplet size at the bottom of the plant position.

It was observed from the statistical analyzed data on droplet size on upper and lower surface (Table 56 and 57) that factors like forward speed (A), actuating mechanism (B), height of spray nozzle (C) and position of the leaves have 5 per cent significant effect on the droplet size both on the upper and lower surface of the leaves. All the interaction effects have 5 per cent significant for both the surfaces but interaction effect (A × D), (C ×D) have 1 per cent significant effect on the droplet size on upper surface. In case of the lower surface, interaction effect (A × D), (B ×C) and (B × C × D) has 1 per cent level of significance on lower side droplet size. The model F value for upper surface 107.86 implies that the model is significant at 5 per cent level of significance. The standard

Table 53. Effect of forward speed and speed of actuating mechanism on droplet size at 30 cm height of spray nozzle

Sl. no	Forward speed (km h^{-1})	Speed of actuating mechanism (cycles min^{-1})	Droplet size (µm)					
			Position of leaves on plant canopy					
			Top		Middle		Bottom	
			Upper	Lower	Upper	Lower	Upper	Lower
1	2.2	54	169	154	159	142	131	0
		60	176	162	164	150	140	0
		65	184	171	172	161	146	0
2	2.4	54	162	146	156	135	126	0
		60	169	151	162	143	132	0
		65	175	162	168	151	139	0
3	2.6	54	151	139	142	130	119	0
		60	160	143	153	136	126	0
		65	172	154	161	143	133	0

Table 54. Effect of forward speed and speed of actuating mechanism on droplet size at 60 cm height of spray nozzle

Sl. no	Forward speed (km h^{-1})	Speed of actuating mechanism (cycles min^{-1})	Droplet size (µm)					
			Position of leaves on plant canopy					
			Top		Middle		Bottom	
			Upper	Lower	Upper	Lower	Upper	Lower
1	2.2	54	151	135	139	123	0	0
		60	162	143	143	134	0	0
		65	171	151	151	140	0	0
2	2.4	54	145	123	136	115	0	0
		60	153	132	139	121	0	0
		65	162	139	143	132	0	0
3	2.6	54	142	119	126	113	0	0
		60	149	126	132	125	0	0
		65	154	134	140	128	0	0

Table 55. Effect of forward speed and speed of actuating mechanism on droplet size at 90 cm height of spray nozzle

Sl. no	Forward speed (km h^{-1})	Speed of actuating mechanism (cycles min^{-1})	Droplet size (µm)					
			Position of leaves on plant canopy					
			Top		Middle		Bottom	
			Upper	Lower	Upper	Lower	Upper	Lower
1	2.2	54	142	125	127	121	0	0
		60	151	132	136	126	0	0
		65	159	144	143	131	0	0
2	2.4	54	135	119	121	115	0	0
		60	142	126	131	121	0	0
		65	150	134	139	132	0	0
3	2.6	54	129	112	118	109	0	0
		60	136	121	125	116	0	0
		65	142	126	132	124	0	0

Table 56. Analysis of variance for droplet size for upper surface of cotton crop

Source	Sum of Squares	df	Mean Square	F Value
Model	932262.52	80.00	11653.28	107.86 *
A-Forward speed	838.16	2.00	419.08	3.88 *
B- Speed of actuating mechanism	4597.88	2.00	2298.94	21.28 *
C-Height of spray nozzle	193458.39	2.00	96729.19	895.27 *
D-Position of crop	535416.10	2.00	267708.05	2477.75 *
AB	4126.74	4.00	1031.69	9.55 *
AC	8006.56	4.00	2001.64	18.53 *
AD	4146.39	4.00	1036.60	9.59 **
BC	3418.61	4.00	854.65	7.91 *
BD	1151.61	4.00	287.90	2.66 **
CD	131826.52	4.00	32956.63	305.03 **
ABC	5720.58	8.00	715.07	6.62 *
ABD	6880.64	8.00	860.08	7.96 *
ACD	7312.80	8.00	914.10	8.46 *
BCD	8917.52	8.00	1114.69	10.32 *
ABCD	16444.03	16.00	1027.75	9.51 *
Pure Error	17503.25	162.00	108.04	
Cor Total	949765.77	242.00		

Std. Dev.	10.39	R-Squared	0.98
Mean	118.44	Adj R-Squared	0.97
C.V. (Per cent)	8.78	Pred R-Squared	0.96
PRESS	39382.31	Adeq Precision	37.77

** = Significant at 1 per cent level, * = Significant at 5 per cent level
NS = Non significant

Table 57. Analysis of variance for droplet size for lower surface of cotton crop

Source	Sum of Squares	df	Mean Square	F Value
Model	1296807.50	80.00	16210.09	41.90 *
A-Forward speed	4239.01	2.00	2119.50	5.48 *
B- Speed of actuating mechanism	2623.12	2.00	1311.56	3.39 *
C-Height of spray nozzle	20677.55	2.00	10338.77	26.72 *
D-Position of crop	1110359.17	2.00	555179.58	1434.91 **
AB	8241.65	4.00	2060.41	5.33 *
AC	10680.27	4.00	2670.07	6.90 *
AD	14847.31	4.00	3711.83	9.59 **
BC	8957.13	4.00	2239.28	5.79 **
BD	4926.49	4.00	1231.62	3.18 *
CD	25950.04	4.00	6487.51	16.77 *
ABC	13231.86	8.00	1653.98	4.27 *
ABD	12239.71	8.00	1529.96	3.95 *
ACD	13080.65	8.00	1635.08	4.23 *
BCD	12007.44	8.00	1500.93	3.88 **
ABCD	34746.11	16.00	2171.63	5.61 **
Pure Error	62679.16	162.00	386.91	
Cor Total	1359486.66	242.00		

Std. Dev.	9.67	R-Squared	0.95
Mean	99.33	Adj R-Squared	0.93
C.V. (Per cent)	9.73	Pred R-Squared	0.90

** = Significant at 1 per cent level, * = Significant at 5 per cent level
NS = Non significant

deviation and co-efficient of variation were found to be 10.39 and 8.78 per cent with a mean value of 118.44.

The model F value (Table 57) for lower surface 41.90 implies that the model is significant at 5 per cent level of significance. The standard deviation and co-efficient of variation were found to be 9.67 and 9.73 per cent with a mean value of 99.33.

viii. Effect of forward speed, speed of actuating mechanism and height of spray nozzle on uniformity coefficient

Uniformity coefficient of spray droplets produced by different operational parameters is given in the Table 58, 59 and 60. The results showed that the uniformity coefficient of spray droplets decreased with increasing the speed of actuating mechanism and height of spray nozzle. It can also be seen that the uniformity coefficient was maximum on upper surface of the leaves and decreased on lower surface of the plant leaves. The maximum uniformity coefficient was observed on top upper position of the plant followed by middle and bottom position. Uniformity coefficient was decreased from 2.50 to 1.92 for 54 cycles min^{-1} actuating mechanism as forward speed increased. Uniformity coefficient was decreased from 2.10 to 1.80 as speed of actuating mechanism increases at 60 cm height of spray nozzle.

The maximum uniformity coefficient was observed at slow speed (2.2 km h^{-1}) with low speed of actuating mechanism (2.2 km h^{-1}) all the heights. The minimum uniformity coefficient was high speed of forward speed (2.6 km h^{-1}) with high speed of actuating mechanism (64 cycles min^{-1}) for all heights of spray nozzle. When the height of spray nozzle changed from 30 to 90 cm, no spray was found at the bottom position of the leaves, hence, zero uniformity coefficients at the bottom of the plant position.

Analysis of variance on uniformity coefficient is presented in the Table 61 and 62. Table showed that main factors *i.e.*, forward speed (A), actuating mechanism (B), height of spray nozzle (C) and position of leaves has 5 per cent significant on uniformity coefficient on both upper and lower surface of the plant leaves. In upper surface of the leaves, all the interaction effects have 5 per cent level of significance except the interaction effect (A × B × C) has 1 per cent level of significance. Where as in lower surface of the plant leaves, the all interaction effects have 5 per cent level of significance except (A × B), (B × C) and (A × B × D) has 1 per cent level of significance. The model F value for upper surface 244.54 implies that the model is significant at 5 per cent level of significance. The

Table 58. Effect of forward speed and speed of actuating mechanism on uniformity coefficient at 30 cm height of spray nozzle

Sl. no	Forward speed (km h^{-1})	Speed of actuating mechanism (cycles min^{-1})	Uniformity coefficient					
			Position of leaves on plant canopy					
			Top		Middle		Bottom	
			Upper	Lower	Upper	Lower	Upper	Lower
1	2.2	54	2.50	2.30	2.30	2.00	1.90	0
		60	2.30	2.20	2.10	1.90	1.80	0
		65	2.00	1.80	1.82	1.70	1.50	0
2	2.4	54	2.30	2.21	1.80	1.64	1.75	0
		60	2.01	1.95	1.66	1.59	1.62	0
		65	1.80	1.83	1.53	1.56	1.54	0
3	2.6	54	1.92	1.70	1.70	1.59	1.62	0
		60	1.70	1.51	1.53	1.42	1.51	0
		65	1.41	1.38	1.38	1.36	1.33	0

Table 59. Effect of forward speed and speed of actuating mechanism on uniformity coefficient at 60 cm height of spray nozzle

Sl. no	Forward speed (km h^{-1})	Speed of actuating mechanism (cycles min^{-1})	Uniformity coefficient					
			Position of leaves on plant canopy					
			Top		Middle		Bottom	
			Upper	Lower	Upper	Lower	Upper	Lower
1	2.2	54	2.30	2.10	2.10	2.00	0	0
		60	2.10	1.90	1.90	1.70	0	0
		65	1.80	1.60	1.74	1.49	0	0
2	2.4	54	2.10	1.90	1.72	1.45	0	0
		60	2.00	1.70	1.70	1.31	0	0
		65	1.90	1.52	1.63	1.29	0	0
3	2.6	54	1.84	1.81	1.68	1.54	0	0
		60	1.82	1.70	1.62	1.39	0	0
		65	1.32	1.31	1.31	1.28	0	0

Table 60. Effect of forward speed and speed of actuating mechanism on uniformity coefficient at 90 cm height of spray nozzle

Sl. no	Forward speed (km h^{-1})	Speed of actuating mechanism (cycles min^{-1})	Uniformity coefficient					
			Position of leaves on plant canopy					
			Top		Middle		Bottom	
			Upper	Lower	Upper	Lower	Upper	Lower
1	2.2	54	1.90	1.70	1.60	1.50	0	0
		60	1.60	1.50	1.40	1.30	0	0
		65	1.56	1.42	1.38	1.27	0	0
2	2.4	54	1.70	1.50	1.40	1.29	0	0
		60	1.50	1.42	1.26	1.21	0	0
		65	1.40	1.32	1.21	1.19	0	0
3	2.6	54	1.50	1.32	1.37	1.24	0	0
		60	1.34	1.28	1.24	1.18	0	0
		65	1.31	1.24	1.19	1.13	0	0

Table 61. Analysis of variance for uniformity coefficient for upper surface of cotton crop

Source	Sum of Squares	df	Mean Square	F Value
Model	138.50	80.00	1.73	244.54 *
A-Forward speed	3.32	2.00	1.66	234.46 *
B- Speed of actuating mechanism	2.22	2.00	1.11	157.00 *
C-Height of spray nozzle	31.36	2.00	15.68	2215.04 *
D-Position of crop	73.93	2.00	36.97	5221.73 *
AB	0.10	4.00	0.03	3.53 **
AC	0.44	4.00	0.11	15.43 *
AD	1.31	4.00	0.33	46.32 *
BC	0.27	4.00	0.07	9.60 *
BD	0.63	4.00	0.16	22.13 *
CD	24.13	4.00	6.03	852.07 *
ABC	0.18	8.00	0.02	3.16 **
ABD	0.15	8.00	0.02	2.63 *
ACD	0.09	8.00	0.01	1.50 *
BCD	0.11	8.00	0.01	1.94 *
ABCD	0.26	16.00	0.02	2.30 *
Pure Error	1.15	162.00	0.01	
Cor Total	139.65	242.00		

Std. Dev.	0.08	R-Squared	0.99
Mean	1.32	Adj R-Squared	0.99
C.V. (Per cent)	6.36	Pred R-Squared	0.98
PRESS	2.58	Adeq Precision	48.98

** = Significant at 1 per cent level, * = Significant at 5 per cent level
NS = Non significant

Table 62. Analysis of variance for uniformity of coefficient for lower surface of cotton crop

Source	Sum of Squares	df	Mean Square	F Value
Model	156.16	80.00	1.95	176.36 *
A-Forward speed	2.42	2.00	1.21	109.45 *
B- Speed of actuating mechanism	0.98	2.00	0.49	44.27 *
C-Height of spray nozzle	5.66	2.00	2.83	255.52 *
D-Position of crop	137.77	2.00	68.88	6223.14 *
AB	0.77	4.00	0.19	17.48 *
AC	1.47	4.00	0.37	33.18 **
AD	1.04	4.00	0.26	23.38 *
BC	0.30	4.00	0.07	6.77 **
BD	0.48	4.00	0.12	10.93 *
CD	2.25	4.00	0.56	50.78 *
ABC	0.76	8.00	0.09	8.55 *
ABD	0.36	8.00	0.04	4.04 **
ACD	0.93	8.00	0.12	10.47 *
BCD	0.47	8.00	0.06	5.28 *
ABCD	0.52	16.00	0.03	2.93 *
Pure Error	1.79	162.00	0.01	
Cor Total	157.96	242.00		

Std. Dev.	0.11	R-Squared	0.99
Mean	1.07	Adj R-Squared	0.98
C.V. (Per cent)	9.80	Pred R-Squared	0.97
PRESS	4.03	Adeq Precision	41.97

** = Significant at 1 per cent level, * = Significant at 5 per cent level
NS = Non significant

standard deviation and co-efficient of variation were found to be 0.08 and 6.36 per cent with a mean value of 1.32.

The model F value for (Table 62) lower surface 176.36 implies that the model is significant at 5 per cent level of significance. The standard deviation and co-efficient of variation were found to be 0.11 and 9.80 per cent with a mean value of 1.07.

ix. Effect of forward speed, speed of actuating mechanism and height of spray nozzle on area covered by droplets

The area covered by droplets on the plant surface under different operational parameters is given in the Table 63, 64 and 65. The area covered by droplets varies from 15.25 to 9.50 mm^2 cm^{-2} as height of spray nozzle increased from 30 to 90 cm. The area covered by droplets decreased with increase in the height of spray nozzle. It can also be seen that the area covered by droplets increased with increase in the speed of actuating mechanism. The maximum area covered by droplets on the top surface of the plant followed by middle and bottom position.

The maximum area covered by droplets for slow speed (2.2 km h^{-1}) for high speed of (65 cycles min^{-1}) actuating mechanism at low height of spray nozzle (30 cm) on top surface of the plant. The minimum area covered by droplets for high speed (2.6 km h^{-1}) for slow speed of actuating mechanism (54 cycles min^{-1}) at height of spray nozzle was 90 cm.

The statistically analyzed data on area covered by droplets (Table 66 and 67) showed that the main effects of forward speed (A), actuating mechanism (B), height of spray nozzle (C) and position of leaves (D) has 5 per cent significant on area covered by droplets on both upper and lower surface of the plant leaves. All the interaction effects have 5 per cent level of significance except interaction effect (C× D) which has 1 per cent level of significance. In case of lower surface of the plant, all the interaction effects have 5 per cent level of significance but interaction effect (A × C× D) has 1 per cent significant. The model F value for upper surface 30.76 implies that the model is significant at 5 per cent level of significance. The standard deviation and co-efficient of variation were found to be 1.58 and 20.25 per cent with a mean value of 7.81.

The model F value (Table 67) for upper surface 16.43 implies that the model is significant at 5 per cent level of significance. The standard deviation and co-efficient of variation were found to be 0.90 and 15.49 per cent with a mean value of 5.81.

Table 63. Effect of forward speed and speed of actuating mechanism on area covered by droplets at 30 cm height of spray nozzle

Sl. no	Forward speed (km h^{-1})	Speed of actuating mechanism (cycles min^{-1})	Area covered by droplets (mm^2 cm^{-2})					
			Position of leaves on plant canopy					
			Top		Middle		Bottom	
			Upper	Lower	Upper	Lower	Upper	Lower
1	2.2	54	15.25	9.50	10.23	8.20	5.12	0
		60	15.29	9.70	10.31	8.30	5.60	0
		65	16.30	10.30	11.20	9.10	6.10	0
2	2.4	54	15.16	9.30	10.15	8.10	4.90	0
		60	15.21	9.50	10.23	8.20	5.30	0
		65	15.26	10.10	10.30	8.40	5.40	0
3	2.6	54	14.60	8.90	9.50	7.60	4.10	0
		60	14.90	9.10	9.60	7.90	4.30	0
		65	15.21	10.10	10.6	8.30	4.60	0

Table 64. Effect of forward speed and speed of actuating mechanism on area covered by droplets at 60 cm height of spray nozzle

Sl. no	Forward speed (km h^{-1})	Speed of actuating mechanism (cycles min^{-1})	Area covered by droplets (mm^2 cm^{-2})					
			Position of leaves on plant canopy					
			Top		Middle		Bottom	
			Upper	Lower	Upper	Lower	Upper	Lower
1	2.2	54	10.92	9.12	9.20	7.60	0	0
		60	11.2	9.30	9.51	7.90	0	0
		65	11.6	10.1	9.90	8.35	0	0
2	2.4	54	10.56	8.60	8.73	7.14	0	0
		60	10.59	8.90	8.90	7.63	0	0
		65	11.20	9.30	9.32	8.20	0	0
3	2.6	54	10.30	8.30	8.10	6.92	0	0
		60	10.50	8.50	8.30	7.20	0	0
		65	10.90	8.90	8.54	7.50	0	0

Table 65. Effect of forward speed and speed of actuating mechanism on area covered by droplets at 90 cm height of spray nozzle

Sl. no	Forward speed (km h^{-1})	Speed of actuating mechanism (cycles min^{-1})	Area covered by droplets (mm^2 cm^{-2})					
			Position of leaves on plant canopy					
			Top		Middle		Bottom	
			Upper	Lower	Upper	Lower	Upper	Lower
1	2.2	54	9.50	7.52	8.30	6.80	0	0
		60	9.60	7.60	8.50	6.83	0	0
		65	10.10	8.21	9.34	7.40	0	0
2	2.4	54	9.30	7.10	7.90	6.30	0	0
		60	9.60	7.31	8.15	6.50	0	0
		65	9.90	8.10	8.32	7.10	0	0
3	2.6	54	8.60	6.52	7.20	5.90	0	0
		60	8.90	6.90	7.51	6.20	0	0
		65	9.10	7.13	8.10	6.40	0	0

Table 66. Analysis of variance for area covered by droplets for upper surface of cotton crop

Source	Sum of Squares	df	Mean Square	F Value
Model	6160.89	80.00	77.01	30.76 *
A-Forward speed	31.52	2.00	15.76	6.29 *
B- Speed of actuating mechanism	15.28	2.00	7.64	3.05 *
C-Height of spray nozzle	912.77	2.00	456.38	182.27 *
D-Position of crop	4444.27	2.00	2222.13	887.46 *
AB	31.46	4.00	7.87	3.14 *
AC	34.68	4.00	8.67	3.46 *
AD	55.05	4.00	13.76	5.50 **
BC	33.36	4.00	8.34	3.33 *
BD	27.74	4.00	6.94	2.77 *
CD	223.99	4.00	56.00	22.36 **
ABC	54.05	8.00	6.76	2.70 *
ABD	42.73	8.00	5.34	2.13 *
ACD	64.09	8.00	8.01	3.20 *
BCD	63.84	8.00	7.98	3.19 *
ABCD	126.06	16.00	7.88	3.15 *
Pure Error	405.64	162.00	2.50	
Cor Total	6566.53	242.00		

Std. Dev.	1.58	R-Squared	0.94
Mean	7.81	Adj R-Squared	0.91
C.V. (Per cent)	20.25	Pred R-Squared	0.86
PRESS	912.68	Adeq Precision	27.40

** = Significant at 1 per cent level, * = Significant at 5 per cent level
NS = Non significant

Table 67. Analysis of variance for area covered by droplets for lower surface of cotton crop

Source	Sum of Squares	df	Mean Square	F Value
Model	4722.47	80.00	59.03	16.43 *
A-Forward speed	35.27	2.00	17.64	4.91 *
B- Speed of actuating mechanism	45.42	2.00	22.71	6.32 *
C-Height of spray nozzle	200.06	2.00	100.03	27.85 *
D-Position of crop	3243.28	2.00	1621.64	451.45 *
AB	96.00	4.00	24.00	6.68 *
AC	83.49	4.00	20.87	5.81 *
AD	50.89	4.00	12.72	3.54 *
BC	164.48	4.00	41.12	11.45 *
BD	43.60	4.00	10.90	3.03 *
CD	142.74	4.00	35.68	9.93 *
ABC	111.22	8.00	13.90	3.87 *
ABD	117.73	8.00	14.72	4.10 *
ACD	114.51	8.00	14.31	3.98 **
BCD	84.00	8.00	10.50	2.92 **
ABCD	189.79	16.00	11.86	3.30 *
Pure Error	581.92	162.00	3.59	
Cor Total	5304.39	242.00		

Std. Dev.	0.90	R-Squared	0.89
Mean	5.81	Adj R-Squared	0.84
C.V. (Per cent)	15.49	Pred R-Squared	0.75
PRESS	1309.32	Adeq Precision	24.19

** = Significant at 1 per cent level, * = Significant at 5 per cent level
NS = Non significant

x. Effect of forward speed, speed of actuating mechanism and height of the spray nozzle on particle drift

Effect of forward speed, actuating mechanism and height of the spray nozzle on particle drift is presented in the Table 68. It was observed from the results, the drift droplets varied from 15 to 26 as the height of the spray nozzle increased from 30 to 90 cm at 4.5 cm distance from the sprayed crop for 54 cycles min^{-1}. The drift droplets were increased from 13 to 25 as the forward speed increased from 2.2 to 2.4 km h^{-1}. It was observed that, drift droplets were reduced as the distance away from the sprayed area increased. Drift droplets decreased from 15 to 7 as the distance from the crop increased. It was also observed that, speed of actuating mechanism did not have influence on the particle drift.

4.4.2 Performance evaluation of tractor operated automatic gun sprayer in pigeonpea crop

The field trials were conducted by maintaining operating pressure of 22 kg cm^{-2}, nozzle size of 2 mm and 15 degree orientation of spray nozzle. The levels selected for performance evaluation of tractor operated automatic gun sprayer is presented in Table 4. The metrological at time of spraying in both the crops are presented in Table 5.

i. Effect of forward speed, speed of actuating mechanism and height of spray nozzle on swath width of spray

The results of swath width of spray obtained from different combinations of forward speed, actuating mechanism and height of spray nozzle is presented in the Table 69. The swath width decreased with increased in forward speed and actuating mechanism. It was also observed that the swath width increased when the height of spray nozzle changed from 30 to 90 cm. Swath width was decreased from 8.21 to 7.84 when forward speed was changed from 2.2 to 2.6 km h^{-1} for 54 cycles min^{-1} actuating mechanism.

The maximum swath width was noticed at low forward speed (2.2 km h^{-1}) with low speed of actuating mechanism (54 cycles min^{-1}) when height of spray nozzle was 90 cm. The minimum swath width was found at high speed of actuating mechanism (65 cycles min^{-1}) for height of spray nozzle was 30 cm when forward speed was operated at 2.6 km h^{-1}.

Table 68. Effect of forward speed, speed of actuating mechanism and height of the spray nozzle on particle drift (No's)

Sl. no	Forward speed (km h^{-1})	Actuating mechanism (cycles min^{-1})	Distance from crop canopy					
			4. 5 m			6.3 m		
			Height of the spray nozzle			Height of the spray nozzle		
			30	60	90	30	60	90
1	2.2	54	15	21	26	7	12	15
		60	14	22	24	8	11	19
		65	13	24	28	7	14	18
2	2.4	54	18	24	29	11	15	21
		60	17	21	31	12	14	23
		65	19	24	28	12	13	25
3	2.6	54	24	31	39	15	19	24
		60	23	28	36	16	23	26
		65	25	30	37	15	20	24

Wind direction: East to west, wind velocity: 1.5 m s^{-1}

Table 69. Effect of forward speed, speed of actuating mechanism and height of spray nozzle on swath width of spray

Sl. no	Forward speed (km h^{-1})	Speed of actuating mechanism (cycles min^{-1})	Swath width of spray (m) Height of spray nozzle (cm)		
			30	60	90
1	2.2	54	8.21	8.60	9.11
		60	7.80	8.10	8.40
		65	7.42	7.64	7.98
2	2.4	54	7.91	8.34	8.69
		60	7.40	7.56	7.79
		65	6.90	7.32	7.64
3	2.6	54	7.84	8.16	8.41
		60	7.24	7.46	7.61
		65	6.52	6.79	7.21

The statistical data on the swath width (Table 70) revealed that the main effects of the forward speed (A), actuating mechanism (B) and height of spray nozzle (C) has 5 per cent significant effect on the swath width. The interaction effects have 5 per cent level of significance effect on the swath width. The model F value for upper surface 6.37 implies that the model is significant at 5 per cent level of significance. The standard deviation and co-efficient of variation were found to be 0.51 and 6.63 per cent with a mean value of 7.74.

ii. Effect of forward speed, speed of actuating mechanism and height of spray nozzle on field capacity

The results presented in the Table 71 shows that the field capacity of the sprayer increased with increase in forward speed and increase in the height of spray nozzle. The field capacity was decreased with increase in the speed of actuating mechanism. The maximum field capacity (1.86 ha h^{-1}) was recorded for 54 cycles min^{-1} actuating speed when a tractor was operated at 2.6 km h^{-1} and height of spray nozzle was 90 cm. the minimum field capacity (1.22 ha h^{-1}) was observed for height of spray nozzle was 30 cm when actuating speed was 65 cycles min^{-1} and forward speed was 2.2 km h^{-1}.

The analysis of variance for field capacity (Table 72) shows that main effects of forward speed, actuating mechanism and height of spray nozzle has 5 per cent level of significance on the field capacity. The interaction effects have 5 per cent level of significance effect on the swath width. The model F value for upper surface 4.18 implies that the model is significant at 5 per cent level of significance. The standard deviation and co-efficient of variation were found to be 0.28 and 17.76 per cent with a mean value of 1.56.

iii. Effect of forward speed, speed of actuating mechanism and height of spray nozzle on actual application rate

The results indicated in the Table 73 revealed that the actual application rate of the sprayer was increased with increase in actuating mechanism. It was also observed that the application rate decreased with increase in the height of spray nozzle ranging from 30 to 90 cm above the crop canopy and in the forward speed in the range of 2.2 to 2.4 km h^{-1}. It can also be seen that the actual application rate was more than that of theoretical application rate.

Table 70. Analysis of variance for swath width of sprayer

Source	Sum of Squares	df	Mean Square	F Value
Model	43.69	26.00	1.68	6.37 *
A-Forward speed	1.79	2.00	0.90	3.40 *
B- Speed of actuating mechanism	8.65	2.00	4.33	16.41 *
C-Height of spray nozzle	13.72	2.00	6.86	26.02 *
AB	2.84	4.00	0.71	2.69 *
AC	3.56	4.00	0.89	3.38 *
BC	3.53	4.00	0.88	3.34 *
ABC	9.59	8.00	1.20	4.55 *
Pure Error	14.24	54.00	0.26	
Cor Total	57.93	80.00		

Std. Dev.	0.51	R-Squared	0.75
Mean	7.74	Adj R-Squared	0.64
C.V. (Per cent)	6.63	Pred R-Squared	0.45
PRESS	32.04	Adeq Precision	10.91

** = Significant at 1 per cent level, * = Significant at 5 per cent level
NS = Non significant

Table 71. Effect of forward speed, speed of actuating mechanism and height of spray nozzle on field capacity

Sl. no	Forward speed (km h^{-1})	Speed of actuating mechanism (cycles min^{-1})	Field capacity (ha h^{-1})		
			Height of spray nozzle (cm)		
			30	60	90
1	2.2	54	1.35	1.42	1.50
		60	1.29	1.34	1.39
		65	1.22	1.26	1.32
2	2.4	54	1.52	1.60	1.67
		60	1.42	1.45	1.50
		65	1.32	1.41	1.47
3	2.6	54	1.73	1.80	1.86
		60	1.60	1.65	1.68
		65	1.44	1.50	1.59

Table 72. Analysis of variance for field capacity of sprayer

Source	Sum of Squares	df	Mean Square	F Value
Model	8.36	26.00	0.32	4.18 *
A-Forward speed	0.95	2.00	0.48	6.18 *
B- Speed of actuating mechanism	1.21	2.00	0.60	7.85 *
C-Height of spray nozzle	0.65	2.00	0.33	4.25 *
AB	0.81	4.00	0.20	2.63 *
AC	1.19	4.00	0.30	3.87 *
BC	1.77	4.00	0.44	5.74 *
ABC	1.78	8.00	0.22	2.89 *
Pure Error	4.16	54.00	0.08	
Cor Total	12.52	80.00		

Std. Dev.	0.28	R-Squared	0.67
Mean	1.56	Adj R-Squared	0.51
C.V. (Per cent)	17.76	Pred R-Squared	0.25
PRESS	9.35	Adeq Precision	10.21

** = Significant at 1 per cent level, * = Significant at 5 per cent level

NS = Non significant

Table 73. Effect of forward speed, speed of actuating mechanism and height of spray on application rate

Sl. no	Forward speed (km h^{-1})	Speed of actuating mechanism (cycles min^{-1})	Application rate (l ha^{-1}) (Theoretical application rate)		
			Height of spray nozzle (cm)		
			30	**60**	**90**
1	2.2	54	415.30 (399.11)	395.20 (380.54)	371.20 (359.64)
		60	449.20 (419.58)	431.20 (404.04)	415.30 (389.61)
		65	485.60 (442.26)	468.30 (428.36)	445.30 (410.11)
2	2.4	54	345.60 (379.74)	331.20 (359.71)	321.60 (345.22)
		60	425.30 (408.16)	412.30 (396.82)	398.60 (385.10)
		65	468.31 (434.78)	441.30 (409.83)	421.30 (392.67)
3	2.6	54	331.20 (353.21)	321.30 (339.36)	314.20 (329.27)
		60	368.20 (382.49)	357.50 (371.21)	351.20 (363.89)
		65	445.20 (426.03)	426.10 (407.83)	400.20 (384.08)

The maximum actual application rate (485.60 l ha^{-1}) was obtained from the 65 cycles min^{-1} actuating mechanism when the forward speed of tractor was 2.2 km h^{-1} with height of spray nozzle was 30 cm. The actual application rate (314.20 l ha^{-1}) was found lowest for 54 cycles min^{-1} speed of actuating mechanism when tractor speed was 2.6 km h^{-1} with height of spray nozzle was 90 cm.

As per the analysis of variance (Table 74) observed main effects of operational parameters have 5 per cent level of significance on the actual application rate. Whereas combined effects of the all the parameters have 5 per cent level of significance on actual application rate. The model F value for upper surface 8.05 implies that the model is significant at 5 per cent level of significance. The standard deviation and co-efficient of variation were found to be 4.31 and 10.54 per cent with a mean value of 408.85.

iv. Effect of forward speed, speed of actuating mechanism and height of spray nozzle on difference in actual and theoretical application rate

The difference in actual and theoretical application rate of the sprayer at different treatment combinations are given in the Table 75. The results showed that the difference was increased with increase in the speed of actuating mechanism. The difference application rate was negative in 30 cm height of spray nozzle at 2.4, 2.6 km h^{-1} forward speed of 30 cm. The negative sign indicates that actual application rate was less than that of the theoretical application rate.

The maximum difference of application rate (9.80 per cent) was observed for 65 cycles min^{-1} at forward speed of 2.2 km h^{-1} when height of spray nozzle was 30 cm. The minimum difference of application rate (-4.58 per cent) was observed for 54 cycles min^{-1} actuating mechanism for forward speed of 2.6 km h^{-1}.

The Difference in actual and theoretical application rate was influenced highly significantly by the all the variables at 5 per cent of significance (Table 76). Interactions of forward speed, actuating mechanism and height of spray nozzle were significant at 5 per cent level of significance. The standard deviation and co-efficient of variation were found to be 1.79 and 13.78 per cent with a mean value of 4.08.

Table 74. Analysis of variance for application rate of sprayer

Source	Sum of Squares	df	Mean Square	F Value
Model	246316.66	26.00	9473.72	8.05 *
A-Forward speed	40826.39	2.00	20413.20	17.34 *
B- Speed of actuating mechanism	127409.66	2.00	63704.83	54.11 *
C-Height of spray nozzle	7661.39	2.00	3830.70	3.25 *
AB	23122.03	4.00	5780.51	4.91 *
AC	11980.33	4.00	2995.08	2.54 *
BC	13865.23	4.00	3466.31	2.94 *
ABC	21451.62	8.00	2681.45	2.28 *
Pure Error	63578.23	54.00	1177.37	
Cor Total	309894.89	80.00		

Std. Dev.	4.31	R-Squared	0.79
Mean	408.85	Adj R-Squared	0.70
C.V. (Per cent)	10.54	Pred R-Squared	0.54
PRESS	143051.02	Adeq Precision	10.68

** = Significant at 1 per cent level, * = Significant at 5 per cent level

NS = Non significant

Table 75. Effect of forward speed, speed of actuating mechanism and height of spray nozzle on difference of actual and theoretical application rate

Sl. no	Forward speed ($km\ h^{-1}$)	Speed of actuating mechanism ($cycles\ min^{-1}$)	Diff. actual and theoretical application rate (Per cent)		
			Height of spray nozzle (cm)		
			30	60	90
1	2.2	54	4.06	3.85	3.21
		60	7.06	6.72	6.59
		65	9.80	9.32	8.58
2	2.4	54	-8.99	-7.93	-6.84
		60	4.20	3.90	3.50
		65	7.71	7.68	7.29
3	2.6	54	-6.23	-5.32	-4.58
		60	-3.74	-3.69	-3.49
		65	4.50	4.48	4.20

Table 76. Analysis of variance for difference between actual and theoretical application rate of sprayer in pigeonpea crop

Source	Sum of Squares	df	Mean Square	F Value
Model	2073.72	26.00	79.76	24.95
A-Forward speed	408.34	2.00	204.17	63.88
B- Speed of actuating mechanism	1324.80	2.00	662.40	207.24
C-Height of spray nozzle	40.50	2.00	20.25	6.34
AB	99.08	4.00	24.77	7.75
AC	95.18	4.00	23.79	7.44
BC	50.02	4.00	12.50	3.91
ABC	55.80	8.00	6.98	2.18
Pure Error	172.60	54.00	3.20	
Cor Total	2246.32	80.00		

Std. Dev.	1.79	R-Squared	0.92
Mean	4.08	Adj R-Squared	0.89
C.V. (Per cent)	13.78	Pred R-Squared	0.83
PRESS	388.35	Adeq Precision	20.21

** = Significant at 1 per cent level, * = Significant at 5 per cent level
NS = Non significant

v. Effect of forward speed, speed of actuating mechanism and height of spray nozzle on fuel consumption of tractor

The fuel consumption of tractor increased with increase in the forward speed in range from 2.2 to 2.6 km h^{-1} (Table 77). The fuel consumption was varied from 2.40 to 3.38 as forward speed changed from 2.2 to 2.6 km h^{-1}. Fuel consumption did not affected when the height of spray was changed from 30 to 90 cm. It was further observed that the fuel consumption of tractor did not affected by speed of actuating mechanism as power to drive the actuating mechanism was taken from the tractor battery.

The fuel consumption (3.45 l h^{-1}) was obtained highest for high forward speed (2.6 km h^{-1}) with 60 cm height of spray nozzle above the plant canopy for 65 cycles min^{-1} speed of actuating mechanism. The fuel consumption was observed lowest (2.36 l h^{-1}) for low tractor speed of 2.2 km h^{-1} with a height of spray nozzle was 90 cm when the actuating mechanism was 65 cycles min^{-1}.

As per the statistical analysis for fuel consumption (Table 78) it was observed that the main effects of forward speed, actuating mechanism and height of spray nozzle was found significantly at 5 per cent level of significance. Combined interaction effects were found non significant at 5 per cent level of significance. The model F value for fuel consumption is 14.20 implies that the model is significant at 5 per cent level of significance. The standard deviation and co-efficient of variation were found to be 0.18 and 6.13 per cent with a mean value of 2.93.

vi. Effect of forward speed, speed of actuating mechanism and height of spray nozzle on droplet density

The droplet density produced by sprayer at different treatment combinations on different plant positions is given in the Table 79, 80 and 81. It was clear from the table that the droplet density decreased with increase in the forward and height of spray nozzle above plant canopy. The droplet density increased with increase in speed of actuating mechanism ranging from 54 to 65 cycles min^{-1}. It was further observed that the droplet density was maximum on the upper surface of the top, followed by middle and bottom for all the treatment combination.

The droplet density was found maximum at low height of spray nozzle (30 cm) for actuating mechanism of 65 cycles min^{-1} at low forward speed. The droplet density was

Table 77. Effect of forward speed, speed of actuating mechanism and height of spray nozzle on fuel consumption of tractor

Sl. no	Forward speed (km h^{-1})	Speed of actuating mechanism (cycles min^{-1})	Fuel consumption (l h^{-1}) Height of spray nozzle (cm)		
			30	60	90
1	2.2	54	2.40	2.40	2.43
		60	2.42	2.45	2.40
		65	2.38	2.39	2.36
2	2.4	54	2.90	2.91	2.96
		60	2.93	2.89	2.94
		65	2.91	2.88	2.93
3	2.6	54	3.38	3.39	3.41
		60	3.42	3.45	3.38
		65	3.38	3.42	3.40

Table 78. Analysis of variance for fuel consumption of tractor

Source	Sum of Squares	df	Mean Square	F Value
Model	11.93	26.00	0.46	14.20 *
A-Forward speed	10.24	2.00	5.12	158.37 *
B- Speed of actuating mechanism	0.09	2.00	0.04	1.35 NS
C-Height of spray nozzle	0.54	2.00	0.27	8.29 NS
AB	0.32	4.00	0.08	2.50 NS
AC	0.33	4.00	0.08	2.55 NS
BC	0.17	4.00	0.04	1.28 NS
ABC	0.25	8.00	0.03	0.98 NS
Pure Error	1.75	54.00	0.03	
Cor Total	13.68	80.00		

Std. Dev.	0.18	R-Squared	0.87
Mean	2.93	Adj R-Squared	0.81
C.V. (Per cent)	6.13	Pred R-Squared	0.71
PRESS	3.93	Adeq Precision	11.88

** = Significant at 1 per cent level, * = Significant at 5 per cent level,
NS = Non significant

Table 79. Effect of forward speed and speed of actuating mechanism on droplet density at 30 cm height of spray nozzle

Sl. no	Forward speed (km h^{-1})	Speed of actuating mechanism (cycles min^{-1})	Droplet density (No's cm^{-2})					
			Position of leaves on plant canopy					
			Top		Middle		Bottom	
			Upper	Lower	Upper	Lower	Upper	Lower
1	2.2	54	76.4	46.6	45.1	27.3	16.1	0
		60	82.0	54.4	73.1	34.7	19.3	0
		65	97.0	62.3	79.6	46.1	26.2	0
2	2.4	54	72.9	43.9	41.3	24.2	14.1	0
		60	79.4	57.4	75.0	29.6	15.8	0
		65	86.1	61.9	81.4	33.1	19.6	0
3	2.6	54	64.5	36.1	38.3	19.6	13.2	0
		60	66.1	46.3	42.5	22.2	14.6	0
		65	72.0	47.2	49.1	26.0	18.4	0

Table 80. Effect of forward speed and speed of actuating mechanism on droplet density at 60 cm height of spray nozzle

Sl. no	Forward speed (km h^{-1})	Speed of actuating mechanism (cycles min^{-1})	Droplet density (No's cm^{-2})					
			Position of leaves on plant canopy					
			Top		Middle		Bottom	
			Upper	Lower	Upper	Lower	Upper	Lower
1	2.2	54	72.9	38.1	41.3	18.9	12.1	0
		60	76.4	43.7	52.43	22.1	15.6	0
		65	81.1	45.4	53.8	29.2	17.0	0
2	2.4	54	66.2	34.3	29.4	15.1	10.9	0
		60	69.8	44.4	34.1	19.6	12.61	0
		65	73.5	49.1	36.4	26.2	14.2	0
3	2.6	54	45.3	29.16	22.1	11.3	9.92	0
		60	52.9	38.9	33.8	16.8	14.9	0
		65	58.7	42.21	36.0	23.3	17.2	0

Table 81. Effect of forward speed and speed of actuating mechanism on droplet density at 90 cm height of spray nozzle

Sl. no	Forward speed (km h^{-1})	Speed of actuating mechanism (cycles min^{-1})	Droplet density (No's cm^{-2})					
			Position of leaves on plant canopy					
			Top		Middle		Bottom	
			Upper	Lower	Upper	Lower	Upper	Lower
1	2.2	54	45.6	22.9	11.1	10.0	0	0
		60	51.7	31.6	23.4	12.3	0	0
		65	63.6	36.2	31.3	16.5	0	0
2	2.4	54	43.1	16.6	8.3	8.1	0	0
		60	46.4	23.9	19.9	13.3	0	0
		65	52.6	29.9	22	18.8	0	0
3	2.6	54	29.2	13.5	8.6	6.9	0	0
		60	33.6	15.1	10.7	10	0	0
		65	36.1	21.9	16.9	16.3	0	0

observed minimum for 90 cm height of spray at high forward speed. It was observed for the sprayer that the droplet density was 16.1 at bottom upper position of the leaves while no spray was found on the underside of the leave for all the treatments at nozzle height was 30 cm above the plant canopy. When the height of spray nozzle changed from 30 to 90 cm, no spray was found at the bottom position of the leaves.

The statistically analyzed data on droplet density (Table 82 and 83) showed that the main effects of forward speed (A), actuating mechanism (B), height of spray nozzle (C) and position of leaves (D) has 5 per cent significant on droplet density on both upper and lower surface of the plant leaves. The combined interaction effects have 5 per cent level of significance on both upper and lower surface. The model F value for droplet density on upper surface 369.18 implies that the model is significant at 5 per cent level of significance. The standard deviation and co-efficient of variation were found to be 2.27 and 6.6 per cent with a mean value of 34.30.

The model F value (Table 83) for droplet density on upper surface 755.62 implies that the model is significant at 5 per cent level of significance. The standard deviation and co-efficient of variation were found to be 1.29 and 6.68 per cent with a mean value of 19.30.

vii. Effect of forward speed, speed of actuating mechanism and height of spray nozzle on droplet size

The droplet size produced by the sprayer under different operational parameters is given in the Table 84, 85 and 86. The droplet size was decreased with increase in the forward speed and height of the spray nozzle above the plant canopy. The droplet size increased with increase in speed of actuating mechanism. It was also noticed that the droplet size decreased as distance from the top surface increased. The droplet size was maximum on the upper surface of the all position of the crop. The droplet size decreased from upper surface of the top position 162 to 146 µm lower surface of the top position. The maximum value of the droplet size was obtained on the top upper surface for 182 µm for 65 cycles min^{-1} speed of actuating mechanism when a sprayer was operated at 2.2 km h^{-1} at 30 cm height of spray nozzle on the plant canopy.

The maximum droplet size was obtained at low forward speed (2.2 km h^{-1}) with high speed of actuating mechanism for 30 cm height of spray nozzle. The minimum droplet size was observed for high forward speed (2.6 km h^{-1}) with low speed of actuating

Table 82. Analysis of variance for droplet density for upper surface of pigeonpea crop

Source	Sum of Squares	df	Mean Square	F Value
Model	183496.16	80.00	2293.70	15.24 *
A-Forward speed	4651.82	2.00	2325.91	15.45 *
B- Speed of actuating mechanism	3763.33	2.00	1881.67	12.50 *
C-Height of spray nozzle	18963.32	2.00	9481.66	62.99 *
D-Position of crop	103637.32	2.00	51818.66	344.22 *
AB	1641.31	4.00	410.33	2.73 *
AC	2042.72	4.00	510.68	3.39 *
AD	3399.41	4.00	849.85	5.65 *
BC	4009.35	4.00	1002.34	6.66 *
BD	2557.44	4.00	639.36	4.25 **
CD	2839.77	4.00	709.94	4.72 *
ABC	5944.91	8.00	743.11	4.94 *
ABD	11105.06	8.00	1388.13	9.22 **
ACD	7288.88	8.00	911.11	6.05 *
BCD	6127.27	8.00	765.91	5.09 *
ABCD	5524.24	16.00	345.27	2.29 *
Pure Error	24387.12	162.00	150.54	
Cor Total	207883.28	242.00		

Std. Dev.	2.27	R-Squared	0.882688
Mean	34.30	Adj R-Squared	0.824757
C.V. (Per cent)	6.6	Pred R-Squared	0.89
PRESS	702.30	Adeq Precision	80.2

** = Significant at 1 per cent level, * = Significant at 5 per cent level
NS = Non significant

Table 83. Analysis of variance for droplet density for lower surface of pigeonpea crop

Source	Sum of Squares	df	Mean Square	F Value
Model	79210.63	80.00	990.13	596.40 *
A-Forward speed	1058.71	2.00	529.36	318.85 *
B- Speed of actuating mechanism	1228.50	2.00	614.25	369.99 *
C-Height of spray nozzle	1185.87	2.00	592.93	357.15 *
D-Position of crop	71770.58	2.00	35885.29	21615.16 *
AB	86.27	4.00	21.57	12.99 *
AC	109.02	4.00	27.26	16.42 *
AD	575.23	4.00	143.81	86.62 *
BC	145.90	4.00	36.47	21.97 *
BD	661.82	4.00	165.46	99.66 *
CD	1209.46	4.00	302.36	182.13 *
ABC	291.87	8.00	36.48	21.98 *
ABD	183.32	8.00	22.91	13.80 *
ACD	77.87	8.00	9.73	5.86 **
BCD	234.60	8.00	29.32	17.66 **
ABCD	391.61	16.00	24.48	14.74 *
Pure Error	268.95	162.00	1.66	
Cor Total	79479.58	242.00		

Std. Dev.	1.29	R-Squared	1.00
Mean	19.30	Adj R-Squared	0.99
C.V. (Per cent)	6.68	Pred R-Squared	0.99
PRESS	605.14	Adeq Precision	70.95

** = Significant at 1 per cent level, * = Significant at 5 per cent level
NS = Non significant

Table 84. Effect of forward speed and speed of actuating mechanism on droplet size at 30 cm height of spray nozzle

Sl. no	Forward speed (km h^{-1})	Speed of actuating mechanism (cycles min^{-1})	Droplet size (µm)					
			Position of leaves on plant canopy					
			Top		Middle		Bottom	
			Upper	Lower	Upper	Lower	Upper	Lower
1	2.2	54	162	146	154	129	125	0
		60	174	151	162	145	131	0
		65	182	164	175	154	142	0
2	2.4	54	144	141	136	121	121	0
		60	153	146	141	132	128	0
		65	161	152	152	144	134	0
3	2.6	54	139	129	134	116	119	0
		60	146	136	139	128	123	0
		65	152	141	143	132	129	0

Table 85. Effect of forward speed and speed of actuating mechanism on droplet size at 60 cm height of spray nozzle

Sl. no	Forward speed (km h^{-1})	Speed of actuating mechanism (cycles min^{-1})	Droplet size (µm)					
			Position of leaves on plant canopy					
			Top		Middle		Bottom	
			Upper	Lower	Upper	Lower	Upper	Lower
1	2.2	54	144	131	134	129	125	0
		60	154	137	143	136	129	0
		65	172	143	161	143	136	0
2	2.4	54	135	126	128	121	121	0
		60	141	133	134	132	124	0
		65	146	140	139	140	130	0
3	2.6	54	130	118	125	114	114	0
		60	136	126	131	122	119	0
		65	141	135	135	132	124	0

Table 86. Effect of forward speed and speed of actuating mechanism on droplet size at 90 cm height of spray nozzle

Sl. no	Forward speed (km h^{-1})	Speed of actuating mechanism (cycles min^{-1})	Droplet size (µm)					
			Position of leaves on plant canopy					
			Top		Middle		Bottom	
			Upper	Lower	Upper	Lower	Upper	Lower
1	2.2	54	132	124	127	115	0	0
		60	141	132	136	126	0	0
		65	152	141	144	133	0	0
2	2.4	54	125	119	123	111	0	0
		60	132	125	130	124	0	0
		65	144	132	139	132	0	0
3	2.6	54	121	115	119	114	0	0
		60	129	124	124	119	0	0
		65	137	129	132	122	0	0

mechanism (54 cycles min^{-1}) at 90 cm height of spray nozzle. When the height of spray nozzle changed from 30 to 90 cm, no spray was found at the bottom position of the leaves, hence, zero droplet size at the bottom of the plant position.

The statistical analysis of droplet size both on upper and lower surface of the plant leaves (Table 87 and 88) revealed the main effect of operational parameters on the droplet size on both upper and lower surface was found significant at 5 per cent level. In case of the lower surface, actuating mechanism was found significant at 1 per cent level of the significance. The combined effects of forward speed, actuating mechanism, height of spray nozzle and position of the plant have significant at 5 per level of significance. The model F value for droplet density on upper surface 106.54 implies that the model is significant at 5 per cent level of significance. The standard deviation and co-efficient of variation were found to be 10.49 and 8.87 per cent with a mean value of 118.33.

The model F value (Table 88) for droplet density on upper surface 159.46 implies that the model is significant at 5 per cent level of significance. The standard deviation and co-efficient of variation were found to be 9.53 and 9.74 per cent with a mean value of 97.81.

viii. Effect of forward speed, speed of actuating mechanism and height of spray nozzle on uniformity coefficient

Uniformity coefficient of spray droplets produced by different operational parameters is given in the Table 89, 90 and 91. The results showed that the uniformity coefficient of spray droplets decreased with increasing in speed actuating mechanism and height of spray nozzle. It can also be seen that the uniformity coefficient was maximum on upper surface of the leaves and decreased on lower surface of the plant leaves. The maximum uniformity coefficient was observed on top upper position of the plant followed by middle and bottom position.

The maximum uniformity coefficient was observed for slow speed (2.2 km h^{-1}) with low speed of actuating mechanism (2.2 km h^{-1}) at all the heights. The minimum uniformity coefficient was found at high speed of forward speed (2.6 km h^{-1}) with high speed of actuating mechanism (64 cycles min^{-1}) for all heights of spray nozzle. When the height of spray nozzle changed from 30 to 90 cm, no spray was found at the bottom position of the leaves, hence, zero uniformity coefficients at the bottom of the plant position.

Table 87. Analysis of variance for droplet size for upper surface of pigeon pea crop

Source	Sum of Squares	df	Mean Square	F Value
Model	938426.46	80.00	11730.33	106.54 *
A-Forward speed	679.44	2.00	339.72	3.09 *
B- Speed of actuating mechanism	4800.55	2.00	2400.27	21.80 *
C-Height of spray nozzle	194743.61	2.00	97371.80	884.35 *
D-Position of crop	539641.36	2.00	269820.68	2450.57 *
AB	3771.76	4.00	942.94	8.56 *
AC	7926.92	4.00	1981.73	18.00 *
AD	4445.16	4.00	1111.29	10.09 *
BC	3282.40	4.00	820.60	7.45 *
BD	1131.66	4.00	282.92	2.57 *
CD	133558.79	4.00	33389.70	303.25 *
ABC	6050.36	8.00	756.30	6.87 *
ABD	6758.36	8.00	844.80	7.67 *
ACD	7018.46	8.00	877.31	7.97 *
BCD	8281.82	8.00	1035.23	9.40 *
ABCD	16335.82	16.00	1020.99	9.27 *
Pure Error	17837.06	162.00	110.11	
Cor Total	956263.52	242.00		

Std. Dev.	10.49	R-Squared	0.98
Mean	118.33	Adj R-Squared	0.97
C.V. (Per cent)	8.87	Pred R-Squared	0.96
PRESS	40133.39	Adeq Precision	37.41

** = Significant at 1 per cent level, * = Significant at 5 per cent level
NS = Non significant

Table 88. Analysis of variance for droplet size for lower surface of pigeonpea crop

Source	Sum of Squares	df	Mean Square	F Value
Model	1158021.64	80.00	14475.27	159.46 *
A-Forward speed	1034.63	2.00	517.31	5.70 *
B- Speed of actuating mechanism	4043.28	2.00	2021.64	22.27 **
C-Height of spray nozzle	12162.87	2.00	6081.43	66.99 *
D-Position of crop	1067815.22	2.00	533907.61	5881.68 *
AB	3036.76	4.00	759.19	8.36 *
AC	4755.59	4.00	1188.90	13.10 *
AD	7566.53	4.00	1891.63	20.84 *
BC	3635.86	4.00	908.97	10.01 *
BD	1040.92	4.00	260.23	2.87 *
CD	17984.54	4.00	4496.13	49.53 *
ABC	4853.30	8.00	606.66	6.68 *
ABD	5250.82	8.00	656.35	7.23 *
ACD	5223.63	8.00	652.95	7.19 *
BCD	4963.28	8.00	620.41	6.83 *
ABCD	14654.43	16.00	915.90	10.09 *
Pure Error	14705.49	162.00	90.77	
Cor Total	1172727.13	242.00		

Std. Dev.	9.53	R-Squared	0.99
Mean	97.81	Adj R-Squared	0.98
C.V. (Per cent)	9.74	Pred R-Squared	0.97
PRESS	33087.35	Adeq Precision	40.80

** = Significant at 1 per cent level, * = Significant at 5 per cent level
NS = Non significant

Table 89. Effect of forward speed and speed of actuating mechanism on uniformity coefficient at 30 cm height of spray nozzle

Sl. no	Forward speed (km h^{-1})	Speed of actuating mechanism (cycles min^{-1})	Uniformity coefficient					
			Position of leaves on plant canopy					
			Top		Middle		Bottom	
			Upper	Lower	Upper	Lower	Upper	Lower
1	2.2	54	3.20	2.80	2.90	2.50	2.10	0
		60	2.81	2.60	2.60	2.30	1.90	0
		65	2.60	2.40	2.20	1.90	1.80	0
2	2.4	54	2.60	2.32	2.40	2.10	1.90	0
		60	2.40	2.20	1.86	1.90	1.73	0
		65	2.20	2.13	1.70	1.86	1.62	0
3	2.6	54	2.10	1.90	1.90	1.80	1.80	0
		60	1.62	1.61	1.55	1.49	1.51	0
		65	1.58	1.54	1.43	1.41	1.39	0

Table 90. Effect of forward speed and speed of actuating mechanism on uniformity coefficient at 60 cm height of spray nozzle

Sl. no	Forward speed ($km\ h^{-1}$)	Speed of actuating mechanism ($cycles\ min^{-1}$)	Uniformity coefficient					
			Position of leaves on plant canopy					
			Top		Middle		Bottom	
			Upper	Lower	Upper	Lower	Upper	Lower
1	2.2	54	2.90	2.60	2.50	2.40	1.92	0
		60	2.60	2.20	2.30	2.10	1.61	0
		65	2.30	1.90	2.10	1.80	1.42	0
2	2.4	54	2.30	1.90	2.10	1.70	1.70	0
		60	1.90	1.86	1.8	1.78	1.67	0
		65	1.70	1.67	1.67	1.62	1.61	0
3	2.6	54	1.90	1.82	1.7	1.64	1.61	0
		60	1.59	1.54	1.51	1.48	1.49	0
		65	1.55	1.51	1.48	1.45	1.45	0

Table 91. Effect of forward speed and speed of actuating mechanism on uniformity coefficient at 90 cm height of spray nozzle

Sl. no	Forward speed (km h^{-1})	Speed of actuating mechanism (cycles min^{-1})	Uniformity coefficient					
			Position of leaves on plant canopy					
			Top		Middle		Bottom	
			Upper	Lower	Upper	Lower	Upper	Lower
1	2.2	54	2.11	1.80	1.90	1.62	0	0
		60	1.80	1.62	1.70	1.59	0	0
		65	1.62	1.58	1.58	1.52	0	0
2	2.4	54	1.91	1.69	1.72	1.58	0	0
		60	1.80	1.61	1.64	1.53	0	0
		65	1.69	1.57	1.61	1.49	0	0
3	2.6	54	1.84	1.56	1.64	1.51	0	0
		60	1.45	1.42	1.42	1.36	0	0
		65	1.42	1.38	1.39	1.29	0	0

According to the statistical analysis of data (Table 92 and 93) seen that main effect of operational parameters on the uniformity coefficient on both upper and lower surface was found significant at 5 per cent level of significance. The combined effects have 5 per cent level of significance except effects of (A × C) and (C × D) have 1 per cent level of significance in case of upper surface of the plant canopy. In case of lower surface (B × C × D) and (A× B × C × D) have 1 per cent level of significance. The model F value for uniformity coefficient on upper 6.21 implies that the model is significant at 5 per cent level of significance. The standard deviation and co-efficient of variation were found to 0.11 and 4.2 per cent with a mean value of 2.57.

The model F value (Table 93) for droplet density on upper surface 8.59 implies that the model is significant at 5 per cent level of significance. The standard deviation and co-efficient of variation were found.

ix. Effect of forward speed, speed of actuating mechanism and height of spray nozzle on area covered by droplets

The area covered by droplets on the plant canopy under different treatment combinations is shown in the Table 94, 95 and 96. The area covered by droplets was decreased with increase in the forward and height of spay nozzle above the plant canopy. Area covered was increased with increase in speed of actuating mechanism ranges from 54 to 65 cycles min^{-1}. Area covered varied from 13.56 to 9.12 as height of spray changed from 30 to 90 cm. It was also noticed that the area covered by droplets decreases with position of the plant canopy. The maximum area covered was found for top upper surface, followed by middle and bottom position. The area covered was 11.23 at the top of upper surface whereas for lower surface it was 6.50 when height of spray was 90 cm.

The maximum area covered by droplets was found for slow speed (2.2 km h^{-1}) for high speed of actuating mechanism (65 cycles min^{-1}) at low height of spray nozzle (30 cm) on top surface of the plant. The minimum area covered by droplets was observed for high speed (2.6 km h^{-1}) for slow speed of actuating mechanism (54 cycles min^{-1}) at height of spray nozzle was 90 cm.

Statistically analyzed data have been presented in the Table 97 and 98. It was clear from the table that the main effects were found significant at 5 per cent level of significance for both upper and lower surface of the leaves. The combined interaction

Table 92. Analysis of variance for uniformity coefficient for upper surface of pigeonpea crop

Source	Sum of Squares	df	Mean Square	F Value
Model	15.41	2.00	7.71	6.21 *
A-Forward speed	17.09	2.00	8.54	6.88 *
B- Speed of actuating mechanism	16.70	2.00	8.35	6.73 *
C-Height of spray nozzle	10.95	2.00	5.47	4.41 *
D-Position of crop	59.77	4.00	14.94	12.04 *
AB	67.42	4.00	16.86	13.58 *
AC	75.50	4.00	18.88	15.20 **
AD	67.06	4.00	16.77	13.50*
BC	70.85	4.00	17.71	14.27 *
BD	61.74	4.00	15.43	12.43 *
CD	120.90	8.00	15.11	12.17 **
ABC	123.77	8.00	15.47	12.46 *
ABD	113.55	8.00	14.19	11.43 *
ACD	115.18	8.00	14.40	11.60 *
BCD	229.53	16.00	14.35	11.55 *
ABCD	201.14	162.00	1.24	
Pure Error	1366.57	242.00		
Cor Total	15.41	2.00		

Std. Dev.	0.11	R-Squared	0.85
Mean	2.57	Adj R-Squared	0.78
C.V. (Per cent)	4.2	Pred R-Squared	0.67
PRESS	452.56	Adeq Precision	31.09

** = Significant at 1 per cent level, * = Significant at 5 per cent level
NS = Non significant

Table 93. Analysis of variance for uniformity coefficient for lower surface of pigeonpea crop

Source	Sum of Squares	df	Mean Square	F Value
Model	16339.49	80.00	204.24	8.95 *
A-Forward speed	184.80	2.00	92.40	4.05 *
B- Speed of actuating mechanism	769.59	2.00	384.79	16.85 *
C-Height of spray nozzle	698.14	2.00	349.07	15.29 *
D-Position of crop	348.67	2.00	174.34	7.64 *
AB	461.89	4.00	115.47	5.06 *
AC	456.46	4.00	114.11	5.00 *
AD	469.90	4.00	117.47	5.15 *
BC	1732.53	4.00	433.13	18.97 *
BD	1647.09	4.00	411.77	18.03 *
CD	1721.14	4.00	430.29	18.85 *
ABC	872.09	8.00	109.01	4.77 *
ABD	873.10	8.00	109.14	4.78 *
ACD	883.57	8.00	110.45	4.84 *
BCD	3447.20	8.00	430.90	18.87 **
ABCD	1773.32	16.00	110.83	4.85 **
Pure Error	3698.85	162.00	22.83	
Cor Total	20038.34	242.00		

Std. Dev.	0.18	R-Squared	0.82
Mean	1.45	Adj R-Squared	0.72
C.V. (Per cent)	12.43	Pred R-Squared	0.58
PRESS	8322.40	Adeq Precision	21.75

** = Significant at 1 per cent level, * = Significant at 5 per cent level
NS = Non significant

Table 94. Effect of forward speed and speed of actuating mechanism on area covered by droplets at 30 cm height of spray nozzle

Sl. no	Forward speed (km h^{-1})	Speed of actuating mechanism (cycles min^{-1})	Area covered by droplets (mm^2 cm^{-2})					
			Position of leaves on plant canopy					
			Top		Middle		Bottom	
			Upper	Lower	Upper	Lower	Upper	Lower
1	2.2	54	13.56	7.20	9.51	5.12	7.51	0
		60	15.79	8.13	10.56	5.64	6.12	0
		65	16.20	9.61	11.12	6.2	6.44	0
2	2.4	54	11.16	6.43	8.55	4.30	5.12	0
		60	14.21	7.24	10.23	5.00	5.32	0
		65	15.26	8.73	10.34	5.34	5.69	0
3	2.6	54	10.01	6.32	7.39	3.4	4.66	0
		60	12.02	5.56	8.23	4.00	4.95	0
		65	14.30	6.24	8.61	4.62	5.10	0

Table 95. Effect of forward speed and speed of actuating mechanism on area covered by droplets at 60 cm height of spray nozzle

Sl. no	Forward speed ($km\ h^{-1}$)	Speed of actuating mechanism ($cycles\ min^{-1}$)	Area covered by droplets ($mm^2\ cm^{-2}$)					
			Position of leaves on plant canopy					
			Top		Middle		Bottom	
			Upper	Lower	Upper	Lower	Upper	Lower
1	2.2	54	11.23	6.50	8.76	4.78	5.51	0
		60	12.56	7.21	9.32	5.27	5.60	0
		65	13.21	7.54	10.00	5.59	6.00	0
2	2.4	54	10.00	6.23	8.25	4.12	4.42	0
		60	10.75	7.04	8.73	4.58	4.82	0
		65	11.66	7.23	9.14	5.24	4.95	0
3	2.6	54	9.11	5.37	7.19	3.20	3.66	0
		60	9.72	5.69	8.13	3.60	4.15	0
		65	10.42	6.14	8.39	41	4.94	0

Table 96. Effect of forward speed and speed of actuating mechanism on area covered by droplets at 90 cm height of spray nozzle

Sl. no	Forward speed (km h^{-1})	Speed of actuating mechanism (cycles min^{-1})	Area covered by droplets (mm^2 cm^{-2})					
			Position of leaves on plant canopy					
			Top		Middle		Bottom	
			Upper	Lower	Upper	Lower	Upper	Lower
1	2.2	54	9.12	4.50	6.21	2.48	0	0
		60	9.66	5.12	7.23	2.92	0	0
		65	11.10	5.74	8.10	3.49	0	0
2	2.4	54	8.50	4.16	5.85	2.12	0	0
		60	9.12	4.59	6.13	2.58	0	0
		65	10.26	5.43	6.64	3.14	0	0
3	2.6	54	7.61	3.67	4.50	1.82	0	0
		60	8.32	3.79	4.73	2.30	0	0
		65	9.10	4.31	5.24	3.00	0	0

effects were found significant at 5 per cent level of significance. The model F value for uniformity coefficient on upper 5.38 implies that the model is significant at 5 per cent level of significance. The standard deviation and co-efficient of variation were found to 0.53 and 9.66 per cent with a mean value of 6.8.

The model F value (Table 98) for droplet density on upper surface 18.75 implies that the model is significant at 5 per cent level of significance. The standard deviation and co-efficient of variation were found to 0.81 and 14.31 per cent with a mean value of 5.56.

x. Effect of forward speed, speed of actuating mechanism and height of the spray nozzle on particle drift

Effect of forward speed, actuating mechanism and height of the spray nozzle on particle drift is presented in the Table 99. It was observed from the results, the drift droplets varied from 17 to 31 as the height of the spray nozzle increased from 30 to 90 cm at 4.5 cm distance from the sprayed crop for 54 cycles min^{-1}. The drift droplets were increased from 19 to 23 as the forward speed increased at 65 cycles min^{-1}. It was observed that, drift droplets were reduced as the distance away from the sprayed area increased. Drift droplets decreased from 17 to 8 as the distance from the crop increased. It was also observed that, speed of actuating mechanism did not have influence on the drift droplets.

4.3.3 Optimization of operational parameters of tractor operated automatic gun sprayer in cotton and pigeonpea crop

Optimum process conditions are required to significantly enhance the performance of tractor operated automatic gun sprayer. Numerical optimization has been conducted to evaluate the optimum forward speed, actuating mechanism and height of spray nozzle for cotton and pigeonpea. Numerical optimization constraints for cotton and pigeon pea are presented in Table 100 and 101 optimized parameter for cotton and pigeonpea is presented in Table 102 and 103.

The desirability index of swath width, field capacity, actual application rate, difference in actual and theoretical application rate, fuel consumption, droplet density, droplet size, uniformity coefficient and area covered by droplets were 0.53, 1, 0.42, 0.96, 0.64, 0.72, 1 and 0.86, respectively for cotton crop. The overall desirability index for combined was found to be 0.70.

Table 97. Analysis of variance for area covered by droplets for upper surface of pigeonpea crop

Source	Sum of Squares	df	Mean Square	F Value
Model	25.19	2.00	12.60	5.38 *
A-Forward speed	18.77	2.00	9.39	4.01 *
B- Speed of actuating mechanism	933.13	2.00	466.56	199.11 **
C-Height of spray nozzle	4385.96	2.00	2192.98	935.86 *
D-Position of crop	32.98	4.00	8.25	3.52 **
AB	40.87	4.00	10.22	4.36 *
AC	46.36	4.00	11.59	4.95 *
AD	34.14	4.00	8.54	3.64 *
BC	29.07	4.00	7.27	3.10 *
BD	239.50	4.00	59.88	25.55 *
CD	46.43	8.00	5.80	2.48 *
ABC	49.42	8.00	6.18	2.64 *
ABD	65.33	8.00	8.17	3.48 *
ACD	55.33	8.00	6.92	2.95 *
BCD	120.44	16.00	7.53	3.21 *
ABCD	379.61	162.00	2.34	
Pure Error	6502.53	242.00		
Cor Total	25.19	2.00		

Std. Dev.	0.53	R-Squared	0.94
Mean	7.79	Adj R-Squared	0.91
C.V. (Per cent)	6.8	Pred R-Squared	0.87
PRESS	854.12	Adeq Precision	28.32

** = Significant at 1 per cent level, * = Significant at 5 per cent level
NS = Non significant

Table 98. Analysis of variance for area covered by droplets for lower surface of pigeonpea crop

Source	Sum of Squares	df	Mean Square	F Value
Model	4919.67	80.00	61.50	18.75 *
A-Forward speed	24.99	2.00	12.49	3.81 *
B- Speed of actuating mechanism	23.43	2.00	11.71	3.57 *
C-Height of spray nozzle	124.74	2.00	62.37	19.02 *
D-Position of crop	3608.08	2.00	1804.04	550.12 *
AB	68.38	4.00	17.10	5.21 *
AC	59.38	4.00	14.84	4.53 *
AD	75.20	4.00	18.80	5.73 *
BC	74.86	4.00	18.71	5.71 **
BD	56.96	4.00	14.24	4.34 **
CD	209.42	4.00	52.35	15.96 *
ABC	79.22	8.00	9.90	3.02 *
ABD	108.58	8.00	13.57	4.14 *
ACD	101.85	8.00	12.73	3.88 *
BCD	91.52	8.00	11.44	3.49 *
ABCD	213.08	16.00	13.32	4.06 *
Pure Error	531.25	162.00	3.28	
Cor Total	5450.92	242.00		

Std. Dev.	0.81	R-Squared	0.90
Mean	5.66	Adj R-Squared	0.85
C.V. (Per cent)	14.31	Pred R-Squared	0.78
PRESS	1195.32	Adeq Precision	25.32

** = Significant at 1 per cent level, * = Significant at 5 per cent level
NS = Non significant

Table 99. Effect of forward speed, actuating mechanism and height of the spray nozzle on particle drift (No's)

Sl .no	Forward speed (km h^{-1})	Actuating mechanism (cycles min^{-1})	Distance from crop canopy					
			4. 5 m			6.3 m		
			Height of the spray nozzle			Height of the spray nozzle		
			30	60	90	30	60	90
1	2.2	54	17	24	31	8	13	18
		60	15	21	30	7	13	16
		65	19	24	33	8	12	19
2	2.4	54	22	29	35	10	15	21
		60	19	28	34	12	14	21
		65	21	27	30	15	11	24
3	2.6	54	24	31	35	13	21	24
		60	25	28	34	15	21	26
		65	23	32	37	16	23	23

Wind direction: East to west, wind velocity: 1.2 m s^{-1}

Table 100. Numerical optimization constraints for field evaluation of tractor operated automatic gun sprayer for cotton crop

Name	Goal	Lower Limit	Upper Limit	Importance
Forward speed (km h^{-1})	is in range	Level 1 of A	Level 3 of A	3
Speed of actuating mechanism (cycles min^{-1})	is in range	Level 1 of B	Level 3 of B	3
Height of spray (m)	is in range	Level 1 of C	Level 3 of C	3
Swath width (m)	maximize	6.8	8.34	3
Field capacity (ha h^{-1})	is in range	1.188	1.83651	3
Application rate (l ha^{-1})	minimize	314.3	523.6833	3
Fuel consumption (l h^{-1})	minimize	2.48	3.56	3
Droplet size (µm)	maximize	132	189	3
Droplet density (No's cm^{-2})	maximize	32	86	3
Uniformity coefficient	maximize	1	2.5	3
Area covered by droplets (mm^2 cm^{-2})	maximum	8.6	16.3	3

Table 101. Optimized operational parameters of tractor operated automatic gun sprayer in cotton crop

Name	Optimized value
Forward speed (km h^{-1})	2.2
Speed of actuating mechanism (cycles min^{-1})	54
Height of spray (m)	30
Swath width (m)	7.63
Field capacity (ha h^{-1})	1.25
Application rate (l ha^{-1})	435.06
Fuel consumption (l h^{-1})	2.52
Droplet size (µm)	169.00
Droplet density (No’s cm^{-2})	71.00
Uniformity coefficient	2.50
Area covered by droplets (mm^2 cm^{-2})	15.25
Desirability	0.70

Table 102. Numerical optimization constraints for tractor operated automatic gun sprayer for pigeonpea crop

Name	Goal	Lower Limit	Upper Limit
Forward speed (km h^{-1})	is in range	Level 1 of A	Level 3 of A
Speed of actuating mechanism (cycles min^{-1})	is in range	Level 1 of B	Level 3 of B
Height of spray (m)	is in range	Level 1 of C	Level 3 of C
Swath width (m)	maximize	6.5	9.1
Field capacity (ha h^{-1})	is in range	1.22	1.85
Application rate (l ha^{-1})	minimize	314.2	485.6
Fuel consumption (l h^{-1})	minimize	2.38	3.62
Droplet size (µm)	maximize	134	192
Droplet density (No's cm^{-2})	maximize	29.2	97
Uniformity coefficient	maximize	1.42	3.2
Area covered by droplets (mm^2 cm^{-2})	maximize	9.2	16.2

Table 103. Optimized parameters for tractor operated automatic gun sprayer for pigeonpea crop

Name	Optimized value
Forward speed (km h^{-1})	2.2
Speed of actuating mechanism (cycles min^{-1})	54
Height of spray (cm)	30
Swath width (m)	8.20
Field capacity (ha h^{-1})	1.35
Application rate (l ha^{-1})	415.3
Fuel consumption (l h^{-1})	2.40
Droplet size (µm)	178
Droplet density (No's cm^{-2})	76.40
Uniformity coefficient	3.20
Area covered by droplets (mm^2 cm^{-2})	15.56
Desirability	0.74

The desirability index of swath width, field capacity, actual application rate, difference in actual and theoretical application rate, fuel consumption, droplet density, droplet size, uniformity coefficient and area covered by droplets were 0.65, 1, 041, 0.98, 0.75, 0.69, 1, and 0.90, respectively for pigeonpea crop. The overall desirability index for combined was found to be 0.74.

4.4.4 Performance evaluation of tractor operated automatic gun sprayer under optimized parameters

The performance evaluation of tractor operated automatic gun sprayer was conducted under optimized parameters *viz*., 2.2 km h^{-1} forward speed, 54 cycles min^{-1} speed of actuating mechanism and 30 cm height of spray nozzle above the crop canopy. Various parameters *viz*., swath width, field capacity, actual application rate, fuel consumption, droplet density, droplet size, uniformity coefficient and area covered by droplets was tested for both cotton and pigeonpea crop. The metrological data was recorded. The wind velocity, temperature and humidity at the time of spraying for cotton were 1.1 m s^{-1}, 29 °C and 65 per cent, respectively. The wind velocity, temperature and humidity at the time of spraying for pigeonpea were 1.4 m sc^{-1}, 27 °C and 61 per cent, respectively. The results obtained from the experiment are given in the Table 104.

i. Plant damage

Plant damage was measured in the field for both cotton and pigeon pea during the spraying operation. Plant damage was 5.7 per cent in case of cotton crop by sprayer and 6.3 per cent for the pigeonpea crop. While operating the tractor mounted sprayer in the field one row was under the tractor was partly affected during the each pass of the machine under the tractor tyres and chassis.

ii. Bio-efficacy of spraying

The data representing the efficacy of insecticides sprayed with the developed sprayer against insects is given in the Table 105 and 106. There was a drastic reduction in sucking pest population after spraying compared to pre count data. This is because of the toxic effect of insecticide on insects. The leaf hoppers were 5.0 before spraying and reduced to 1.0 per leaf after spraying. In case of T2 (conventional tractor operated gun sprayer) pre count leaf hoppers were 7.0 and reduced to 2.8 per leaf.

The populations of aphids were 10 DBS and after 5 days reduced to 2.5 numbers. Pre counts of aphids were 12 before spraying in conventional sprayer reduced to 4.2

Table 104. Performance evaluation of tractor operated automatic gun sprayer under optimized condition

Particulars			Details	
Name of the crop			Cotton	Pigeonpea
Variety			*Bt* MRC 7351	Maruthi ICP 8863
Average height of crop (mm)			630	1350
Stage of crop (days)			120	110
Row to row spacing (mm)			900	900
Plant to plant spacing (mm)			400	600
Leaf area index			3.2	2.14
Forward speed (km h^{-1})			2.2	2.2
Speed of actuating mechanism (cycles min^{-1})			54	54
Height of spray (cm)			30	30
Swath width (m)			10.1	9.3
Field capacity (ha h^{-1})			1.8	1.73
Application rate (l ha^{-1})			340.5	364.18
Fuel consumption (l h^{-1})			2.9	2.4
Droplet density (No's cm^{-2})	Top	Upper	63.4	71.4
		Lower	22.3	30.9
	Middle	Upper	45.5	34.9
		Lower	18.6	15.2
	Bottom	Upper	26.4	0
		Lower	0	0

Conti….

Droplet size (µm)	Top	Upper	165	172
		Lower	142	153
	Middle	Upper	153	161
		Lower	129	144
	Bottom	Upper	146	0
		Lower	0	0
Uniformity coefficient	Top	Upper	2.4	1.9
		Lower	1.6	1.3
	Middle	Upper	1.8	1.6
		Lower	1.3	1.2
	Bottom	Upper	1.6	0
		Lower	0	0
Area covered by droplets (mm^2 cm^{-2})	Top	Upper	10.40	12.3
		Lower	5.63	6.45
	Middle	Upper	7.12	7.60
		Lower	3.15	5.25
	Bottom	Upper	6.13	0
		Lower	0	0
Particle drift (No's)	Distance from sprayed canopy	4.5 m	20	19
		6.3 m	11	14

Table 105. Bio-efficacy of spraying against leaf hopper in cotton

Treatment	Population of leaf hopper (No. of hoppers leaf $^{-1}$)		
	Pre count	**3 DAS**	**5 DAS**
T1	5.0	2.0	1.0
T2	7.0	4.0	2.8

DAS: Days after spraying

Table 106. Bio-efficacy of spraying against aphids in cotton

Treatment	Population of aphids (No. of aphids leaf^{-1})		
	Pre count	**3 DAS**	**5 DAS**
T1	10	6.5	2.5
T2	13	7.0	4.2

DAS: Days after spraying

Table 107. Bio-efficacy of spraying against *Helicoverpa armigera* in pigeonpea crop

Treatment		Population of *Helicoverpa armigera* (No. of *larva* plant^{-1})		
	Per cent pod damage	**DBS**	**3 DAS**	**5 DAS**
T1	15	4.2	2.2	0.8
T2	18	6.0	3.5	2.2

DBS: Day before spraying

DAS: Days after spraying

numbers. This shows that automatic gun sprayer was effective against cotton sucking pest.

Bio-efficacy of spraying against *Helicoverpa armigera* in pigeon pea crop is presented in Table 107. It shows that population of *Helicoverpa armigera* was 4.2 larva per plant before spraying and reduced to 0.8 numbers after 5 days whereas in conventional method it was 6.0 number reduced to 2.2 numbers. The pod damage by *Helicoverpa armigera* for tractor operated automatic gun sprayer and conventional tractor operated gun sprayer were 15 and 18 per cent.

4.5 Economics of tractor operated automatic gun sprayer for selected field crops

The cost of operation of the developed tractor operated automatic gun sprayer was found to be Rs. 320.06 ha^{-1} and 302.7 ha^{-1} (Appendix-II) for cotton crop and pigeonpea crop. The breakeven point and payback period of sprayer in cotton and pigeonpea crop was 87.8 h $annum^{-1}$ and 81 h $annum^{-1}$ and 1.48 years and 1.36 years, respectively.

4.6 Comparison of performance between developed tractor operated automatic gun sprayer with conventional tractor operated gun sprayer

The results representing comparison of performance between two sprayers is presented in the Table 108 and 109. It was observed that the swath width of the conventional gun sprayer was more than the tractor operated automatic gun sprayer. Number of swings required to cover without overlap and miss application was 54 cycles min^{-1} but in case of conventional method, number of swings was less. The actual application rate (430.1 l h^{-1}) of the conventional sprayer for cotton was more compared to developed. The cost of operation of tractor operated automatic gun sprayer was more compared to conventional. Total cost of operation including chemical cost was 20.62 per cent and 19.31 per cent less compared to conventional method of spraying.

Table 108. Comparison of performance between developed tractor operated automatic gun sprayer and conventional tractor operated gun sprayer in cotton crop

Particulars			Automatic gun sprayer	Conventional gun sprayer
Forward speed (km h^{-1})			2.20	2.20
Oscillation (cycles min^{-1})			54.00	43±2
Height of spray (cm)			30.00	30.00
Swath width (m)			8.40	12.90
Field capacity (ha h^{-1})			1.57	1.99
Field efficiency ((Per cent))			83.50	69.52
Application rate (l ha^{-1})			370.40	430.00
Droplet size (µm)			154.00	163.00
Droplet density (No’s cm^{-2})	Top		94.20	81.30
			26.40	22.10
	Middle		56.70	46.40
			18.30	16.30
	Bottom		22.10	0.00
			0.00	0.00
Cost of operation (Rs h^{-1})			320.06	284.04
Cost of operation with chemical (Rs ha^{-1})			2653.39	3200.71

Table 109. Comparison of performance between developed tractor operated automatic gun sprayer and conventional tractor operated gun sprayer in pigeonpea crop

<table>
<tr><th colspan="3">Particulars</th><th>Automatic gun sprayer</th><th>Conventional gun sprayer</th></tr>
<tr><td colspan="3">Forward speed (km h^{-1})</td><td>2.20</td><td>2.20</td></tr>
<tr><td colspan="3">Oscillation (cycles min^{-1})</td><td>54.00</td><td>47±2</td></tr>
<tr><td colspan="3">Height of spray (cm)</td><td>30.00</td><td>30.00</td></tr>
<tr><td colspan="3">Swath width (m)</td><td>8.90</td><td>13.50</td></tr>
<tr><td colspan="3">Field capacity (ha h^{-1})</td><td>1.66</td><td>2.08</td></tr>
<tr><td colspan="3">Field efficiency (Per cent)</td><td>83.00</td><td>69.71</td></tr>
<tr><td colspan="3">Application rate (l ha^{-1})</td><td>392.40</td><td>460.40</td></tr>
<tr><td colspan="3">Droplet size (µm)</td><td>143.00</td><td>151.00</td></tr>
<tr><td rowspan="6">Droplet density (No’s cm^{-2})</td><td rowspan="2">Top</td><td>Upper</td><td>62.10</td><td>58.20</td></tr>
<tr><td>Lower</td><td>23.60</td><td>18.30</td></tr>
<tr><td rowspan="2">Middle</td><td>Upper</td><td>43.10</td><td>34.60</td></tr>
<tr><td>Lower</td><td>15.20</td><td>15.80</td></tr>
<tr><td rowspan="2">Bottom</td><td>Upper</td><td>19.20</td><td>12.10</td></tr>
<tr><td>Lower</td><td>0.00</td><td>0.00</td></tr>
<tr><td colspan="3">Cost of operation without chemical (Rs h^{-1})</td><td>302.70</td><td>271.75</td></tr>
<tr><td colspan="3">Cost of operation with chemical (Rs ha^{-1})</td><td>2692.30</td><td>3301.88</td></tr>
</table>

Discussion

V. DISCUSSION

This chapter represents the results of the crop parameters of the cotton and pigeon pea, design and development of tractor operated automatic gun sprayer and performance evaluation of developed tractor operated automatic gun sprayer under laboratory and field condition are discussed in this chapter. Numerical optimization of various operational parameters under laboratory and field along with cost economics of developed sprayer in comparison with conventional tractor operated gun sprayer are also discussed. The results are described and discussed under the following subheadings.

5.1 Crop and machine parameters for design and development of tractor operated automatic gun sprayer for selected field crops

5.1.1 Crop parameters

Before commencement of the experiments, the data on targeted field crops were collected. Some basic calculation related to crop was also worked out and presented as below.

The targeted field crops selected for this study were cotton and pigeonpea. Cotton is dense foliage and in particular is the main cash crop in Raichur district of Karnataka, The cotton (Hybrid: *Bt* cotton hybrid (MRC - 7351) grown in the farmers field have been used for spraying and recommended spacing was 0.9 × 0.4 m. The plant parameters were recorded during different stages of the crop and accordingly leaf area index was calculated. The data on plant parameter is presented in Table 7 and 8. The leaf area index of the cotton plant was 3.04 when the plant was 110 days. The maximum height of the plant was 550 mm.

Pigeonpea is one of the major pulse crops of the Raichur region of Karnataka. Pigeonpea is a tall growing, wide spaced crop. The crop variety was Maruthi ICP 8863 with recommended spacing was 0.9 × 0.6 m. The height of the pigeon pea was 900 mm when the stage of the crop was 120 days after sowing. The leaf area index was 2.34.

5.1.2 Machine parameters

Machine parameters considered in designing of sprayer are discussed below. Properly designed sprayer will increase the deposition, field efficiency and reduces the production cost. Some of parameters were measured during laboratory and field study.

ix. Filling time for spray tank

Filling time is the time required to fill the spray tank. The fitted HTP pump was used to fill the tank from lakes or wells through a bypass valve. Connections to two ways clock was closed while filling. The pump was operated at maximum speed. The time taken to fill the spray tank was 35 minutes.

x. Emptying time of spray tank

Emptying time of spray tank depends on the discharge, pressure and speed of operation. Emptying time was noted during the spraying. This time provides the number of acres that can be sprayed when spray tank is full. Emptying time ranges between 30 to 45 minutes.

xi. Track width of tractor

Track width of tractor was changed based on the row spacing of the crop by changing removing the complete wheel and assembling them in the new position. The track width of the tractor at the front wheel is 1540 mm and at the rear wheel it is 1460 mm.

xii. Speed of actuating mechanism

The speed of actuating mechanism was selected based on the trials conducted in the open field. Number of oscillations taken to cover 2.2, 2.4 and 2.6 km h^{-1} was 54, 60 and 65 cycles min^{-1}, respectively.

5.2 Laboratory evaluation of the tractor operated automatic gun sprayer for field crops

Experiment was conducted under the different variables namely operating pressure, diameter of nozzle and orientation of spray nozzle to determine optimum value. The optimum values of those are important to ascertain the working of sprayer in the field condition. The laboratory calibration of sprayer was carried out in the same way as prescribed by the BIS code of IS: 11429 (1985): Methods for calibration of sprayers**.**

The laboratory experiments were carried out by using the actual cotton and pigeonpea plant. The cotton and pigeonpea plants were raised in the polyethylene bags and after certain age placed in pot as same (Gholap *et al*., 2012). The height of the crop was 450 and 650 for cotton and pigeon pea, respectively. It was an attempt made to establish actual plant canopy in the laboratory to get the correct results.

viii. Effect of operating pressure, nozzle size and orientation of spray nozzle on discharge

The discharge of spray liquid delivered by different nozzle size at different operating pressure in the range of 20 to 24 kg cm^{-2} for different orientation of spray nozzle are presented in Fig 17. It is clearly indicated that generally the discharge rate increased with increasing the orifice diameter for all the operating pressure. Higher the pressure, higher will be the discharge. The nozzle discharged increased by 38.23 per cent as the operating pressure increased from 20 to 24 kg cm^{-2} for 2 mm nozzle size and discharged increased by 31.70 per cent when the nozzle size changed from 2 to 6 mm at operating pressure of 20 kg cm^{-2}. Kepner *et al*. (1987) reported that, flow rate for a particular nozzle was proportional to the square root of the operating pressure. Statistical data revealed that both pressure and nozzle size was found significant at 1 per cent level of significance. Discharge is the product of cross sectional area of orifice and velocity. Discharge is directly proportional to the cross sectional area of orifice. These results confirmed the statements made by Iqbal (2005a), Kathirvel *et al*. (2002), Durairaj *et al*. (2002), Senthilkumar and kumar (2007), Shukla *et al*. (1987), Shashi *et al*. (2005) and Ejaz *et al*. (2004). Among all the parameter studied, nozzle pressure influenced the discharge most significantly followed by nozzle size.

It was also observed from the anova table that, orientation of nozzle was found non significant at 1 per cent level of significance. Orientation of nozzle did not affect the discharge of the sprayer. The combined effects operating pressure and nozzle has significant effect on the discharge but combined effects along with orientation of the spray nozzle was found not significant at 99 per cent confidence level . If the prob > value of the model is considerably less than the 0.01, then the terms in the model have a significant effect on the model. The model F- value of 57.37 implies the model is significant. There is only 0.01 per cent chance for a model F-value of this large could occur due to noise. The interaction effects (A × B) has 1 per cent significant.

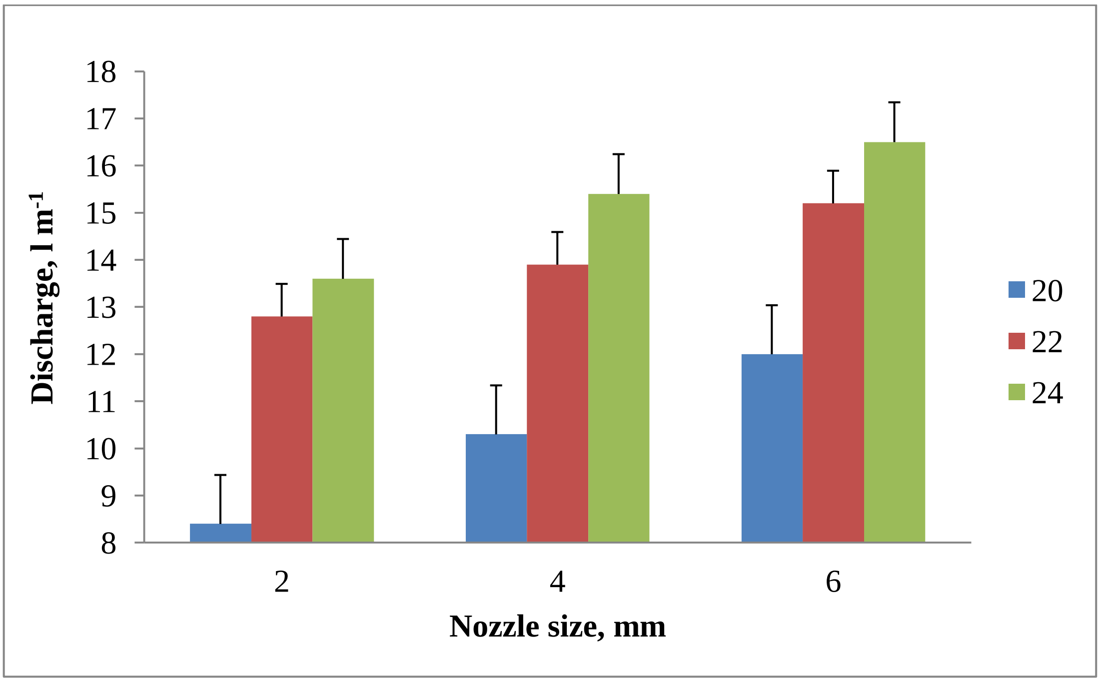


Fig.17 Effect of nozzle size and operating pressure on discharge at 0 degree orientation of spray nozzle

ix. Effect of operating pressure, nozzle size and orientation of spray nozzle on length of throw

The length of throw of the spray under different treatment combination of operating pressure, nozzle size and orientation of spray nozzle is shown in the Fig. 18, 19 and 20. The length of throw increased by 38.23 per cent with increase in the operating pressure for 2 mm nozzle size. Analysis of variance for length of throw showed that operating pressure was found significant at 5 per cent level of significance. This may be due to as pressure increases, the initial emission velocity of water droplets increases resulting more distance of throw. Nordbo (1992) found that, by doubling the pressure with three droplet sizes found 32 per cent increase in velocity. The length of throw increased by 34.37 as nozzle size increased for 20 kg cm^{-2}. As nozzle size increases, the discharge increases and discharge is the product of velocity of the water, therefore, it increases the length of throw.

It is clear from the figure that length of throw decreased by 14.17 per cent as the orientation of nozzle increased for 4 mm nozzle size. This may be due to fact that the point of reach of the spray decreased. The higher pressure (24 kg cm^{-2}) with three levels of nozzle size at 0 degree orientation of spray gave highest length of throw. Low pressure (20 kg cm^{-2}) with 30 orientation of spray nozzle produced a minimum length of throw.

Statistical analysis on the length of throw clearly indicated that interaction which contributes significantly to the model. These interaction effects were significant at 99 per cent confidence level. Among all the interaction effects operating pressure has highest effects followed by nozzle size and least for orientation of spray nozzle. The model F-value of 44.88 implies the model is significant. There is only 0.01 per cent chance for a model F-value of this large could occur due to noise.

x. Effect of operating pressure and nozzle size on the volumetric distribution of water

The effects of operating pressure and nozzle size on the volumetric distribution of water is presented in the Fig. 21, 22 and 23. It can be observed that the volumetric distribution was more in the centre of the patternator. Volumetric distribution was less as the distance increased from the centre of the patternator. As the gun oscillate from side to side on the patternator, at end of each side receives a less amount of water. This shows

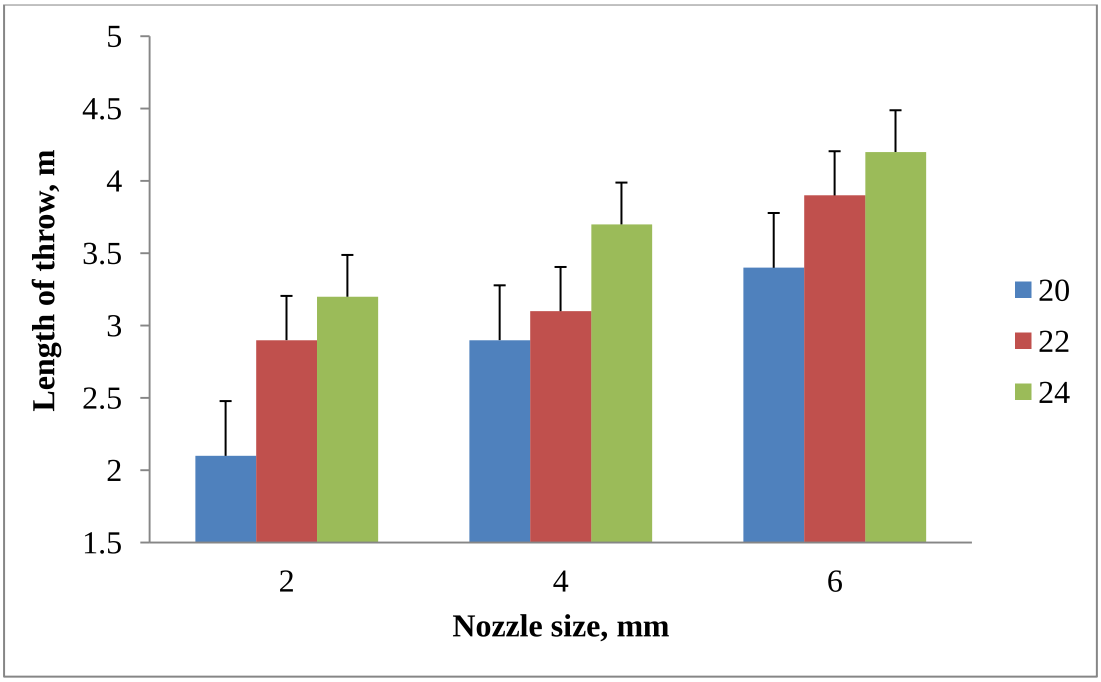


Fig.18 Effect of nozzle size and operating pressure on length of throw at o degree orientation of spray nozzle

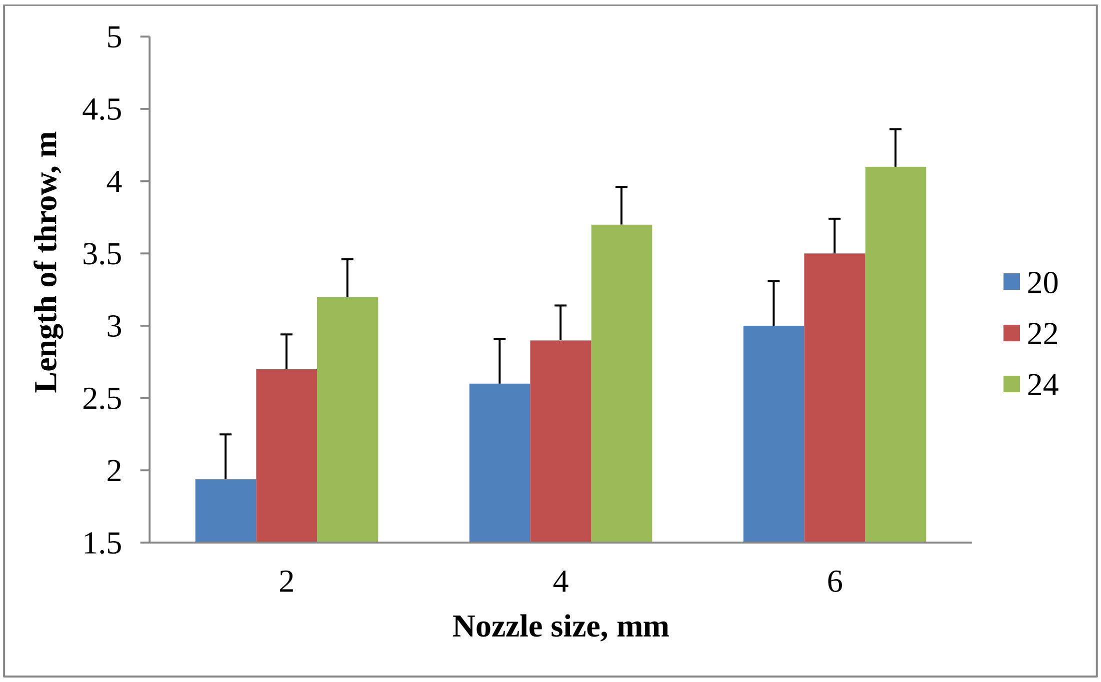


Fig. 19 Effect of nozzle size and operating pressure on length of throw at 15 degree orientation of spray nozzle

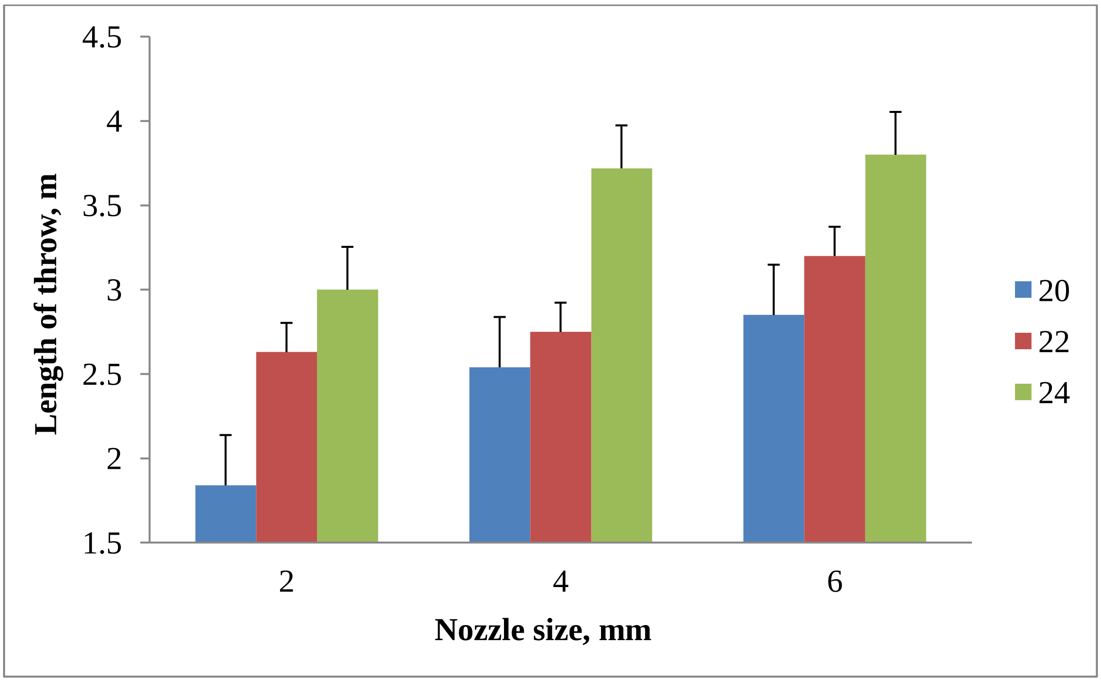


Fig. 20 Effect of nozzle size and operating pressure on length of throw at 30 degree orientation of spray nozzle

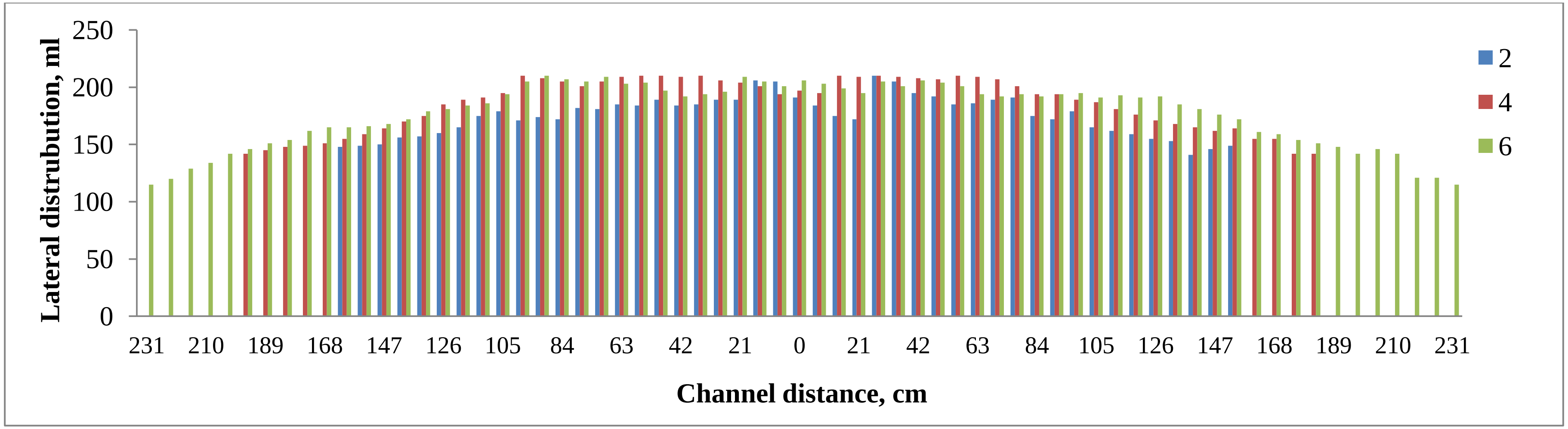


Fig. 21 Lateral distribution of three nozzle sizes at operating pressure of 20 kg cm^{-2}

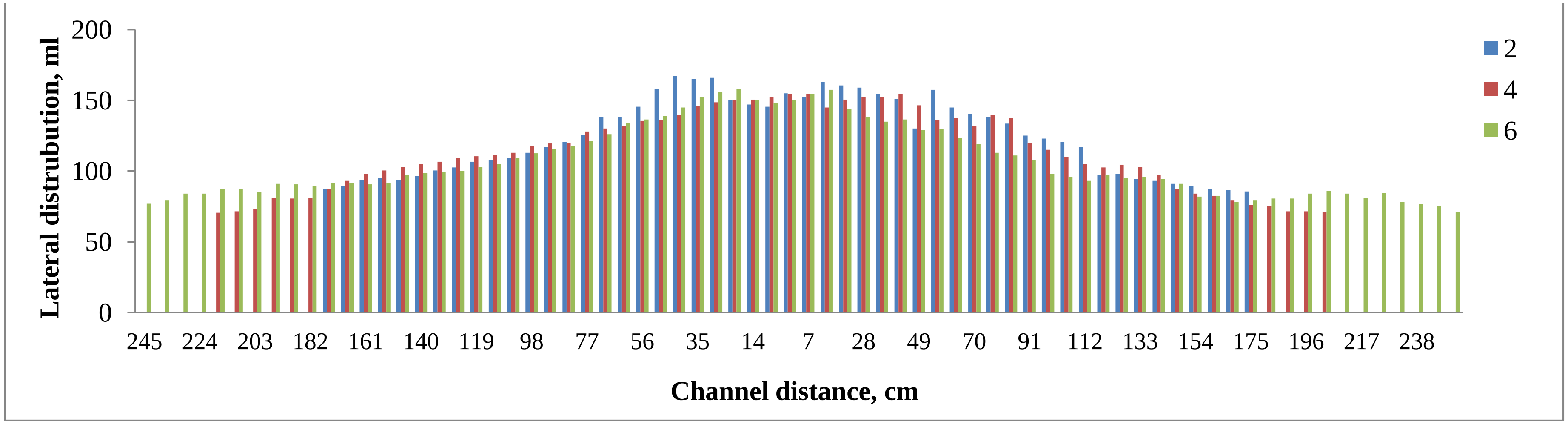


Fig. 22 Lateral distribution of three nozzle sizes at operating pressure of 22 kg cm^{-2}

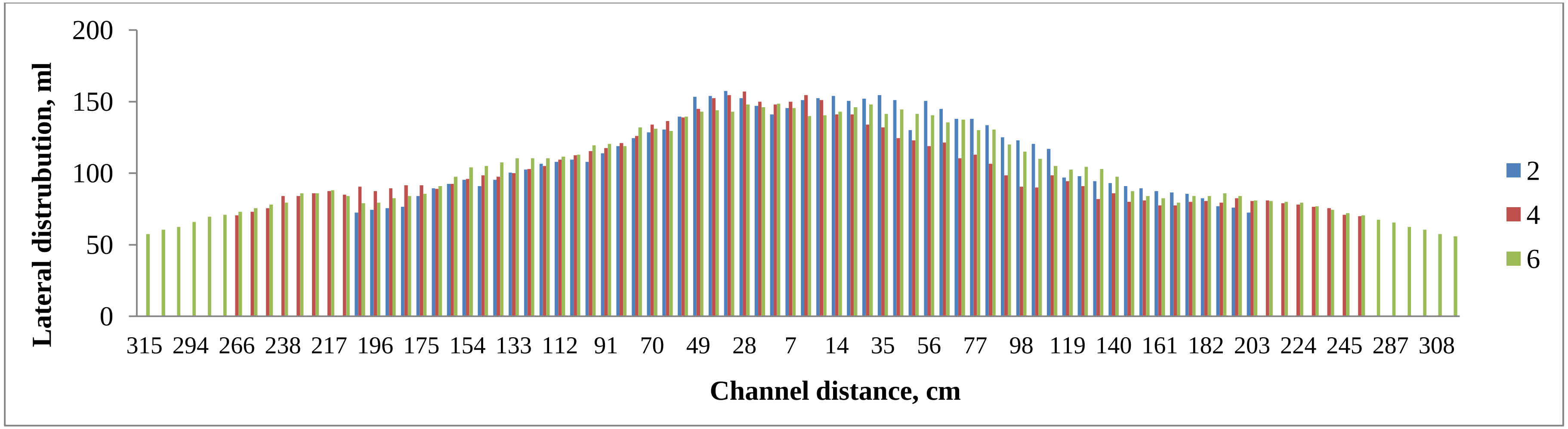


Fig. 23 Lateral distribution of three nozzle sizes at operating pressure of 24 kg cm^{-2}

that at the rows which covers at side, needs to be overlap during next row of spraying. It can also be found that volumetric distribution was more as the pressure increased from the 20 to 24 kg cm^{-2}. This may be attributed to the fact that discharge of the sprayer increased as pressure increased.

xi. Effect of operating pressure, nozzle size and orientation of spray nozzle on droplet density in cotton crop

The droplet density produced from the sprayer at different operating pressure and nozzle size at different degree of orientation of the spray nozzle is shown in the Fig. 24, 25 and 26. The droplet density was more in the upper surface of the top, middle and bottom position of the plant canopy. The droplet density at the lower surface of the top position decreased by 73.48 per cent for 6 mm nozzle size when the spray was operated at 20 kg cm^{-2} when the orientation of the spray nozzle was 0 degree. Droplet density at the upper surface of the top position of the leaves was considered as 100 per cent, the percentage reduction of the droplet density was 5 and 67 per cent for middle and bottom position of the top surface. Upper side of the leaves showed higher droplet density than the underside of the leaves. It was due to direct exposure of the upper side of leaves to the spray. The droplet density decreased as distance from the top of the plant canopy increased. The decreasing trend might be due to the fact that the leaves resisted the penetration of spray deep into the canopy and at the bottom, plant leaves are smaller compared to the top surface. These trends were in agreement with the findings of Wandkar and Mathur (2012), Gholap *et al*. (2013) and Narang *et al*. (2015a). Distance along the crop canopy influenced droplet density most.

The droplet density increased with increase in the nozzle size. The droplet density was increased by 38.09 per cent when the nozzle size was changed from 2 to 6 mm. This trend might be the reason that as orifice diameter of nozzle increased, discharge of the sprayer increased. More discharge leads to more number of the droplets deposited on the surface of the plant canopy. These trends were in agreement with the findings of Powar *et al*. (2006) and Bauer and Raetano (2003) who have reported that large application volumes, provide higher level of deposition on the leaves. Furthermore, with the higher volume often associated with the use of larger-orifice nozzles, some run-off from leaves will often take place.

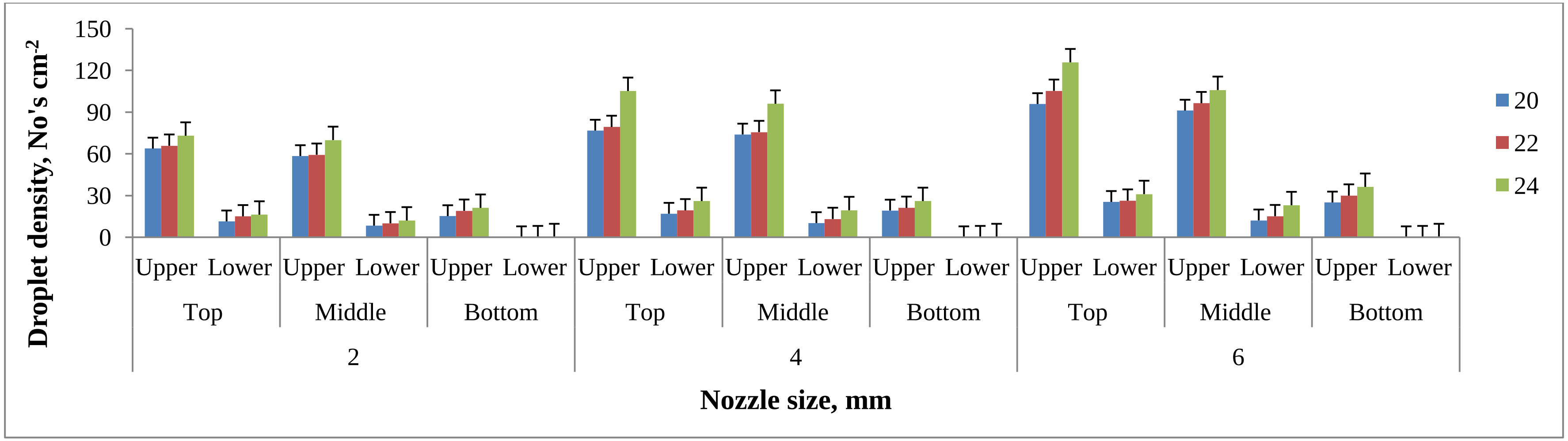


Fig. 24 Effect of nozzle size and operating pressure on droplet density at 0 degree orientation of spray nozzle for cotton crop

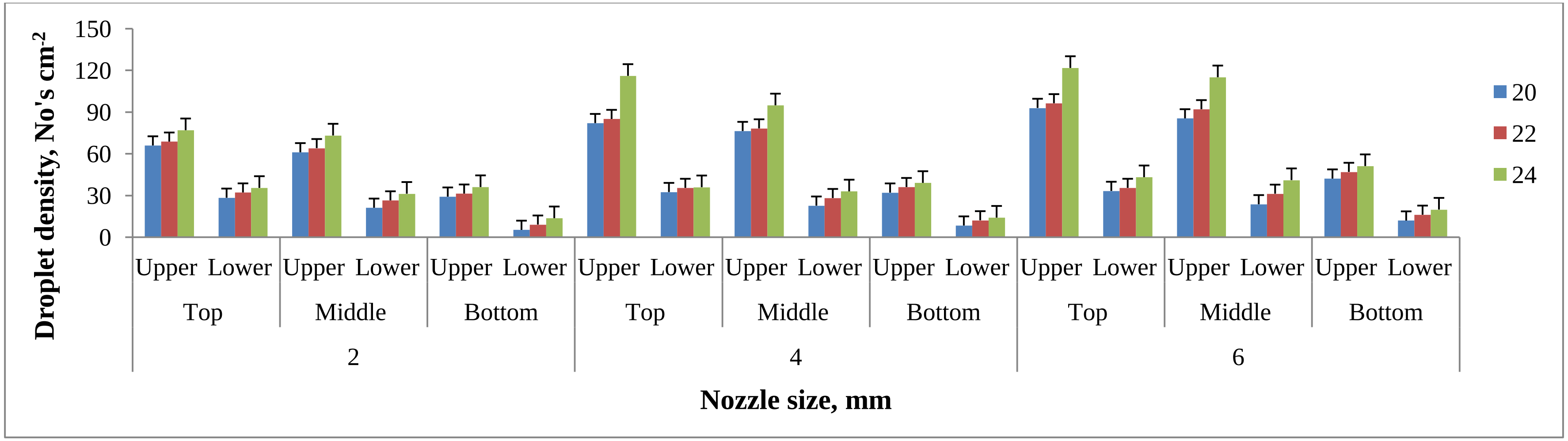


Fig. 25 Effect of nozzle size and operating pressure on droplet density at 15 degree orientation of spray nozzle for cotton crop

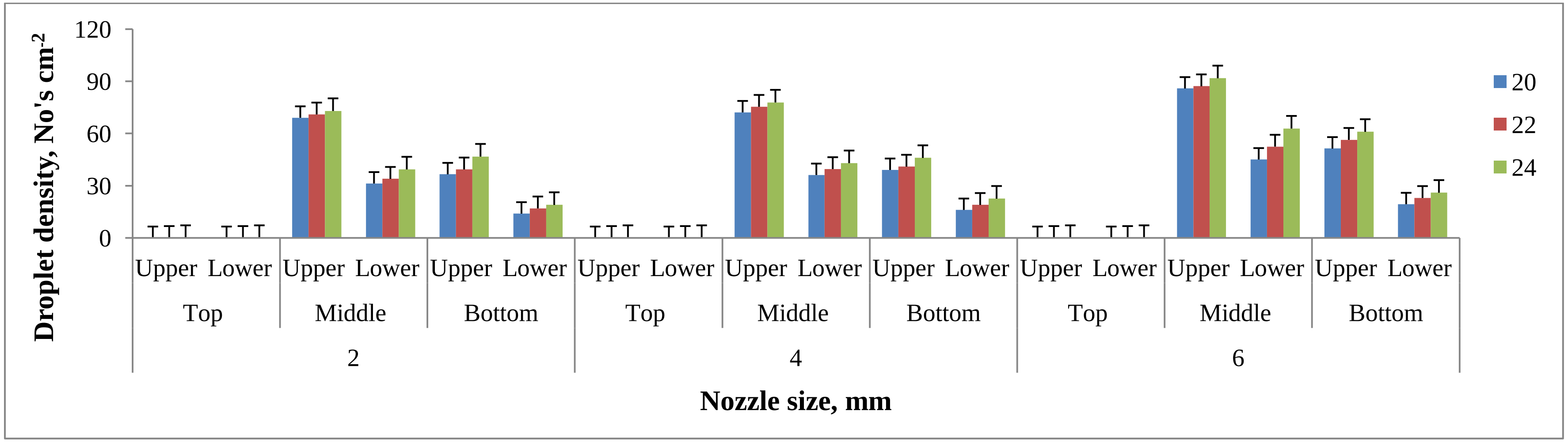


Fig. 26 Effect of nozzle size and operating pressure on droplet density at 30 degree orientation of spray nozzle for cotton crop

The droplet density increased by 25 per cent as the pressure increased from 20 to 24 kg cm^{-2} for 4 mm nozzle size when orientation of spray nozzle was 0 degree. Operating pressure of the hydraulic nozzle determined the size of the droplets in the spray spectrum. High nozzle pressure disintegrates the liquid into smaller droplets and thus enhanced the total number of the droplets, which resulted in the more deposition of the droplets. These results concur with what was reported by Gupta *et al*. (2011), Dahab and Eltahir (2010), Ferguson *et al*. (2016) and Azizpanah *et al*. (2015).

The effect of three different nozzle angles on the spray droplet density is shown in the Fig 25. The droplet density falling on the lower side of the leaves at 0 degree orientation of nozzle was less compared to other angles. This is because of spray nozzle was over the plant canopy. Most of the spray droplets fall on the top surface of the plant. The reason behind this is plant leaves offers more resistance to spray to penetrate deep into canopy when spray nozzle was over the plant. The droplet deposition on both upper and lower surface of the plant canopy was maximum when the orientation of the nozzle was 15 degree. This is because of nozzle was inclined to the plant and height between the crop and nozzle was less. Both upper and lower leaves directly exposed to the spray deposition. Spray droplets penetrate to the various position of the plant canopy due to the hydraulic energy of the spray droplets. Keeping in view of droplet density throughout the canopy, 15 degree orientation of spray nozzle was chosen for field studies. For mobile insects, the droplet densities of 20-30 no’s cm^{-2} and in most cases pests of sedentary nature would co-exist with other pests, a threshold limit of droplet density of 40 no’s cm^{-2} was considered necessary (Gupta *et al*., (2011)). It may be seen that droplet densities obtained were sufficient to kill the pests and insecticides, except at the bottom of the canopy.

As the orientation of the spray nozzle from 15 to 30 degree, most of the spray was directed to middle and bottom position of the plant. It was also observed that most of the spray solution reached to the ground surface.

xii. Effect of operating pressure, nozzle size and orientation of spray nozzle on droplet size (VMD) in cotton crop

The droplet size produced from the sprayer at different operating pressures and nozzle sizes for different orientation is shown in the Fig. 27, 28 and 29. Droplet size decreased with distance increased from top surface of the plant canopy. Droplet size was

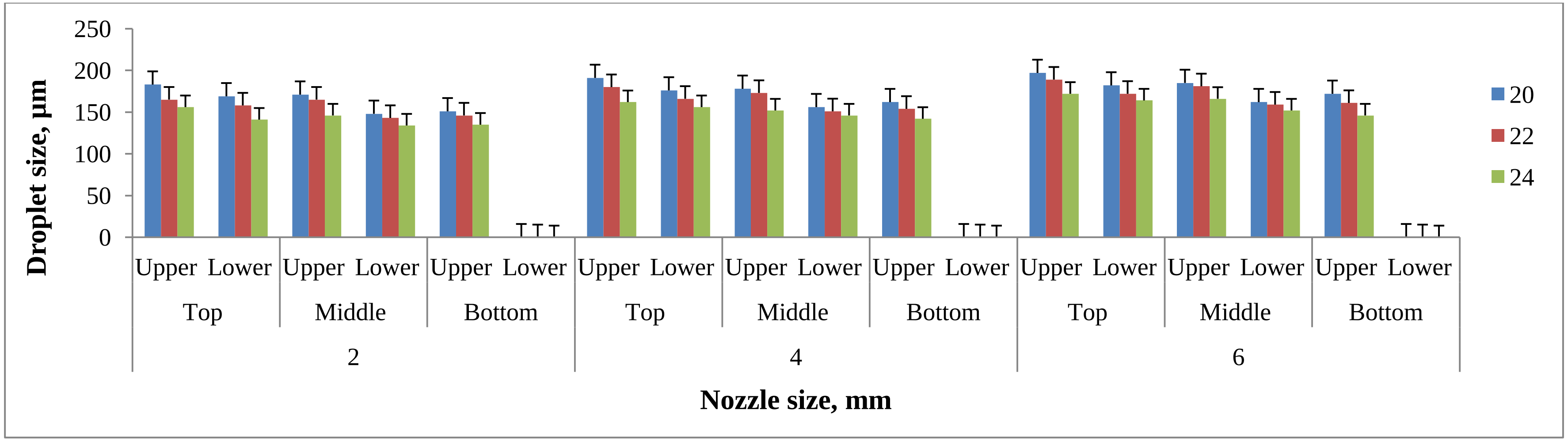


Fig. 27 Effect of nozzle size and operating pressure on droplet size at 0 degree orientation of spray nozzle for cotton crop

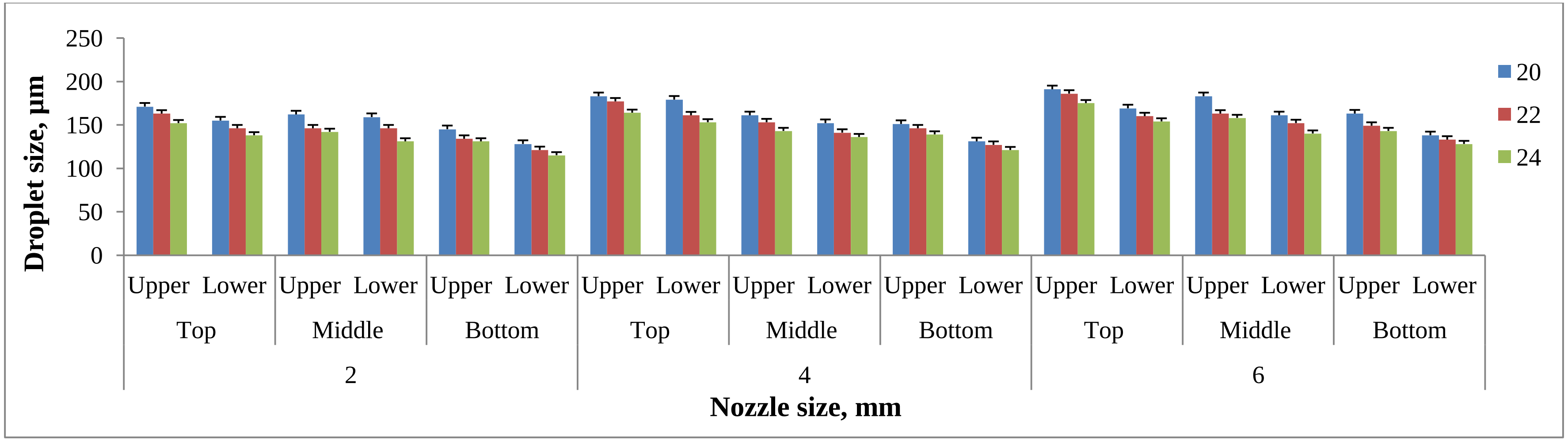


Fig. 28 Effect of nozzle size and operating pressure on droplet size at 15 degree orientation of spray nozzle for cotton crop

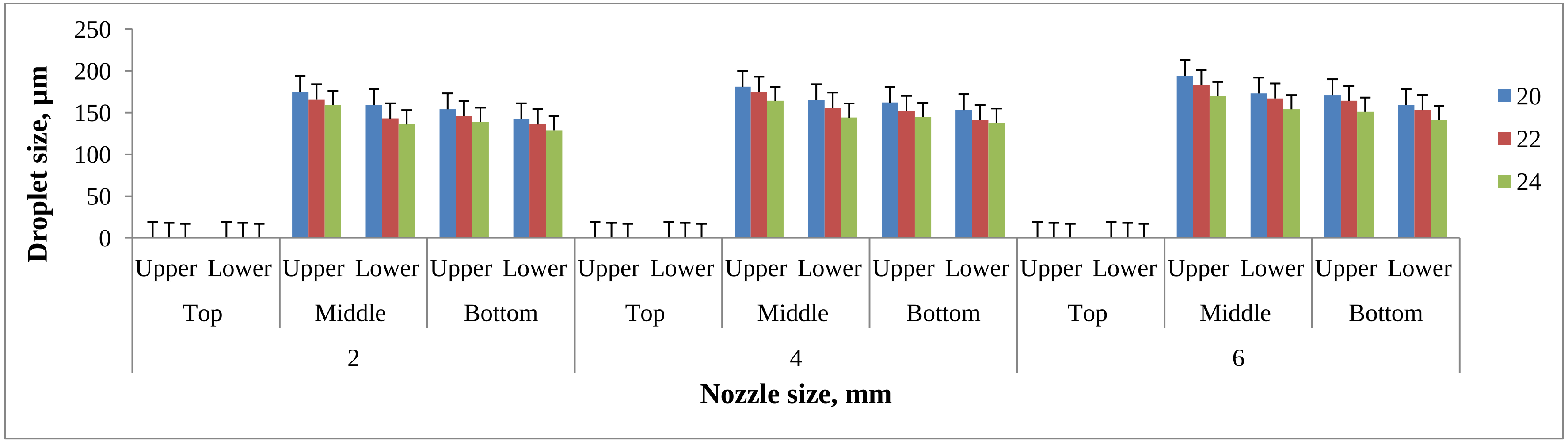


Fig. 29 Effect of nozzle size and operating pressure on droplet size at 30 degree orientation of spray nozzle for cotton crop

maximum on the upper surface of the plant than the underside of the leaves for all the treatments. The VMD observed on lower leaf surface was smaller compared to upper leaf surface. This might be due to the fact that the heavy droplets which were larger in size got easily deposited on the upper surface directly whereas, the lower leaf surface receives only droplets which were smaller in size. Droplets are intercepted by leaves as moves through the canopy. It could also be inferred that the bigger droplets broke into smaller droplets after they struck to leave. In the process, some droplets are deposited to canopy and some were fell to ground surface. No spray deposition was observed for lower surface of the bottom position of the crop due to less hydraulic energy of droplets as it moves from the crop canopy. These results concur with what was reported by Gupta *et al*. (2011).

The droplet size decreased with increase in the operating pressure. Operating pressure of the hydraulic nozzle determined the size of the droplets in the spray spectrum. High nozzle pressure disintegrates the liquid into smaller droplets. Due to that, the plant canopy got better deposition and less runoff from the plant leaves. The maximum droplet size was obtained for low operating pressure and minimum droplet size was recorded for high operating pressure. Among the three operating pressure, 20 kg cm^{-2} produced higher droplet size and deposition was poor in the plant canopy. This was in conformity with the reports of Dahab and Eltahir (2010), Jain *et al*. (2006) and Azizpanah *et al*. (2015). At higher pressure of the nozzle, the size of droplets delivered from the nozzle decreased and more droplets became vulnerable for drift in field condition. The nozzle pressure of 22 kg cm^{-2} resulted in a better performance compared to other two pressures and hence, it was chosen as the optimum operating pressure of the nozzles for field studies.

When the nozzle size was changed from 2 to 6 mm, droplet size was increased by 7 per cent for 20 kg cm^{-2} pressure at 0 degree orientation of spray nozzle. The reason could be that as nozzle size increase, discharge of the sprayer increases. High volume spray produces large droplets. A few droplets of large diameter accounted for a major portion of the spray thereby increasing the value of VMD. The orientation of spray nozzle did affect the droplet size but it largely affects the deposition on different positions. As the orientation of the spray nozzle from 15 to 30 degree, most of the spray was directed to middle and bottom position of the plant. It was also observed that most of the spray solution reached to the ground surface. The maximum droplet size was observed at middle position of the crop followed by lower position. The droplet size observed at 15 degree orientation of spray nozzle was within the recommended values. Therefore 15 degree orientation of spray nozzle was selected for field evaluation of the sprayer.

xiii. Effect of operating pressure, nozzle size and orientation of spray nozzle on droplet density in pigeonpea crop

The droplet density on the upper and underside of the leaves at different plant position for different operating pressure and nozzle size is shown in the Fig. 30, 31 and 32. The droplet density on underside of the top position of the leaves decreased by 73 per cent compared to top surface of plant. Upper side of the leaves showed higher droplet density than the underside of the leaves. It was due to direct exposure of the upper side of leaves to the spray. The droplet density decreased as the spray droplets move from top to bottom surface of the plant canopy by 10 percent on middle and 70 per cent on bottom position. Spray droplets had to travel longer distance to reach bottom position of the canopy, which caused evaporation and consequent reduction in droplet density. This showed that, distance from the top had highly significant effect on droplet density.

The droplet density increased by 14.23 per cent as the pressure increased from 20 to 24 kg cm^{-2} for 6 mm nozzle size when orientation of spray nozzle was 15 degree. Operating pressure of the hydraulic nozzle determined the size of the droplets in the spray spectrum. High nozzle pressure disintegrates the liquid into smaller droplets and thus enhanced the total number of the droplets for the same volume. These results corroborate the earlier findings Gupta *et al*. (2011) and Dahab and Eltahir (2010).

The droplet density increased with increase in the size of nozzle. The droplet density increased by 33.19 per cent when the nozzle size was changed from 2 to 6 mm. This trend might be the reason that as orifice diameter of nozzle increased, discharge of the sprayer increased. More discharge leads to more number of the droplets deposited on the surface of the plant canopy. These trends were in agreement with the findings of Powar *et al*. (2007) and Bauer and Raetano (2003) who have reported that large application volumes, provide higher level of deposition on the leaves. Both operating pressure and nozzle size effects were helpful in increasing the droplet density within the crop canopy.

Effect of orientation of nozzle on the droplet density shown in the figure showed that as the orientation increases from 0 to 15 degree, the droplet density at all the position

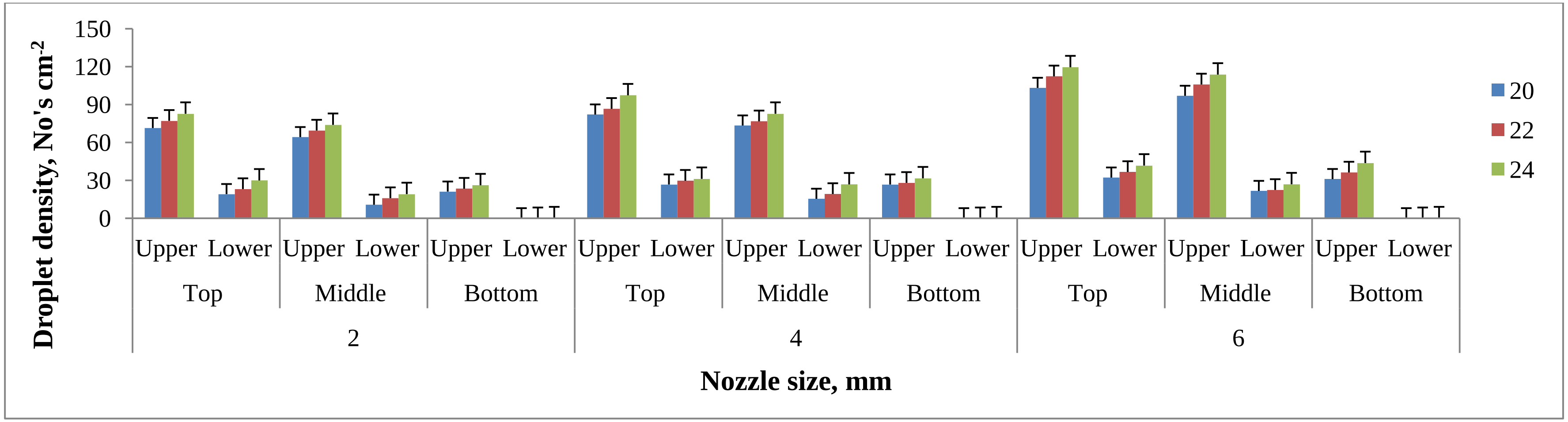


Fig. 30 Effect of nozzle size and operating pressure on droplet density at 0 degree orientation of spray nozzle for pigeonpea crop

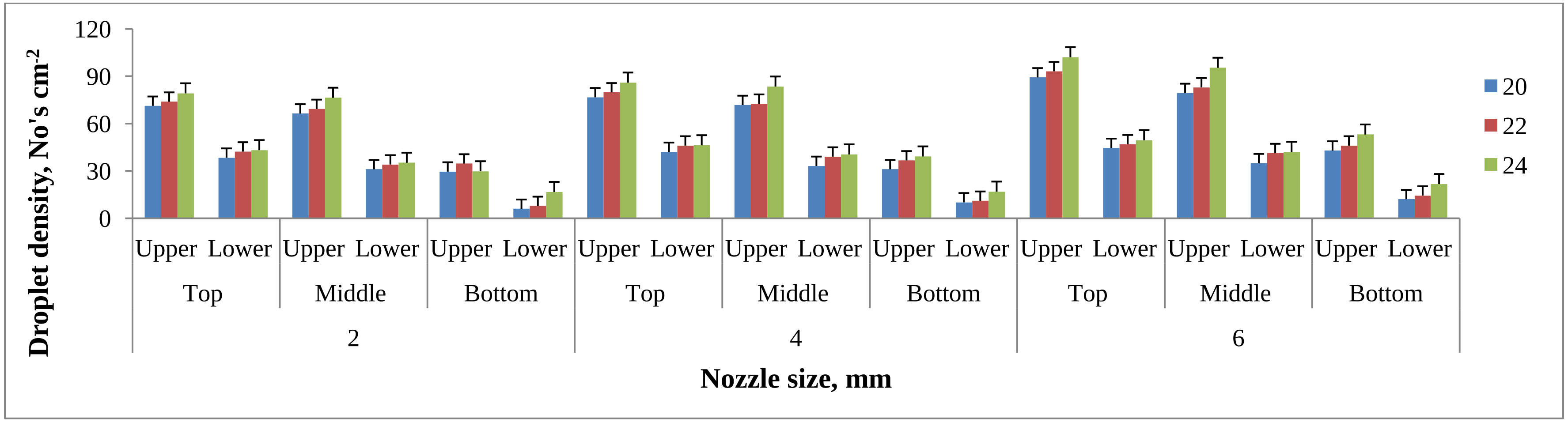


Fig. 31 Effect of nozzle size and operating pressure on droplet density at 15 degree orientation of spray nozzle for pigeonpea crop

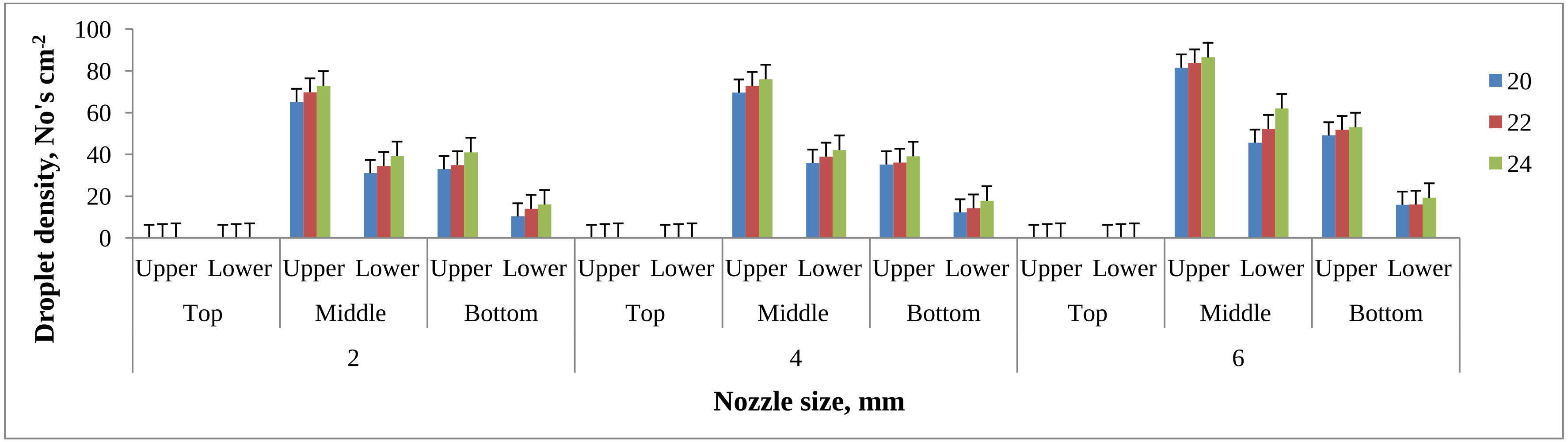


Fig. 32 Effect of nozzle size and operating pressure on droplet density at 30 degree orientation of spray nozzle for pigeonpea crop

of the plant canopy increased. It was observed that the deposition of droplets increased throughout the plant canopy. Beyond 15 degree of orientation of spray nozzle, it was observed that the droplet depositon on the upper surface was nill as most of the spray was on the middle and bottom of the plant canopy. The best angle of orientation of spray nozzle was 15 which produced recommended droplet size.

xiv. Effect of operating pressure, nozzle size and orientation of spray nozzle on droplet size (VMD) in pigeonpea crop

The droplet size produced on the upper and underside of the leaves at different treatment combination is shown in the Fig. 33, 34 and 35. The droplet size decreased from the top to bottom of the plant canopy. The VMD observed on lower leaf surface was smaller compared to upper leaf surface. This might be due to the fact that the heavy droplets which were larger in size got easily deposited on the upper surface directly whereas, the lower leaf surface receives only droplets which were smaller in size. No spray deposition was observed for lower surface of the bottom position of the crop due to obstruction from leaves and branches.

It can be observed that droplet size decreased by 11.7 per cent as the operating pressure changed from the low to high pressure at 0 degree orientation of spray nozzle for 2 mm nozzle size. High nozzle pressure disintegrates the liquid into smaller droplets. The maximum droplet size was obtained for low operating pressure and minimum droplet size was observed for high operating pressure. This was in conformity with the reports of Dahab and Eltahir (2010) and Tayel *et al*. (2009). Kepner *et al*. (1987) observed that, volume mean diameter was increased by 10 to 30 per cent as the nozzle pressure decreased from 690 to 170 kPa. Smith *et al*. (1975) found that increasing pressure in hydraulic sprayer reduced the spray droplet size. The highest droplet density produced the droplets of least VMD with good droplet density and thorough deposition within the canopy. Small droplets may be lost by drift while those too big in size do not adhere to the target surface resulting in reduced deposition. Thus, operating pressure of 22 kg cm^{-2} was chosen as the optimum operating pressure for sprayer.

The droplet size increased by 15.79 per cent as the nozzle size increased from 2 to 6 mm for 20 kg cm^{-2} at 0 degree orientation of spray nozzle. The increase in VMD forma is due to coarser particles generated due to higher spray volume. The maximum droplet size was obtained for 6 mm nozzle size and minimum was observed for 2 mm nozzle size

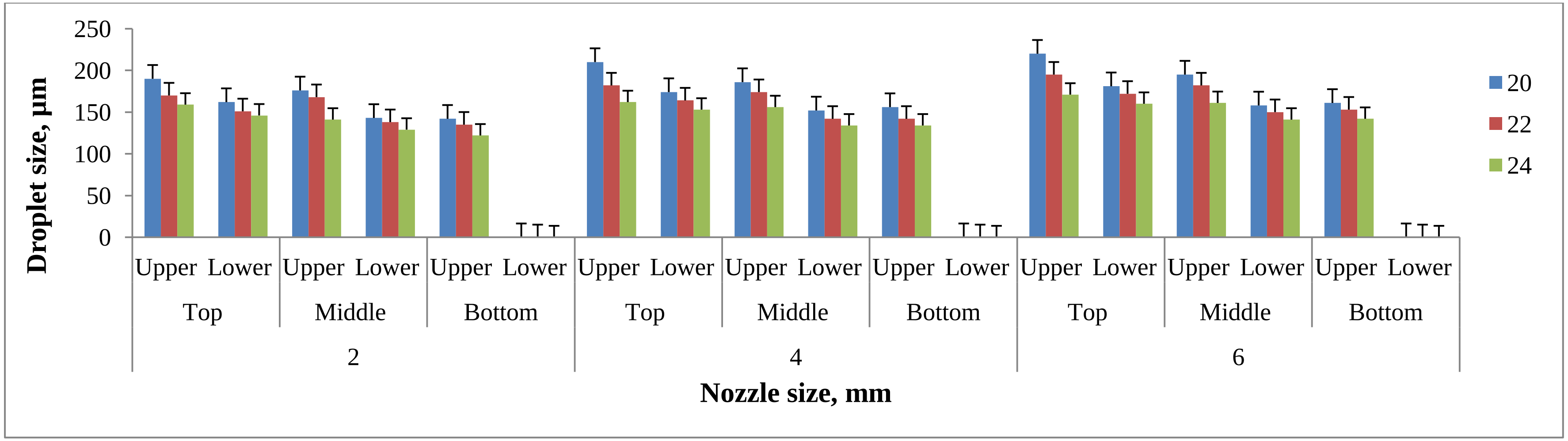


Fig. 33 Effect of nozzle size and operating pressure on droplet size at 0 degree orientation of spray nozzle for pigeonpea crop

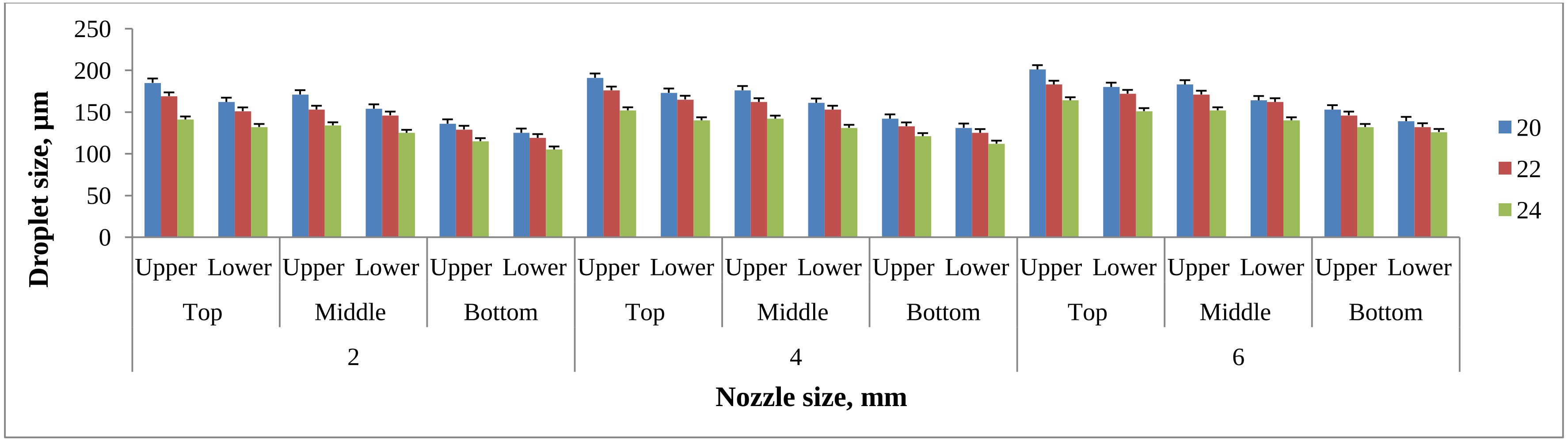


Fig. 34 Effect of nozzle size and operating pressure on droplet size at 15 degree orientation of spray nozzle for pigeonpea crop

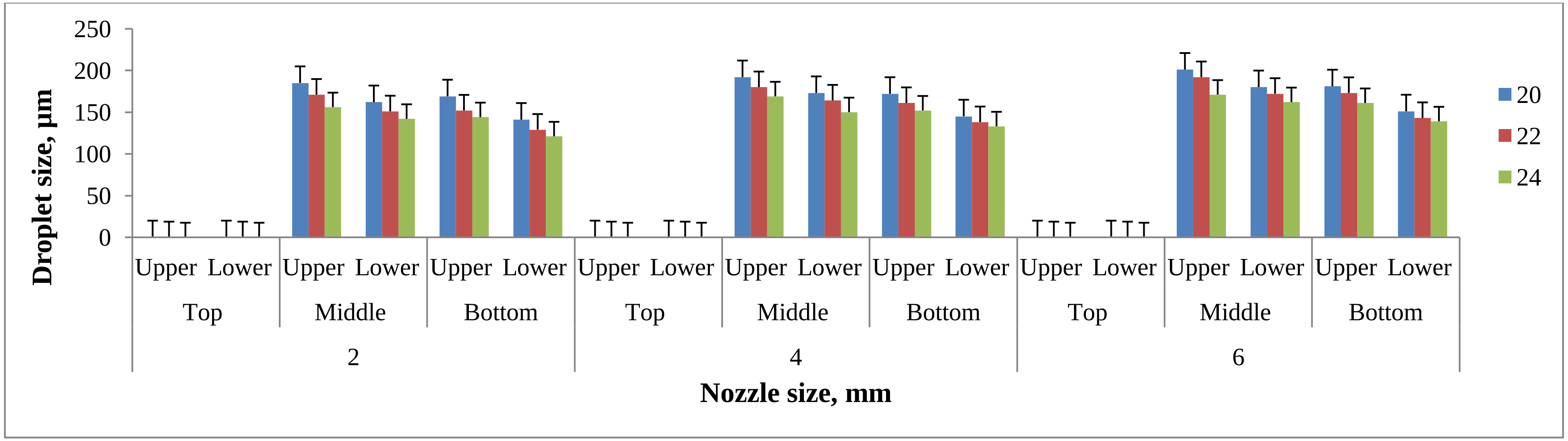


Fig. 35 Effect of nozzle size and operating pressure on droplet size at 30 degree orientation of spray nozzle for pigeon pea crop

at 15 degree orientation of spray nozzle. Tayel *et al*. (2009) and Kepner *et al*. (1987) reported the similar readings.

The droplet size with respect to different orientation of the spray nozzle shown in the figures indicated that the droplet size produced by orientation of spray nozzle angle 15 degree was within the range of the recommended values. Therefore, the nozzle angle 15 degree was selected for field evaluation of the sprayer.

5.2.1 Optimization of operational parameters of tractor operated automatic gun sprayer in laboratory conditions

Numerical optimization technique was followed to levels of independent and dependent variables for designed and developed model by using Design Expert. The desirability index for operational parameters of tractor operated automatic gun sprayer under laboratory is shown in the Fig. 36. The desirability index of the discharge, length of throw, droplet density and droplet size were 0.41, 0.51, 0.78 and 1. The overall desirability index of the all the treatment combination was 0.60 for 22 kg cm^{-2} operating pressure, 2 mm nozzle size and 15 degree orientation of spray nozzle. These optimized parameters were considered for evaluating the tractor operated gun sprayer for field crops.

5.3 Performance evaluation of tractor operated automatic gun sprayer for selected field crops

The performance evaluation of tractor operated automatic gun sprayer for selected field crops viz., Cotton (*Bt*) and Pigeonpea (Maruthi) was carried out in the farmer's field and University Research Farm, Raichur. The performance was evaluated based on the standard procedure. Some parameter of the sprayer was measured in the field without having vegetation to get exact results and some of the parameters were measured in the standing crop.

5.3.1 Performance evaluation of tractor operated automatic gun sprayer in cotton crop

The field trials were conducted by maintaining operating pressure of 22 kg cm^{-2}, nozzle size of 2 mm and 15 degree orientation of spray nozzle. The metrological data was recorded before doing experiment. The experimental data were processed using an analysis of variance (ANOVA) to determine the effects of the three independent variables

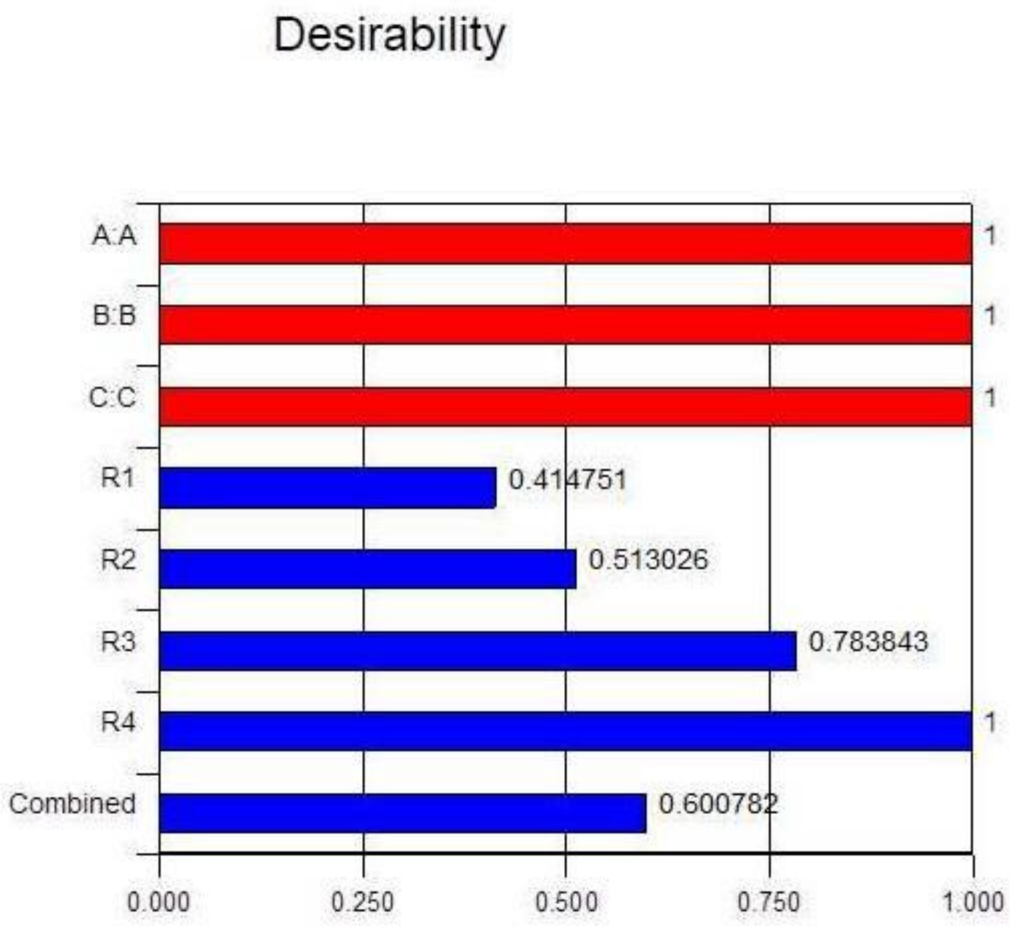


Fig. 36 Desirability index of tractor operated automatic gun sprayer in laboratory condition

of both laboratory and field parameters. The effect of interaction of these two independent variables was also studied through this analysis. The statistical software package "Design –Expert", [version 10.0.4 for windows, Stat-Ease, Inc.,] was used for statistical analysis.

xi. Effect of forward speed, speed of actuating mechanism and height of spray nozzle on swath width of spray

The swath width of spray under different combinations of operational parameters is shown in the Fig 37, 38 and 39. The swath width of spray increased by 9.7 per cent as the height of spray nozzle was changed from 30 to 90 cm. This is because of the as height of spray nozzle increased, wind physically affects the droplets to move farther away from the boom section. The maximum swath width was obtained for 90 cm height of spray nozzle. At this height all droplets were strongly exposed to the air movement. Babashani *et al*. (2013) reported that, swath width was increased with more extent from the wind conditions.

The swath width decreased by 5.2 per cent as actuating mechanism increased from 54 to 65 cycles min^{-1}. This may be due to the fact that the time available for completion of the cycles was less. Speed of actuating mechanism is less means will be hold the spray gun horizontal for a while to cover.

As forward speed increased from 2.2 to 2.6 km h^{-1}, the swath width decreased by 5 per cent. This was probably due to fact that as forward speed increased, instead of spread of water droplets in horizontal distance, spreads to forward direction. It was also observed that water spreads scattered manner as the forward speed increased. At higher operating forward speed, the droplets released from the sprayer had higher horizontal component of velocity, as a result droplets are drifted away from the canopy. Similar findings were reported by Gupta *et al*. (2011).

Statistically analyzed data showed that a main effect of forward speed, actuating mechanism and height of spray nozzle was significant at 5 per cent level of significance. The combined effects and interaction also have found at 5 per cent level of significance. The model F value 6.05 implies that the model is significant at 5 per cent level of significance. The standard deviation and co-efficient of variation were found to be 0.30 and 3.92 per cent with a mean value of 7.71.

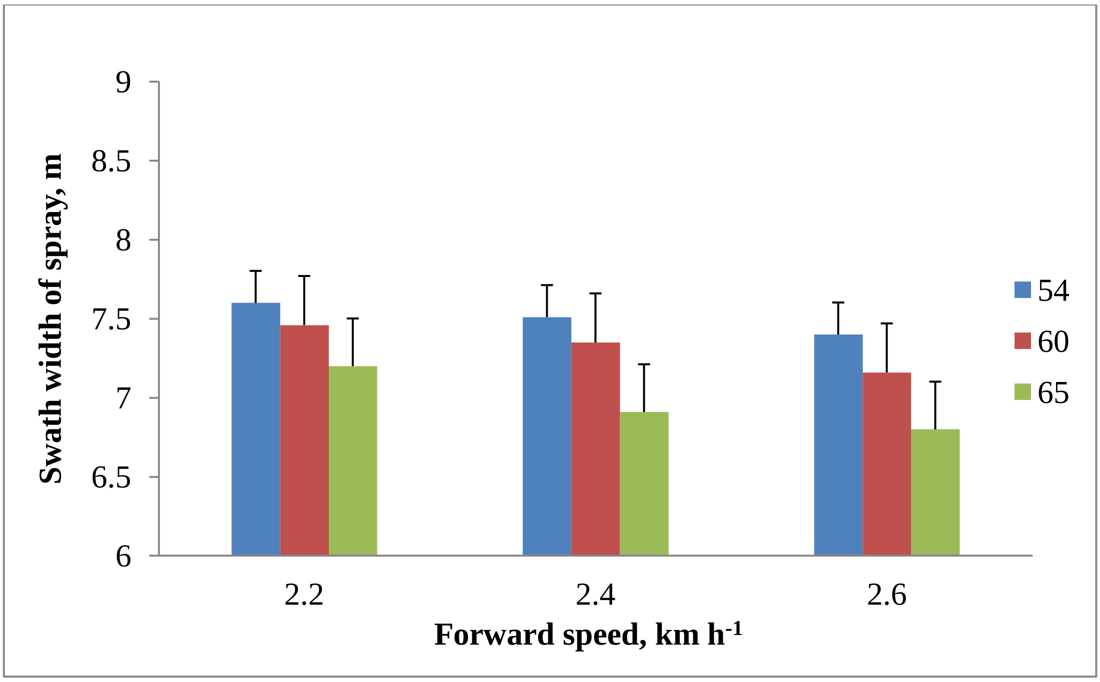


Fig. 37 Effect of forward speed, speed of actuating mechanism on swath width of spray at 30 cm height of spray nozzle

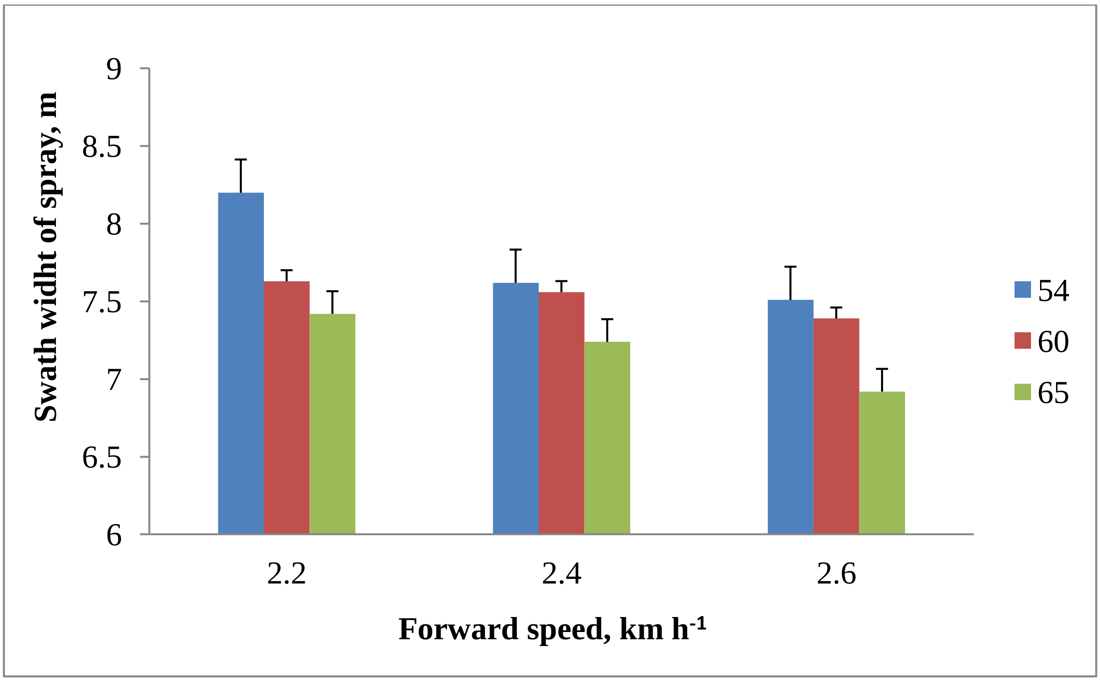


Fig. 38 Effect of forward speed, speed of actuating mechanism on swath width of spray at 60 cm height of spray nozzle

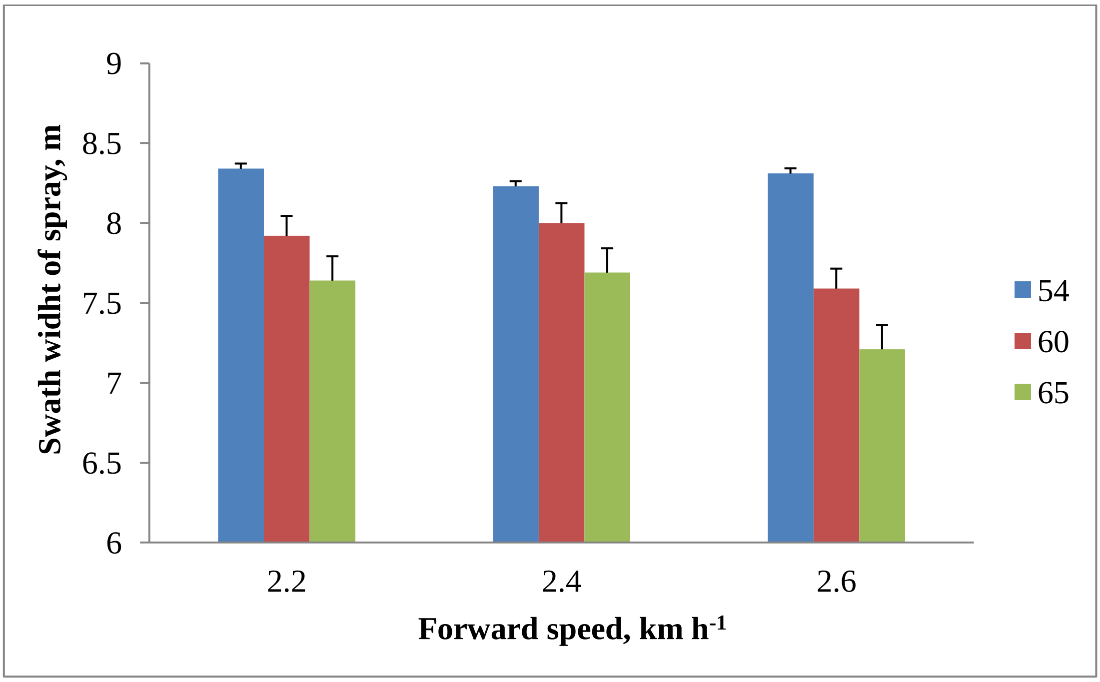


Fig. 39 Effect of forward speed, speed of actuating mechanism on swath width of spray at 90 cm height of spray nozzle

xii. Effect of forward speed, speed of actuating mechanism and height of spray nozzle on field capacity

The field capacity of the sprayer at different treatment combinations *i.e.*, forward speed, actuating mechanism and height of spray nozzle is shown in the Fig. 40, 41 and 42. Field capacity of the sprayer increased by 10 per cent as height of spray nozzle increased from 30 to 90 cm, as the height of spray nozzle increased, the swath width of the spray increased intern increased the area covered by water droplets.

The field capacity was decreased by 7 per cent as actuating mechanism increased from 54 to 65 cycles min^{-1} for 2.2 km h^{-1} at height of spray nozzle was 30 cm. Field capacity is directly proportional to the swath width of sprayer. Swath width of spray decreased as actuating mechanism increased intern area covered by sprayer decreased.

When the forward speed of tractor increased, the field capacity was increased by 34.4 per cent. Field capacity is the product of the swath width and forward speed. Field capacity is linear with forward speed. The forward speed increased the field efficiency, which includes reduces the time taken to cover the required area. Though, swath width was decreased with increase in forward speed, field capacity was increased due to forward motion of the tractor. Similar readings were reported by Karale *et al*. (2014).

The analysis of variance for forward speed showed that the main effects of all independent parameters have found significant at 5 per cent level of significance. Among the interaction effects, forward speed had highly significant followed by height of the spray nozzle and actuating mechanism. It is clear that the more field capacity was observed for forward speed. The model F value 3.22 implies that the model is significant at 5 per cent level of significance. The prob > F value of the model is considerably less than 0.05 (*i.e.*, 95 per cent confidence level), then the terms model have a significant effect on the response. There is only 0.14 per cent chance for a “model F-value” of this large could occur due to noise. The standard deviation and co-efficient of variation were found to be 0.43 and 13.82 per cent with a mean value of 1.80.

xiii. Effect of forward speed, speed of actuating mechanism and height of spray nozzle on actual application rate

The application rate of the sprayer was decreased with increase in the height of spray nozzle (Fig.43, 44 and 45). When the forward speed changed from the 2.2 to 2.6

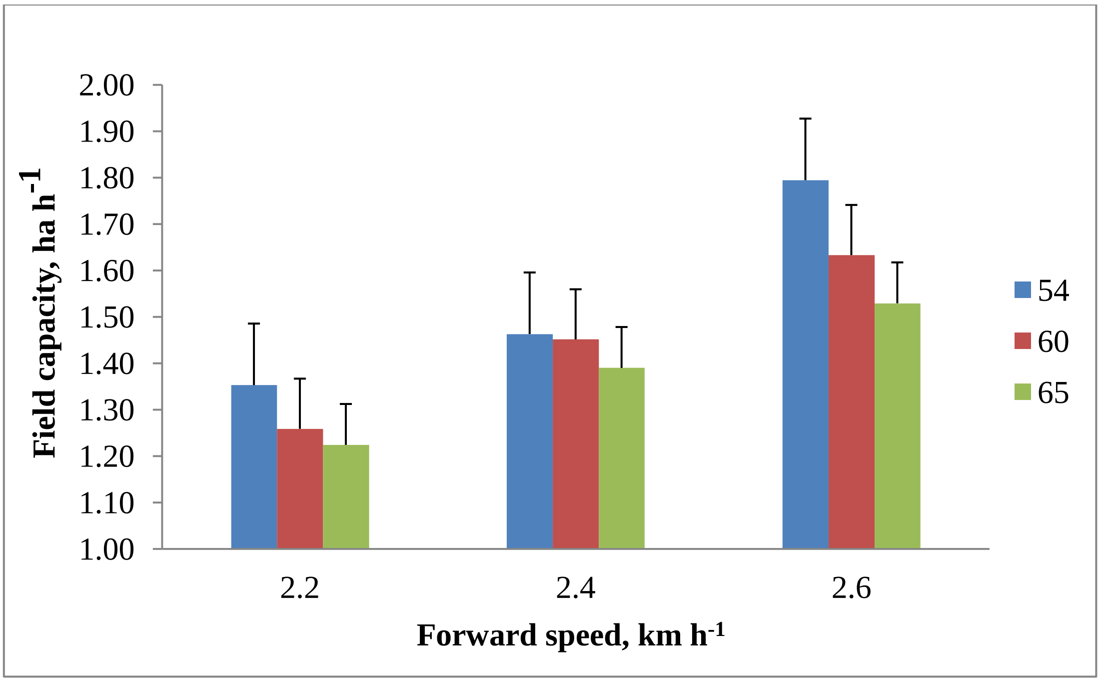


Fig. 40 Effect of forward speed, speed of actuating mechanism on field capacity at 30 cm height of spray nozzle

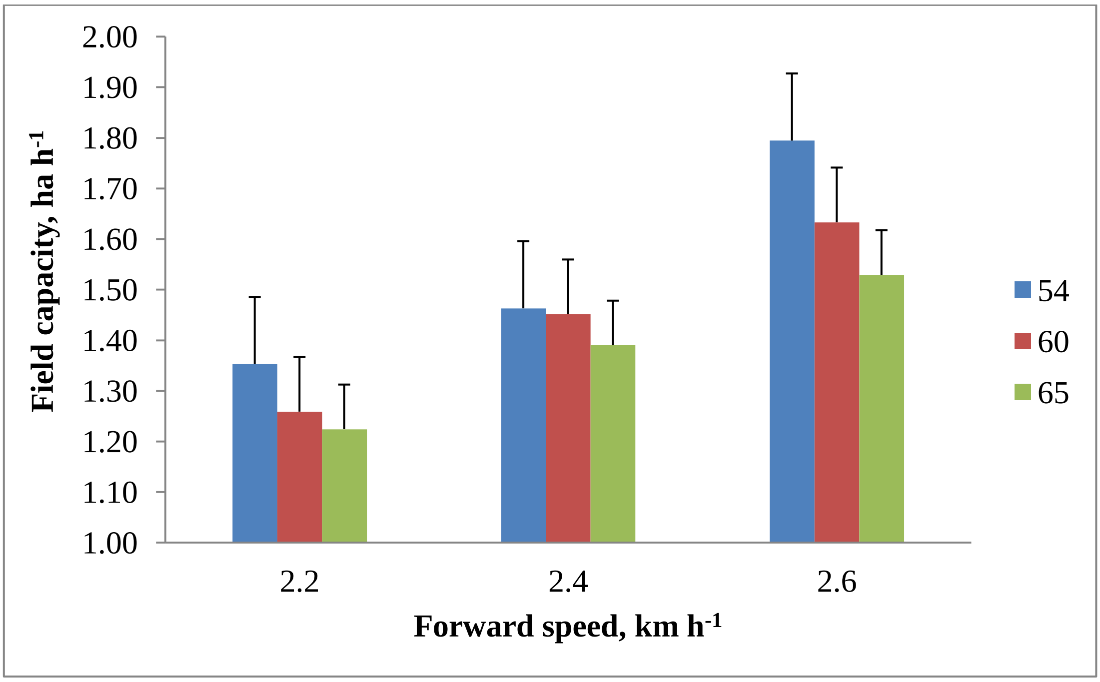


Fig. 41 Effect of forward speed, speed of actuating mechanism on field capacity at 60 cm height of spray nozzle

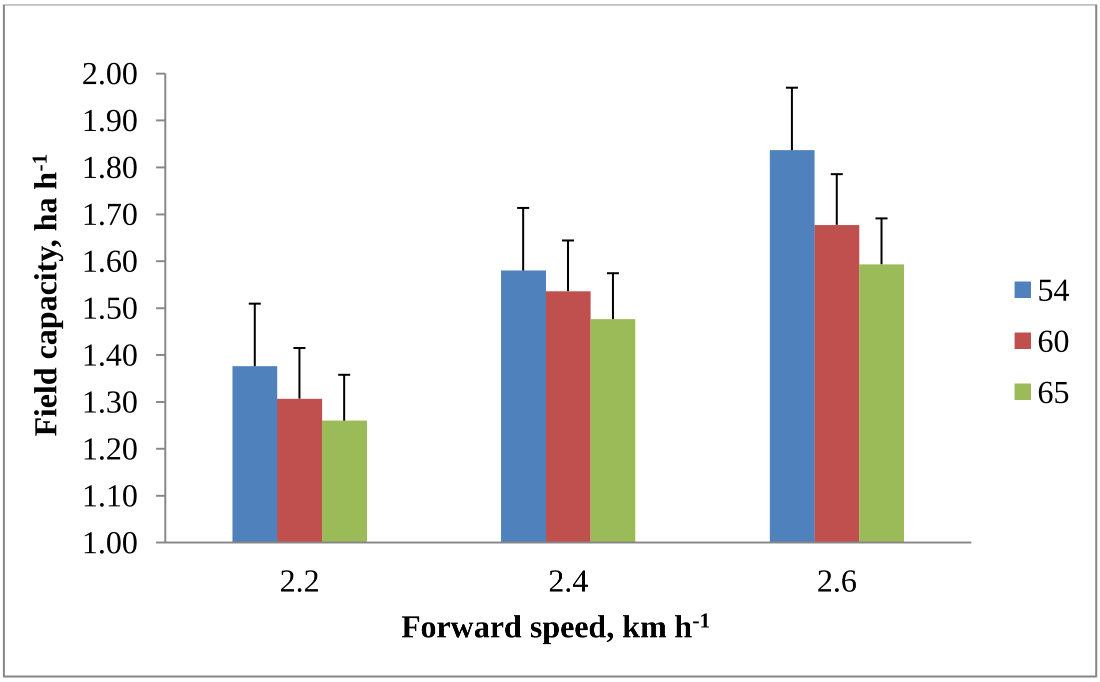


Fig. 42 Effect of forward speed, speed of actuating mechanism on field capacity at 90 cm height of spray nozzle

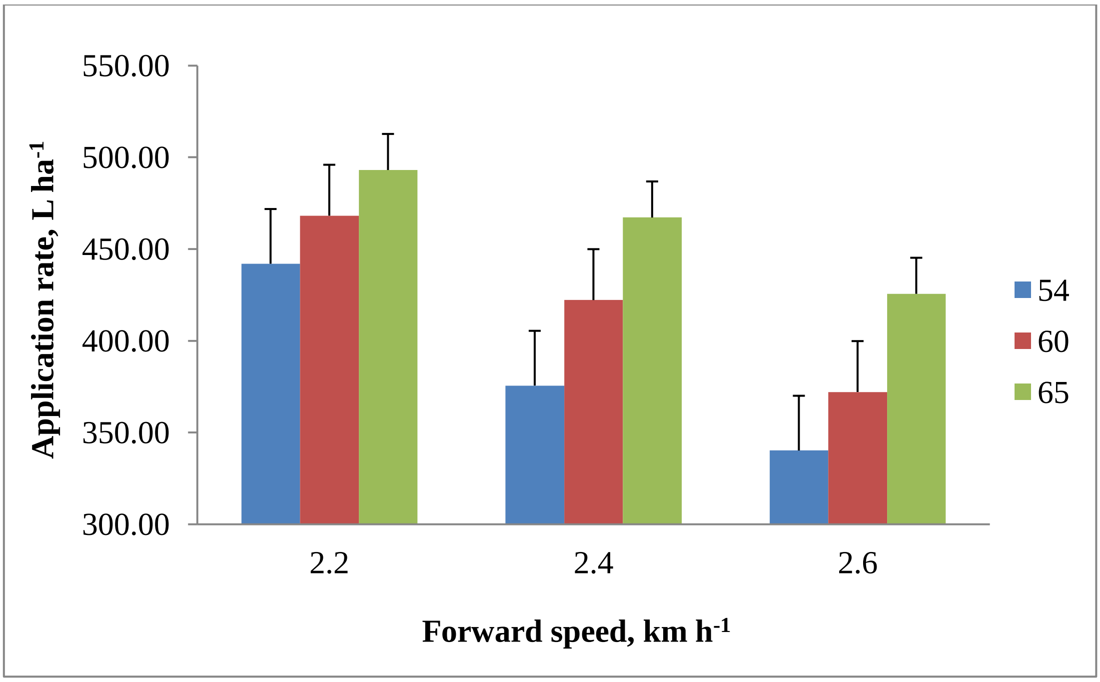


Fig. 43 Effect of forward speed, speed of actuating mechanism on application rate at 30 cm height of spray nozzle

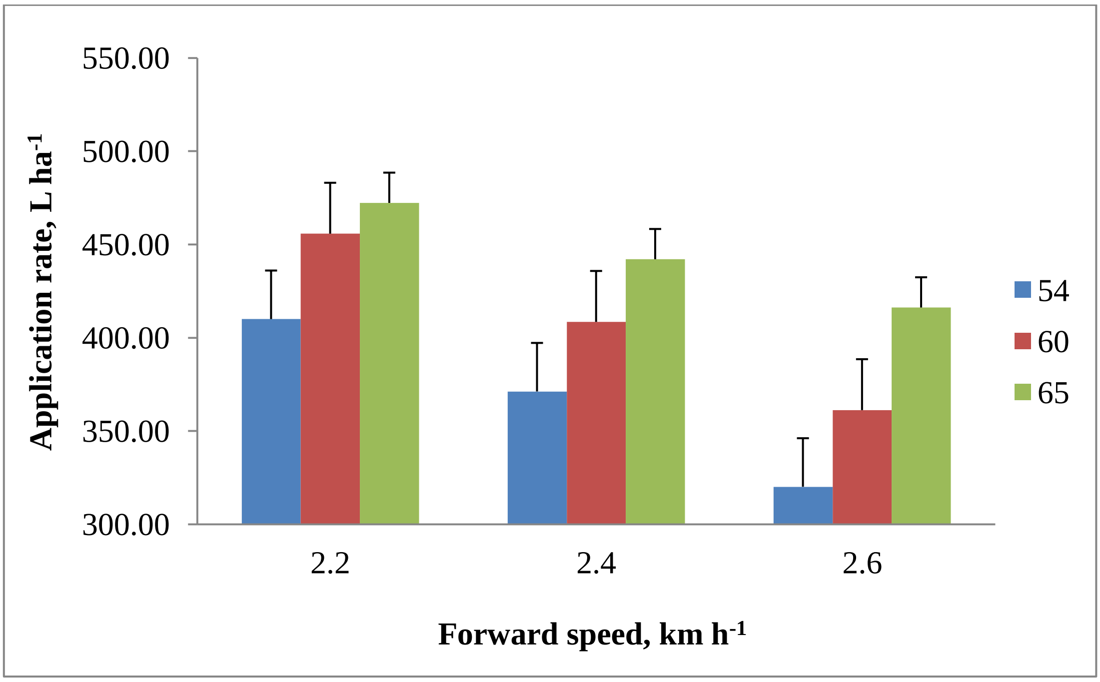


Fig. 44 Effect of forward speed, speed of actuating mechanism on application rate at 60 cm height of spray nozzle

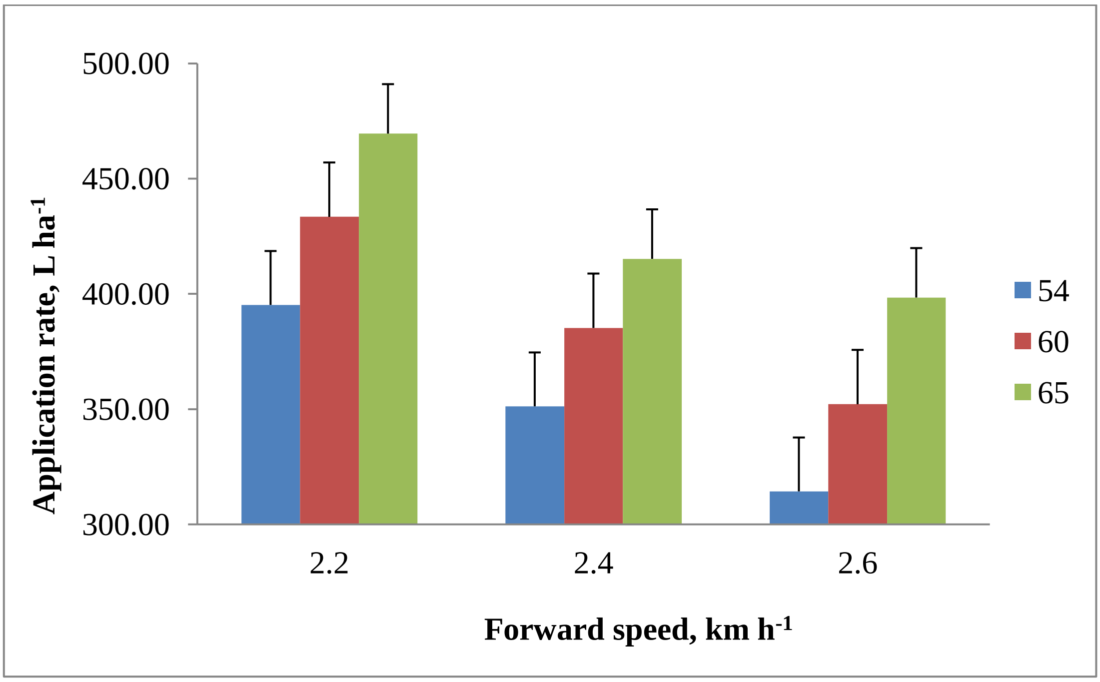


Fig. 45 Effect of forward speed, speed of actuating mechanism on application rate at 90 cm height of spray nozzle

km h^{-1}, the application rate decreased by 21.79 per cent for 2 mm nozzle size at 30 cm height of spray nozzle when the actuating mechanism was 54 cycles min^{-1}. The main reason for this is, application rate is indirectly proportional to area covered by sprayer. Application rate decreased if area covered is more. At higher forward speeds, the amount of spray per unit length of run was less, thereby reducing application rate

The application rate was decreased by 12 per cent when the height of spray nozzle was changed from 30 to 90 cm. As the height of spray nozzle increased, the swath width of spray increased. Application rate is indirectly proportional to the swath width of spray with fixed discharge of the sprayer. Babashani *et al*. (2013) reported the same trend of results.

When the actuating mechanism changed from 54 to 65 cycles min^{-1}, the application rate was increased by 20 per cent for 2.2 km h^{-1} at height of spray nozzle was 30 cm. This is because of mismatch between speed of forward and actuating mechanism. For 2.2 km h^{-1}, the best speed of actuating mechanism was 54 and for 2.4 km h^{-1}, it was 60 and for 2.6 km h^{-1}, the matched speed of actuating mechanism was 65 cycles min^{-1}. It was also observed that the actual application rate was more than the theoretical application rate. In actual application, spraying at the head land and turning loss was considered.

Statistical analysis showed that the main factor of different treatment combination significantly affected the actual application rate at 5 per cent level of significance. Among the main factor, the actuating mechanism has highly significant effect on the application rate followed by forward speed and actuating mechanism. It is clear that application rate was more when actuating mechanism was changed from 54 to 65 cycles min^{-1}. The model F value 3.22 implies that the model is significant at 5 per cent level of significance. The standard deviation and co-efficient of variation were found to be 14.33 and 15.10 per cent with a mean value of 426.08.

xiv. Effect of forward speed, speed of actuating mechanism and height of spray nozzle on difference in actual and theoretical application rate

The difference in actual and theoretical application rate of the sprayer at different treatment combinations revealed that, for 2.2 km h^{-1}, the matched speed of actuating mechanism was 54 cycles min^{-1}. The application rate was decreased from 3.05 to 2.35 per cent as height of spray nozzle increased. As actuating mechanism changed from 54 to 65 cycles min^{-1}, the application rate increased. This is because of number of spray applications over the sprayed area, which leads to over application in a unit area and area covered was less as speed of actuating mechanism was increased. The negative sign indicates that, speed of actuating mechanism was less than the required speed. Less application means there was more unsprayed area.

The statistically analyzed data on difference in actual and theoretical application rate showed that the main effect of each factor of forward speed (A), actuating mechanism (B) and height of spray nozzle has significantly influenced on the difference in actual and theoretical application rate at 5 per cent level of significance. The interaction effects have 5 per cent significant. The model F- value 26.02 implies that the model is significant at 5 per cent level of significance. The standard deviation and co-efficient of variation were found to be 1.75 and 13.10 per cent with a mean value of 4.07.

xv. Effect of forward speed, speed of actuating mechanism and height of spray nozzle on fuel consumption of tractor

Fuel consumption of tractor under the different operating parameters is shown in the Fig. 46. it was observed that fuel consumption was increased by 31.98 per cent with increase in forward speed. The maxiumum fuel consumption was observed for high speed of tractor (2.6 km h^{-1}). Figure shows that the fuel consumption of sprayer did not affected by the speed of actuating mechanism as power to drive actuating mechanism was taken from the battery.

As per the statistical analysis for fuel consumption, it was observed that forward speed was highly significant at 95 per cent confidence level. The combined interaction effects have found no significance at 95 per cent confidence level. The “model F” value for fuel consumption 14.20 implies that the model is significant at 5 per cent level of significance. The standard deviation and co-efficient of variation were found to be 0.18 and 6.13 per cent with a mean value of 2.93.

xvi. Effect of forward speed, speed of actuating mechanism and height of spray nozzle on droplet density

The droplet density falls on the upper and lower surface of the plant canopy under different treatment combinations are shown in the Fig. 47, 48 and 49. It was observed that

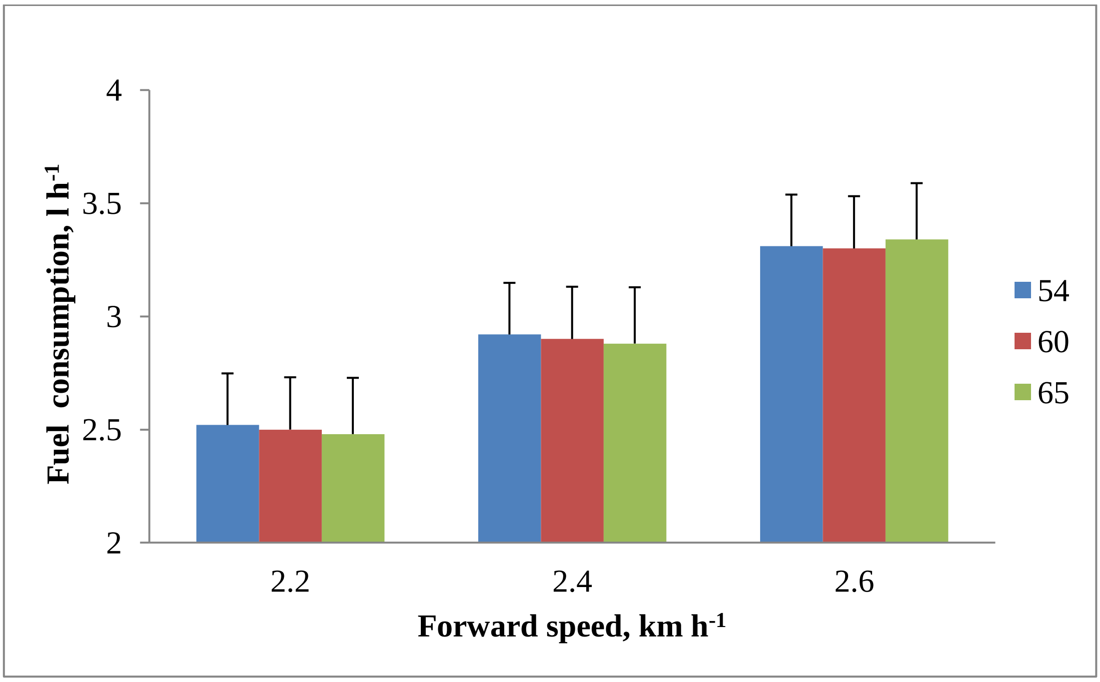


Fig. 46 Effect of forward speed, speed of actuating mechanism on fuel consumption of tractor at 30 cm height of spray nozzle

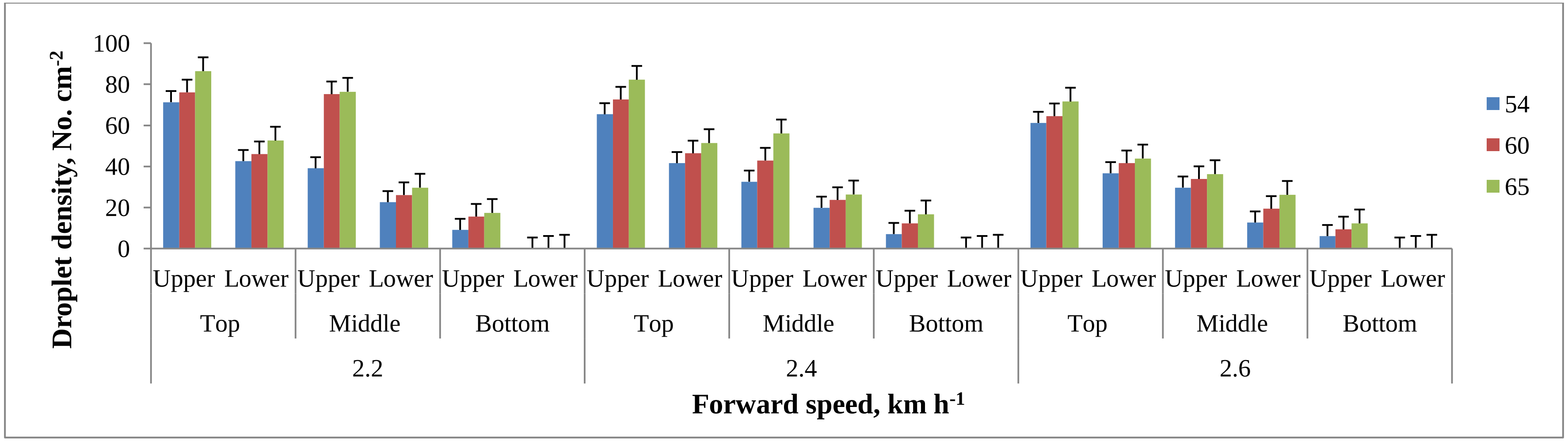


Fig. 47 Effect of forward speed, speed of actuating mechanism on droplet density at 30 cm height of spray nozzle

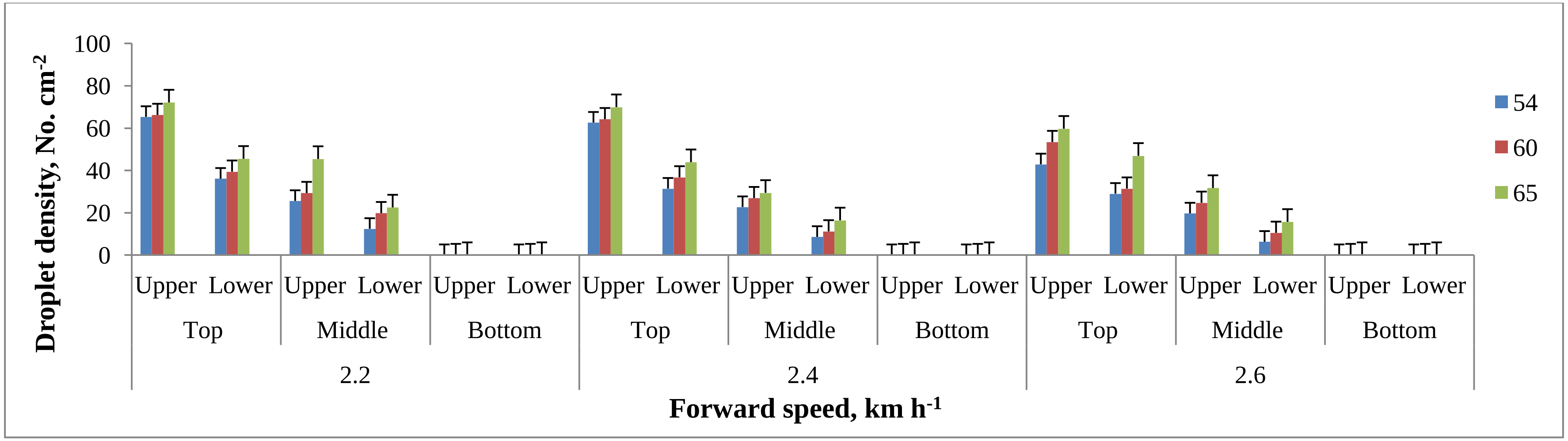


Fig. 48 Effect of forward speed, speed of actuating mechanism on droplet density at 60 cm height of spray nozzle

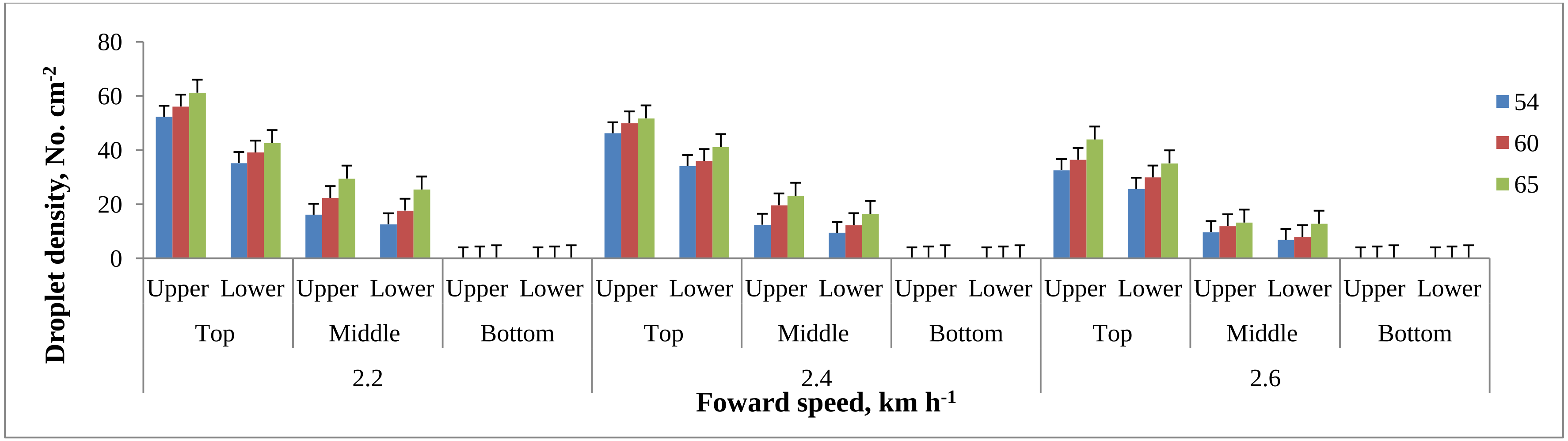


Fig. 49 Effect of forward speed, speed of actuating mechanism on droplet density at 90 cm height of spray nozzle

droplet density decreased as distance from top surface of the plant increases. Top surface of the plant canopy invariably receives maximum droplet density due to direct exposure to spray. The droplet density decreased in middle and bottom position of the plant canopy for all the treatments. This might have been due to droplets had to travel longer distance, while travelling droplets disintegrate into small droplets and small droplets are carried away from the wind. The droplet density on underside of the leaves increased due to inclination of the sprayer towards the plant canopy.

When the forward speed changed from 2.2 to 2.6 km h^{-1}, the droplet density decreased by 34.30 per cent at 60 cm height of spray nozzle. The forward speed determines the exposure time of plant to the spray. More exposure time resulted in increased deposition density and sometime results in overlapping of droplets and some cases runoff losses also. Lower operating speeds resulted in more spray per unit area of plant canopy, thereby increasing the droplet density. The forward speed should be such that the canopy receives adequate spray deposition for effective control of pests. At slower speed, canopy got more deposition of droplets from the nozzle resulting in higher amount of overlap. As forward speed increased, droplet density at bottom surface did not received droplet. Such low density of droplets would not be sufficient to effectively control the pest population there. The droplet density at higher speed was less than the recommended. It is desirable to operate sprayer at slower speed to get maximum deposition. This was in conformity with the reports of Gupta *et al*. (2011). From the figure, it could be conclude that forward speeds higher than 2.6 km h^{-1} were not desirable to achieve adequate levels of droplet density.

The droplet density increased with increase in speed of actuating mechanism. The droplet density increased by 25.68 per cent as speed of actuating mechanism increased at 2.4 km h^{-1} forward when height of spray nozzle was 30 cm. This is due to as increased number of spray over the sprayed area. More spray results more droplet density and sometimes for higher actuating mechanism especially for 2.2 km h^{-1}, more runoff took place. The correct matched speed resulted exact spray droplets.

The height of spray nozzle above the plant canopy affected the droplet density on different positions of the plant. The droplet density was decreased by 13 per cent as height of spray nozzle was increased from 30 to 90 cm for 64 cycles min^{-1} speed of actuating mechanism. This is because of as height increased more space was available for entrainment of air with spray droplets and disintegration of droplets took place and the smaller droplets were easily carried to the off target and resulted in less droplet density. Boom height is an important factor in reducing drift losses. Operating at a spray boom height as close as possible to the vegetation, without sacrificing the uniformity of the spray pattern, is a good way to reduce drift. It was concluded that the maximum droplet density at top, middle and bottom position of the plant and upper leaf surface as well as on top position of plant and lower leaf surface was observed at the height of spray nozzle was 30 cm above the plant canopy and found within the recommended range.

As Jain *et al*. (2006) stated that droplet density of 20-25 droplets cm^{-2} was proven most effective for control of insects on cotton. The droplet density produced from tractor operated automatic gun sprayer was higher than the recommended limit. Hence sprayer can be used for applying pesticide and insecticide.

xvii. Effect of forward speed, speed of actuating mechanism and height of spray nozzle on droplet size (VMD)

The droplet size produced from the sprayer at different combinations of treatments is shown in the Fig. 50, 51 and 52. It was seen from the fig that the droplet size decreased from the top to bottom of the plant canopy. The VMD observed on lower leaf surface was smaller compared to upper leaf surface. This might be due to the fact that the heavy droplets which were larger in size got easily deposited on the upper surface directly whereas, the lower leaf surface receives only droplets which were smaller in size. Droplets had to travel longer distance to reach the bottom of the canopy and consequently some portion of droplets evaporated and their diameter decreased. This was in conformity with the reports of Gupta *et al*. (2011).

The droplet size decreased by 10.65 per cent as forward speed of the tractor increased from 2.2 to 2.6 km h^{-1} for 30 cm height of spray nozzle. Forward speed changed exposure time of the spray to plant canopy. More exposure time more droplets and overlapping cases, results in more droplet size. The droplets size on the underside of the leaves at top surface of the canopy also increased with decrease in forward speed. Tayel *et al*. (2009) reported that, droplet size was decreased 10 per cent as forward changed.

The droplet size increased by 8.84 per cent as speed of actuating mechanism increased from 54 to 65 cycles min^{-1}. This is probably due to number of spray over the

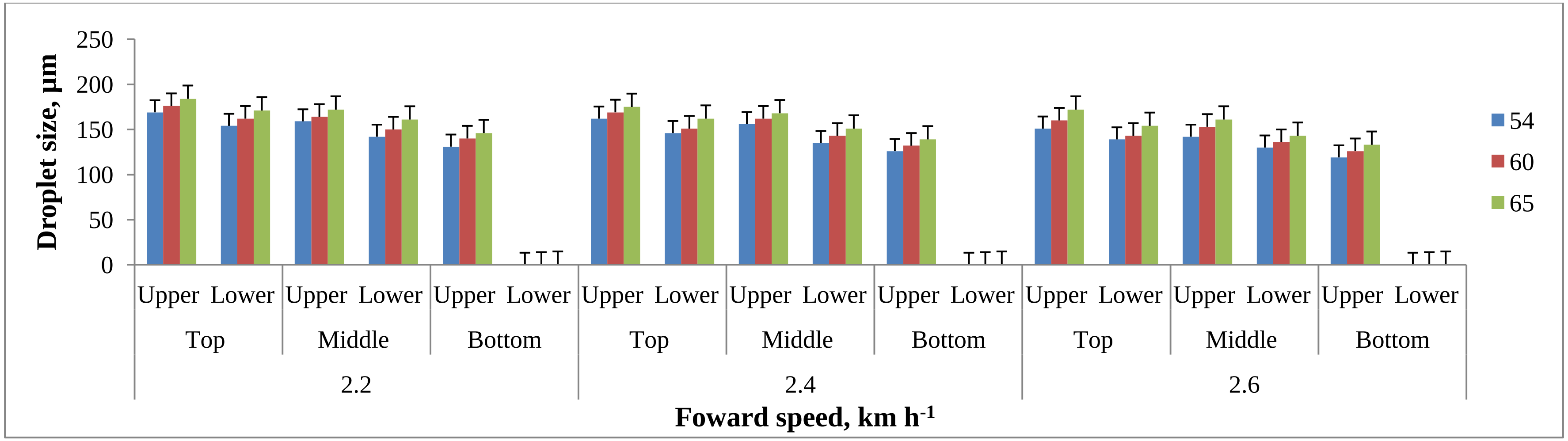


Fig. 50 Effect of forward speed, speed of actuating mechanism on droplet size at 30 cm height of spray nozzle

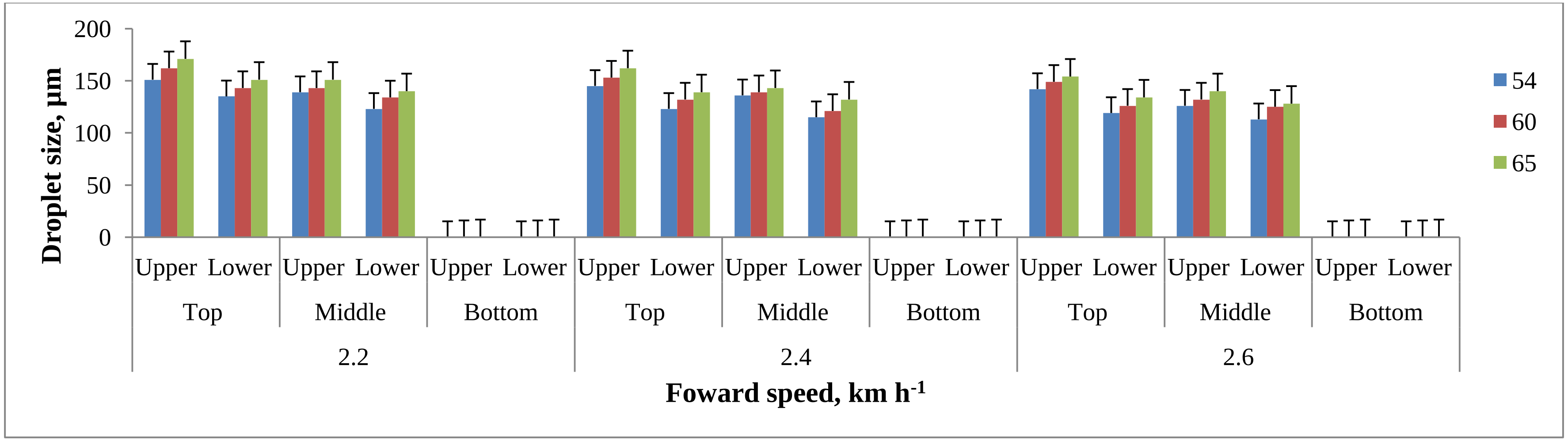


Fig. 51 Effect of forward speed, speed of actuating mechanism on droplet size at 60 cm height of spray nozzle

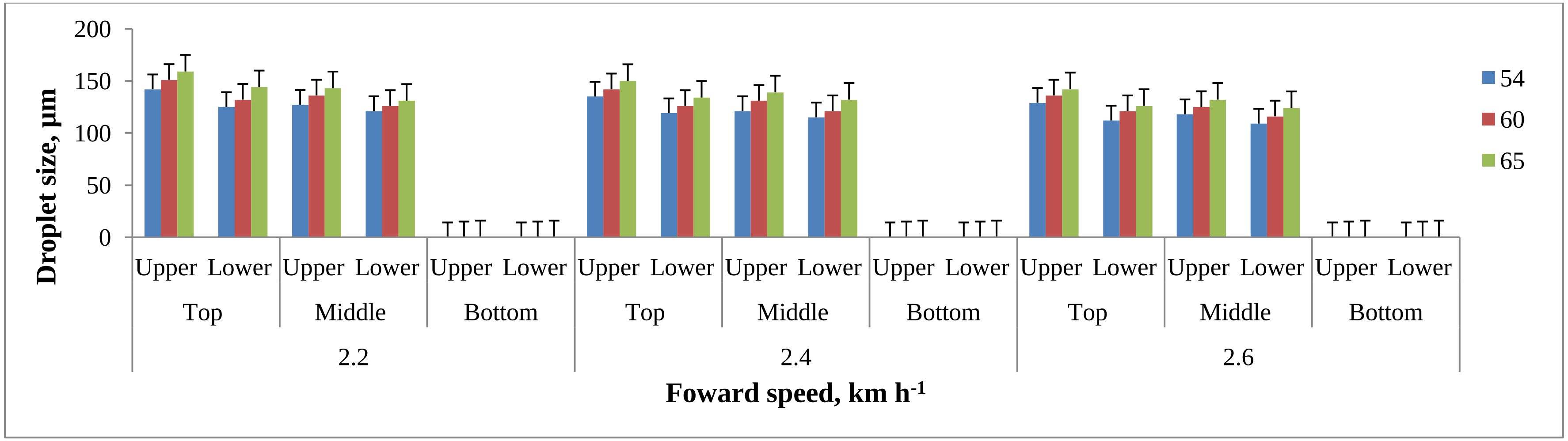


Fig. 52 Effect of forward speed, speed of actuating mechanism on droplet size at 90 cm height of spray nozzle

sprayed area, this leads to overlapping of the droplets and sometimes runoff took place especially in 2.2 km h^{-1}. The mismatched speed was produced large droplets and matched speed between forward speed and actuating mechanism was produced small in case of low speed and medium droplet size in case of high speed.

When the height of spray changed from 30 to 90 cm, droplets had to travel distance longer distance to reach plant canopy. While travelling disintegration of droplets took place and only small diameter droplets which had higher kinetic energy were reached to the middle and bottom position of the crop canopy. The figure also revealed that the VMD on top position of the at lower and upper leaf surface and also at the upper leaf surface on the middle and bottom position of the plant canopy were within the limit when the height of spray was 30 cm. Azizpanah *et al*. (2015) observed the smaller diameters of droplet with increasing the height of the spray nozzle above the ground surface.

As Jain *et al*. (2006) stated that the droplet size between 140 and 200 µm was recommended for spraying most of the crops. For most of the pests and disease control, 100-200 µm as recommended as optimum droplet size. The droplet size produced from the developed tractor operate sprayer well within the recommended zone.

xviii. Effect of forward speed, speed of actuating mechanism and height of spray nozzle on uniformity coefficient

The uniformity coefficient of droplet size emitted from the sprayer under operational parameters *i.e*., forward speed, actuating mechanism and height of spray nozzle is depicted in the Fig. 53, 54 and 55. Uniformity coefficient indicated that maximum values were on the top position of the plant at the upper surface followed by middle leaf and bottom leaf surface at the bottom position. Uniformity coefficient is the ratio of volume mean diameter and number mean diameter. The volume mean diameter is affected by large droplets and number mean diameter is affected the small diameter of the droplets. The minimum uniformity coefficient indicates that, VMD was increased. This was in concurring with the reports of Gupta *et al*. (2011). The variation in uniformity coefficient at different position of the plant canopy may be due to effect of other parameters.

The uniformity coefficient was decreased with increase in forward speed. This is due to as the forward speed increased, volume mean diameter decreased and number mean

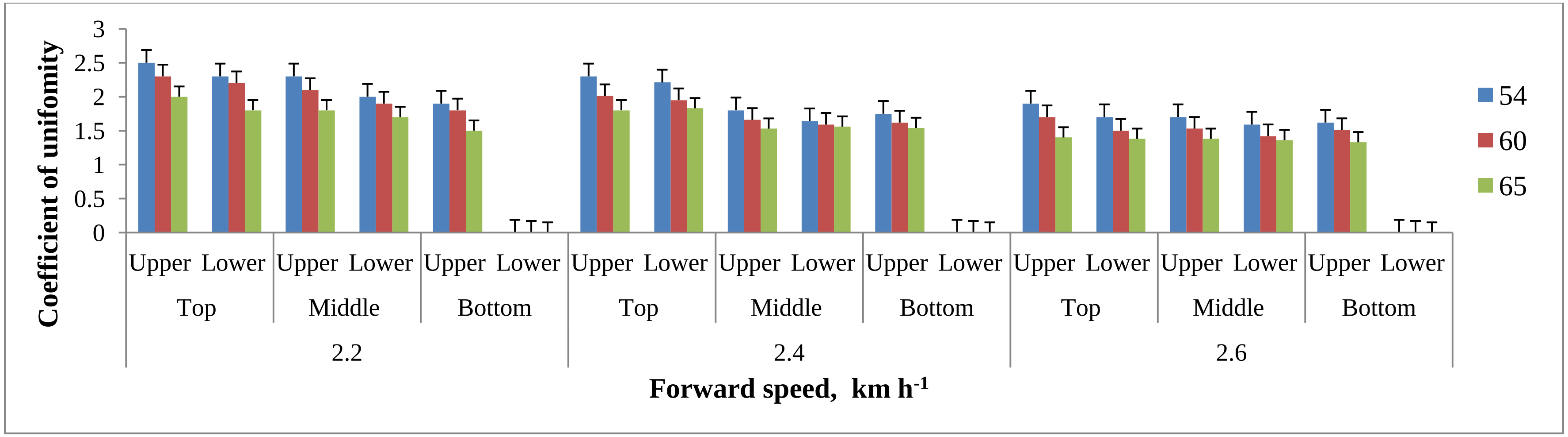


Fig. 53 Effect of forward speed, speed of actuating mechanism on uniformity coefficient at 30 cm height of spray nozzle

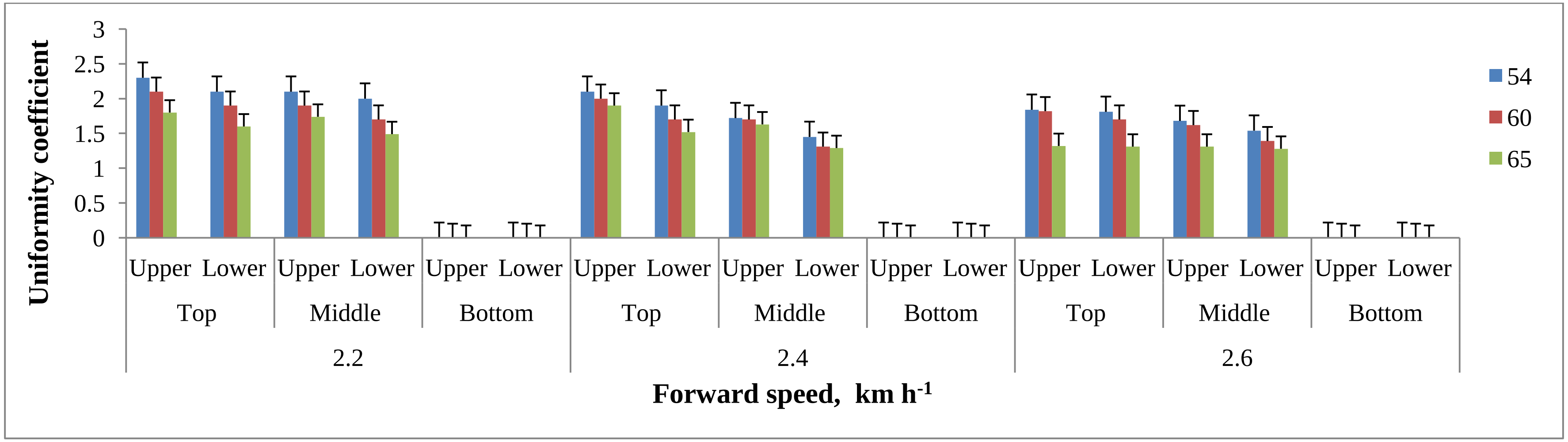


Fig. 54 Effect of forward speed, speed of actuating mechanism on uniformity coefficient at 60 cm height of spray nozzle

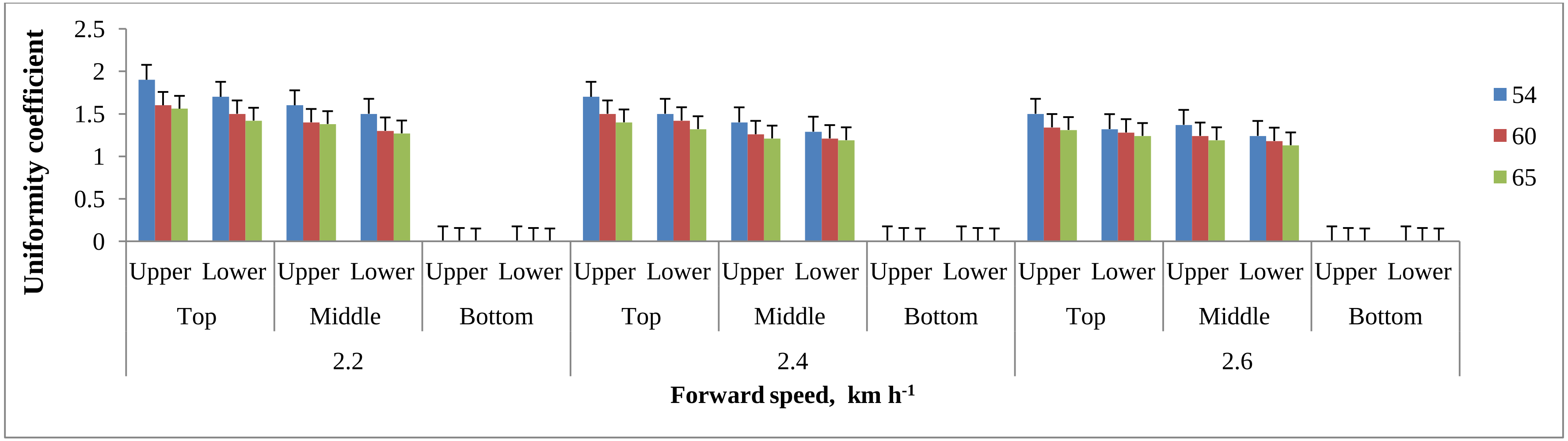


Fig. 55 Effect of forward speed, speed of actuating mechanism on uniformity coefficient at 90 cm height of spray nozzle

diameter increased. Effect of forward speed slightly influenced on the volume mean diameter but greatly influenced on the number mean diameter. This statement is agreed with statement of Gupta *et al*. (2011). Karale *et al*. (2014) corroborated this result by stating that, increase speed decreases the uniformity of droplets at faster rate.

The uniformity coefficient decreased as the speed of actuating mechanism increased. This is due to fact that, the droplet size (VMD) increased. The maximum value of the uniformity coefficient was achieved for 65 cycles min^{-1} speed of actuating mechanism for all the treatments. Droplet size increased due to overlap and sometimes observed a run off.

When the height of spray nozzle increased from 30 to 90 cm, it was observed that small droplets were formed due to disintegration by atmospheric conditions. The minimum uniformity coefficient was observed for 90 cm height of the spray nozzle. This may be due to fact that both volume mean diameter and number mean diameter are relatively small. Similar trend was observed in Gite and Deogirikar (2010). The VMD observed on upper leaf surface at top and middle the plant as well as on lower leaf surface at top position of the plant was well within the recommended zone when nozzle height was 30 cm.

xix. Effect of forward speed, speed of actuating mechanism and height of spray nozzle on area covered by droplets

The area covered by droplets when sprayed on the plant canopy at upper and lower surface of the plant under various operational parameters is shown in the Fig. 56, 57 and 58. The area covered was maximum at top surface of the upper leaves followed by middle and bottom surface. The area covered by calculated taking consideration of droplet density and droplet size. The upper surface receives maximum spray droplets due to direct exposure, hence the area covered by droplets was maximum. The lower surface of the top surface was also received maximum droplets compared to lower middle and bottom due to sprayer inclination towards the plant canopy. Middle and bottom position received less because of the low droplet density and droplet size.

When the forward speed changed from the low to high speed, the area covered by droplets 6.7 per cent for 65 cycles min^{-1} at the height of spray nozzle was 30 cm above the plant canopy. As the forward speed increased, the droplet size and droplet density reduced intern reduced the area coverage. The area coverage is directly proportional to droplet

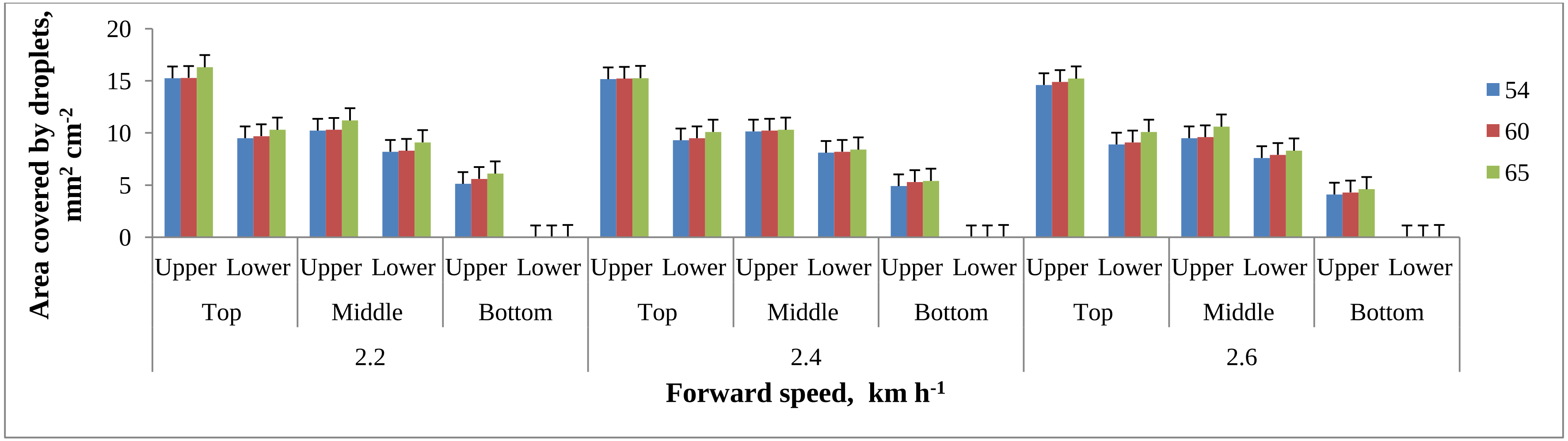


Fig. 56 Effect of forward speed, speed of actuating mechanism on area covered by droplets at 30 cm height of spray nozzle

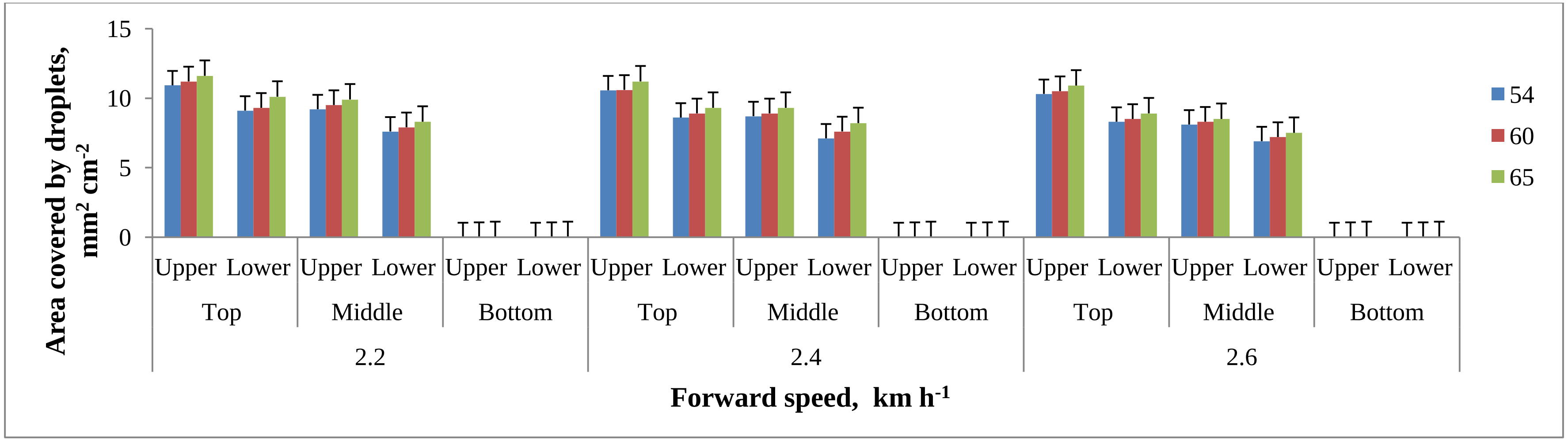


Fig. 57 Effect of forward speed, speed of actuating mechanism on area covered by droplets at 60 cm height of spray nozzle

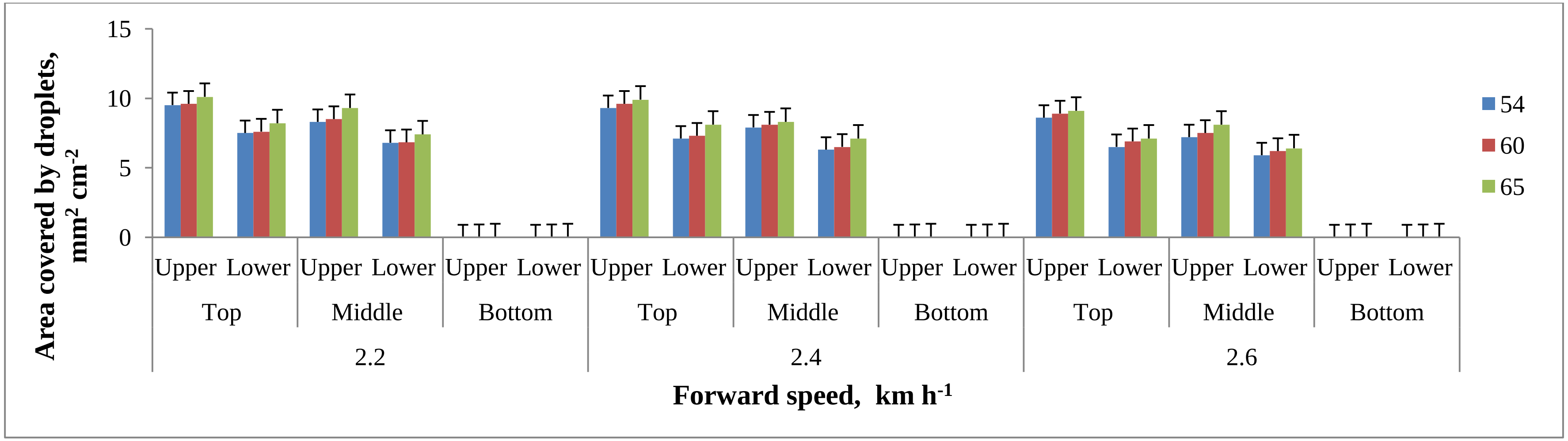


Fig. 58 Effect of forward speed, speed of actuating mechanism on area covered by droplets at 90 cm height of spray nozzle

density and droplet size. As the height of the spray nozzle the bottom position of the plant did not receive a depositon. This is might be due to fact that, droplets evaporated and might be due to obstructions of the branches and leaves. Among the variables studied, height of the spray nozzle had most significantly followed by forward speed and actuating mechanism.

The area covered by droplets increased by 6.85 per cent as speed of actuating mechanism increased. This is because of the fact that speed of actuating mechanism influenced the droplet size and droplet density. The speed increased both droplet density and droplet size increased.

The area coverage by droplets decreased as the height of the spray nozzle increased from 30 to 90 cm. This is because of the fact that, the droplet size and droplet density were decreased. As the height increased, the spray droplets lose their kinetic energy and carried away by weather parameters. This effect could be reduced by operating the spray nozzle close to the surface of the crop canopy.

xx. Effect of forward speed, speed of actuating mechanism and height of the spray nozzle on particle drift

The particle drift was increased with increase in forward speed. At higher forward speeds, the droplets released from the nozzle had higher horizontal component of the velocity. As a result, the droplets were carried in air over the top of canopy to a longer distance, which made them more prone to drift away from the canopy (Gupta *et al*. 2011). It is, therefore, desirable that forward speed of the sprayer is kept low to reduce particle drift. The drift droplets were reduced as the height of the spray nozzle increased. This is because of the spray droplets lose their hydraulic energy and carried away by weather parameters. Drift can be reduced by keeping the nozzle close to the crop surface

5.3.2 Performance evaluation of tractor operated automatic gun sprayer in pigeonpea crop

The field trials were conducted by maintaining operating pressure of 22 kg cm^{-2}, nozzle size of 2 mm and 15 degree orientation of spray nozzle. The metrological data were noted and tabulated. Sprayer adjustments were made before spraying operation. The sprayer was operated in a straight path along the row of the crop such that the distance between the nozzle and the surface of crop canopy was nearly 30 cm.

i. Effect of forward speed, speed of actuating mechanism and height of spray nozzle on swath width of spray

The width of the spray from the sprayer decreased by 12.10 per cent as the forward speed increased for 65 cycles min^{-1} at 30 cm height of spray nozzle (Fig. 59). This probably due to fact that as forward speed increased, instead of spread of water droplets in horizontal distance, spreads to forward. The maximum swath width was observed for low forward speed (2.2 km h^{-1}).

When actuating speed changed from 54 to 65 cycles min^{-1}, the swath width decreased by 9.62 per cent (Fig. 60). This is because of availability of time to complete the cycles was less, due to this spray nozzle has less time to be in horizontal position.

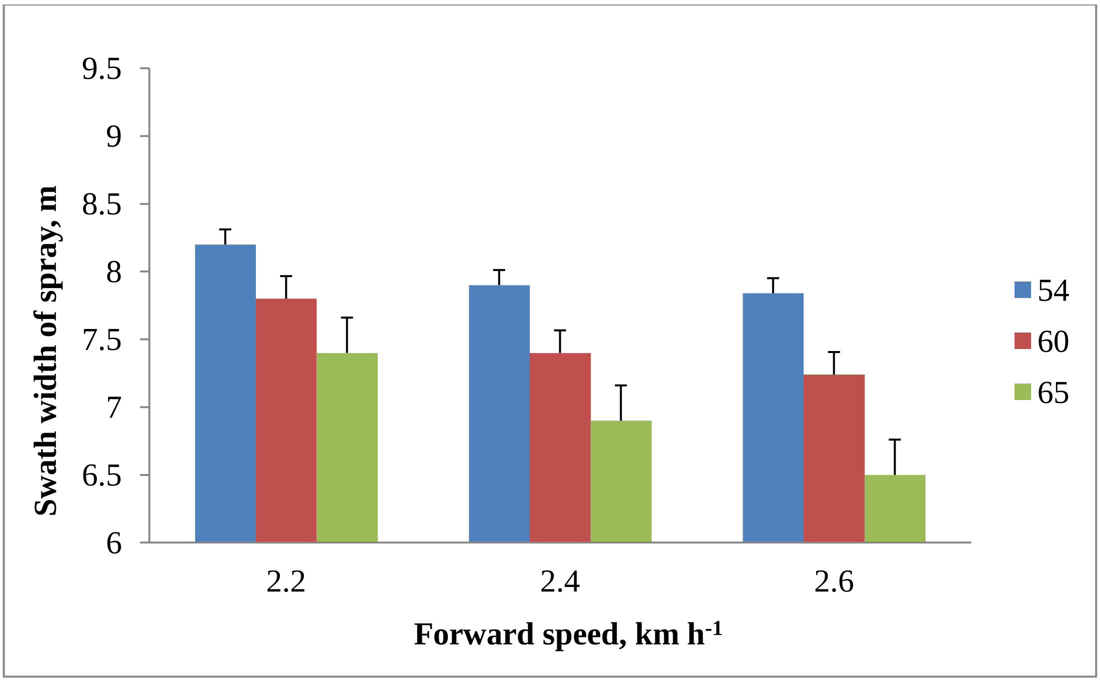
The swath width of the spray increased by 10.96 per cent as the height of spray nozzle was changed from 30 to 90 cm above the plant canopy (Fig.61). This is due to space avaible for air entrainment with the spray droplets and carries the droplets further distance. The maximum swath width was found for 90 cm height of spray. Iqbal *et al.* (2006) reported that, swath width increased as increased the nozzle height.

ii. Effect of forward speed, speed of actuating mechanism and height of spray nozzle on field capacity

The field capacity of the sprayer increased with increase about 28.14 per cent in forward speed (Fig. 62, 63 and 64). As the forward speed increased area covered per unit time was increased. Field capacity is linear with forward speed. The forward speed increased the field efficiency, which includes reduces the time taken to cover the required area. Though, swath width was decreased with increase in forward speed, field capacity was increased due to forward motion of the tractor.

When the actuating mechanism changed from 54 to 65 cycles min^{-1}, the field capacity was decreased by 10.65 per cent at 2.2 km h^{-1} for 30 cm height of spray nozzle. This is because of as the decreasing the width of spray.

The field capacity of the sprayer increased by 8.98 per cent as the height of the spray nozzle increased. As the height increased, more space avaible for air to entertain with spray droplet and move the droplets further, increases the swath width.



`Fig. 59 Effect of forward speed, speed of actuating mechanism on swath width of spray at 30 cm height of spray nozzle

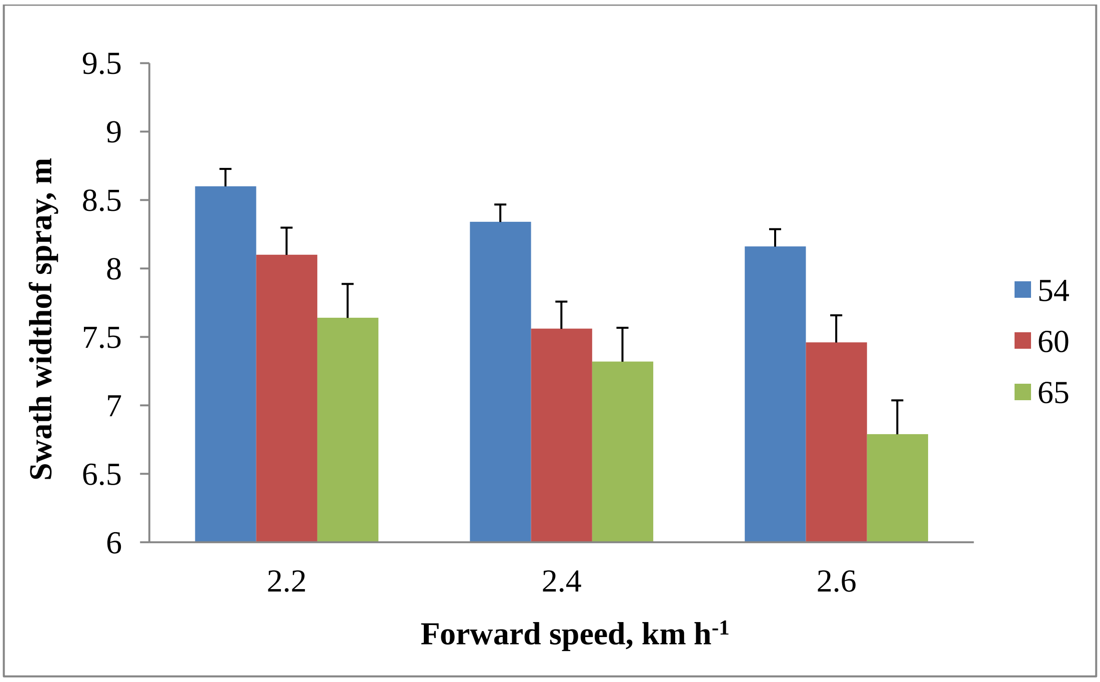


Fig. 60 Effect of forward speed, speed of actuating mechanism on swath width of spray at 60 cm height of spray nozzle

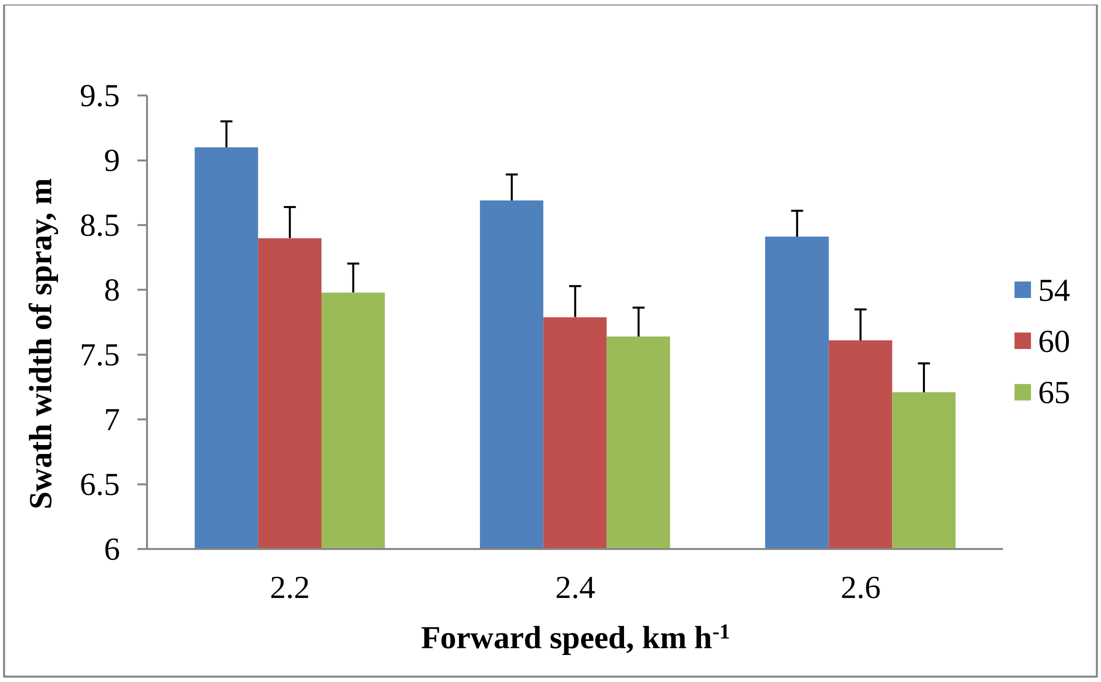


Fig. 61 Effect of forward speed, speed of actuating mechanism on swath width of spray at 90 cm height of spray nozzle

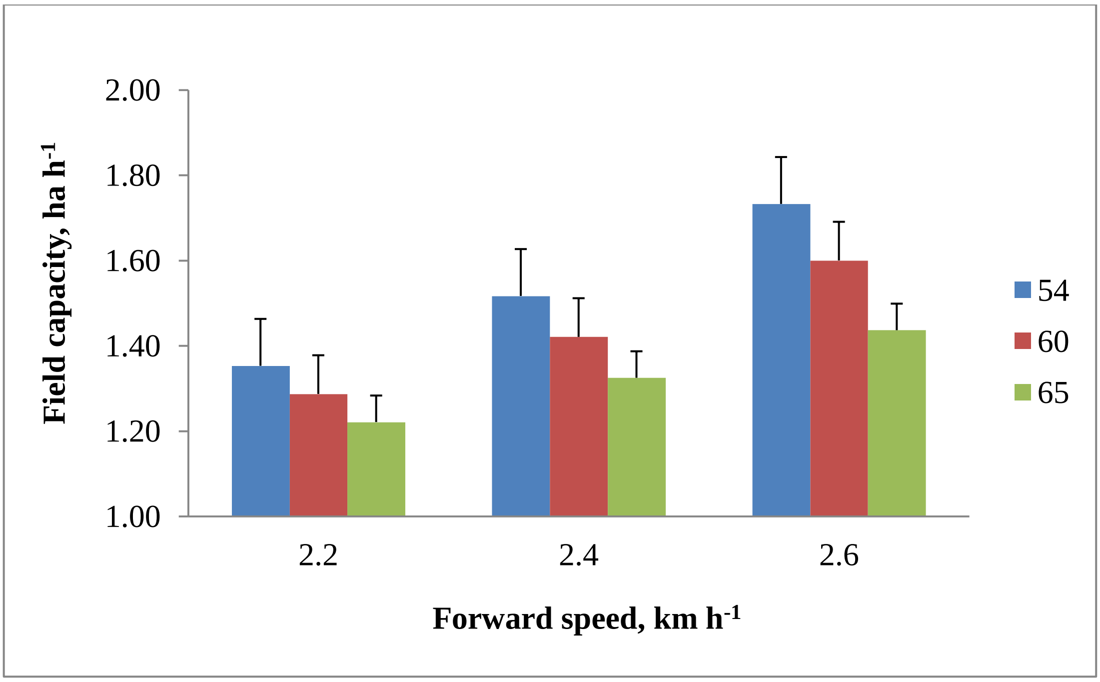


Fig. 62 Effect of forward speed, speed of actuating mechanism on field capacity at 30 cm height of spray nozzle

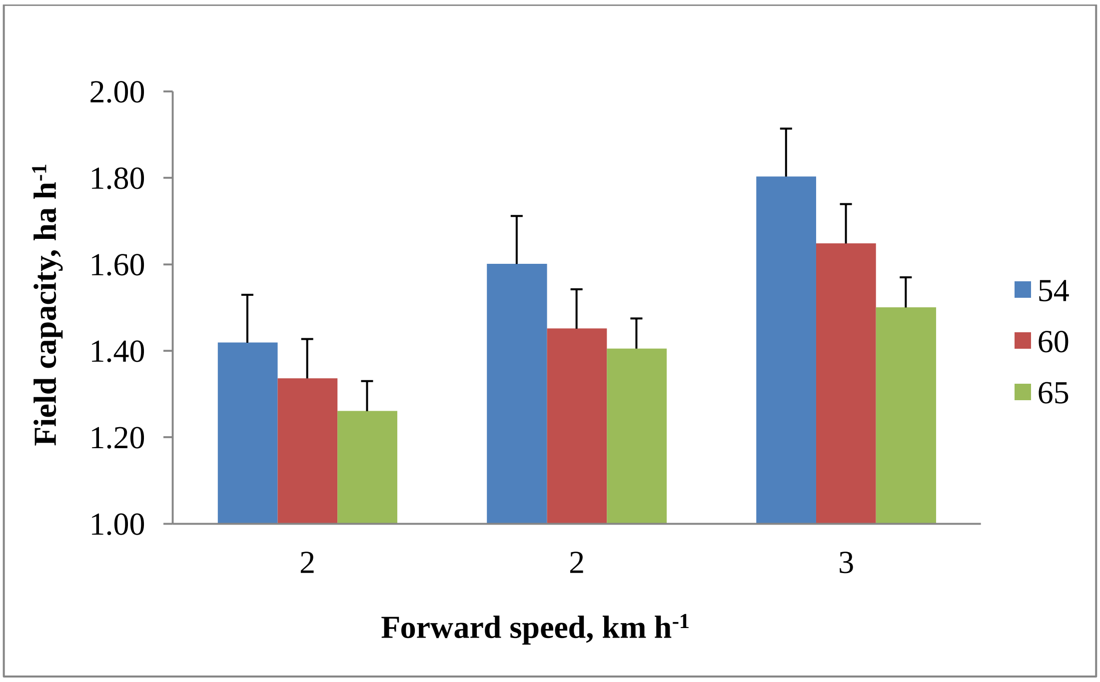


Fig. 63 Effect of forward speed, speed of actuating mechanism on field capacity at 60 cm height of spray nozzle

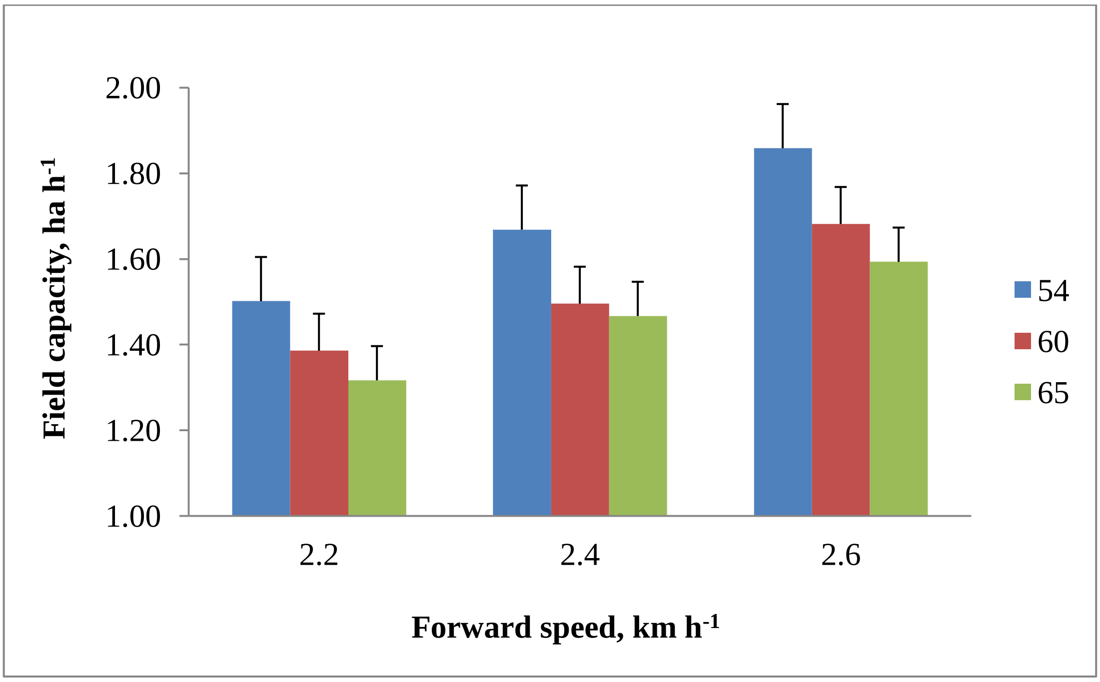


Fig. 64 Effect of forward speed, speed of actuating mechanism on field capacity at 90 cm height of spray nozzle

The analysis of variance for field capacity showed that the main factor *i.e*., forward speed had highly significant effect on the field capacity followed by actuating mechanism and height of the spray nozzle. The model F value 3.22 implies that the model is significant at 5 per cent level of significance. The prob > F value of the model is considerably less than 0.05 (*i.e*., 95 per cent confidence level), then the terms model have a significant effect on the response. There is only 94.18 per cent chance for a "model F-value" of this large could occur due to noise. The standard deviation and co-efficient of variation were found to be 0.28 and 17.76 per cent with a mean value of 1.56.

iii. Effect of forward speed, speed of actuating mechanism and height of spray nozzle on actual application rate

The actual application rate of the sprayer under different operating parameters is shown in the Fig. 65, 66 and 67. The actual application rate was decreased 25.39 per cent as the forward speed increased from 2.2 to 2.6 km h^{-1}. Application rate of the sprayer is indirectly proportional to forward speed and swath width. Actual application of the sprayer was more than the theoretical application rate due to turning losses.

It was observed from the figure that the application rate was increased with increasing in speed of actuating mechanism in 2.2 km h^{-1}. The matched speed of actuating mechanism and forward speed, consumed less amount of the liquid. Increased application was due to increased number of the spray over the spray area. The less application rate compared to theoretical is due to mismatched speed, number of spray needed for unit area was less. Hermosilla *et al*. (2011) stated that forward speed had inverse relationship with the application rate

When the height of the spray nozzle increased from 30 to 90 cm, the application rate decreased by 11.90 per cent for 2.2 km h^{-1} at 30 cm height of spray nozzle. As the height of spray nozzle increased, the swath width of the spray increased. The application rate is indirectly proportional to the forward speed and swath width. As the swath width increases, application rate decreases.

Statistical analyzed data showed that forward speed had highly influenced the application rate, followed by height of spray and actuating mechanism. The model F value 8.02 implies that the model is significant at 5 per cent level of significance. The prob > F value of the model is considerably less than 0.05 (*i.e*., 95 per cent confidence

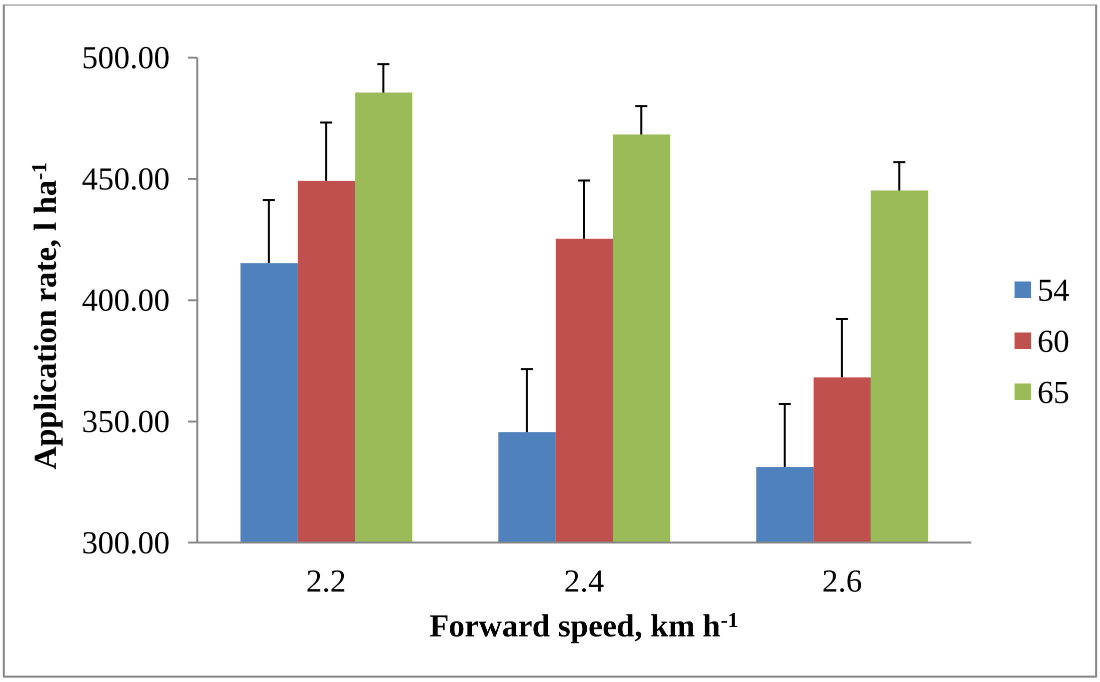


Fig. 65 Effect of forward speed, speed of actuating mechanism on application rate at 30 cm height of spray nozzle

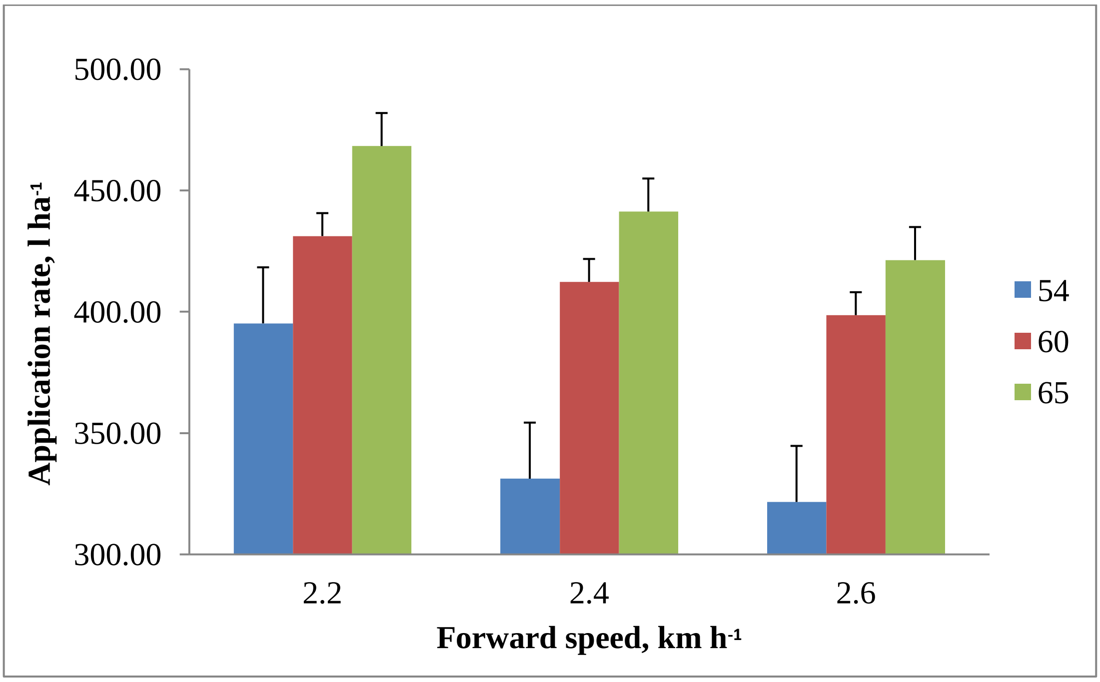


Fig. 66 Effect of forward speed, speed of actuating mechanism on application rate at 60 cm height of spray nozzle

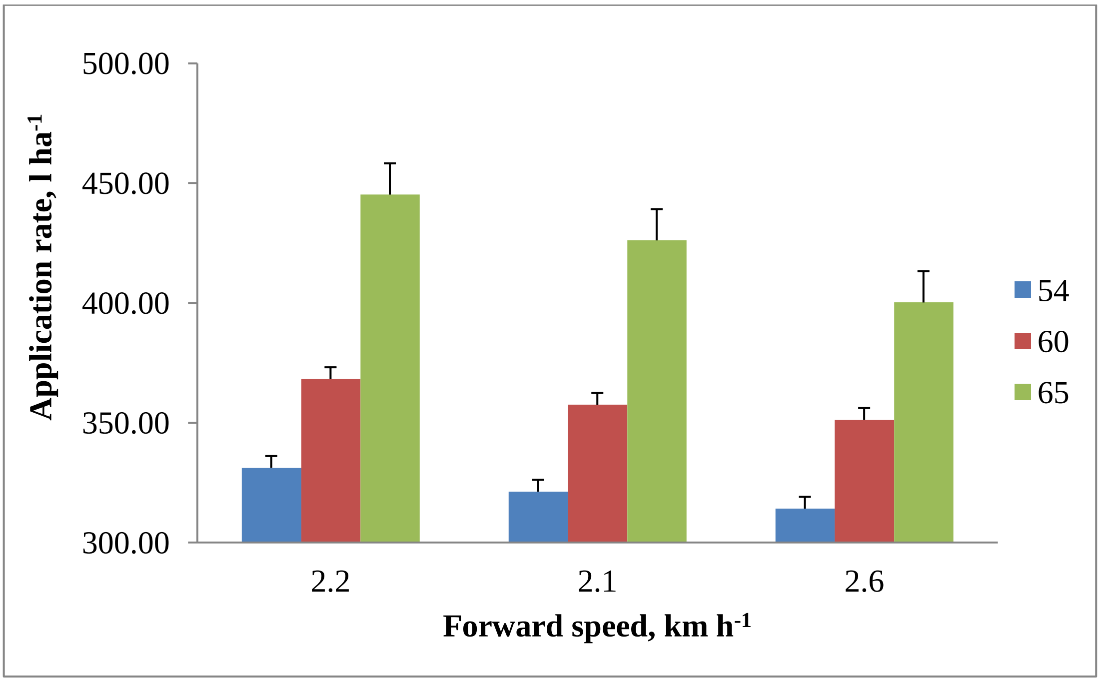


Fig. 67 Effect of forward speed, speed of actuating mechanism on application rate of sprayer at 60 cm height of spray nozzle

level), then the terms model have a significant effect on the response. There is only 94.18 per cent chance for a “model F-value” of this large could occur due to noise. The standard deviation and co-efficient of variation were found to be 4.31 and 8.39 per cent with a mean value of 408.85.

iv. Effect of forward speed, speed of actuating mechanism and height of spray nozzle on difference in actual and theoretical application rate

The difference in actual and theoretical application rate of the sprayer at different treatment combination is indicated that, all matched speed of actuating mechanism and forward speed of tractor was produced within the recommended range. The positive sign indicates that number of spray application was more on the same sprayed area. The negative sign indicates that, speed of actuating mechanism was less than the required speed. Less application means there was more unsprayed area.

The statistically analyzed data on difference in actual and theoretical application rate showed that the main effect of each factor of forward speed (A), actuating mechanism (B) and height of spray nozzle has significantly influenced on the difference in actual and theoretical application rate at 5 per cent level of significance. Among the main factor, forward speed had highest significant on difference. The interaction effects have 5 per cent significant. The model F- value 24.95 implies that the model is significant at 5 per cent level of significance. The standard deviation and co-efficient of variation were found to be 1.79 and 13.78 per cent with a mean value of 4.08.

xiii. Effect of forward speed, speed of actuating mechanism and height of spray nozzle on fuel consumption of tractor

The fuel consumption of the tractor under different operational parameters is shown in the Fig. 68. The fuel consumption increased by 28.92 per cent as the forward speed increased. This is may be due to resistance force between soil and traction wheels and might be due to carry the spray tank. It was also observed that the fuel consumption of sprayer did not affected by the speed of actuating mechanism as power to drive actuating mechanism was taken from the battery.

The analysis of the variance showed that forward speed effected fuel consumption highly. The forward speed was found 95 level of confidence level. The interaction effect of forward speed and height of spray nozzle had 5 per cent non significance. The model F-

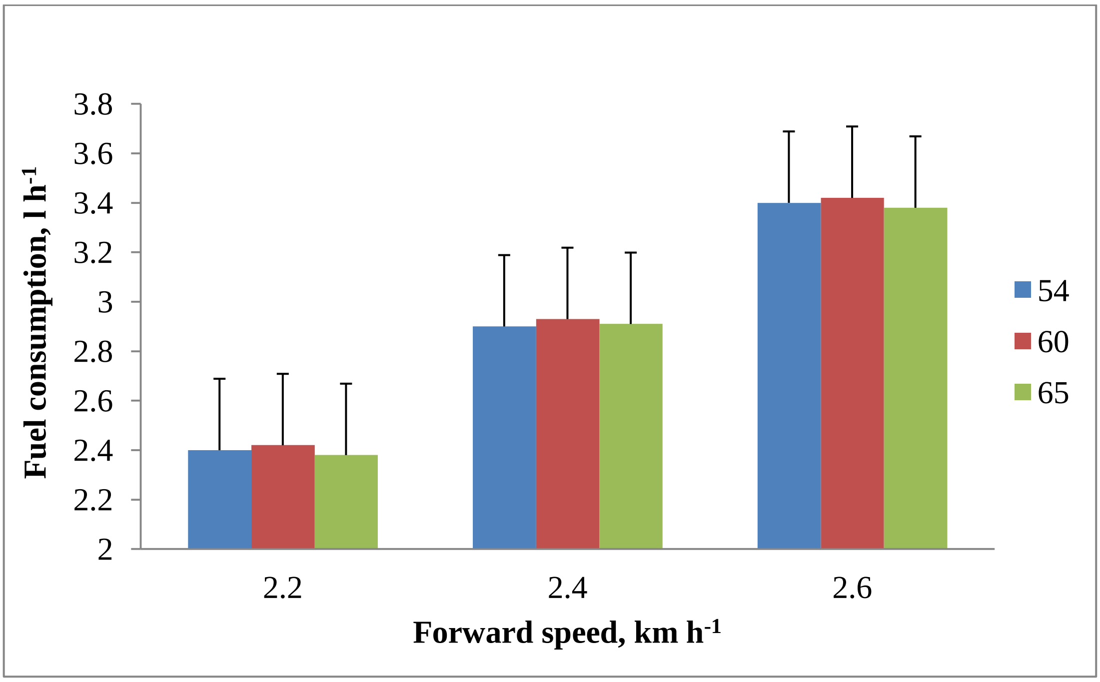


Fig. 68 Effect of forward speed, speed of actuating mechanism on fuel consumption of tractor at 30 cm height of spray nozzle

value 14.20 implies that the model is significant at 95 per cent confidence level. The standard deviation and co-efficient of variation were found to be 0.18 and 6.13 per cent with a mean value of 2.93.

xiv. Effect of forward speed, speed of actuating mechanism and height of spray nozzle on droplet density

The droplet density produced from the sprayer on upper and underside of different plant position is shown in the Fig. 69, 70 and 71. It is clear that, the droplet density was more in top of upper surface followed by middle and bottom. This is because direct exposure to spray. The droplet density decreases as the droplet moves from top to bottom due to disintegration of the spray droplets. The droplet density on underside leaves of the top surface was found 37.12 per cent as compared to top upper surface. This is because of the inclination of the spray nozzle towards the plant canopy.

The droplet density was decreased by 18.45 per cent on top surface of upper leaves as the forward speed increased from 2.2 km h^{-1} to 2.6 km h^{-1} at 30 cm height of spray nozzle. The forward speed influence on the exposure time. More exposure to plant canopy receives more droplets density. The speed should be such that, maximum droplet density should give. At higher forward speeds, the droplets released from the nozzle had higher horizontal component of the velocity. As a result, the droplets were carried in air over the top of canopy to a longer distance, which made them more prone to be drifted away from the plant canopy. Jassowal *et al*. (2016), Sirohi *et al*. (2008) and Travis (1987) reported similar results. The droplet densities at 2.2 km h^{-1} forward speed were sufficient to kill insects and pests except at the bottom of canopy. It was also observed that as forward speed increased, droplet density was zero at the bottom of upper and lower, it may be due to evaporation of the spray droplets and the crop canopy did not allowed the droplet density to penetrate on the surface.

The droplet density increased with increase in speed of actuating mechanism. The droplet density increased by 21.23 per cent as speed of actuating mechanism increased at 2.2 km h^{-1} forward when height of spray nozzle was 30 cm. This is due to, as increased number of spray over the sprayed area. More spray results more droplet density and sometimes for higher actuating mechanism especially for 2.2 km h^{-1}, more runoff occured. The correct matched speed resulted exact spray droplets.

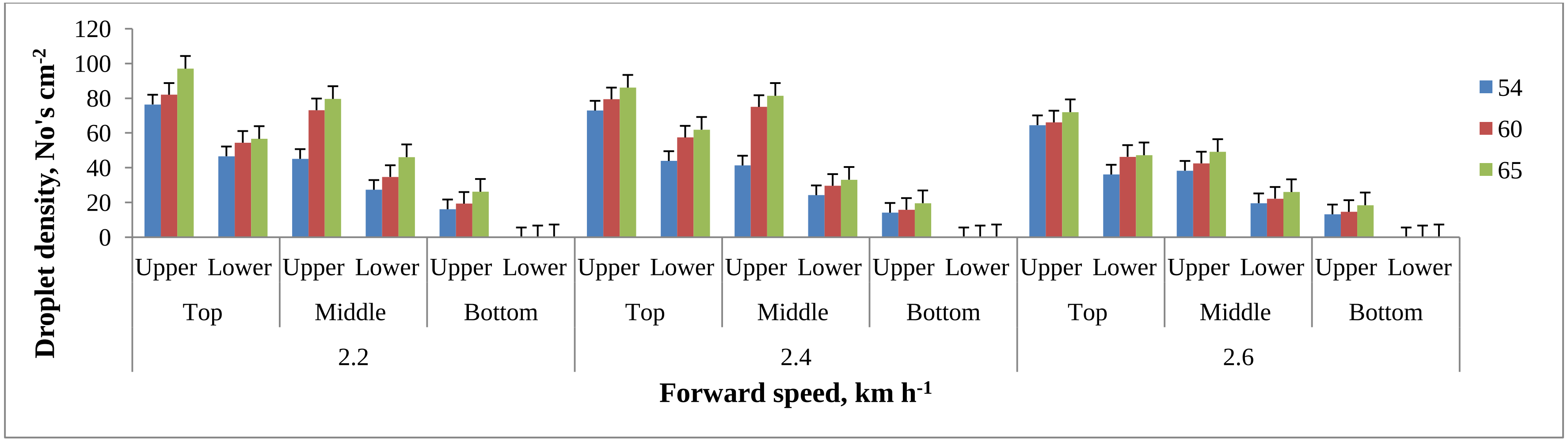


Fig. 69 Effect of forward speed, speed of actuating mechanism on droplet density at 30 cm height of spray nozzle

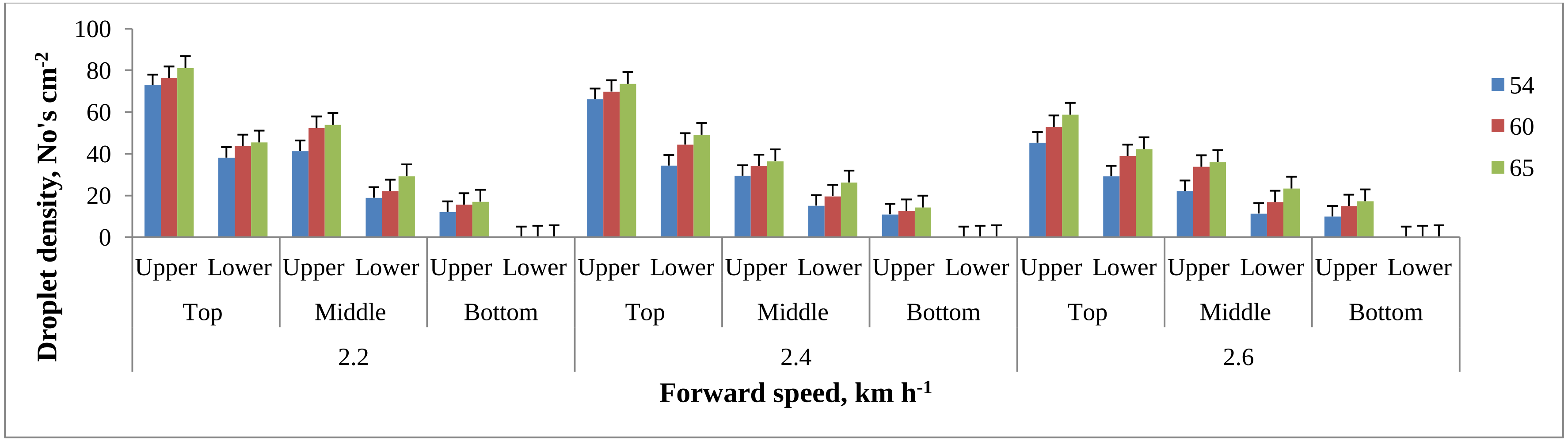


Fig. 70 Effect of forward speed, speed of actuating mechanism on droplet density at 60 cm height of spray nozzle

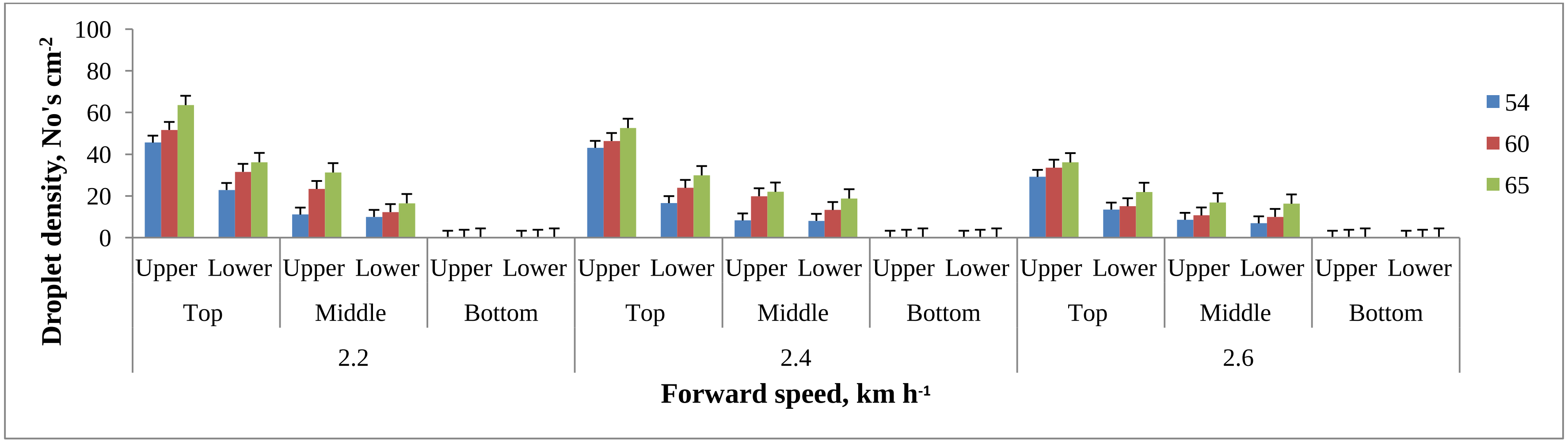


Fig. 71 Effect of forward speed, speed of actuating mechanism on droplet density at 90 cm height of spray nozzle

The height of spray nozzle above the plant canopy affected the droplet density on different positions of the plant. The droplet density decreased by 58.67 per cent as the height of the spray nozzle increased. This may be due to fact that, the droplets had to longer distance to reach the canopy surface. This long distance may cause droplets to evaporate and goes as drift. It clear from the results that, bottom position of the crop did not received droplets. This is probably reason that droplets evaporated and canopy of the plant is less in the lower region. Al-Gaadi (2010) reported the same results. Such low droplet density would not be sufficient to control pest and insects effectively. The effect height of spray nozzle of 30 cm above plant canopy showed significantly higher droplet density as per the recommendation at almost all position on target plant except bottom position.

xv. Effect of forward speed, speed of actuating mechanism and height of spray nozzle on droplet size (VMD)

The droplet density produced from the sprayer at different forward speed, actuating mechanism and height of the spray nozzle is shown in the Fig. 72, 73 and 74. According to the figures, the VMD of the spray droplets were larger compared to lower surface of the leaves. The VMD was maximum on all upper surface of the different plant position. Larger VMD on upper surface might be due to heavy droplets deposited on the upper surface and sometime it is due to overlapping of droplets each other. The droplet size decreased, when the droplets move from the top to bottom position. During movement of the droplets, bigger droplets broke into smaller droplets after they struck the leaves and some were carried further by air movement. Smaller droplets might not have sufficient potential to reach the target. Similar results were reported by Gholap *et al*. (2012), Gupta *et al*. (2011) and Shahare *et al*. (2010).

VMD falling on the top upper surface of the plant canopy decreased slightly with increased forward speed by 8.9 per cent for 60 cycles min^{-1} when the height of the spray was 60 cm above the plant canopy. The forward speed influenced the exposure time. More exposure increases the droplet density and sometimes overlapping leads to increase the droplet size. Droplet size on the middle surface was also affected by the forward speed but VMD changed less than the top.

The droplet size decreased by 22.72 per cent as the height of the spray nozzle increased from 30 to 90 cm above the plant canopy for 54 cycles min^{-1} speed of actuating

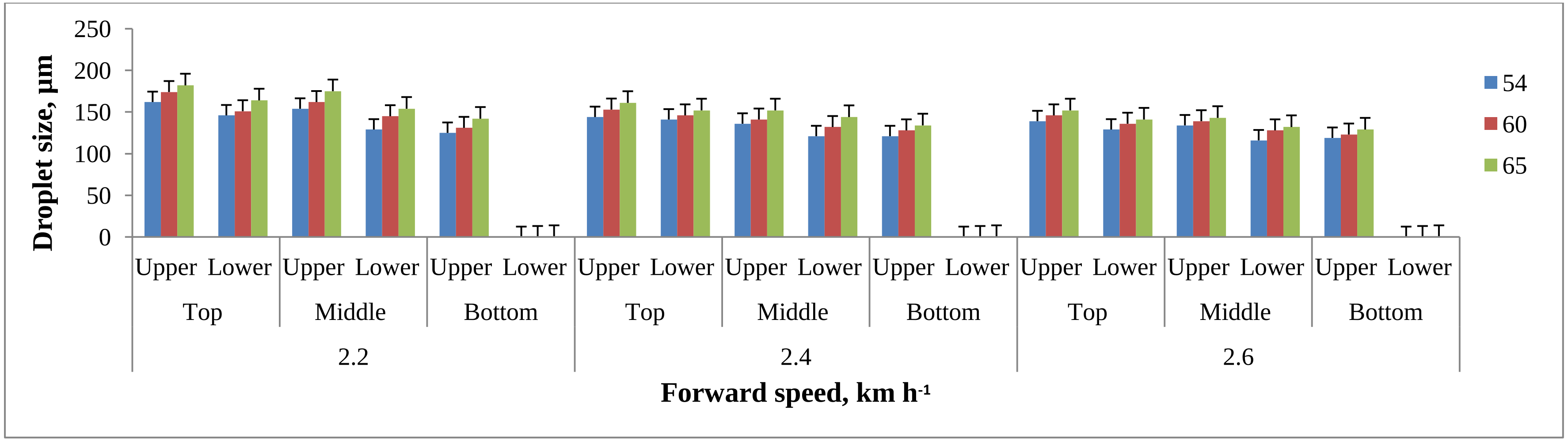


Fig. 72 Effect of forward speed, speed of actuating mechanism on droplet size at 30 cm height of spray nozzle

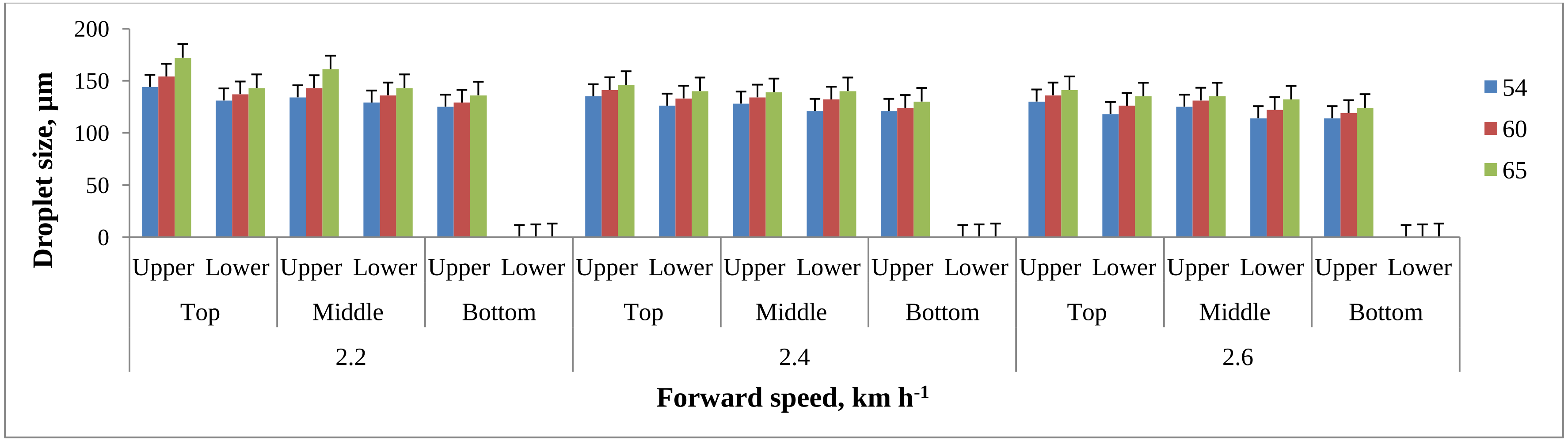


Fig. 73 Effect of forward speed, speed of actuating mechanism on droplet size at 60 cm height of spray nozzle

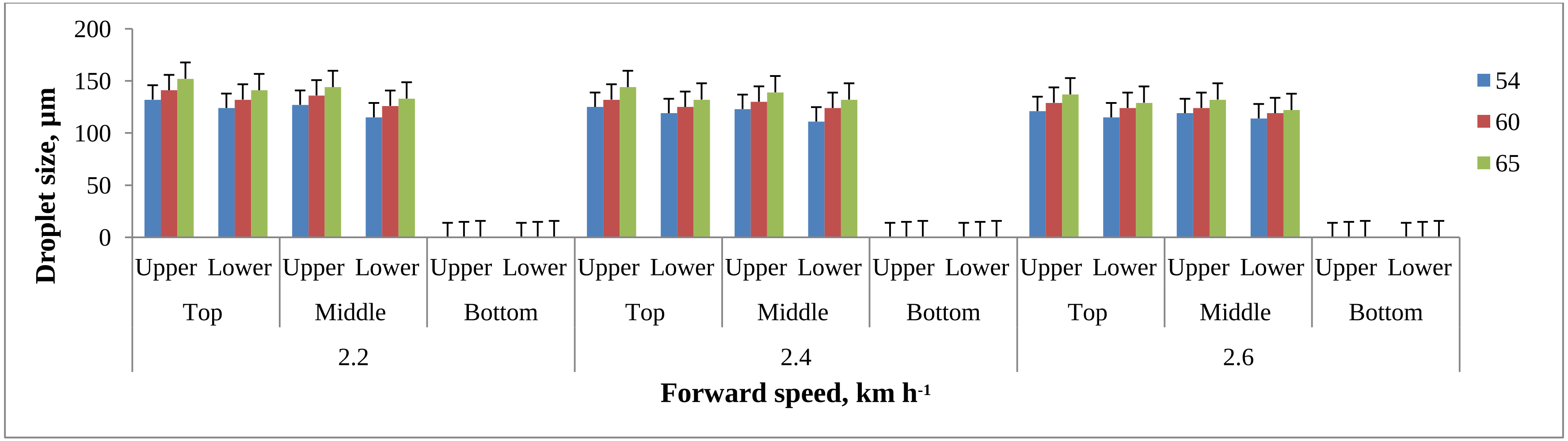


Fig. 74 Effect of forward speed, speed of actuating mechanism on droplet size at 90 cm height of spray nozzle

mechanism. This is probably due to, most of the heavier droplets falls on the upper surface of the crop, while droplets disintegrate into small droplets as the height increased. During movement to crop canopy, some of the droplets get evaporated and some carried away by air. As the height increased, the droplet deposition at the bottom of the plant canopy did not receive. This probably due to droplets loses of their kinetic energy of the droplets and carried away by air. It was concluded that the maximum droplet size at top, middle and bottom position of the plant and upper leaf surface as well as on top position of plant and lower leaf surface was observed at the height of spray nozzle of 30 cm above the plant canopy and found within the recommended range.

xvi. Effect of forward speed, speed of actuating mechanism and height of spray nozzle on uniformity coefficient

The uniformity coefficient of spray droplets produced from the sprayer is shown in the Fig. 75, 76 and 77. Uniformity coefficient indicated that maximum values were on the top position of the plant at the upper surface followed by middle leaf and bottom leaf surface of plant canopy position. Uniformity coefficient is the ratio of volume mean diameter and number mean diameter. The volume mean diameter is affected by large droplets and number mean diameter is affected the small diameter of the droplets. The minimum uniformity coefficient indicates that, VMD was decreased. As the droplets moves from top to bottom of the position, they lose their kinetic energy and break down of the droplets take place. Hence, both volume mean and numerical mean diameters are decreased. This was in concurring with the reports of Gupta *et al*. (2011), Wandkar and Mathur (2012) and Gholap and Kushwah (2015).

The uniformity coefficient was decreased with increase in forward speed. This is due to as the forward speed increased both droplets size and density decreased. The number mean diameter and volume mean diameter of the droplets decreased. Effect of forward speed slightly influenced on the volume mean diameter but greatly influenced on the number mean diameter. This statement is agreed with statement of Gupta *et al*. (2011).

The uniformity coefficient was decreased as the speed of actuating mechanism increased. This is due to fact that, the droplet size (VMD) increased. As the speed of actuating mechanism increased, the droplet size increased due to overlapping and heavier droplets. The maximum value of the uniformity coefficient was achieved for 65 cycles min^{-1} speed of actuating mechanism for all the treatments.

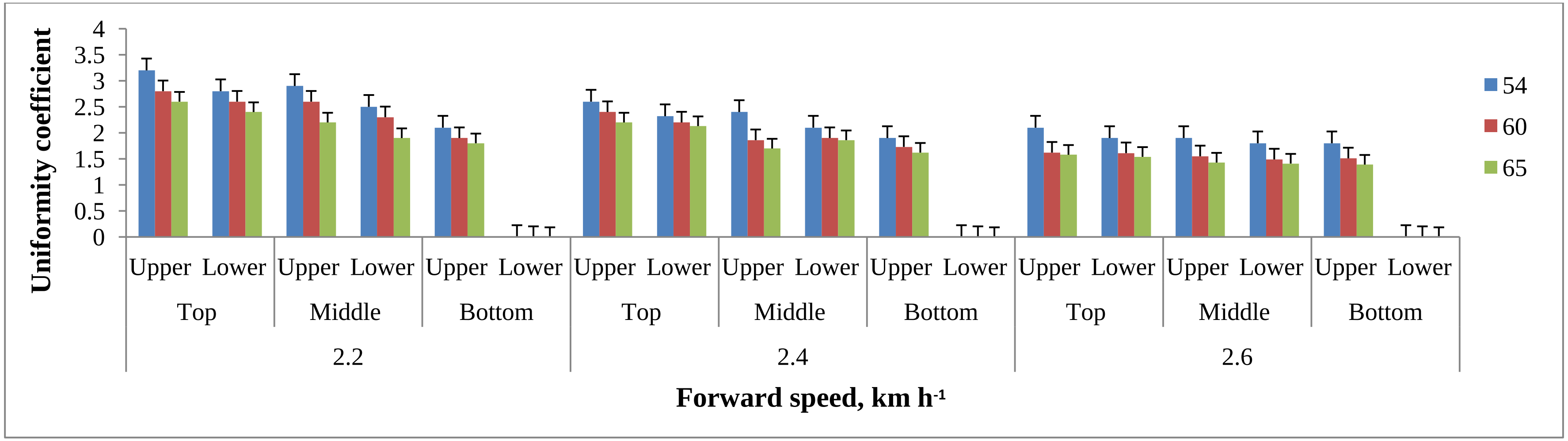


Fig. 75 Effect of forward speed, speed of actuating mechanism on uniformity coefficient at 30 cm height of spray nozzle

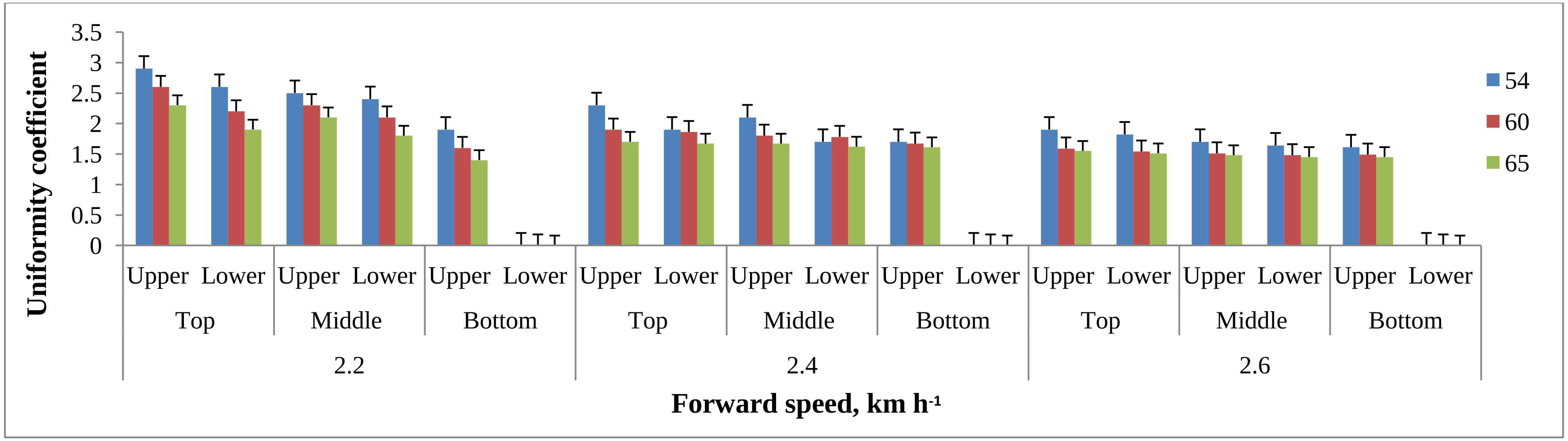


Fig. 76 Effect of forward speed, speed of actuating mechanism on uniformity coefficient at 60 cm height of spray nozzle

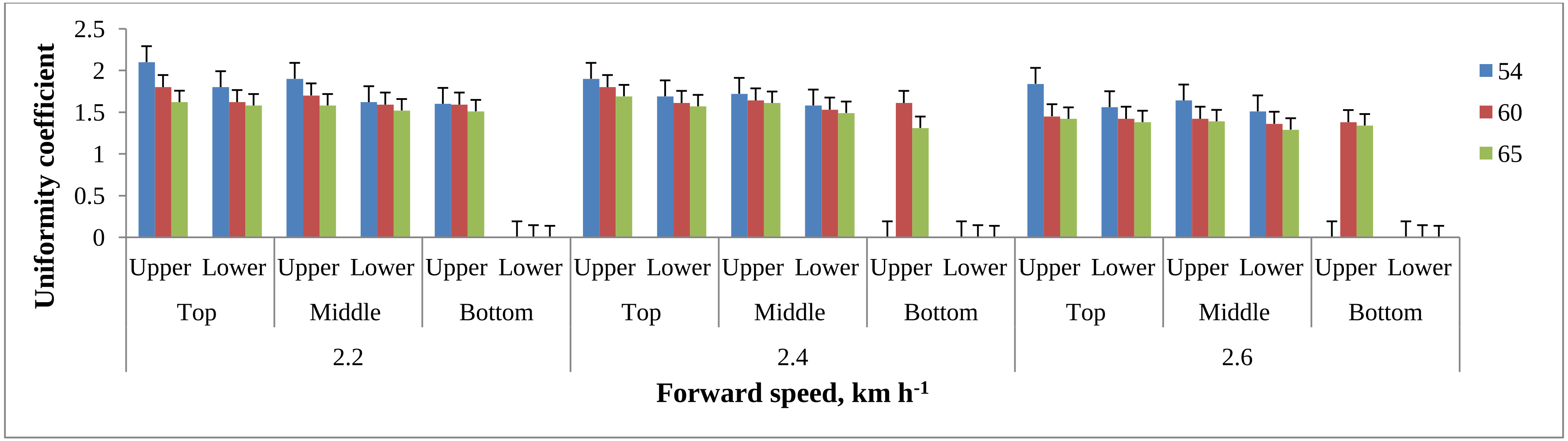


Fig. 77 Effect of forward speed, speed of actuating mechanism on uniformity coefficient at 90 cm height of spray nozzle

When the height of spray nozzle increased from 30 to 90 cm, it was observed that small droplets were formed due to disintegration by atmospheric conditions. Only a large droplets, those who have high kinetic energy had reached to the plant canopy. The minimum uniformity coefficient was observed for 90 cm height of the spray nozzle. This may be due to fact that both volume mean diameter and number mean diameter are relatively small. Young (1990) found that the number median diameter for droplets moving vertically down from the nozzle decreased by 10 per cent and the corresponding volume median diameter by 8 per cent. Similar trend was observed in Gite and Deogirikar (2010).

xvii. Effect of forward speed, speed of actuating mechanism and height of spray nozzle on area covered by droplets

The area covered by the droplets after impinges on the leave surface under different treatment combination is shown in the Fig. 78, 79 and 80. The area covered was maximum at top surface of the upper leaves followed by middle and bottom surface. The area covered by droplets was calculated taking consideration of droplet density and droplet size. The upper surface receives maximum spray droplets due to direct exposure, hence the area covered by droplets was maximum. The lower surface of the top surface was also received maximum droplets compared to lower middle and bottom due to sprayer inclination towards the plant canopy. Middle and bottom position, area covered by droplets was less because of the low droplet density and droplet size. Singh *et al*. (2010) found the similar readings in air assisted sprayer.

When the forward speed changed from the low to high speed, the area covered by droplets 6.7 per cent for 65 cycles min^{-1} at the height of spray nozzle was 30 cm above the plant canopy. As the forward speed increased, the droplet size and droplet density reduced intern reduced the area coverage. At higher speeds, the exposure time per unit area of plant canopy was less, which reduced the amount of spray received on that area. The area coverage is directly proportional to droplet density and droplet size. It was also observed that, as speed increased the deposition on the bottom position of the plant was zero. This is probably due to droplets get evaporated. The obtained data are in agreement with Jassowal *et al*. (2016) who reported that, forward speed had highly influence on the area covered by droplets.

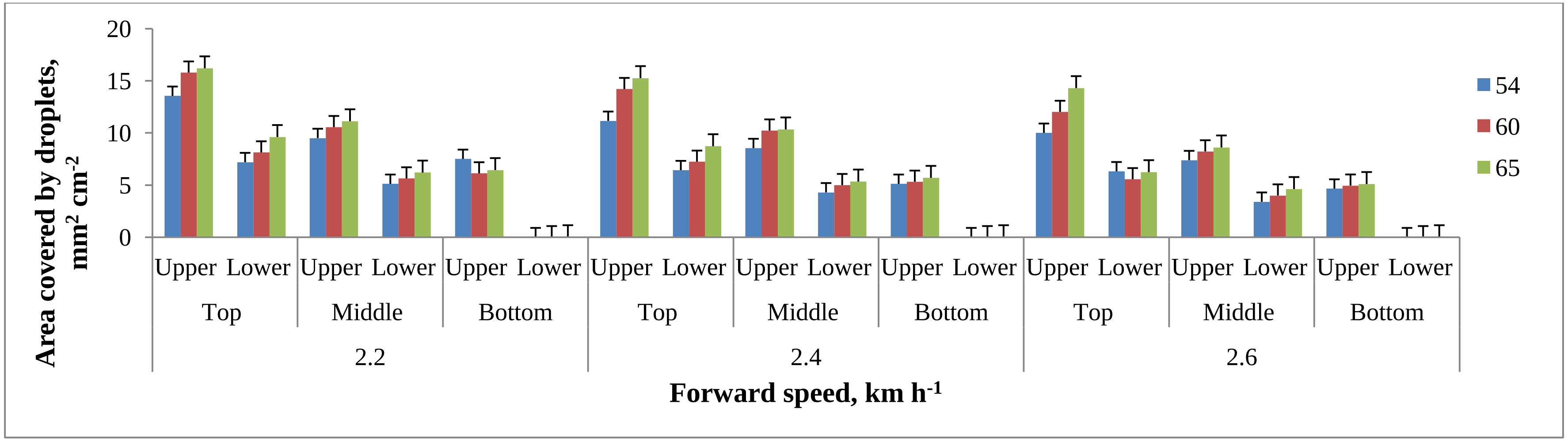


Fig. 78 Effect of forward speed, speed of actuating mechanism on area covered by droplets at 30 cm height of spray nozzle

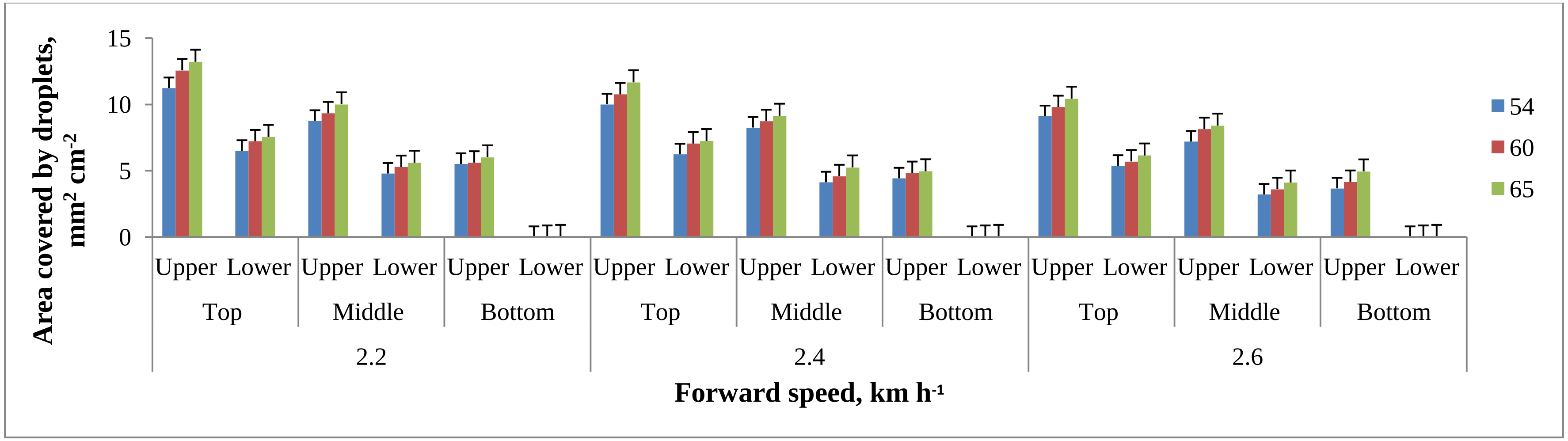


Fig. 79 Effect of forward speed, speed of actuating mechanism on area covered by droplets at 60 cm height of spray nozzle

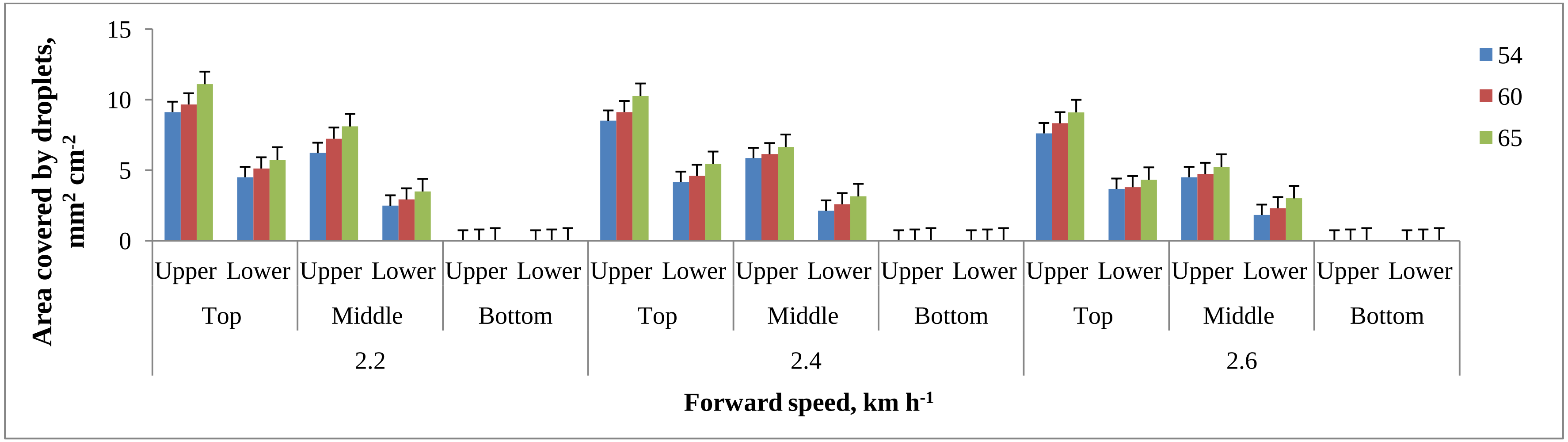


Fig. 80 Effect of forward speed, speed of actuating mechanism on area covered by droplets at 90 cm height of spray nozzle

The area covered by droplets increased by 6.85 per cent as speed of actuating mechanism increased. This is because of the fact that speed of actuating mechanism influenced the droplet size and droplet density. The speed increased both droplet density and droplet size increased. More spray on unit area of the plant canopy receives more droplets resulting in more area coverage.

When the height of the spray nozzle changed from 30 to 90 cm, the area covered by droplets decreased. This is probably due to the fact that, the droplet size and droplet density decreased as the area covered was dependent on these two. This could be mitigated by operating the spray nozzle close to the plant canopy. The value of the area covered by droplets was significantly higher over the value obtained as a result of increasing the height of spray nozzle above the plant canopy. All the above three factors influenced on the area covered by droplets significantly at different position of the plant canopy.

xviii. Effect of forward speed, speed of actuating mechanism and height of the spray nozzle on particle drift

The particle drift was increased with increase in forward speed. At higher forward speeds, the droplets released from the nozzle had higher horizontal component of the velocity. As a result, the droplets were carried in air over the top of canopy to a longer distance, which made them more prone to drift away from the canopy (Gupta *et al*., 2011). It is, therefore, desirable that forward speed of the sprayer is kept low to reduce particle drift. The drift droplets were reduced as the height of the spray nozzle increased. This is because of the spray droplets lose their kinetic energy and carried away by weather parameters. Drift can be reduced by keeping the nozzle close to the crop surface

5.3.3 Optimization of operational parameters of tractor operated automatic gun sprayer in cotton and pigeonpea crop

Optimum process conditions are required to significantly enhance the performance of tractor operated automatic gun sprayer. Numerical optimization has been conducted to evaluate the optimum forward speed, actuating mechanism and height of spray nozzle for cotton and pigeonpea. The desirability index of the operational parameters of the tractor operated automatic gun sprayer is shown in the Fig. 81 and 82 for cotton and pigeonpea.

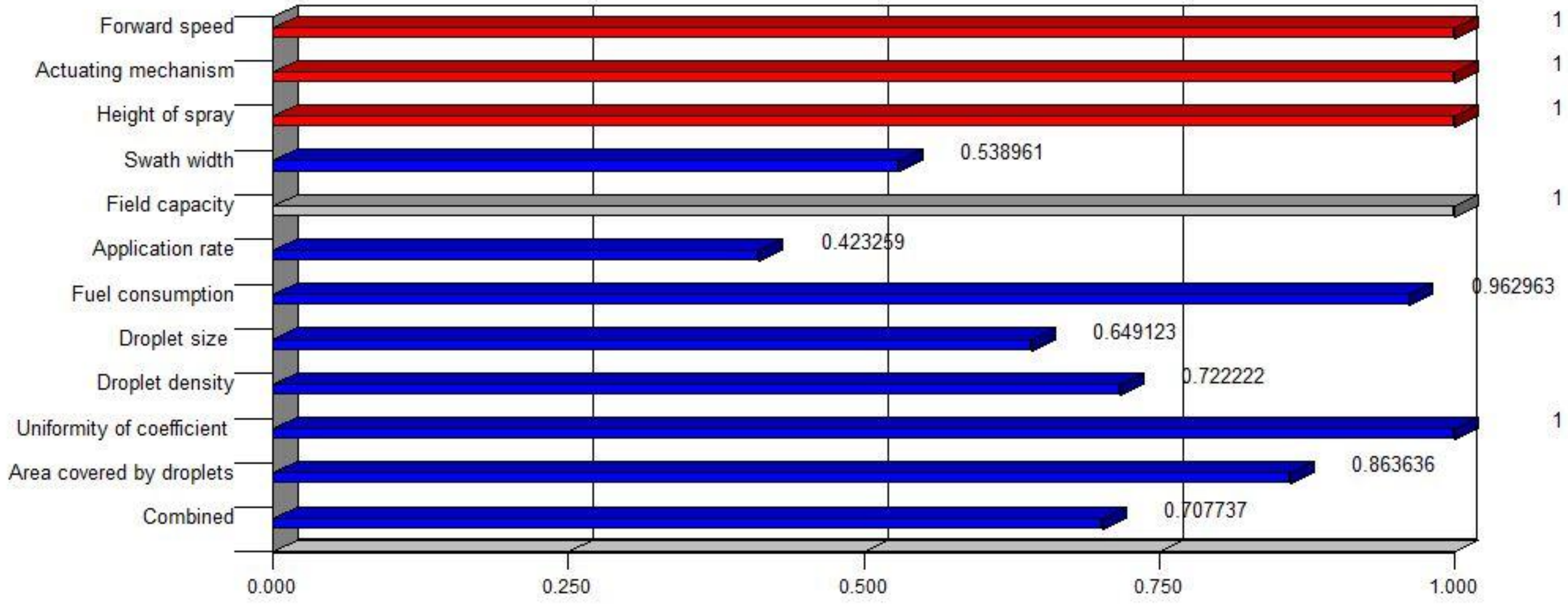


Fig. 81 Desirability index of tractor operated automatic gun sprayer in cotton crop

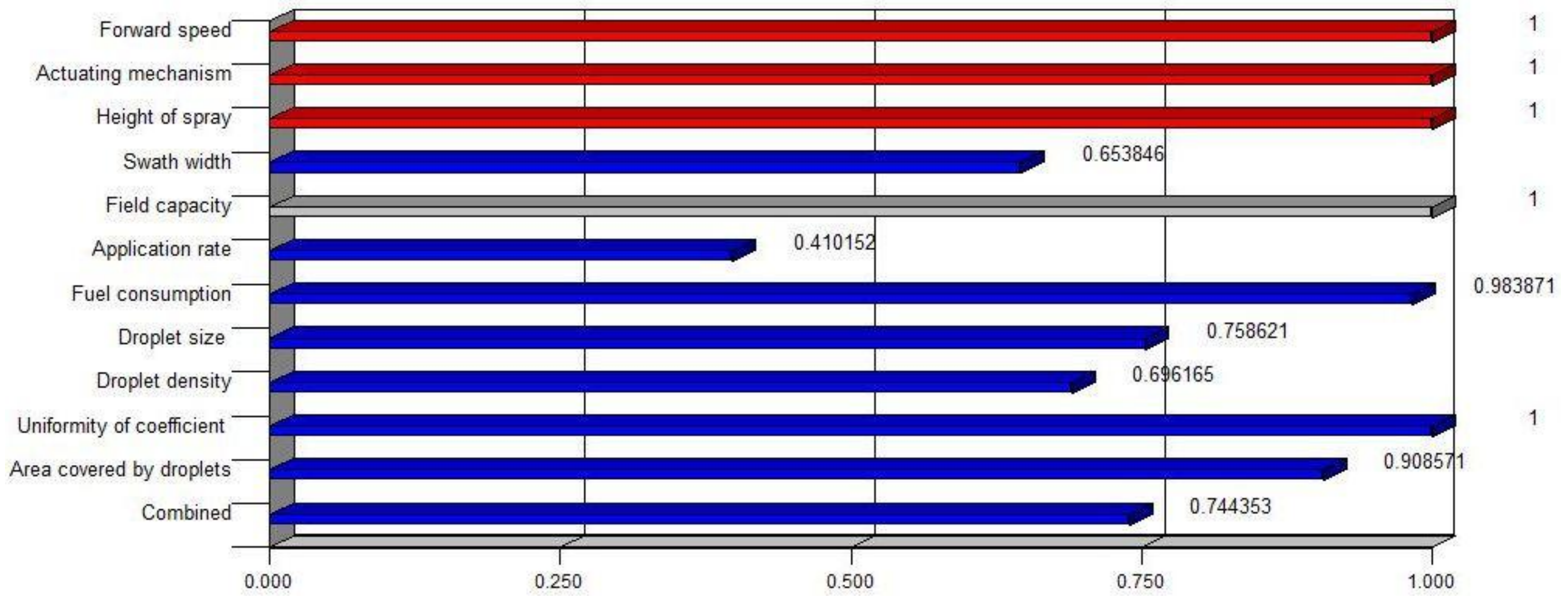


Fig. 82 Desirability index of tractor operated automatic gun sprayer in pigeonpea crop

The desirability index of swath width, field capacity, actual application rate, difference in actual and theoretical application rate, fuel consumption, droplet density, droplet size, uniformity coefficient and area covered by droplets were 0.53, 1, 0.42, 0.96, 0.64, 0.72, 1 and 0.86, respectively for cotton crop. The overall desirability index for combined was found to be 0.70.

The desirability index of swath width, field capacity, actual application rate, difference in actual and theoretical application rate, fuel consumption, droplet density, droplet size, uniformity coefficient and area covered by droplets were 0.65, 1, 041, 0.98, 0.75, 0.69, 1, and 0.90, respectively for pigeon pea crop. The overall desirability index for combined was found to be 0.74.

5.3.4 Performance evaluation of tractor operated automatic gun sprayer under optimized parameters

The performance evaluation of tractor operated automatic gun sprayer was conducted under optimized parameters *viz*., 2.2 km h^{-1} forward speed, 54 cycles min^{-1} speed of actuating mechanism and 30 cm height of spray nozzle above the crop canopy for both crops. Its results revealed that, the droplet density and droplet size produced within the recommended limit for effective pest and insect control at almost all positions of the target plant except bottom position of the plant.

iii. Plant damage

Plant damage was measured in the field for both cotton and pigeonpea during the spraying operation. Plant damage was 5.7 per cent in case of cotton crop by sprayer and 6.3 per cent for the pigeonpea crop. Plant damage is due to higher impact action on the plant branches and leafs. While operating the tractor mounted sprayer in the field one row was under the tractor was partly affected during the each pass of the machine under the tractor tyres and chassis. In case of the tractor operated the ground clearance was 450 mm, in this case more than 450 mm crop plant was deflected.

iv. Bio-efficacy of spraying

The data representing the efficacy of insecticides and pesticide against insects and pests is given in the Table 105 and 106. The insects were reduced from pre counting as the number of days increased after the spraying. This is because of the toxic effect of insecticide on insects. The leaf hoppers were 5.0 before spraying reduced to 1.0. In case of T2 (conventional tractor operated gun sprayer) pre count leaf hoppers were 6.0 reduced to 2.8 after 5 days of spraying.

The populations of aphids were 10, after 5 days reduced to 2.5 numbers. Pre counts of aphids were 13 before spraying in conventional sprayer reduced to 4.2 numbers. This shows that automatic sprayers were effective against cotton sucking pest.

Bio-efficacy of spraying against *Helicoverpa armigera* in pigeonpea crop is presented in Table 107. It shows that population of *Helicoverpa armigera* was 4.2 numbers reduced to 0.8 numbers after 5 days whereas in conventional method it was 6.0 number reduced to 2.2 numbers. The pod damage by *Helicoverpa armigera* for tractor operated automatic gun sprayer and conventional tractor operated gun sprayer were 15 and 18 per cent.

5.4 Economics of tractor operated automatic gun sprayer for selected field crops

The cost of operation of the developed tractor operated automatic gun sprayer was found to be Rs. 320.06 ha^{-1} and Rs. 302.7 ha^{-1} for cotton crop and pigeonpea crop. The breakeven point and payback period of sprayer in cotton and pigeonpea crop was 87.8 hours per annum and 81 hour per annum and 1.48 years and 1.36 years, respectively.

5.5 Comparison of performance between developed tractor operated automatic gun sprayer with conventional tractor operated gun sprayer

It was observed that the swath width of the conventional sprayer was more than the tractor operated automatic gun sprayer. Number of swings required to cover without overlap and miss application was 54 cycles min^{-1} but in case of conventional method, number of swings was less. The actual application rate (430.1 $l\ h^{-1}$) of the conventional sprayer for cotton was more compared to developed automatic gun sprayer. This is due to unconditional overlap in conventional method. The field capacity of the conventional method was more. This is probably due to the fact that labour can cover a long distance due to extension of human arm along with lance. For both the sprayers, the number of droplets deposited per square centimeter was more than the desired except bottom position of the plant canopy. There was a sufficient droplet deposition on the upper side of the leaves of any section of the plant for both the sprayers. The cost of operation of tractor operated automatic gun sprayer was more compared to conventional. This is because of, area covered was less. Total cost of operation including chemical cost was 20.62 per cent and 19.31 per cent less compared to conventional method of spraying for cotton and pigeonpea.

Summary and Conclusions

VI. SUMMARY AND CONCLUSION

Chemical control still remains one of the most important methods of controlling insects, weeds and diseases in the present agricultural scenario. From the point of view of pests and diseases control, spraying is one of the most important operation in plant protection. In the present conventional spraying system manually and power operated sprayers are often used for field crops and orchards. The pest control could not reach to the expected level.

Many types of application equipment are available with a function to store, meter, atomize and distribute pesticide to control the target pest. Generally, in field crops like cotton and pigeon pea conventional types of boom sprayer and conventional tractor operated gun sprayer are being used. But in case of boom sprayer, over head spraying onto leaf surface usually results in zero deposition of droplets deep into the canopy and on the lower surface of the leaves. It is required that the pesticide droplets must travel in and around plant canopy in order to cover as many leaves as possible. Despite having more insecticide and pesticides, the extent of control has been very limited on account of dense canopy of the plant. These sprayers need large quantity of water and chemical to cover plant canopy and result in uneven distribution of chemical over the entire canopy and wastage of chemical.

Conventional tractor operated gun sprayer requires three labour. The main drawback of this sprayer is, it consumes large volume of liquid per ha and required more amount of labour and time. Availability of labour for farm work is also decreasing day by day. Main drawback of this sprayer is fatigue to the operator hand because of continuous swinging of gun sprayer behind the tractor or bullock cart. On the other hand, operator is also affected by chemical being sprayed in front of his way. Therefore, there is an useful need to develop a tractor operated automatic gun sprayer for selected field crops which improves coverage, boosts chemical effectiveness, reduce labour and time and makes spraying job easier and faster.

A prototype of tractor operated automatic gun sprayer for spraying of chemical for field crops has been developed and fabricated by using crop and machine parameters. The development of tractor operated automatic gun sprayer was carried out in central workshop, Department of farm machinery and power engineering, CAE, Raichur. The essential components of sprayer are frame structure, spray tank, horizontal triplex pump, control valves, spray gun nozzle, pressure gauge, strainer, hydraulic agitator and actuating mechanism. A 3 hp Usha triplex pump was used to provide prerequisite pressure and discharge. Two spray guns are mounted on the boom behind tractor for spraying. Actuating mechanism for operating the spray gun was provided by two 12 V dc motor. The power to drive motor is taken by tractor battery.

The performance evaluation of tractor operated automatic gun sprayer was carried out in the laboratory to optimize the operational parameters in the laboratory. Based on the results obtained from the laboratory study conducted, the following conclusions were drawn.

- The discharge of the sprayer increased with increase in the operating pressure and nozzle size.
- The nozzle discharge increased by 38.23 per cent as the operating pressure increased from 20 to 24 kg cm^{-2} for 2 mm nozzle size and discharge increased by 31.70 per cent when the nozzle size changed from 2 to 6 mm at operating pressure of 20 kg cm^{-2}.
- It was observed that, orientation of the nozzle did not affect the discharge of the sprayer
- The length of throw increased with increase in the operating pressure and nozzle size. The length of throw decreased with changing the orientation of spray nozzle.
- Volumetric distribution of the water was more in the centre, less as the distance moved from the centre.
- The actual plant canopy was used to observe the droplet size and droplet density on the leaves of the plant.
- The droplet density increased with increase in the operating pressure and nozzle size. When the orientation of the spray nozzle changed from 0 to 15 degree, the droplet density was maximum in all position and portion of the leaves. When the

orientation of spray nozzle changed to 30 degree, only middle and bottom position of the leaves received deposition for both the crop.

- The droplet size decreased with increase in the operating pressure and nozzle size. The droplet density was maximum on the upper leaves of top surface followed by middle and bottom of the plant canopy.

- The droplet deposition was maximum when the orientation of the spray nozzle was 15 degree with respect to horizontal for both cotton and pigeon pea crop.

- The best angle of orientation of spray nozzle was 15 which produced recommended droplet size.
- Among three operating pressure, the lowest level of 20 kg cm^{-2} produced droplets more highest VMD and least droplet density inside the canopy.

- The highest nozzle pressure of 24 kg cm^{-2} produced droplets of least VMD with good droplet density and spectrum within the canopy.

Based on the results obtained from the field study conducted, the following conclusions were drawn.

i. Cotton crop

- The maximum swath width was observed for 54 cycles min^{-1} actuating mechanism at 90 cm height of spray nozzle whereas the minimum swath width was obtained for 65 cycles min^{-1} actuating mechanism when 30 cm height of spray nozzle.

- The swath of the spray increased with increase in the height of the spray nozzle. The swath width decreased with increase in the speed of actuating mechanism and forward speed

- Field capacity of the sprayer increased by 10 per cent as height of spray nozzle increased from 30 to 90 cm, as the height of spray nozzle increased.

- When the forward speed of tractor increased, the field capacity was increased by 34.4 per cent.

- Among all the treatments, the maximum actual application (493.10 l ha^{-1}) was obtained for 65 cycles min^{-1} at forward speed of 2.2 km h^{-1} when height of spray nozzle was 30 cm. The minimum actual application rate (314.30 l ha^{-1}) was observed for 54 cycles min^{-1} actuating mechanism at height of spray nozzle was 90 cm for 2.6 km h^{-1}.

- The fuel consumption of tractor increased with increase in forward speed. The fuel consumption was not affected when the height of spray nozzle increased from 60 to 90 cm.

- The maximum droplet density was obtained for low forward speed (2.2 km h^{-1}). The droplet density decreased as the forward speed increased.

- Droplet density on top, middle and bottom surface for upper was 76.1, 75.2 and 15.6 no's cm^{-2} whereas for lower surface of leaves received low droplet density *i.e.*, 46, 26.1 and 0 no' cm^{-2} for 30 cm height of spray nozzle.

- The height of spray nozzle of 30 cm above plant canopy showed significantly higher droplet density as per the recommendation at almost all position on target plant except bottom position.

- The droplet size decreased with increase in the forward speed and height of spray nozzle.

- The uniformity coefficient of spray droplets increased with increasing the actuating mechanism and decreased with increase in height of spray nozzle.

- The maximum uniformity coefficient was observed for slow speed (2.2 km h^{-1}) with low speed of actuating mechanism (2.2 km h^{-1}) at all the heights. The minimum uniformity coefficient was obtained at high speed of forward speed (2.6 km h^{-1}) with high speed of actuating mechanism (64 cycles min^{-1}) for all heights of spray nozzle.

- The area covered decreased with increase in forward speed and height of spray nozzle but area covered by droplets increased with increase in the actuating mechanism.

ii. Pigeon pea

- The maximum swath width (9.11 m) was observed for low forward speed (2.2 km h^{-1}) with low speed of actuating mechanism (54 cycles min^{-1}) at height of spray nozzle was 90 cm. The minimum swath width (6.52 m) was obtained at high speed of actuating mechanism (65 cycles min^{-1}) for height of spray nozzle was 30 cm when tractor was operated at 2.6 km h^{-1}.
- The swath width increased with increase in height of spray nozzle and decreased with increase in the speed of actuating mechanism and forward speed
- The actual application rate decreased with increase in the height of spray nozzle and decreased with increase in the forward speed.
- The maximum droplet density was obtained for 65 cycles min^{-1} speed of actuating mechanism for 30 cm height of spray nozzle when the forward speed was 2.2 km h^{-1}.
- The droplet size increased with increase in the speed of actuating mechanism and decreased with increase in the forward speed and height of the spray nozzle.
- Among the three forward speeds under study the highest speed of 2.6 km h^{-1} resulted in least amount of droplets deposition on the surfaces of plant leaves. Droplet density decreased with increase in forward speed.
- The desirability index of swath width, field capacity, actual application rate, difference in actual and theoretical application rate, fuel consumption, droplet density, droplet size, uniformity coefficient and area covered by droplets were 0.53, 1, 0.42, 0.96, 0.64, 0.72, 1 and 0.86, respectively for cotton crop.
- The desirability index of swath width, field capacity, actual application rate, difference in actual and theoretical application rate, fuel consumption, droplet density, droplet size, uniformity coefficient and area covered by droplets were 0.65, 1, 041, 0.98, 0.75, 0.69, 1, and 0.90, respectively for pigeon pea crop. The overall desirability index for combined was found to be 0.74.

- The cost of operation of the developed tractor operated automatic gun sprayer was found to be Rs. 320.06 ha^{-1} and 302.7 ha^{-1} for cotton crop and pigeon pea crop, respectively

- The breakeven point and payback period of sprayer in cotton and pigeon pea crop was 87.8 hours per annum and 81 hour per annum and 1.48 years and 1.36 years, respectively.

- Total cost of operation including chemical cost was 20.62 per cent and 19.31 per cent less compared to conventional method of spraying.

- The developed tractor operated automatic gun sprayer could be well utilized for all the types of the row crops since it has provision to accommodate different height of the spray.

- The automatic gun sprayer is safe to handle chemical where risk is a considerable issue to the operator.

- The developed tractor operated automatic gun sprayer is promising solution rather than the traditionally used tractor operated gun sprayers.

Suggestion for future work

The following are the suggestions for future work on a similar or related research problem for further work and some of the suggestions in this respect are listed below.

1. High clearance wheels of tractor fitted with gun sprayer may be used.

2. Performance of tractor operated automatic gun sprayer on orchard crop may be evaluated.

3. Studies should be conducted to determine off-target losses to quantify the effectiveness of sprayer.

4. The sprayer should also be tested in other field crops and modifications can be carried out.

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Appendices

APPENDIX- I

Cost of material used for development of tractor operated automatic gun sprayer

Sl. no	Particular	Material	Quantity	Cost (Rs.)
1	Main frame	MS	1	25000
2	Hitch assembly	MS	1	1200
3	Pump	Steel	1	4500
4	Propeller shaft	MS	1	1500
5	V groove pulley	Cast iron	2	3000
6	V- belt	Type- B	2	500
7	Spray tank	Plastic	1	4450
8	Pressure guage	Steel	1	250
9	Hose pipes	Rubber	4	1000
10	Spray guns	Stainless steel	2	1500
11	Motor (12 V dc)	Steel	2	1200
12	Spray boom	MS	2	1200
13	Clamps	Steel	6	250
Total cost of material				48750
Labour charges @ 25 per cent				12187.5
Production materials cost @ 30 per cent				14625
			Total (Rs.)	75562.5

APPENDIX-II

Cost of operation for tractor operated automatic gun sprayer

The following data were considered for determining the cost economics of tractor operated automatic gun sprayer for selected field crops. Cost of operation was calculated as given by IS 9164: Guide for estimating cost of farm machinery operation.

Initial cost of tractor	: Rs 8, 00,000
Initial cost sprayer	: Rs 75,000
Life of tractor	: 10 years
Life of sprayer	: 8 years
Salvage value	: 10 per cent
Interest rate	: 15 per cent
Shelter and insurance	: 2 per cent of purchase price
Price of diesel	: Rs 60 l^{-1}
Annual use of tractor	: 1000 h
Annual use sprayer	: 250 h
Depreciation	: Straight line method

I. Cost for operating the tractor

a. Annual fixed cost

i) Depreciation (D):

The annual depreciation value can be calculated by the following equation

$$D = \frac{P - S}{L \times H}$$

Where,

D = Depreciation (Rs h^{-1})

P = Purchase price (Rs h^{-1})

S = Salvage value, 10 per cent of purchase price

L = Life of the machine (years)

H = Number of working hours per year

$$D = \frac{8,00,000-80000}{10 \times 1000} = \text{Rs } 72\ h^{-1}$$

ii) Interest (I):

Annual interest is calculated by the following expression

$$I = \frac{P+S}{2} \times \frac{i}{H}$$

Where,

I = Annual interest charge (Rs h^{-1})

i = Interest rate (per cent)

$$I = \frac{8,00,000 + 80,000}{2} \times \frac{0.15}{1,000} = \text{Rs } 66\ h^{-1}$$

iii) Shelter and Insurance:

Insurance and shelter charges taken as 2 per cent of the original cost

$$\text{Shelter \& Insurance} = \frac{\text{2 per cent of P}}{H}$$

$$\text{Shelter \& Insurance} = \frac{0.02 \times 8,00,000}{1000} = \text{Rs } 16\ h^{-1}$$

Total fixed cost = i + ii + iii

= 72 + 66 + 16 = Rs 154 h^{-1}

b. Operating cost

i. Repair and maintenance costs:

Repairs and maintenance cost was taken 10 per cent of the purchase price of the machine per year.

$$\text{Repair and maintenance costs} = \frac{8,00,000 \times 0.10}{1000}$$

= Rs 80 h^{-1}

ii. Fuel cost:

Cost of fuel taken Rs.60.

Fuel required for 1 hour = 3 lit h^{-1}

Fuel cost = 3×60 = Rs. 180 h^{-1}

Lubricants cost:

Charge of lubricant was taken 20 per cent of the total fuel cost.

Lubricating cost = 180×0.20 = Rs. 36 h^{-1}

iv. Driver charge:

The cost of the operator was taken based on the labour charge paid per day.

Rs. 250 day^{-1} is paid for tractor operator, 8 hour taken for one day

$$\text{Driver charge} = \frac{250}{8} = 31.25/\text{h}$$

Total operating cost = iv + v + iv = 55 + 180 + 31.25 = Rs.236.25 h^{-1}

The total cost of operating the tractor = a + b

= 154+236.25 = 390.25

II. Cost of operation for sprayer

a. Annual fixed cost

i) Depreciation

$$D = \frac{75000\text{-}7500}{8 \times 250} = \text{Rs } 33.75 \text{ h}^{-1}$$

ii) Interest

$$D = \frac{75000+7500}{2} \times \frac{0.15}{205} = \text{Rs } 30.18 \text{ h}^{-1}$$

iii) Shelter and Insurance

$$\text{Shelter \& Insurance} = \frac{0.02 \times 75000}{205} = \text{Rs } 7.31 \text{ h}^{-1}$$

Total fixed cost = i + ii + iii

= 33.75+30.18+7.31 = Rs 71.24 h^{-1}

b. Operating cost

i) Repair and maintenance costs

$$\text{Repair and maintenance costs} = \frac{75000 \times 0.10}{205}$$

$= \text{Rs } 36.58 \text{ h}^{-1}$

Total cost for operating sprayer = a + b

$= 71.24 + 36.58$

$= \text{Rs } 107.82 \text{ h}^{-1}$

Total cost of operating the tractor operated automatic gun sprayer

= total cost for operating the tractor + total cost for operating

= 390.25+ 107.82

$= \text{Rs } 502.5 \text{ h}^{-1}$

Breakeven point, h annum^{-1}

$$= \frac{\text{Annual fixed costs, (Rs h}^{-1}\text{)}}{\text{Custom hiring charges,(Rs h}^{-1}\text{)-Total operating costs, (Rs h}^{-1}\text{)}}$$

a. Effective field capacity of tractor operated automatic gun sprayer was 1.57 ha h^{-1} for cotton crop, hence cost of operation per hectare

$$\text{Cost of operation} = \frac{502.5}{1.57} = \text{Rs } 320.06 \text{ ha}^{-1}$$

Over head charges, @ 25 per cent of the total cost of operation = Rs 100.5 h^{-1}

Profit, @ 25 per cent of the overhead charges = Rs 20.1 h^{-1}

Custom hiring charges, = Rs 522.66 h^{-1}

$$\text{Breakeven point} = \frac{17812}{(522.6 - 320.06)}$$

$= 87.8 \text{ h annum}^{-1}$

$$\text{Payback period, year} = \frac{\text{Initial cost of machine}}{\text{Average net annual profit}}$$

Average net annual profit, Rs

= (Custom hiring charges (Rs h^{-1}) − Total operating cost (Rs h^{-1})) × Annual usage

= (522.66-320.06) × 250

= 50650

$$\text{Payback period (year)} = \frac{75000}{50650}$$

= 1.48 years

b. Effective field capacity of tractor operated automatic gun sprayer was 1.66 ha h^{-1} for pigeon pea crop, hence cost of operation per hectare

$$\text{Cost of operation} = \frac{502.5}{1.66} = \text{Rs } 302.7 \text{ ha}^{-1}$$

Over head charges, @ 25 per cent of the total cost of operation = Rs 100.5 h^{-1}

Profit, @ 25 per cent of the overhead charges = Rs 20.1 h^{-1}

Custom hiring charges, = Rs 522.66 h^{-1}

$$\text{Breakeven point} = \frac{17812}{(522.66 - 302.7)}$$

= 81 h $annum^{-1}$

$$\text{Payback period, year} = \frac{\text{Initial cost of machine}}{\text{Average net annual profit}}$$

Average net annual profit, Rs

= (Custom hiring charges (Rs h^{-1}) − Total operating cost (Rs h^{-1})) × Annual usage

= (522.66-302.7) × 250

= 54990

$$\text{Payback period (year)} = \frac{75000}{54990}$$

= 1.36 years

c. Cost of operation for conventional tractor operated gun sprayer

The cost of the operator was taken based on the labour charge paid per day. Rs. 250 day^{-1} was paid for tractor operator, 8 hour taken for one day. Three labours required for conventional method. Total cost of labour is Rs. 750 per 8 hour

$$\text{Labour cost} = \frac{750}{8} = 93.75\ h^{-1}$$

Total operating cost of conventional tractor operated gun sprayer was Rs. 565.25

a. Effective field capacity of conventional tractor operated automatic gun sprayer in cotton crop was 1.99 ha h^{-1} for cotton crop, hence cost of operation per hectare

$$\text{Cost of operation} = \frac{565.25}{1.99} = \text{Rs } 284.04\ ha^{-1}$$

b. Effective field capacity of conventional tractor operated automatic gun sprayer in pigeon pea was 2.08 ha h^{-1} for cotton crop, hence cost of operation per hectare

$$\text{Cost of operation} = \frac{565.25}{2.08} = \text{Rs } 271.75\ ha^{-1}$$

c. Cost of chemical

- Chemical cost per tank was considered Rs. 3500
- Area covered per tank by tractor operated gun sprayer was 1.5 ha and 1.3 in cotton and pigeon pea crop, respectively.
- Area covered per tank by conventional tractor operated gun sprayer was 1.3 ha and 1.08 ha for cotton and pigeon pea, respectively.
- Cost of chemical per ha in tractor operated gun sprayer was Rs. 2333.3 and Rs. 2692.3 for cotton and pigeon pea, respectively.
- Cost of chemical per ha in tractor operated gun sprayer was Rs 2916.3 and Rs. 3301.3 for cotton and pigeon pea, respectively.

DESIGN, DEVELOPMENT AND EVALUATION OF TRACTOR OPERATED AUTOMATIC GUN SPRAYER FOR FIELD CROPS

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ABSTRACT: The tractor operated automatic gun sprayer was designed and developed by considering crop and machine parameters. The tractor operated automatic gun sprayer was evaluated under the laboratory to ascertain the performance under different variables. Its performance was evaluated in the Department of Farm Machinery and Power Engineering, plant protection laboratory, College of Agricultural Engineering, University of Agricultural Sciences, Raichur during 2016-17 under the controlled conditions to eliminate the effects caused by environmental parameters. The laboratory experiments were carried out by using the actual cotton plant. the developed sprayer was evaluated under three different nozzle size, operating pressure and orientation of spray nozzle The nozzle discharged increased by 38.23 per cent as the operating pressure increased from 20 to 24 kg cm^{-2} for 2 mm nozzle size and discharged increased by 31.70 per cent when the nozzle size changed from 2 to 6 mm at operating pressure of 20 kg cm^{-2}. The droplet density increased with increase in the nozzle size. The droplet density was increased by 38.09 per cent when the nozzle size was changed from 2 to 6 mm. The droplet deposition on both upper and lower surface of the plant canopy was maximum when the orientation of the nozzle was 15 degree. The performance evaluation of tractor operated automatic gun sprayer was carried out in cotton (Bt) at the farmer's field and Research Farm, Raichur. A anemometer was used to measure the wind velocity over the target crop. A thermo hygrometer was used to measure the temperature and humidity. Methylene blue MS dye mixed @5 g l^{-1} in water was sprayed on cotton crop and pigeon pea. The droplet density was decreased by 13 per cent as height of spray nozzle was increased from 30 to 90 cm for 64 cycles min^{-1} speed of actuating mechanism. The droplet size decreased by 10.65 per cent as forward speed of the tractor increased from 2.2 to 2.6 km h^{-1} for 30 cm height of spray nozzle. The cost of operation of the developed tractor operated automatic gun sprayer was found to be Rs. 320.06 ha^{-1} and Rs. 302.7 ha^{-1} for cotton crop and pigeonpea crop.

Keywords: Gun spraying, droplet size, droplet density, discharge and spray depositon

[a] CAE, Raichur, [b]AC, Raichur