

**DEVELOPMENT OF POWER SPRAYER
FOR SOYBEAN CROP**

M.Tech. (Agril.Engg.) Thesis

by

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(Chhattisgarh)**

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**DEVELOPMENT OF POWER SPRAYER
FOR SOYBEAN CROP**

Thesis

**Submitted to the
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**By
Ghanshyam Sahu**

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CERTIFICATE-I

This is to certify that the thesis entitled "**Development of power sprayer for soybean crop**" submitted in partial fulfilment of the requirements for the degree of **Master of Technology in Agricultural Engineering** of the Indira Gandhi Krishi Vishwavidyalaya, Raipur, is a record of the bonafide research work carried out by **Ghanshyam Sahu** under my/our guidance and supervision. The subject of the thesis has been approved by the Student's Advisory Committee and the Director of Instructions.

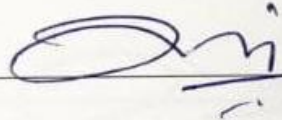
No part of the thesis has been submitted for any other degree or diploma or certificated course. All the assistance and help received during the course of investigations have been duly acknowledged by him.


Chairman

Date: 06/03/2021

THESIS APPROVED BY THE STUDENT'S ADVISORY COMMITTEE

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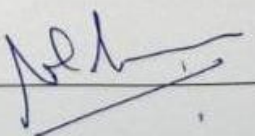
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Place: Raipur


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TABLE OF CONTENTS

Chapter	Title	Page
	ACKNOWLEDGEMENT	i
	TABLE OF CONTENTS	ii
	LIST OF TABLES	vii
	LIST OF FIGURES	viii
	LIST OF ABBREVIATIONS	x
	ABSTRACT	xii
I	INTRODUCTION	1
II	REVIEW OF LITERATURE	6
	2.1 Pesticide Application	6
	2.1.1 Effect of nozzle type, size, orientation and pressure	8
	2.1.2 Classification of spraying equipment	9
	2.1.3 Factors responsible for effective spraying	10
	2.1.3.1 Droplet size	10
	2.1.3.2 Measurement of droplet size	14
	2.1.3.3 Droplet density	16
	2.1.3.4 Spray distribution pattern	16
	2.1.4 Spray drift and volume	17
	2.2 Development aspects	18
	2.2.1 Boom sprayer	18
	2.2.2 Power sprayer	20
	2.3 Cost economics	20
III	MATERIALS AND METHODS	22
	3.1 Details of Experimental Field	22
	3.1.1 Experimental site	22
	3.1.2 Climatic and weather conditions during experiments	22

3.2 General Development Considerations	23
3.3 Steps involved in development of machine	23
3.4 Determination of soybean plant physical characteristics	24
3.5 Components of boom	25
3.5.1 Nozzle	25
3.5.1.1 Selection of nozzle	25
3.5.1.2 Types of nozzles and their characteristics	28
3.5.1.2.1 Hollow cone	28
3.5.1.2.2 Flat fan nozzle	28
3.5.1.2.3 Full cone	29
3.5.1.2.4 Flood nozzle	29
3.5.2 Brass tee coupling	30
3.5.3 Brass male reducer	30
3.5.4 Control valve	31
3.6 Development of boom support span	31
3.7 Development of chemical storage cum power unit	34
3.7.1 Chemical storage tank	34
3.7.2 Holding belt for tank	36
3.7.3 Power source	36
3.7.4 Pressure pump	36
3.7.5 Strainer	37
3.7.6 Hydraulic agitator	37
3.8 Power transmission calculation for HTP pump	37
3.9 Laboratory evaluation	42
3.9.1 Patternator test for swath uniformity	42
3.9.1.1 Patternator	43
3.9.1.2 Pressure gauge	45

3.9.1.3 Control valve	45
3.9.2 Evaluation of sprayer at different pressure and heights	47
3.9.2.1 Nozzle discharge rate	47
3.9.2.2 Uniformity of coverage	47
3.9.2.3 Angle of spray and swath width	48
3.9.2.4 Spray overlapping	48
3.10 Brief details of developed power sprayer for soybean crop	49
3.11 Computer aided design of power sprayer	50
3.12 Actual view of developed sprayer	54
3.13 Field test	55
3.13.1 Application rate of boom	55
3.13.2 Field capacity of the sprayer	56
3.13.2.1 Theoretical field capacity	56
3.13.2.2 Actual field capacity	56
3.13.2.3 Field efficiency	57
3.14 Sample collection for droplet size	57
3.15 Fuel consumption	58
3.16 Cost economics of developed sprayer	58
3.16.1 Fixed cost	58
3.16.2 Variable cost	60
3.16.3 Total cost of operation of developed power sprayer	61
3.16.4 Break-even point	61
3.16.5 Payback period	61
IV RESULTS AND DISCUSSION	63
4.1 Laboratory testing of components of soybean power sprayer	63
4.1.1 Selection of nozzles	63
4.1.2 Uniformity of spray distribution	63

4.1.2.1 Spray liquid distribution of Hollow cone nozzle (N1)	64
4.1.2.2 Spray liquid distribution of Flat fan nozzle (N2)	66
4.1.3 Effect of nozzle height, type and pressure on coefficient of variation	67
4.1.4 Effect of nozzle type, pressure and height on spray angle and swath width	71
4.1.4.1 Spray angle	76
4.1.4.2 Swath width	76
4.2 Effect of pressure on discharge rate	76
4.3 Effect of nozzle type, height and pressure on average droplet size	78
4.4 Measurement of droplets deposition	80
4.5 Measurement of spray overlapping	80
4.6 Spray application rate of developed boom sprayer	81
4.7 Evaluation of field capacity of sprayer	81
4.7.1 Theoretical field capacity	81
4.7.2 Effective field capacity	82
4.7.3 Field efficiency	82
4.8 Fuel consumption of power sprayer	82
4.9 Cost estimation of developed machine	83
4.9.1 Operational cost of machine	83
4.9.2 Break-even point	84
4.9.3 Pay back period	85
V SUMMARY AND CONCLUSIONS	86
REFERENCES	89
APPENDICES	94

LIST OF TABLES

Table	Title	Page
2.1	Classification of spray droplets.	11
2.2	Classification of spray droplet size	11
2.3	Deposition efficiency of smaller droplets	13
3.1	Plant growth stages and time from one stage to the next	24
3.2	Levels of independent and dependent parameters for laboratory study	46
3.3	Different treatments on uniformity of spray patterns	46
3.4	Different parameters of developed power sprayer of soybean crop	50
4.1	Effect of nozzle type and height on coefficient of variation	68
4.2	Effect of nozzle types and pressure on coefficient of variation.	69
4.3	Effect of interaction for nozzle type, nozzle height and the nozzle pressure on the coefficient of variation	69
4.4	Effect on spray angle and swath width due to nozzle height	71
4.5	Effect on spray angle and swath width due to pressure	72
4.6	Effect on spray angle and swath width due to nozzle type, height and pressure	73
4.7	Effect of nozzle type and pressure on average discharge on nozzle	77
4.8	effect of nozzle type, height and pressure on average droplet size	78
4.9	Average number of droplets at pre determined pulling speed	80
4.10	of different pulling speed on theoretical field capacity of sprayer	81
4.11	Total time during spraying at different pulling speed	82
4.12	Average fuel consumption	83
4.13	Details of fixed and variable cost	84

LIST OF FIGURES

Figure	Title	Page
3.1	Components of nozzle	27
3.2	Types of nozzles	30
3.3	Fabrication of frame	32
3.4	Fabrication of trolley wheels	33
3.5	Taking away irregularities	33
3.6	Chemical storage tank	35
3.7	Diagram of HTP pump	37
3.8	Power transmitting trough V-belt	42
3.9	Nozzle arrangement in patternator	44
3.10	Pressure gauge provide in patternator	45
3.11	Terminology of spray overlapping	49
3.12	Isometric view of boom support span	53
3.13	Isometric view of chemical storage cum power unit	54
3.14	Actual view of boom support span	54
3.15	Actual view of chemical storage cum power unit	55
3.16	Field test of developed machine	56
3.17	Image analyzer application window	57
4.1	Hollow cone nozzle (N_1) volumetric distribution of liquid due to different operating pressures at 25 cm height	64
4.2	Hollow cone nozzle (N_1) volumetric distribution of liquid due to different operating pressures at 35 cm height	64
4.3	Hollow cone nozzle (N_1) volumetric distribution of liquid due to different operating pressures at 45 cm height	65
4.4	Flat fan nozzle (N_2) volumetric distribution of liquid due to different operating pressures at 25 cm height	66
4.5	Flat fan nozzle (N_2) volumetric distribution of liquid due to different operating pressures at 35 cm height	66

4.6	Flat fan nozzle (N_2) volumetric distribution of liquid due to different operating pressures at 45 cm height	67
4.7	Effect of different pressures and heights on spray angle of Hollow cone nozzle (N_1).	74
4.8	Effect of different pressures and heights on spray angle of Flat fan nozzle (N_2)	74
4.9	Effect of pressure and height on Swath width of Hollow cone nozzle (N_1)	75
4.10	Effect of pressure and height on Swath width of Flat fan nozzle (N_2)	75
4.11	Effect of different pressure on nozzle discharge	77
4.12	Effect of nozzle type and height on droplet size	80
4.13	Spray overlaps of boom sprayer	81
4.14	Distribution of cost of operation of power sprayer	83

LIST OF ABBREVIATIONS

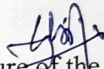
APFE	Agricultural Processing and Food Engineering
ASAE	American Society of Agricultural Engineering
C.G.	Chhattisgarh
cm	centimeter
CV	Coefficient of variation
Dept.	Department
Dia.	Diameter
Engg.	Engineering
et al.	et alibi
Fig.	Figure
FMPE	Farm Machinery and Power Engineering
GI	Galvanized Iron
H	System height
ha	hectare
HTP	Horizontal Triplex Piston
<i>i.e.</i>	that is
IGKV	Indira Gandhi Krishi Vishwavidyalaya
IS	Indian Standard
ISAE	Indian Society of Agricultural Engineers
ISO	International Organization for Standardization
kPa	kilo Pascals
kW	kilo Watt
l	liter
l h ⁻¹	litres per hour
min	minute
ml min ⁻¹	milliliter per minute

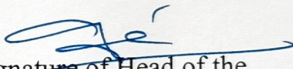
MS	Microsoft
N	Nozzle type
N/A	Not Applicable
N/S	Not Significant
NMD	Number Mean Diameter
O.D.	Outer Diameter
P	System pressure
RNAM	Regional Network for Agricultural Machinery
RPM	Revolutions Per Minute
Rs y ⁻¹	Rupees per year
SV	Swami Vivekananda
SWE	Soil and Water conservation Engineering
UC	Uniformity coefficient
UPVC	Un-plasticized Polyvinyl Chloride
V	Volts
VMD	Volumetric Mean Diameter
μm	micrometer

THESIS ABSTRACT

Title of the thesis	:	"Development of power sprayer for soybean crop"
Full name of Student	:	Ghanshyam Sahu
Major Subject	:	Farm Machinery and Power engineering
Name and Address of the Advisor	:	Dr. Ajay Kumar Verma, Professor, SV college of agrill. engg. and technology, IGKV Raipur
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Signature of Major Advisor


Signature of the Student


Signature of Head of the
Department

Date: 06/03/2021

ABSTRACT

Spraying of pesticides and insecticides are very essential operation to protect crop from unwanted insects and pests. Presently soybean contributes about 43% to the total oilseeds and 25% to total oil production in India. The insect and pests in soybean crop can affect the crop yield up to 30.8%. By timely spraying of pesticide can help to reduce these losses. But major problem of spraying in soybean field is that, at the growing stage the plant became more leafy so that it is very difficult to see the field between the plants. So there is very much chances to have confrontation with poisonous creature like snakes, scorpions etc. To encounter this difficulty it is necessary to have a spraying machine which can eliminate the entry of operator in the field.

Presently there are the only manual sprayers only ways of spraying which are used by the marginal farmers in the country. Most of farmers do not have tractors yet even tractor also have to enter the field and caused problem like compaction of soil and plant damage in the field. That's why a study was undertaken to develop a power sprayer which can spray in the soybean field without need of entry of operator in field.

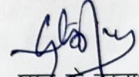
The purpose of the machine development was to eliminate the threat of poisonous creatures from the farmers mind. At first the concept of machine was developed in the solid work computer software and then fabricated accordingly in the workshop of SVCAET & RS, IGKV, Raipur. Major components of the machine are boom support span with pulling trolley provision and a chemical storage cum power unit. The power unit was consisting of an HTP pump and kerosene engine of 2.2 kW. The rpm of engine was adjusted through suitable pulleys to meet rated requirement of HTP pump. Liquid was delivered through a high pressure delivery pipe to the boom support span.

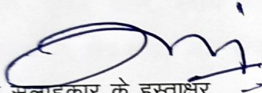
Selections of boom nozzles were based on the requirement as well as laboratory evaluations at 3 pressures (3 kg cm⁻², 4 kg cm⁻² and 5 kg cm⁻²) and 3 heights (25 cm, 35 cm and 45 cm). Based on these two independent parameters many dependent parameters are calculated as volumetric uniformity distribution, spray angle, swath width, nozzle discharge, droplet diameter, droplet density, spray overlapping, Field capacity and cost of operation were calculated.

After all the evaluation it was found that selected nozzle had best performance at 35 cm height and 4 kg cm⁻² combination. The nozzle had coefficient of variation in volumetric distribution was 4.04%, spray angle 86.5°, swath width 43.5 cm, discharge 0.744 l min⁻¹ and average droplet size of 168.34 µm. In the field evaluation the machine gave the following results as droplet density of 44.30 droplets cm⁻², overlapping of 45%, fuel consumption of 0.608 lit h⁻¹, application rate of 1146 lit ha⁻¹, effective field capacity of 1.10, 0.928 and 0.64 ha h⁻¹ at 1.8, 1.26 and 0.9 km h⁻¹ pulling speed. The developed machine had best field efficiency of 65.6% at pulling speed of 1.26 km h⁻¹. The total cost of spraying was calculated as Rs.415.

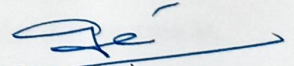
शोध सारांश

शोध शीर्षक का नाम	: सोयाबीन फसल के लिए ईजन चलित छिड़काव यंत्र का विकास
छात्र का नाम	: धनश्याम साहू
प्रमुख विषय	: प्रक्षेत्र यांत्रिकी एवं शक्ति अभियांत्रिकी विभाग
मुख्य सलाहकार का नाम व पता	: डॉ. अजय कुमार वर्मा प्राध्यापक, प्रक्षेत्र यांत्रिकी एवं शक्ति अभियांत्रिकी विभाग, स्वामी विवेकानंद कृषि अभियांत्रिकी एवं प्रौद्योगिकी महाविद्यालय एवं अनुसंधान केन्द्र रायपुर इंदिरा गांधी कृषि विश्वविद्यालय रायपुर, छत्तीसगढ़
उपाधि से सम्मानित किया जाना है	: कृषि अभियांत्रिकी में स्नातकोत्तर (मास्टर ऑफ टेक्नोलॉजी) प्रक्षेत्र यांत्रिकी एवं शक्ति अभियांत्रिकी विभाग


छात्र के हस्ताक्षर


मुख्य सलाहकार के हस्ताक्षर

दिनांक 06/03/2021


विभागाध्यक्ष के हस्ताक्षर

सारांश

अवांछित बीमारियों और कीटों से बचाव के लिए कीटनाशक और कीटाणुनाशक का छिड़काव अत्यंत आवश्यक है। वर्तमान में सोयाबीन का भारत के कुल तिलहन में 43 प्रतिशत तथा तेल उत्पादन में 25 प्रतिशत का योगदान है। कीटाणु और कीट सोयाबीन के उत्पादन को 30.8 प्रतिशत तक प्रभावित कर सकते हैं। समय पर कीटनाशकों के छिड़काव से इस क्षति को कम किया जा सकता है। परन्तु सोयाबीन की फसल में कीटनाशक छिड़काव की सबसे बड़ी समस्या यह है कि इसका पौधा विकास के चरण में बहुत अधिक पत्तेदार हो जाता है। इसलिए पौधों के बीच की जमीन देख पाना बहुत मुश्किल हो जाता है।

अतः वहां सॉपए बिच्छुओं जैसे जहरीले जीवों से सामना होने की संभावना बहुत अधिक होता है। अतः इस समस्या के निदान के लिए ऐसे छिड़काव यंत्र का होना आवश्यक है, जिससे संचालक को खेत में घुसना ना पड़े।

वर्तमान में केवल मानव चलित स्प्रेयर ही एक मात्र रास्ता है जा देश के सीमांत किसानों के द्वाना उपयोग किया जाता है। ज्यादातर किसानों के पास टैक्टर उपलब्ध नहीं है, बल्कि टैक्टर को भी खेत में उतरन पड़ता है जिसके कारण मिट्टी के संघनन और पौधों के क्षति की समस्या होती है। इसलिये एक ऐसे छिड़काव यंत्र की विकास के लिए अध्ययन शुरू किया गया जिसमें संचालक को खेत में उतरना ना पड़े।

यंरु के विकास का उद्देश्य किसानों के मन से जहरीले जीवों के डर को दूर करना था। सबसे पहले यंत्र को कम्प्यूटर साफ्टवेयर 'सॉलिड वर्क्स' में बनाया गया तदनुसार स्वामी विवेकानंद कृषि अभियांत्रिकी एवं प्रौद्योगिकी महाविद्यालय की कार्यशाला में विकसित किया गया। यंत्र के मुख्य घटकों में खींचने की सुविधा युक्त ठेले वाला बूम सहायक विस्तार तथा रसायन भंडारण सह शक्ति इकाई है।

शक्ति इकाई एक एचटीपी पंप और 2.2 किलोवॉट के मिट्टीतेल ईंजन से बना है। ईंजन के घूर्णन को एचटीपी पंप की मानक घूर्णन से समयोजित करने के लिए उपयुक्त घिरनी का प्रयोग किया गया है।

आवश्यकता और प्रयोगशाला परीक्षण के आधार पर बूम के नोजल का चुनाव किया गया। दो स्वतंत्र मापदंडों के आधार पर कई अवलम्बित मापदण्डों की गणना की गई जैसे कि आयतनिक समरूपता वितरण, फुहार कोण, स्वॉथ चौड़ाई, नोजल बहाव, छोटी बूंद व्यास, छोटी बूंद का घनत्व, फुहार परस्परव्याप्ति, क्षेत्र क्षमता और संचालन का खर्च।

सभी गणनाओं के पश्चात यह पाया गया कि चुने हुए नोजल ने 35 सेमी की ऊँचाई और 4 किग्रा सेमी⁻² के संयोजन में सबसे अच्छा प्रदर्शन किया। आयतनिक समरूपता वितरण में विविधता गुणांक 4.04 प्रतिशत, फुहार कोण 86.5 डिग्री, स्वॉथ चौड़ाई 43.5 सेमी, बहाव 0.744 लीटर मिनट⁻¹ और औसत छोटी बूंद का आकार 168.34 माइक्रो मीटर था। क्षेत्र मूल्यांकन में यंत्र ने निम्न परिणाम जैसे छोटी बूंद घनत्व 44.30 बूंद प्रति सेमी, फुहार परस्परव्याप्ति 45 प्रतिशत, ईंधन खपत 0.608 लीटर घण्टा⁻¹, प्रयोग दर 1146 लीटर हेक्टेयर⁻¹, वास्तविक क्षेत्र क्षमता 1.08 किमी घण्टा⁻¹ की गति पर 1.10 हेक्टेयर घण्टा⁻¹, 1.26 किमी घण्टा⁻¹ की गति पर 0.928 हेक्टेयर घण्टा⁻¹ और 0.9 किमी घण्टा⁻¹ की गति पर 0.64 हेक्टेयर घण्टा⁻¹ दर्ज किया गया।

विकसित यंत्र का सबसे अच्छा क्षेत्र दक्षता 65.6 प्रतिशत, 1.26 किमी घण्टा⁻¹ की खींचने की गति पर था। गणना से छिड़काव की कुल लागत 415 रुपये आयी।

INTRODUCTION

1.1 Introduction

Soybean (*Glycine max* (L.) Merrill) is one of the most important oil seed crop of India, particularly in central part of the country. It contributes about 8% edible oil requirement of the country. It is also one of the world's most useful and cost effective sources of protein, vitamin mineral, salt and other ingredients.

Soybean in India, occupies an important place because of getting more foreign exchange from export of soya meal or powder due to its great demand in the international market. The major oilseed crops grown in India are groundnut, mustard, sesamum, linseed, castor etc. Now-a-days, soybean is the premier oilseed crop among all traditional oilseed crops in the country.

Production of soybean in India is dominated by Maharashtra and Madhya Pradesh which contribute 89 percent of the total production. Rajasthan, Andhra Pradesh, Karnataka, Chhattisgarh and Gujarat contribute the remaining 11 per cent production. In recent year soybean yield was around 59 lakh MT in Madhya Pradesh, whereas the national yield was 120.832 lakh MT. The soybean crop has faced several challenges in the previous 2-3 years and has lost its status as preferred crop among farmers due to reduced yields. The occurrence of pests and diseases is one of the most significant factors for low yields. In order to keep pest and disease infestations within normal limits, advanced soybean pest management methods are recommended for adoption by farmers. Singh and Verma; 1992 reported that there are 150 insects and pests damaging soybean in M.P. and about a dozen of insects have been reported causing damage seriously to soybean from sowing to harvesting. For successful production of soybean insects and pests should be controlled within tolerable limits by timely management.

The application of pesticides refers to the realistic way in which pesticides are applied to their biological targets (e.g. pest organism, crop or other plant). The need to make this process as successful as possible to mitigate its release into the

environment and human exposure has been elaborated by public concern regarding the use of pesticides (including bystanders, operator and consumers of produce).

The application of pesticides is a tedious process which needs some unique characteristics to be successful during operation. Spray uniformity and swath width are main factors of it. These factors are mainly affected by type of machine, working environment and properties of spray chemicals. For efficient control of pests, the sprayer should distribute uniform spray to target area.

It is important to apply the pesticide to specific target areas inhabited by insects, rodents, diseases or weeds. Environmental pollution from chemicals drifting out of the areas under treatment has contributed to criticism of the use of pesticides. The studies found that by using high spray volumes, pesticide contamination in the soil caused changes in the earthworm population to an extent of 60%. In order to maintain control of a pest, dosages are sometimes elevated. It was estimated that only 30 mg of insecticide was needed to control the target of a population of 1 million. (Narang *et al.*, 2015).

The efficacy of insect control pesticides is mainly influenced by the quantity of chemical used in the target unit area, the quantity of chemical deposited in the target area and the percentage of the pesticide reception target area. viz., the dose, delivery, and coverage of the factors mentioned above depend on the type of use. The aim of pesticide application should be to maximize the quantity of deposits with the minimum quantity of chemicals at the expected target. Various techniques are needed to minimize the frequency and quantity of application. Each spraying process, though, has its own merits and demerits.

The use of mechanical sprayers is one of the popular forms of spaying, especially in traditional farming. Hydraulic sprayers essentially consist of a tank, a pump, a lance or boom (for single nozzles) and a nozzle (or multiple nozzles), sometimes containing a mixture of water and chemicals. Sprayers transform pesticide formulations into droplets that can be big rain-type drops or small, almost invisible flakes. By forcing the spray mixture under pressure through a spray nozzle, this conversion is achieved. By the use of various nozzle sizes, or by

altering the pressure under which it is squeezed, or a combination of both, the droplet size can be altered. The benefit of large droplets is that they are less prone to spray drift, but require more water per covered land unit. Small droplets can optimize interaction with a target organism due to static electricity, but very quiet wind conditions are needed. Nozzle selection is an important task to develop the desired spray pattern. The specific use of nozzles, (such as the broadcast application of herbicides on spraying of insecticides on row crops), determines the types of nozzle needed.

It is necessary to remember that the non-targeted desirable organism can be affected during application, even provided suitable chemical choices, high ambient temperatures or other environmental influences. As plants have already germinated, in order to reduce losses due to crop and soil damage, post-emergent pesticide application requires minimal field contact. Typical industrial application equipment will use very tall and narrow tyres and will combine this with a sprayer body that, depending on crop height, can be raised and lowered. Typically, these sprayers hold the 'high-clearance' mark as they can rise above growing crops, but usually not much higher than 1 or 2 meters. Moreover, in order to minimize the number of passes needed over a field, these sprayers also have very large booms, again designed to reduce crop damage and optimize performance. Spray booms that are 36.6 meters (120 feet) wide are not unusual in industrial agriculture, especially in prairie agriculture with large, flat fields. Aerial pesticide application is a method of top-dressing a pesticide on a developing crop that avoids physical contact with soil and crops.

There is growing believe that continuous growing of soybean in the same land from year to year brings soil sickness and nutrient deficiency. The possible solution may be crop rotation and intercropping. More research into soybean management will lead to a better understanding of its production because of its significant role as one of the most important crops. With regard to the value of soybean output worldwide, its production, including its symbiosis with soil microbes, must be assessed from various perspectives. Soybeans are an essential source of food, protein, and oil, and further research is therefore required to

increase its yield under various conditions, including stress. The countries producing high levels of soybeans are the USA, Brazil, Argentina, China, and India.

Small to medium farmers frequently using chemicals by lever or power operated knapsack sprayer in the field crops. But, spraying with knapsack sprayer is energy consuming operation because operator has to carry the weight of fluid throughout entire covering area. During spraying, the operator's body assumes awkward position giving severe discomfort to body (Tamilselvi and Krishna, 2016). Some researcher reported that there is a chance of overlap or missed areas during swing of lever operated knapsack sprayer lance operation and the nozzle height is changed by 10 per cent in each swing of lance (Piggin *et al.*, 2000). Also performance depends on skill of the operator. Manual application often results in an uneven distribution of 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).

As the traditional way of spraying need labour to enter in the field and reach to every plant targets which increases the chances of confrontation between man and venomous creatures like snakes and scorpions in the field.

India is among the countries most heavily impacted by snakebite and accounts for nearly half of the world's estimated annual deaths. In a nationally representative mortality survey, The article entitled 'Trends in snakebite mortality in India from 2000 to 2019' reported that India had 1.2 million snakebite deaths (yearly average of 58,000) (Wilson *et al.*, 2020).

In the states of Bihar, Jharkhand, M.P., Odisha, U.P., A.P., Telangana, Rajasthan and Gujarat, 70% of deaths occurred during the period 2001-2014 in people living in densely populated low-altitude agricultural areas, especially during the rainy season when encounters between snakes and humans are more frequent.

Since deaths are mostly confined to lower altitudes, this should make the annual epidemics easier to handle within a single season each year. The risk of snakebites may be minimized by targeting these areas with education about basic

techniques, such as 'snake-safe' harvesting techniques, wearing boots, gloves and using torch (WHO, 2020).

1.2 Justification

Agricultural field is the place where the intercultural operations need the labours to be entered in the field, among them pesticide application is the major operation which need the farmer to walk around each plant. In the present context, the level of mechanization varies greatly by region such as high in the north states followed by western-south states and north-eastern states. Only about 40 to 45 percent of agriculture in India is mechanized.

Most of farmers in India are still not able to purchase heavy tractor drawn boom sprayer to counter threat of poisonous creatures, during spraying operation. Since all the cheap spraying machine needs to be operated with entering in the field. Therefore such sprayer is needed that can be operated without entering in the field.

In view of these circumstances, the present study was undertaken with the following specific objectives.

1. To develop a power sprayer for soybean crop.
2. To conduct a performance evaluation studies on developed power sprayer.
3. To estimate cost of spraying of developed sprayer.

CHAPTER-II

REVIEW OF LITERATURE

This chapter gives a brief account of the previous research work carried out on aspects such as effect of insects and pests on soybean yield, effect of various parameters on spraying, boom spraying machine etc. Spraying of soybean crop at its vegetative stage is full of threats of snake and other poisonous creatures.

The main problem in traditional approaches to spraying is that the labour has to enter in the field and walk around the entire field where there is possibility of meeting out with snakes and other poisonous creatures. There are also some problems in traditional spraying like uneven spray distribution and uneven maintaining the height of spray nozzle. Excessive application of spray liquid may harm both the treated and the following crops, while reduced application may have little or no effect on target. Boom spray technique has the potential to provide several benefits to farmers like boom sprayer reduces labour requirement and also covers large area within short period of time so that time and energy required can be minimized. The boom and nozzle system produces consistent results and, within a defined time. This scheme creates the operator, bystanders and the community with minimal risk.

Jaybhave *et al.* (2015) conducted an experiment on the effect of date of sowing and spacing on growth properties and yield components. The experiment was carried out as sub-treatments in three distinct spacing of 30x10 cm, 45x05 cm, 60x05 cm. The data was statistically analyzed and found that, early sowing gave higher yields and better output, relative to late sowing. The results showed that crop spacing of 30x10 cm resulted in the highest number of pods and soybean yield.

2.1 Pesticide Application

To be biologically successful, the application of pesticides requires efficient techniques. This requires far more than correct use of the specified

amount of spray mix. The need for greater productivity has become crucial as the cost and application of chemicals have increased.

Tarun Kumar *et al.*, (2019) studied on various pesticides and insecticides effects on soybean crop. Throughout its growth process, the crop is infested by more than 275 insects and pests in different segments of the soybean plant and around a dozen of them have recorded significant soybean damage from growing to maturity.

Insects such as maggots can reduce grain yield by up to 33% (Singh and Singh, 1992). He urges necessitating of effective management strategy which includes quick and effective control of pests.

Giles *et al.*, (2008) reported that the application of pesticides and other insecticides is a tedious mechanical method that led to the generation of complex biological response. The generation includes not only the mechanical system but also the create favorable condition to protect non-targets such as vulnerable environmental areas, human and animal environments and operator, and natural species. For proper irrigated and special crops in the USA, improved means of transportation, atomization devices, analytical methods for drift and droplet size sensing device and on-board electronic control systems have been developed.

Zaman and Salyani (2004) used ultra-sonic sensors to admeasure and draw tree canopy volume. These were helpful in planning site-specific management activities and estimating crop yield within a grove. These values were compared to those that were manually measured. The density of the canopy foliage showed a noticeable impact on ultra-sonic canopy volume measurements. The difference in value was higher for light than for dense trees. There was a substantial gap between the two-sided tree volumes.

Derksen and Breth (1994) reported that for controlling pest issues and reducing pesticide usage, proper timing of pesticide application is important. The successful application of pesticides depends on the time of application, equipment selection, spray formulation and calibration. They were of the opinion that the consistency of the application is essential to an application's effectiveness.

2.1.1 Effect of nozzle type, size, orientation and pressure

Matthews *et al.*, (2004) discussed the key factors to be included in the definition of the use of a pesticide in field studies. Nozzle type, volume of spray, chemical concentration, operating pressure, spray efficiency, angle of spray, nozzle or nozzle location relative to crop canopy, etc., are variables that should be taken into consideration when spraying chemicals.

Nuyttens *et al.*, (2007) studied about the effect of nozzle type, pressure and size on the spray droplet characteristics. The goal of this study was to set up a test rig and protocol using a phase doppler particle analyzer to characterize the spray nozzles (PDPA). Based on light-scattering principles, this test rig was in a position to calculate the droplet sizes and rates. The dimensions of the droplet and the velocity properties of the different nozzle pressure mixes were noted and then distinguished using the different measurement techniques and procedures with the results obtained by other researchers. In all, the 32-nozzle-pressure mix was tested and categorized based on the classification scheme of the droplet size spectra and the British Crop Protection Council (BCPC). From the experiments it was concluded that the hollow cone nozzle is more sensitive to drift than flat- fan and air injection nozzles. It is very clear from the observations and their findings that both the nozzle form and the nozzle size have a very significant effect on both the droplet size and the velocity range.

Koszel (2009) analyzed the effect on the size of the drop tracks of pressure, speed and changes in the flow rate level from the flat fan nozzles. He found that the increase in the discharge depends on the nozzle size and the working time, and that the wear of the nozzles causes the increase in the drop track size. The joining of drops is triggered by extremely low working pressure or operating pressure. This situation is extremely dangerous when using agricultural spray nozzles with a substantial degree of wear, as they pose a high environmental hazard. So for each operation the size of spray droplets should be match as per recommendation.

Butts *et al.*, (2019) found that in order to preserve the uniform overlap of the spray, the increasing popularity of pulse-width modulation (PWM) sprayers

demands that the application interaction effects on spray pattern uniformity be thoroughly understood, thus reducing the potential for crop damage and increasing the coverage of target pests. An indoor spray pattern located at the University of Nebraska in Lincoln, USA, was used for testing. To describe the uniformity of the spray pattern, the coefficient of variation (CV), the root mean square error (RMSE), and the average percent error (APE) were used. Normally, the service cycle has scarcely influenced the CV of spray patterns through nozzles and pressures. The CV should be minimum for getting more uniform spraying.

Bouse *et al.*, (1994) carried out a model operation on an aircraft droplet size distribution analysis for several forms of aerial spray nozzles in an air stream. To quantify the droplet and to determine the effects of spray pressure, air velocity and nozzle orientation on droplet size for various types of nozzles, a laser imaging spray droplet spectrometer was used. viz: solid stream, disc cone hollow. Swirl type, hollow cone type, elliptical orifice fan and reflector fan type nozzle. Results indicated that spray nozzle orientation was extremely important in droplet size control and hollow cone nozzle was more suitable for the aircraft simulation for lower pressure.

2.1.2 Classification of spraying equipment

The selection of suitable spraying equipment plays a key role in the effective and economic use of it. The size of devices should be such that it is always critical to cover the field in a short time. A sprayer is referred to as a device applying pesticide in liquid form. Manual or power control of this application equipment can be possible. For the application of pesticides formulated in liquid, dust and granule formats, different types of application equipment are used.

Bindra and Singh (1977) reported various types of nozzles, which are used for pesticide atomization. Nozzles are known as hydraulic energy nozzles, gaseous energy nozzles, centrifugal energy nozzles, kinetic energy nozzles and thermal energy nozzles according to the type of energy used to atomize spray liquids.

Ozkan *et al.*, (2006) studied various spraying equipment for the effective application of fungicides to control the *Asian soybean rust*. The spray coverage and

deposition of nine spray nozzles from the application equipment were analyzed. In general, air aid spray treatments were more effective in spraying rust fungicides compared to traditional boom sprayer treatments. The discharge was very similar to the air-assisted spray treatments from the boom sprayer with a canopy opener and was much better than any other boom sprayer treatments.

Reduced spray discharge was provided by the Twin-jet, the Turbo dual pattern and the hollow-cone nozzles than by the orthodox flat-fan nozzles. The medium spray consistency offered greater spray coverage within canopies than the coarse and fine spray properties for treatments with the boom sprayer.

The maximum spray coverage in the middle part of the canopy was provided by the air-assisted sprayer, followed by the air jet sprayer and the boom sprayer with the canopy opener. In the middle part of the canopy, the boom sprayer with the TX-1 hollow cone nozzles generated the least spray coverage, followed by the Turbo duo and then XR8002 nozzles.

The reviews revealed that the boom sprayer is a good spraying technique to cover more area in minimum passes with a great coverage to target.

2.1.3 Factors responsible for effective spraying

Nozzle pressure, height, spray angle, travel speed, spacing between the nozzles, droplet size, etc. are the different factors responsible for uniform spray distribution of chemical across the field, and this section includes work done by researchers on different factors affecting spraying.

2.1.3.1 Droplet size

There are a large number of very small spheres of liquid known as droplets in the spray. If pesticides are to be applied efficiently with minimum chemical exposure, the droplet size is very important. The requirement for the droplet size depends on the pest, the pesticide, its mobility and the mode of action. The "Micron" (μ) equivalent to 0.001 mm is the unit of measurement of droplet diameters. The droplet is approximately spherical, undisturbed by relative airflow.

Droplet diameter and size distribution have claimed great significance in pesticide spray. Droplet size usually present in VMD (volumetric mean diameter), i.e. sample of spray droplets dividing the spray into two equal parts so that one half of the volume contains droplets smaller than the droplet whose diameter is VMD and the other half of the volume contains large droplets.

The spray was divided by NMD (Number Mean Diameter) into two equal parts by number without volume reference. An indication of the range of sizes is often the ratio between these two parameters. The uniformity coefficient is, therefore, the VMD/NMD ratio. In general, pesticide sprays are categorized according to droplet size. Pesticide spray is generally classified according to droplet size as shown in Table 2.1.

Table 2.1 Classification of spray droplets.

S.No.	VMD (μm)	Droplet size classification
1	>400	Coarse Spray
2	201-400	Medium Spray
3	101-200	Fine Spray
4	51-100	Mist
5	<50	Aerosol

For drift spraying against flying insects, aerosol sprays are mainly used. For foliage treatment, some aerosols (30-50 μm) and mist are suitable. A medium or coarse spray is needed to minimize drift. A fine spray is needed for decreased drift and coverage. The classification of spray droplet size is presented in Table 2.2.

Table 2.2 Classification of spray droplet size

S.No.	VMD (μm)	Droplet classification	Recommended use
1	>300	Coarse	Herbicides
2	201-300	Medium	Most of application

3	101-200	Fine	Insecticides and pesticides
4	51-100	Mist	Closed areas
5	26-50	Coarse Mist	Closed areas
6	<25	Fine mist	Closed areas

Source: Pesticide Application Method, G.A. Mathew (1992)- Bulletin 112/1 FAO-ONU

As per recommendation by Mathew the droplet size for insecticides and pesticide application in the range of 101-200.

Ennis and Williamson (1963) conducted experiment on foliar applications using volumes of 250-1250 ml ha⁻¹ to determine the effect of droplet size on herbicide toxicity to five plant species. They reported that VMD of 300-400 µm are not as much effective as 100-135µm.

Shengde *et al.*, (2019) carried out experiments on various orifice sizes (droplets with a median volume diameter of 95.21, 121.43, 147.28 and 185.09 µm, respectively) and the distribution of deposition and penetration of droplets in the target area and the distribution of drift of droplets in the non-target area were analyzed. He found that droplet size affected the deposition distribution and penetration of droplets in the target area and the drift distribution of droplets in the non-target area. The rate of deposition and droplet penetration increased with the increase in the size of droplets. But as droplet size increased, the total drift rate and drift distance of droplets decreased.

Miles *et al.* (1975) made a model to determine deposition efficiencies with different droplet diameters. The deposition efficiency was calculated at 4.57 m s⁻¹ air stream velocity of 91% and 11% for 200 and 20 µm droplets, respectively.

Smith *et al.* (1975) for spraying the majority of crops, they recommended droplet size is between 140 µm and 200 µm. they found that the 20-25 droplet cm⁻² density was the most effective for the required pesticide consistency and optimum droplet size of µm.

Mathew (1984) claimed that the smaller droplet spectrum prevented the development of larger droplets because they were inefficient from the point of view of pesticide effectiveness and also stopped the production of small droplets vulnerable to drift.

Perghar *et al.* (1997) found that droplets of 60-80 μ m were carried in the airstream at a distance of 6 to 12 m from the point of release. The droplets were transmitted to a distance of more than 12 m at a scale of about 100 μ m. They also stated that shearing action between air streams causes droplets below 60 μ m in size to evaporate at a higher rate. For most pest and disease control, they suggested 100-200 μ m as the optimum size of droplets.

Weidenhoff (1991) referred the research of Porskamp *et al.*, (1985). He stated that small droplets gave the target and deposition more coverage. The details of efficiency of deposition of fine drops are shown in Table 2.3.

Table 2.3 Deposition efficiency of smaller droplets

Spray Volume (l ha ⁻¹ of surface)	Droplet Diameter(micron)	Number Deposited (cm ⁻²)	% Cover	Distance between drops (mm)
40	400	12	1.5	2.5
	200	96	3.0	0.8
	100	764	6.0	0.3
400	400	119	15.0	0.5
	200	995	30.1	0.1
	100	7639	60.1	0.01

He further concluded that the spreading efficiency improved as the droplet size decreased. He indicated that it was impossible to decrease the droplet size

indefinitely. The smaller droplets do not hit the target effectively and is more vulnerable to evaporative drift and also loss.

Xu, *et al.* (2010) observed that when droplet diameter increased from 300 to 600 μm , the overall mean evaporation time increased to 279% without surfactant and to 452% with surfactant, while the total mean wetted area increased to 166% without surfactant and to 229% with surfactant. On the interveinal region on each surface of the leaver, the longest evaporation time on both solutions with and without surfactant occurred.

The reviews related to droplet size confirm that smaller size of droplets gives more coverage than bigger droplets but it susceptible to drift and evaporation.

2.1.3.2 Measurement of droplet size

The droplet size may be determined either by measuring strains or impressions, or by indirect measurement. So many methods have been developed to sample and quantify the size of spray droplets. Such techniques are basic methods of collection for advanced non-instructive techniques. The easiest and cheapest method used in droplet size calculation is to capture the spectrum of droplets in or in some type of medium.

May (1950) measured droplet size with MgO coated slide. This included the creation of magnesium oxide film from the burning magnesium ribbon on the glass slide by depositing MgO. The carter developed a droplet (20-200 μm) on the te effect with the magnesium oxide, which was 1.15 times greater than the true droplet size. He also identified other coated slide techniques to calculate the droplet size, including gelatin-coated slides and petroleum-coated slides. Water sensitive films, based on 35 mm photographic film, were used by Farlow and Frence (1956).

Turner and Huntingdon (1970) used a water-sensitive paper based on a Ph predictor. When water-based droplet falls on these paper produced a blue stain

from the paper's yellow background that could be easily discerned. Turning blue provide advantage to easy detection of stain.

Ciba-Geicy (1985) used method proposed by Turner and Huntingdon (1970) for papers with water sensitivity. They considered that it was also acceptable for elevated humidity conditions. Any type of stain, impression or image analysis must be made for the collected droplets on a surface in order to measure droplet size. The research ranged from manual approaches to automatic ones.

Panneton and Drummond (1991) identified the electronic digitizing camera system, which was capable of digitizing a 1504x3008 pixel sample using 256 grey scales. The resolution on the image plane was 10 μ m and the droplet diameter was determined to be 3.5 μ m in error.

Zhu *et al.*, (2011) built a portable scanning model that could analyze the distribution and coverage area of spray deposit collectors such as water sensitive papers or krometoke cards easily. Computer software was build to scan and measure the stains and dots on the scanned card. This software was able to measure size of individual spot and also it could show total area covered by droplets on cards. The results can be copied to the MS excel. *DepositScan* overlooked spot diameters smaller than 23.9 μ m when a resolution of 2400 dpi was used.

Cerruto *et al.*, (2013) conducted an experiment to know the parameters affecting the deposition of spray droplet on water sensitive paper. Diameter of droplets, CV, density of impact and deposition were analyzed with these papers in addition to the covered surface. The photographs of water-sensitive papers deposited by spray were taken. The study was carried out to calculate the percentage of the surface covered the number of droplets in unit area, using image processing software.

Salyani *et al.*, (2013) examined the areal deposition of droplets from air blaster sprayer at several distances from the sprayer by targets of absorbent paper and water-sensitive papers. Flourometry evaluated spray deposits on AP targets, and three separate image analysis systems assessed spray coverage on water

sensitive papers. Among the three imaging systems, strong correlation was observed in measuring WSP percent area coverage. Smaller droplet had more useful than higher volume rate as result analysis of papers.

The computer softwares have become easy and reliable means of droplet parameters measuring technique. AI has become helping in many tedious measurements like droplet size, droplet density, VMD and NMD etc.

2.1.3.3 Droplet density

The density of droplets is the number of drops in the region of a unit. For the consistency of the spray, the droplet density along with droplet size is significant because droplet density directly affects the amount of spray applied depending on the size of the droplet.

Alms *et al.*, (1987) conducted experiment to know effect of droplet size and segmentation of different size of droplets as 12, 145, 200 μm consist of 0.0075% pendamethalin were sprayed on leaf (177 cm^2) in distribution ranging from 0-182 droplets cm^{-2} . It was found that egg laying was decreased to 80% with 41 droplets cm^{-2} of 120 μm corresponded to 3.71 l ha^{-1} and 18 cm^{-2} of 200 μm correspond to 7.5 l ha^{-1} .

Anonymous (2002) studied the sufficiency of density using sprays of ultra low volume. He proposed average of 15-20 droplets cm^{-2} is sufficient for most insects and pests to be managed. This study also included with the traditional spray deposition results and found that the deposition of pesticides on the upper surface of the leaves was higher than on the lower surface. The outside deposition was wider than the inside deposition of the canopy. Approximately half of the amount of spray deposited outside the tree was provided to the middle of the canopy of the canopy.

2.1.3.4 Spray Distribution Pattern

Singh *et al.*, (2002) studied the spray distribution pattern of various nozzles, namely; hollow cone; solid cone; adjustable and fan type, mainly used for agricultural purposes, at three different pressures (0.75, 3.0 and 6.0 kg cm^{-2}) and

three nozzle angular settings. The nozzle spray pattern was overlapped at specific pressure and angular settings to find the spacing of the nozzle for a uniform spray. The study found that both the uniformity of the spray pattern and the working width of the nozzle were affected by the angular setting of the nozzle. With an increase in pressure for all nozzles, swath width, working width and discharge rate have increased.

Di Prinzio *et al.*, (2010) assessed the effect of spray pressure on the distribution and loss of pesticide while using a conventional air-blast sprayer to spray fruit trees. 1,800 kPa and 500 kPa were the assessed pressures. In the trees, in columns, and on the ground, samples were collected. No differences in the total quantity collected from the leaves were found in the results. It was also found that one-third less drift resulted from the lower-pressure treatment. However, with the low-pressure treatment, there were no differences in the amount on the ground placing a higher concentration of material on the ground near the sprayed tree row.

Singh *et al.*, (2011) analysed distribution pattern of various sprayers with spray droplet analyzer. Performance of knapsack sprayer, air-blast sprayer, self propelled sprayer, power operated knapsack sprayer were analyzed on the basis of VMD, UC, NMD. They used glossy paper to collect the sample of spray droplets. The samples were taken from both upper and lower parts of plant canopy. Computer software named “USB digital scale” was used to analyze glossy paper cards. Results showed that the lower parts of canopy received more deposition than upper part of canopy.

2.1.4 Spray drift and volume

During the application of plant protection products applications in the field, spray drift can occur. Due to wind, poor calibration or application practices or incorrect nozzles, spray drift is characterized as the transfer of small spray droplets out of the target region.

Sensitive areas like housing area or other human and animal habitat can be affected due to excessive drifting of pesticides. Bigger droplets cause less drifting as compared to smaller droplets. Since bigger droplets cannot be as much effective

in case of insecticides or pesticides. There are various researchers recommended a limit for drifting.

Hall (1993) found that planting size, shape of plant, plant height, growing pattern and operator's ability are the important points which should be kept in mind to match target pattern. Accurate travel speed control and spray and wind flow effect the efficiency of spraying. To get more efficient spraying direction of operation should match wind direction.

Nuyttens *et al.* (2010) compared indirect and direct spray drift measurement approaches. In order to reflect the reduction potential in the field with various pressure combinations, the total droplet volume smaller than 75% diameter was better suited. This was accompanied by approaches to the wind tunnel to test air-borne spray, which yielded inferior performance. They were of the opinion that it was possible to make a practical estimation of field drift data at driving speeds of 8 km h⁻¹ and 0.50 m boom height, based on indirect drift calculation and a mathematical drift prediction equation for reference spraying.

Kruckeberg *et al.* (2012) evaluated relative accuracy of *DRIFTSIM* for spray drift measurement. In comparison with the other alternative models, the *DRIFTSIM* was best suited for predicting near field drift. The more accurate representation of drift in the intermediate or far-field (20 to 50 m from the boom edge) regions was not present in these models. In forecasting far-field drift, many alternative models have proven to be significantly more precise.

Costa *et al.*, (2015) conducted an experiment for optimum amount of spray liquid for best pathogen control of soybean plants. They took the treatments of the volumes 50, 100 and 150 l ha⁻¹. After comparison the recommended that volume of 150 l ha⁻¹ with droplets formed by hydraulic energy was the best pathogen control ability.

2.2 Development Aspects

2.2.1 Boom sprayer

Anibude *et al.*, (2016) developed prototype of animal drawn hydraulic boom sprayer because knapsack sprayers were much time consuming, laborious and creates narrow swath width on the other hand tractor mounted boom sprayers are too expensive for farmers. In view of the agronomic and practical requirements for the application of chemicals on field crops, the sprayers were designed and the main components included a 100 liter spray tank, 3 HP petrol engine, mainframe, operator bench, boom, 10 flat fan nozzles, piston pump, and wheel and axle shaft. As the power source for running during spraying piston pump, the petrol engine was used and pairs of bullocks were used for hauling purposes. 260 l ha⁻¹ application rate, 1.16 ha h⁻¹ theoretical field capacity, 89.6% field efficiency, 1.04 ha h⁻¹ effective field capacity was achieved. Thus, by comparing the results with the manually operated knapsack sprayer, the productive field power and field performance was improved by 62% and 37%, respectively.

Sanchavat *et al.*, (2018) evaluated the tractor mounted boom sprayer under local agro-climatic conditions at farmer's field village *Timbapada* in *Dediapada*. The sprayer was tested at various pressure levels, such as 500, 600 and 700 kPa, respectively, under laboratory conditions. Nozzle discharge, spray angle, spray distribution and swath width were analysed for each spray angle pressure stage. With pump pressures of 500, 600 and 700 kPa, the spray angle of the nozzles was 80°, 85° and 88°, while the swath width was 1235, 1294 and 1375 mm at pump pressures of 500, 600 and 700 kPa, respectively.

Ade *et al.*, (2006) evaluated the efficiency of commercial spraying equipments. It was evaluated in the contrast of air-assisted boom sprayer with conventional boom sprayer efficiency and delivery efficacy. Tests were carried out in randomized block design with three replications on air-assisted overleaf, underleaf, and conventional. Compared to conventional treatment, the treatment at overleaf was found to be 18% more deposited and also 37% less off target losses. It was also found that more leafy canopy gets less off-target losses.

2.2.2 Power sprayer

Ruas *et al.*, (2011) compared the application efficiency with regard to coastal manual sprayer and power engine sprayer. The experiment was randomized which have 4 replications, comparing 2 spraying equipments to find area covered in three different heights, two different leaf positions and two foliar faces at total 48 plots. The spray rate used was 100 l ha^{-1} , in which water mixed with tracer. It was concluded that for the leaves located in the external position of the coffee plant, as well as for the leaves of the medium height in the internal position, the use of the motorized sprayer (air assistance) was more efficient in the percentage of coverage of the leaves than the conventional sprayer.

Kumbhare *et al.*, (2016) developed a tricycle type power sprayer which runs from DC motor. He reported that the knapsack type backpack sprayers causes many health problems for operator. Operating sprayer faces the problem of lumber pain. So in way of countering such problems an automatic pesticide spraying machine will work as an alternative concept. When he compared developed machine and existing equipments he found that his developed machine was more efficient with respect to coverage, time and cost of spraying process, also that machine seems economical.

Hence for countering need of entering operator into the field the power sprayer will best suited that can be a reliable mean of spraying equipment.

2.3 Cost Economics

Mathew *et al.*, (1992) studied a power tiller operated boom sprayer. Experiment was conducted for varying pressure using hollow cone nozzle. At higher pressure of 3 kg cm^{-2} more even distribution was observed than that of 2 kg cm^{-2} . It was also noted that, relative to hand compression knapsack spray, the cost of running the boom sprayer decreased by 29 %.

Yadav *et al.*, (2020) studied about the cost economics of developed wheel operated sprayer and the traditional knapsack sprayer. The cost of spraying operation consists of fabrication cost, insurance cost and rental cost, repair and maintenance

and labour wages. The cost of operation of developed boom sprayer was divided in two parts first was fixed cost and second was variable cost. The fixed cost was independent of the operational work while variable cost varies according to use of spraying machine. Cost of the machine and its operation was calculated in Rs ha^{-1} using straight line method of depreciation and economic evaluation of machine were calculated.

Total cost of operation for one hectare by hand operated and developed sprayer were assessed as $\text{Rs } 725 \text{ ha}^{-1}$ and $\text{Rs } 237 \text{ ha}^{-1}$ respectively.

CHAPTER III

MATERIALS AND METHODS

This chapter deals with the methods and material used for selection of nozzle, it's mounting on the boom with respect to different pressure and height/ distance from the target development of boom sprayer and its evaluation in actual field conditions and has been described under the following heads.

1. Determination of soybean plant physical characteristics
2. General development considerations
3. Laboratory evaluation
4. Development of power sprayer
5. Field evaluation of developed machine
6. Economic calculation of machine

3.1 Details of Experimental Field

3.1.1 Experimental site

Development of sprayer and related experiment was carried out at Swami Vivekananda College of Agricultural Engineering and Technology & Research Station, Faculty of Agricultural Engineering, Raipur Chhattisgarh during 2018-2020. The experimental site was situated at 21.70° N latitude, 81.53° E longitudes and altitude of 278 m above mean sea level. It is located in Chhattisgarh Plains Agro Climatic Zone of Chhattisgarh state.

3.1.2 Climatic and weather conditions during experiments

Raipur has a tropical wet and dry climate, temperature that remains mild throughout the year, with the exception of March to June, (extremely hot), The average annual rainfall is around 1300 mm, 85% of which is received rainfall during the rainy season (June to September) and the rest during the winter and summer seasons (October to May).

The southwestern monsoon is the primary source of rainfall. The monsoon enters the southern part of Bastar about 10th June and reaches the other areas of Chhattisgarh by 20th June.

The hottest and coolest temperatures are in the months of May and December. The weekly maximum temperature rises to 46°C the summer season, and the minimum temperature decreases to 6°C during the winter season. The maximum and minimum weekly temperatures were reported as 33.6°C and 20.4°C, respectively.

3.2 General Development Considerations

The development of power sprayer for soybean crop consists of several sequential steps. Initially, following basic information was acquired:

- (a) Soybean plant characteristics
- (b) Soil and climatic condition during spraying
- (c) Difficulties in spraying pesticides
- (d) Source of power of sprayer
- (e) Land holding size of farmers
- (f) Ease of spraying
- (g) Expected cost of machine and cost of operation

3.3 Steps involved in development of machine

Following steps were taken in development of power sprayer for soybean.

1. Recognition of need and preparation of specifications as per requirements.
2. Consideration of structure of machine design.
3. Preliminary studies on consideration of nozzles, boom supporting structure, pressure pump, engine power, chemical unit, tank capacity and other attachments.
4. Fabrication of prototype of machine according to the development considerations.

5. Testing of machine as per standard methods.

3.4 Determination of soybean plant physical characteristics

Determination of clearance to consider the boom height for which the knowledge about growth stages is required. In general, soybean has two growth habits: determinate and indeterminate. Determinate cultivars finish vegetative growth when the plant enters reproductive stages. On the other hand, varieties with indeterminate growth habit possess simultaneous vegetative growth and flowering during the reproductive phase. Most soybean varieties in the 00 to IV groups have an indeterminate growth habit, whereas varieties in the V to IX groups exhibit a determinate growth habit.

The biological cycle of the soybean plant is divided into the vegetative and reproductive phases. The vegetative phase starts when the seed absorbs water to induce germination process. The vegetative phase ends and the reproductive stages begins with the appearance of first flora buds in soybean varieties of determinate growth habit, or the appearance of the first raceme in varieties of indeterminate growth habit.

Table 3.1 Plant growth stages and time from one stage to the next. (Modified from

Naeve, 2011; Pedersen, 2007; and Kansas State university, 1997)

Stage number	Average Time Between Stages #days	Time	Height (cm)
Vegetative Stages			
V _E	Pit to V _E 10D	Emergence	-
V _C	V _E to V _C 5d	Cotyledon	-
V ₁	V _C to V ₁ 5d	1 st trifoliolate	-
V ₂	V ₁ to V ₂ 5d	2 nd trifoliolate	15-20
V ₃	V ₂ to V ₃ 5d	3 rd trifoliolate	18-23
V ₄	V ₃ to V ₄ 5d		20-27

V ₅	V ₄ to V ₅ 5d		25-30
V ₆	V ₅ to V ₆ 5d		30-36
V _(n)	V ₆ to V _n 3d	N th trifoliate	
Reproductive Stages			
R ₁	R ₁ to R ₂ 3d	Beginning flowering	38-46
R ₂	R ₂ to R ₃ 10d	Full bloom	43-56
R ₃	R ₃ to R ₄ 9d	Beginning pod	58-81
R ₄	R ₄ to R ₅ 9d	Full pod	71-100
R ₅	R ₅ to R ₆ 15d	Beginning seed	76-109
R ₆	R ₆ to R ₇ 18d	Full seed	70-120
R ₇	R ₇ to R ₈ 9d	Beginning maturity	120
R ₈		Full maturity	120

3.5 Components of Boom

3.5.1 Nozzle

Nozzle is the main component of the sprayer. It atomizes the liquid into different sizes of droplets at a controlled rate of flow in a given direction. There are various types of nozzles in the market. We can select the nozzle as per our requirements.

Nozzle breaks the liquid into droplets and propels the droplets in the target direction. It determines the amount of spray volume at given working pressure, a different swath from different target distances of the nozzles, and spacing between the nozzles.

3.5.1.1 Selection of nozzle

Nozzle plays a significant role in determining the amount, rate of discharge, and uniformity of application. For the pesticides spray proper application rate is

required to avoid the wastage of pesticides in the field. Thus, proper selection of nozzle type is essential for uniform pesticide application.

A poor choice in spray nozzles selection, or use of under-performing nozzles, can lead to re-spraying and reduced performance, so one should be very particular regarding the use of nozzles.

Out of the large availability of nozzles of different standards, two nozzles were selected for used in pesticide spraying operations. These nozzles were tested on various parameters. For a better understanding of the physical shape of these nozzles, images are shown, in fig. 3.1.

Hydraulic nozzles are in common use for applying herbicides and have been used successfully for most of this century with little change. They are relatively inexpensive and are available in a variety of types which provide a range of flow rates and spray patterns.

For extended spray distances, the spray angle does not hold. As the figure below shows, as you step away from the orifice, the spray angle appears to collapse or diverge. The theoretical coverage is described below for spray patterns at different distances from the nozzle orifice.

These values presume that for all the spray lengths, the spray angle remains constant. Approximate spray coverage using water is the tabulated spray angles mentioned. Spray spacing varies with the angle of spray.

Depending on nozzle power, spray pressure and viscosity, liquids that are more viscous than water for narrower spray angles, or solid streams wider spray angles than those mentioned for water are created by liquids with surface tensions lower than water.

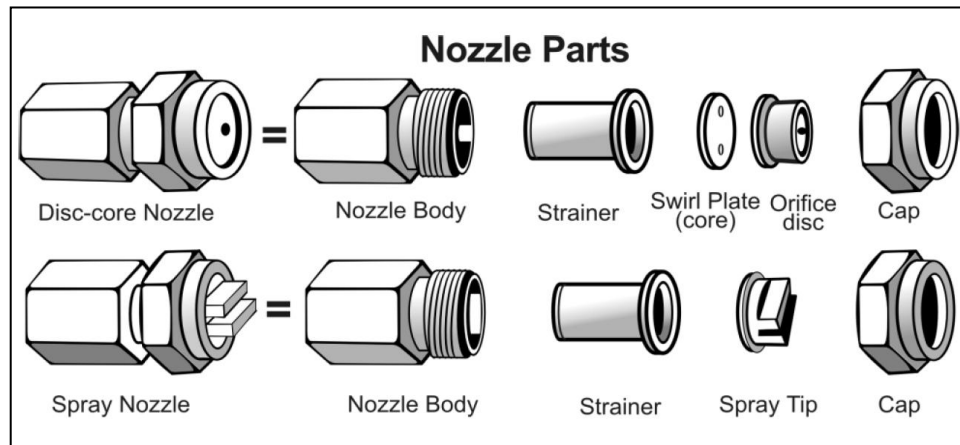


Fig.3.1 components of nozzle

Following steps were taken as mentioned below to determine the correct nozzle type and capacity needed.

Step 1: Consulting the label: The packet label is the most useful source of information. In order to specify the application speeds, controllable pests, and conditions required for the application of the fertilizer or pesticide, the label will also have included details on the classification of droplets, type of nozzle, and spacing. Therefore the instructions were followed as outlined on the label of the herbicide cover.

Step 2: Selecting operating conditions: Several spray characteristics such as drift potential, droplet size, coverage, chemical volume and efficacy is influenced by spray volume. Therefore, the desired nozzle spacing and volume were calculated by measuring ground speed in km h^{-1} .

Step 3: Calculating required nozzle discharge: To select a nozzle of specific orifice size, the spray volume, nozzle spacing and travel speed are necessary. Therefore, these parameters were calculated as below:

$$\text{Nozzle discharge} = \text{Travel speed} \times \text{nozzle spacing} \times \text{spray volume} \quad (3.1)$$

Where,

$$\text{Nozzle discharge} = \text{litre per minute (lit min}^{-1}\text{)}$$

Travel speed = meters per minute (m min^{-1})

Nozzle spacing = meters (m)

Spray volume = litre per meter (lit m^{-2})

Step 4: Consulting a nozzle catalogue: After determination of nozzle discharge, a nozzle catalogue was consulted for a specific nozzle size or number. The specifications of these nozzles in the discharge capacity column were reviewed.

3.5.1.2. Types of nozzles and their characteristics

3.5.1.2.1 Hollow cone

Hollow-cone nozzles generally makes spray pattern of circular ring of liquid. By the use of an inlet orifice tangential to a cylindrical swirl chamber that is open at one end, the pattern is achieved. The outlet of the circular orifice has a diameter smaller than the chamber of the swirl. A circular structure results from the whirling liquid; the middle of the ring is hollow. For applications requiring good atomization of liquids at low pressures or when fast heat transfer is required, hollow cone nozzles are best. These nozzles also feature wide and unobstructed flow passages, providing a relatively high clogging resistance. The smallest drop size distributions are given by hollow cone nozzles. The relative range of drop sizes appears to be smaller than other types of hydraulics.

The hollow cone pattern can also be achieved using the nozzle spiral style. This nozzle reaches a protruding spiral with the fluid. This spiral form splits the fluid into many patterns of hollow cones.

3.5.1.2.2 Flat fan nozzle

The spray pattern appears as a flat sheet of liquid, as the title implies. The pattern on a deflective surface that is tangent to the exit orifice is formed by an elliptical or round orifice. The orifice has an external groove, or "cat's eye" shape, with a contoured internal cylindrical radius. The pattern sprays out of the orifice in line with the pipe in the pattern of the elliptical orifice.

The spray pattern is perpendicular to the pipe in the deflector configuration. Based on the uniformity of the spray over the spray pattern, there are two types of flat spray, tapered and even. Straight-through elliptical spray nozzles create smooth spray patterns with tapering edges.

For overlapping patterns between multiple nozzle headers, this spray pattern is useful. The effect is a uniform distribution over the sprayed surface as a whole. In cleaning applications that demand a uniform spray pattern without any overlap in the spray field, non-tapered flat spray nozzles are used.

3.5.1.2.3 Full cone

In a round, oval or square shaped field full cone nozzles yield complete spray coverage. Inside the nozzle, the liquid is normally swirled and blended with non-spinning liquid that has bypassed an internal vane.

Liquid then escapes, creating a conical pattern, through an orifice. Inside the cone pattern, spray angle and liquid distribution depend on the nature of the vane and position relative to the exit orifice. The geometry of the exit orifice and the relative geometric proportions also influence the angle and distribution of the spray.

A uniform spray distribution of medium to large size drops resulting from their core design, which features large flow passages, is provided by complete cone nozzles. The type most widely used in the industry is full cone nozzles.

3.5.1.2.4 Flood nozzle

Clogging issues are reduced by a circular orifice and wide, unobstructed flow passages. Also ideal for use with air and steam are flood jet flat fan spray nozzles. All flood jet nozzles have a precision-machined deflector surface that offers effective, precise deflection and spray angle control.

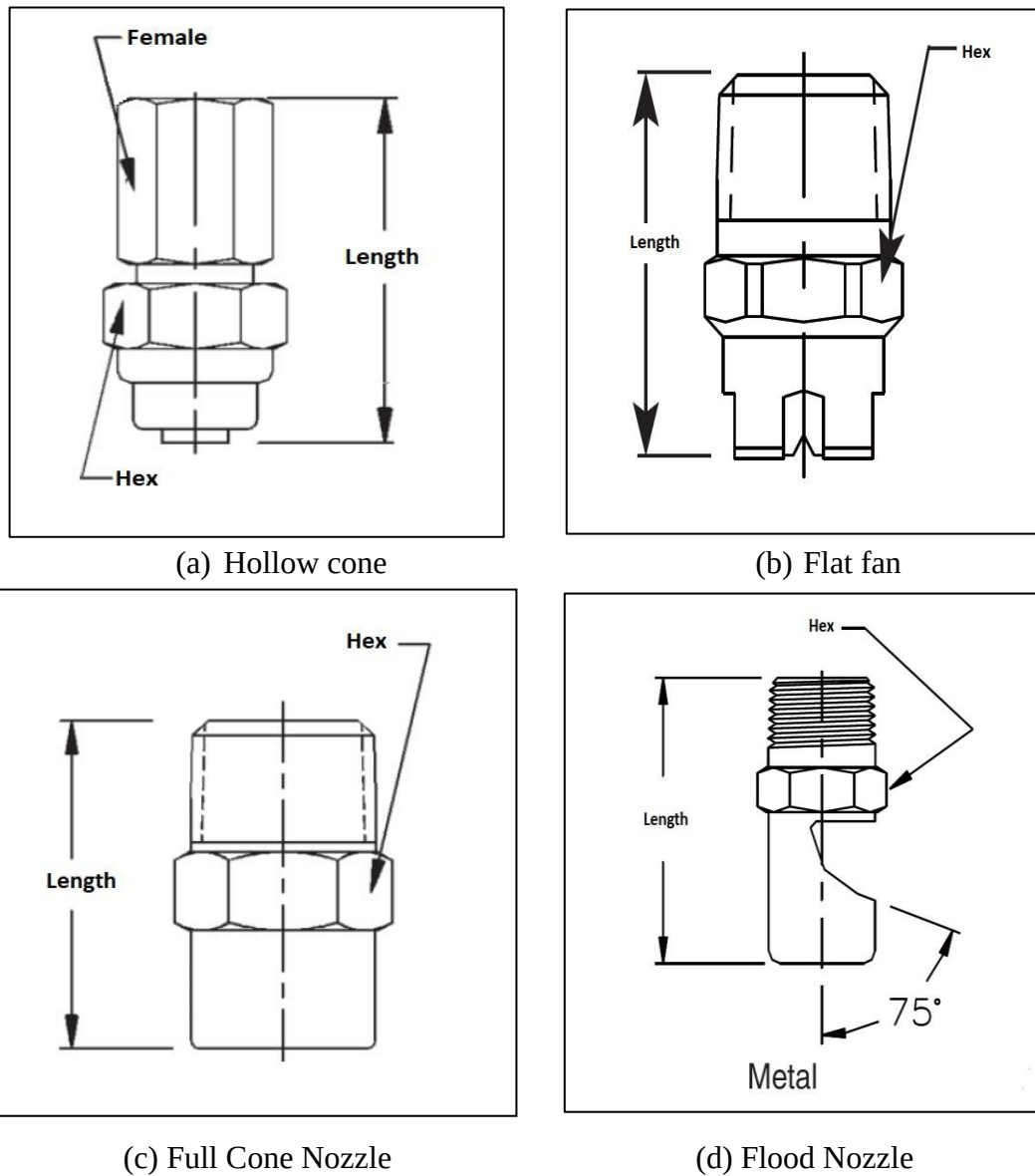


Fig 3.2 Types of nozzles

3.5.2 Brass tee coupling

To arrange nozzles in the UPVC (Un-plasticized Polyvinyl Chloride) pipe, tee couplings are provided at every 30 cm spacing. This tee couplings were connected to pipe with suitable adhesive.

3.5.3 Brass male reducer

For connecting nozzles to tee coupling a 1.905 x 1.27 cm size male reducer was used. This reducer was furl with Teflon tape to avoid any type of leakage.

3.5.4 Control valve

To control the desired liquid to the boom and so nozzles a control valve was provided at the end of Un-plasticized Polyvinyl Chloride boom pipeline so that the operator could control the delivery of liquid at nearby himself. A control regulator valve was also given at the upper side of HTP pump so that the pre decided pressure could be easily adjusted.

3.6 Development of Boom Support Span

As the farmer's worry about the soybean field is that when the plants reach to its leafy stage the plant canopy becomes denser and so that fields between the rows of soybean got very hard to see. The unseen places under these leafy canopies often have many poisonous creatures like snakes and scorpions. In respective to this problem main motive of development of power sprayer for soybean crop is to develop such a machine which can eliminate the entrance of operator in the field and so reduction in confrontation to poisonous creatures.

The idea of design of boom support span was taken from the centre pivot irrigation system structure. The structure is made with 25 mm angle iron, 32 mm GI pipe and 4.8 mm steel wire rope, this structure gives the boom a clear horizontal platform to maintain a decided height the structure is also able to control swinging effect during operation.

The structure had enough capability to support the boom along the length. The boom length was taken as 10 meter to cover 36 rows of soybean plants with row spacing of 30 cm.

The main supporting trolley (4 wheelers) has been provided with facility of easy adjusting the boom height according to the plant height. The adjustment systems are provided in a 30 x30 cm column frame.

The adjustments are provided at every 10 cm height. So the lowest height which can be adjusted is 60 cm and the highest is 178 cm. The spacing/distance between nozzles mounted on boom was as per the effective swath width obtained after overlapping at different target distance of spraying.

The boom was made of UPVC pipe of 2.134 cm outer diameter and 42.18 kg cm⁻² pressure bearing capacity which is enough to bear the chemical pressure. UPVC brass tee couplings and Brass nozzles are connected with the help of 1.905 x 1.27 cm ($\frac{3}{4}$ x $\frac{1}{2}$ inch) reducer male connector.

The UPVC pipe has capability to much bending capacity and it has very good strength. At the one side end is provided with end cap and second side end is provided with 1.27 X 1.27 cm ($\frac{1}{2}$ x $\frac{1}{2}$ inch) male connector which can be easily connected to HTP pump with the help of delivery hose pipe.

This boom was connected by chemical unit with high pressure sprayer hose of 0.85 cm had bearing capacity of 160 kg cm⁻².



Fig. 3.3 Fabrication of frame



Fig 3.4 Fabrication of trolley wheels



3.5 Taking away irregularities

3.7 Development of Chemical Storage Cum Power Unit

The chemical storage unit was made separately to keep the boom structure light weight and also to make easy pull of the boom span in field. It benefited the operator to work away from noise and vibration of engine. The heavy tank of chemical was taken nearby the field with the help of its wheels. The chemical unit was kept out of field at any convenient space.

The chemical unit had a tank of 55 cm diameter and 90 cm length. It was mounted on chemical unit trolley (120x77 cm) framed with angle iron of 4 X4X 0.5cm. The tank acted as a reservoir for the chemical liquid to be sprayed. The unit was also provided with 4 wheels of 40 cm diameter for easy transportation. Power source for delivery of chemical was a 4 stroke single cylinder air cooled engine.

The engine had rated speed of 3000 RPM and rated power of 2.2 kW. A HTP pump was connected to produce high pressure to flow to boom and also fulfill tank agitation requirement.

In tank separate agitator was not provided because when the overflow pipe flow back chemical with enough pressure, it creates some agitation so that the solution in the tank remains in proper suspension. The carrier trolley for mounting the chemical tank, Power source engine and HTP pump was fabricated in the workshop. Angle iron size of 4 X 4 X 0.5 cm was used to fabricate the pump base. The carrier tank (52 cm dia.) was rigidly tied using two circular metal belts wrapped around the tank with trolley base. This is necessary to avoid tank from falling down during field spray operations.

3.7.1 Chemical storage tank

In every sprayer system has a tank which acts as a reservoir for chemical fluid. In this chemical and power unit a tank is provided for storage of chemical. This tank is provided at the opposite side from trolley handle by balancing with the engine weight. The chemical was prepared by adding some dyeing agent. The chemical was thoroughly mixed. The suction pipe is connected to the nethermost point of tank, this suction pipe bring up chemical to the HTP pump and the suction pipe is

also provided with a strainer to avoid foreign material and other dirt's from entering in suction line and so pump and nozzle orifice. Capacity 200 l of cylindrical plastic tank was chosen.

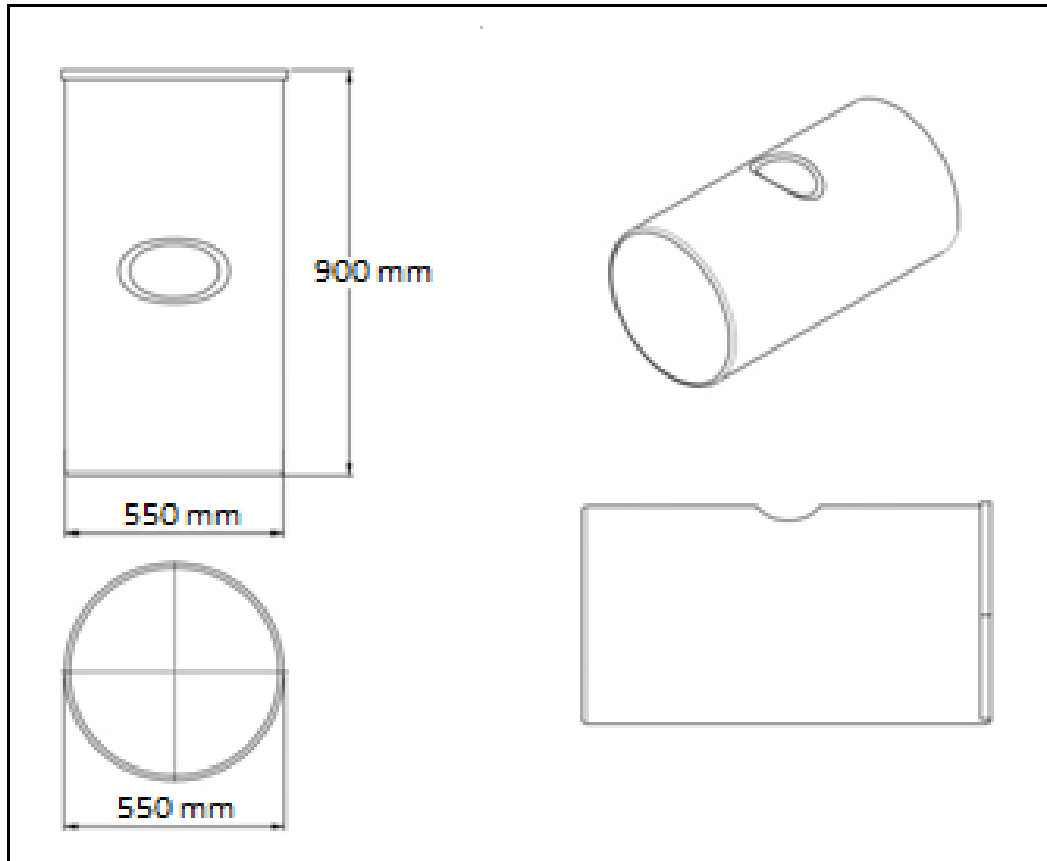


Fig 3.6. Chemical storage tank

The capacity of storage tank was determined by using the following mathematical expression

$$C = \frac{\pi d^2 h}{4} \quad (3.2)$$

Volume of total plastic material used for tank

$$V_{mt} = \left(\frac{\pi d^2}{2} + \pi d h \right) \times M_t \quad (3.3)$$

Where;

C = tank capacity

d = tank diameter

h = tank height

M_t = thickness of drum

3.7.2 Holding belt for tank

To avoid the problem of cylindrical drum holding belt was made by moulding MS sheet of 4 cm length and 0.5 cm thickness to semi-circular shape. The holes are drilled in 1.5 cm apart from the both ends.

3.7.3 Power source

The power to deliver HTP pump was taken from a 4 stroke single cylinder engine. The engine was supposed to develop power of 2.2 kW at its 3000 rated RPM as per information available on its label. But the engine was rotating at 2450 RPM at its full throttle and 1550 RPM at its minimum throttle.

3.7.4 Pressure pump

The pump should generate enough pressure to fulfill the required pressure of nozzles and hydraulic agitation of tank chemical. The pressure should not be very high so it starts foaming of tank liquid and also should not very low that it can not develop an effective swath. The HTP pump provided by the department of FMPE was a good capacity pump to develop a good pressure and discharge to boom. The pump was developing the discharge of 5 to 36 liters per minute and pressure varying from 1 to 50 kg cm⁻². The pump was working at good capacity under the range of 800 to 1000 rpm. The power to pump was transmitted through the engine pulley by means of V-belt and pulley arrangement. The capacity of pump was calculated with the following equation:

$$\text{Total flow requirement} \left(\frac{l}{min} \right) = \frac{\text{Swath(m)} \times \text{application rate} \left(\frac{l}{ha} \right) \times \text{speed (km/h)}}{600} \quad (3.4)$$

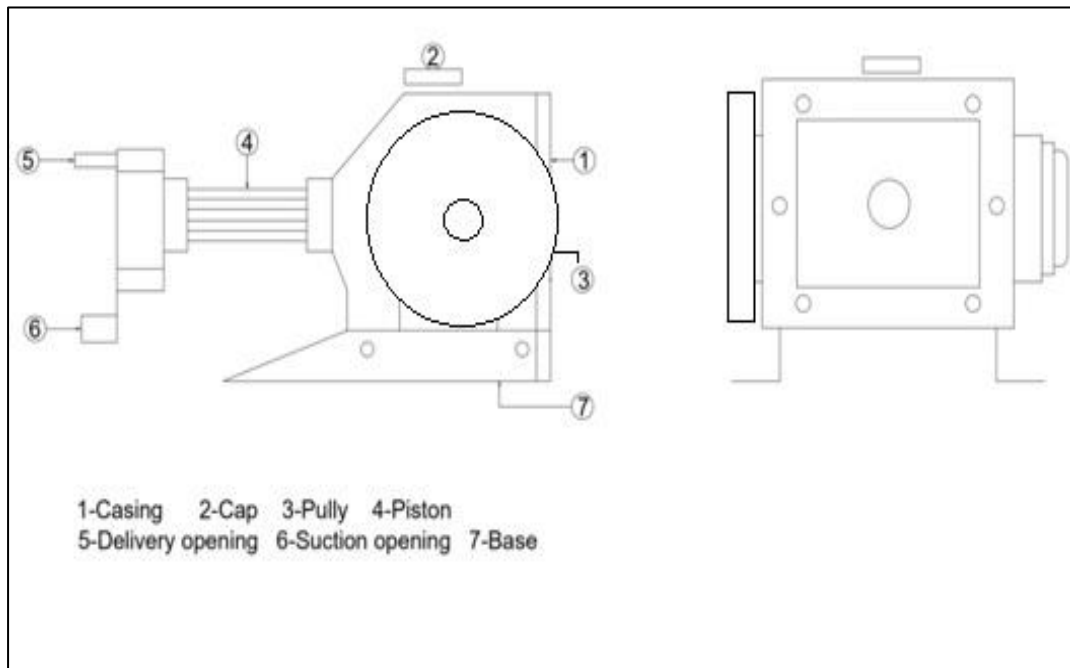


Fig 3.7. Diagram of HTP pump

3.7.5 Strainer

The foreign materials can effect the performance of the nozzles in the boom and reduce the performance of sprayer. Fine silica or metal particles can wear the nozzle orifices, so a fine wire mesh strainer was provided at the entry of suction line and tank so liquid can be filtered out at starting point and prevent the clogging of nozzles.

3.7.6 Hydraulic agitator

When the control valve is kept at some more than required discharge then the excessive liquid returns to the tank again which makes agitation in it. So any other means of agitation was not provided. A return line was provided in the HTP pump so that required agitation could be obtained.

3.8 Power Transmission Calculation for HTP Pump

V belts were used for solve the slippage and alignment problem. Generally V-belts are used for short range power transmissions. V –belts needs larger pulleys for there thicker cross-section than flat belts. Due to their high flanges the belt

cannot slip off the pulley. V-belts may be homogeneous rubber or polymer, or some fibers are included for better strength and reinforcement. These fiber material can be of textile materials such as cotton, nylon or polyester for greater strength.

Since the shafts of engine and HTP pump has only the distance of 51 cm so V-belt was chosen to transmit rotating power. The belt was certified through ISO 9001:2008 and was of size B58.

The engine has greater RPM than requirement of HTP pump, so to reduce the speed of engine to meet the rated RPM of HTP pump small pulley of 10 cm diameter was fitted on engine. Since the engine was rotating at 2350 RPM and HTP pump had rated RPM of 1000, so the diameter of pulley of HTP pump was calculated by the equation;

$$\frac{N_1}{N_2} = \frac{D_2}{D_1} \quad (3.5)$$

$$\frac{2350}{1000} = \frac{D_2}{10} \quad (3.6)$$

$$D_2 = 23.5 \text{ cm}$$

So, as the availability of market 22.86 cm (9 inch) pulley was used for HTP pump shaft as driven pulley.

The properties of a V-belt of B cross-section viz. density, cross-sectional area and allowable tensile stress (σ) were taken as 1000 kg m^{-3} , 143.7 mm^2 and 2.5 MPa (Khurmi and Gupta, 2005). A groove angle 2β of 35° pulley of 2.25 was considered as co-efficient of friction (μ) between pulley and belt (Khurmi and Gupta, 2005).

The mass of the belt per unit length

$$m = \text{Cross –section area, } m^2 \times \text{Length, m} \times \text{Density, } kg \text{ m}^{-3} \quad (3.7)$$

$$m = 143.7 \times 10^{-6} \times 0.51 \times 1000$$

$$m = 0.07328 \text{ kg per meter length of belt}$$

The centrifugal tension of belt (T_c) of the belt is given by

$$T_c = m \times V^2, \text{ N} \quad (3.8)$$

Where,

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

m = Mass of belt, kg

$$V = \frac{(\pi \times d_2 \times N)}{60} \quad (3.9)$$

$$V = \frac{3.142 \times 0.1 \times 2350}{60}$$

$$V = 12.3061 \text{ ms}^{-1}$$

$$\text{So, } T_c = mV^2 \quad (3.10)$$

$$= 0.07328 \times (12.3061)^2$$

$$T_c = 11.09753 \text{ N}$$

Maximum tension in the belt

$$T = \text{Allowable tensile stress, N mm}^{-2} \times \text{Section area of belt, mm}^2 \quad (3.11)$$

Where,

σ = Allowable tensile stress = 2.5 MPa

$$T = 2.5 \times 10^6 \times 143.7 \times 10^{-6}$$

$$= 359.37 \text{ N}$$

Therefore, tension in tight side of the belt

$$T_1 = T - T_c \quad (3.12)$$

$$T_1 = 359.37 - 11.09 \text{ N}$$

$$T_1 = 348.28 \text{ N}$$

Where,

T_1 =Friction tension

T_c = Centrifugal tension

T = Tension in tight side

The tension in the slack side of the belt (T_2) was calculated as follows

For open belt drive

$$\sin\alpha = \frac{O_2 M_1}{O_1 M_2} = \frac{r_2 - r_1}{x} = \frac{d_2 - d_1}{2x} \quad (3.13)$$

$$\sin\alpha = \frac{0.225 - 0.1}{2 \times 0.51} \quad (3.14)$$

$$\alpha = 7.0392^\circ$$

Angle of lap on smaller pulley (i.e. pulley on the engine shaft)

$$\theta = 180^\circ - (2 \times \alpha) \quad (3.15)$$

$$\theta = 180^\circ - (2 \times 7.0392^\circ)$$

$$\theta = 165.92^\circ$$

$$\theta = 172 \times \pi / 180 \quad (3.16)$$

$$\theta = 2.89 \text{ rad}$$

To find tension at slack side, following formula was used,

$$\frac{T_1}{T_2} = e^{\mu\theta} \quad (3.17)$$

Where,

μ =coefficient of friction

θ =angle of lap of the belt over the pulley in radians and

e = base of Napierian log = 2.728

$$\frac{T_1}{T_2} = e^{0.25 \times 2.89}$$

$$\frac{T_1}{T_2} = 2.05$$

$$T_2 = 348.28/2.05 = 169.1026 \text{ N}$$

$$\text{The power transmitted from belt } (T_1 - T_2) V \quad (3.18)$$

$$= (348.28 - 169.10) 12.3061$$

$$= 2204.97 \text{ Watt}$$

$$= 2.2049 \text{ kW}$$

Number of V-belts required to transfer power to pulley from engine pulley was calculated by following equation

$$= \frac{\text{Total power transmitted}}{\text{Power transmitted per belt}} \quad (3.19)$$

$$= \frac{2.2}{2.2049} = 0.9977$$

Therefore, only one V-belt is enough to transmit power.

Since we know the diameters of driving and driven pulley and also center to center distance between the pulleys. The length of belt was calculated as shown below;

$$L = 2x + \pi\left(\frac{D_2 + D_1}{2}\right) + \frac{(D_2 - D_1)^2}{4x} \quad (3.20)$$

$$L = 2 \times 0.51 + \pi(0.01 + 0.225)/2 + (0.01 - 0.225)^2/4 \times 0.8$$

$$L = 1.39 \text{ m}$$

$$\text{Length of the belt} = 1398 \text{ mm}$$

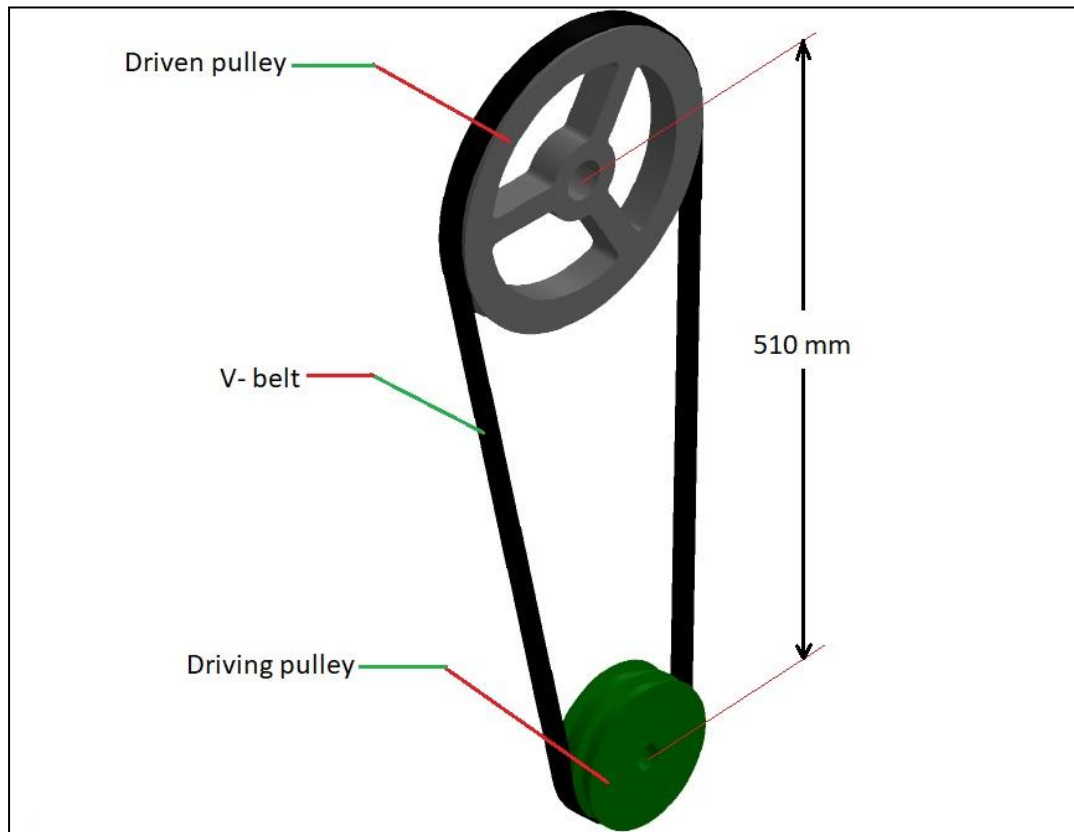


Fig.3.8 Power transmitting through V-belt

3.9 Laboratory Evaluation

3.9.1 Patternator test for swath uniformity

To achieve full chemical efficiency at minimal cost and minimal non-target contamination, the uniformity of the spray distribution across the boom or within the spray swath is important. On a patternator, the transverse swath uniformity of nozzles and sprayers can be tested. This gives the average distribution in the relatively still air of a laboratory over a period of time, but the knowledge is useful for detecting nozzles and sprayers that offer inherently poor uniformity.

For that as per the requirement a hollow cone nozzle and flat fan nozzle having medium/low discharge was selected. To have a view of uniformity of swath the nozzle was run at patternator at different pressures and different heights. A stationary view of nozzle for showing study is given in Fig 3.1

Selected nozzle was evaluated in the laboratory at four different pressure and six height of nozzle from the target using patternator available in the Farm Machinery Testing laboratory, Department of Farm Machinery and Power Engineering, Swami Vivekananda College of Agricultural Engineering & Technology, IGKV University, Raipur.

3.9.1.1 Patternator

A 196x120 cm spray patternator having 40 rectangular channels of metal sheet with inner dimensions of each channel equal to 120X 3.6 cm was used for study. Volume of liquid at different nozzle settings was collected in tubes having bore diameter of 2.5 cm and measured at different nozzle pressure, and nozzle height on spray pattern.

The Inclination of the spray channel section was fixed at the angle of 4.5°. The nozzle holding arrangement was made at the top in the middle of the main frame.

The height of nozzle assembly was also adjustable so there is a provision to increase or decrease the target distance between the nozzles and surface of the patternator. The pressure gauge was installed on the centre nozzle to check the operating pressure. All nozzles were operated at 3.0, 4.0 and 5.0 kg cm⁻² respectively

Based on the of BIS test codes and general practices being used for power source. The whole setup consisted of multistage pump, pressure gauge, throttling valve and plastic container for water collection. A stationary view of set up used for the evaluation of nozzles is given in Fig 3.9.

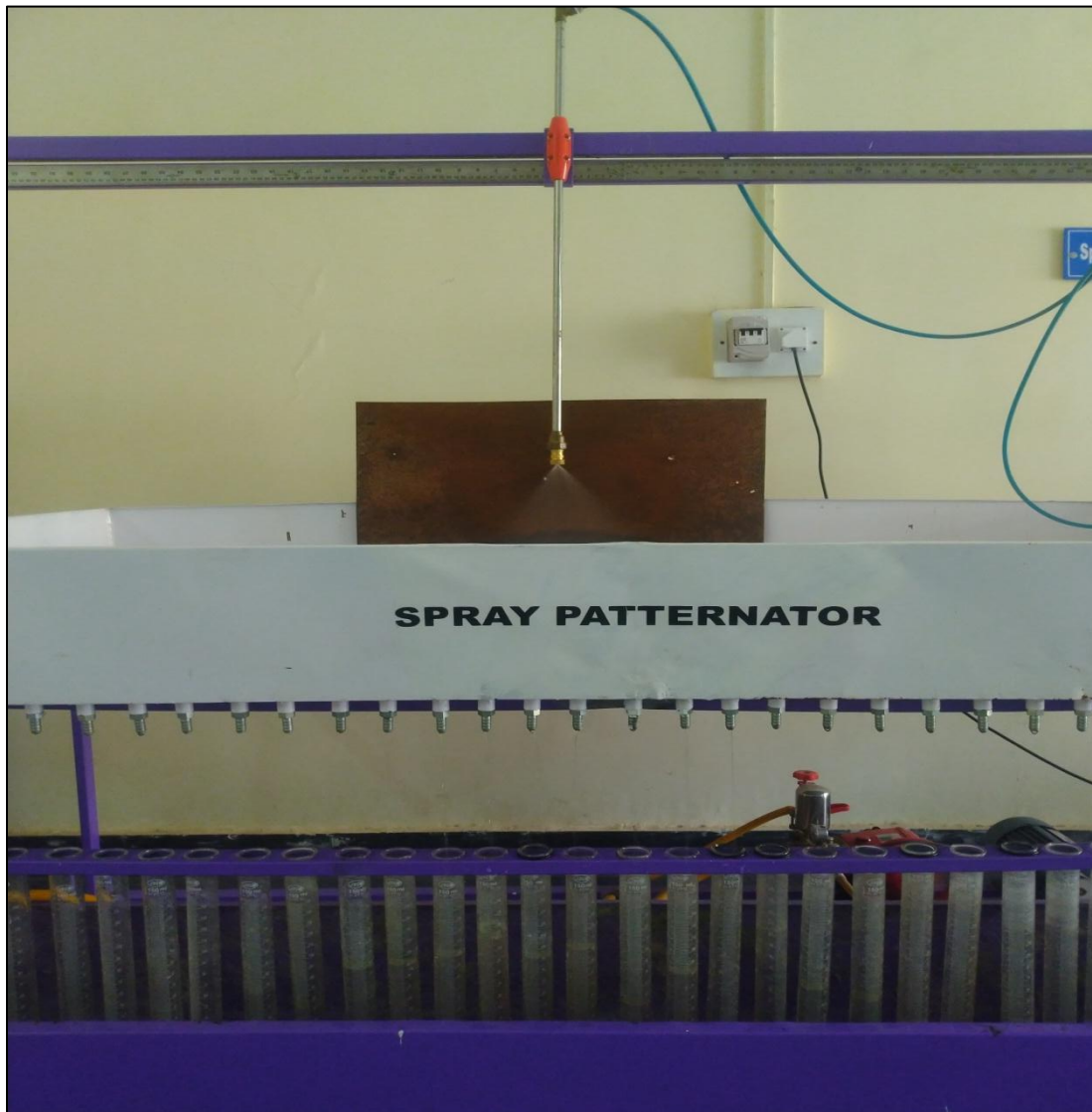


Fig.3.9 Nozzle arrangement in patternator

Each nozzle was mounted at a different target distance of 45 cm, 35 cm, and 25 cm to get effective spraying at different target distance available for spray on crop at different growth stage.

The nozzles were mounted above the patternator in such as way that the axis of the spray cone was at the right angle to the horizontal. Sprayed liquid was collected in the glass tubes for one minute and the volume of the collected liquid form each channel of the patternator was recorded. The procedure was replicated three times.

3.9.1.2 Pressure gauge

Pressure gauge was provided in between the pump and nozzle so that the desired pressure for experiment could be adjusted. The testing was conducted on four different pressures. A pressure gauge of range of 0-14 kg cm⁻² of laboratory is shown in fig.3.8



Fig.3.10 Pressure gauge provided in patternator

3.9.1.3 Control valve

To maintain the required pressure during the test procedure a control valve was provided in between the pump and nozzle line. A pressure release valve was also provided on HTP pump so that excessive liquid could be returned to the tank.

The liquid collected at each tube was noted. The coefficient of variation of average data were calculated in MS excel to detect uniformity of distribution. The independent and dependent parameters are given in Table 3.1.

Table 3.2: Levels of independent and dependent parameters for laboratory study.

Independent parameters	Levels	Remarks	Dependent parameters
Nozzle (N)	2	N ₁ , N ₂	• Discharge rate,
Height (H)	3	H ₁ , H ₂ , H ₃	• Uniformity of distribution
Nozzle Pressure (P), kg cm ⁻²	3	P ₁ , P ₂ , P ₃	• Angle of spray,
			• Swath width,
			• Droplet Density.
• N ₁ - Hollow cone		• P ₁ - 3 kg cm ⁻²	• H ₁ - 25 cm
• N ₂ - Flat Fan		• P ₂ - 4 kg cm ⁻²	• H ₂ - 35 cm
		• P ₃ - 5 kg cm ⁻²	• H ₃ - 45 cm

The type of spray pattern produced determines the characteristics of a particular nozzle. Spraying without proper uniformity may result in to inefficient pest control (Bindra and Singh, 1977). To get uniform spraying, spray patterns need proper overlapping. The overlapping of spray pattern was using a single nozzle pattern for each nozzle at different pressures and target distance. The minimum coefficient of variation (CV) of overlapped pattern will determine the effective swath width (spacing of nozzle to be mounted on a boom) and effective discharge rate.

Table 3.3 Different treatments on uniformity of spray patterns

Nozzle type	Pressure	Height of nozzle		
	(kg cm ⁻²)	H ₁	H ₂	H ₃
Flat fan-N ₁	P ₁	N ₁ P ₁ H ₁	N ₁ P ₁ H ₂	N ₁ P ₁ H ₃
	P ₂	N ₁ P ₂ H ₁	N ₁ P ₂ H ₂	N ₁ P ₂ H ₃

	P ₃	N ₁ P ₃ H ₁	N ₁ P ₃ H ₂	N ₁ P ₃ H ₃
Hollow	P1	N ₂ P ₁ H ₁	N ₂ P ₁ H ₂	N ₂ P ₁ H ₃
Cone-N ₂	P2	N ₂ P ₂ H ₁	N ₂ P ₂ H ₂	N ₂ P ₂ H ₃
	P3	N ₂ P ₃ H ₁	N ₂ P ₃ H ₂	N ₂ P ₃ H ₃

3.9.2 Evaluation of sprayer at different pressures and heights

The performance of sprayer was evaluated both in laboratory as well as on field. For this the several parameter were considered, and these were evaluated both in laboratory and on field. The relevant data were collected after evaluations.

3.9.2.1 Nozzle discharge rate

Nozzle discharge test was carried out to evaluate the amount of liquid discharge from each nozzle and to check the variation between the discharge rates of each nozzle within 1 minute intervals of 5minutes. The selected nozzles were tested at 3.0, 4.0, 5.0 kg cm⁻² pressures. Liquid was pumped as the sprayer moves and in each 1m interval the time taken and discharge data were collected and recorded for each nozzle by tying a plastic bag on each nozzle. Within each 1 minute the spray liquid was collected, and each liquid was measured using beaker. Coefficient of variation was used to analyze variation of discharge rate among the nozzles for each 5 minute interval.

3.9.2.2 Uniformity of coverage

The performance of liquid chemical application through sprayer was evaluated by the uniformity of coverage and spray patterns, droplet size and size distribution, and target deposition and drift. After collecting the test data, the best data was determined by using C.V. formula. The treatment which had minimum C.V. was considered the best. As per the IS test code IS:8548-1977 the test was conducted and a set of different measuring parameters like swath width, angle of

spray, nozzles discharge rate and spray pattern etc. with best height and pressure combination was considered.

3.9.2.3 Angle of spray and swath width

According to Bureau of Indian Standards the working width of nozzle is considered as the outer edges of swath where the channels receives about 50% or more quantity of liquid of the largest collected liquid quantity in millimeter at any of the patternator channels.

The spray angle is considered as the angle made by nozzle at its final orifice at any decided pressure. The angle was calculated by measuring the working width and height of nozzle from patternator channel surface.

Spray angle of nozzles were calculated by following equation

$$W = 2h \tan \frac{\theta}{2} \quad (3.21)$$

Where,

W = width of spray cone, mm

h = height nozzle, mm

θ = angle of spray, degrees

3.9.2.4 Spray overlapping

The overlap is defined as the width covered by two adjacent nozzles divided by the width covered by a single nozzle, expressed in percentage. It mainly affects spray pattern of the sprayer it depends on the boom height and nozzle spacing.

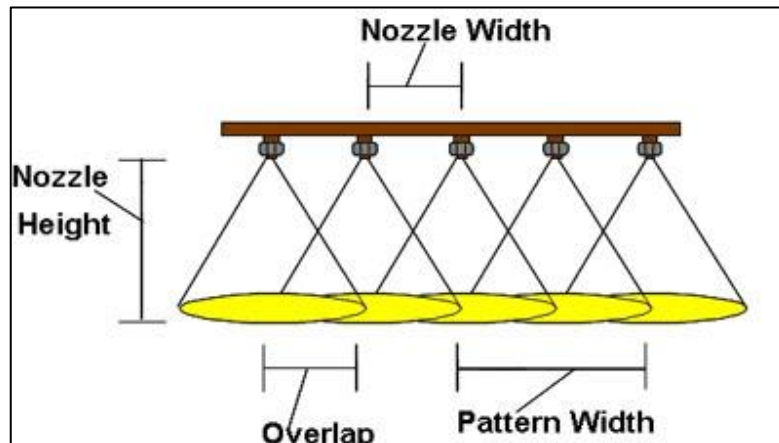


Fig. 3.11 Terminology of spray overlapping

For spray pattern to be overlap it is essential that

$$S_n < D_p \quad (3.22)$$

The degree of overlap is expressed by following equation:

$$\tan \frac{\theta}{2} = \frac{D_p}{S_n} \quad (3.23)$$

the above equation specifies that degree of overlap depends on θ , S_n , and D_p

$$\text{But, } D_p = S_n \times O_l \quad (3.24)$$

Where,

D_p is diameter of spray pattern at deposition surface

S_n is nozzle spacing

O_l is multiplying factor for overlap

3.10 Brief Details of Developed Power Sprayer for Soybean Crop

A power operated sprayer with 36 nozzles pesticides spraying machine has been developed for soybean crop. The machine consists of boom support structure and chemical storage cum power unit which consists of kerosene engine and HTP pump. Hollow cone pattern nozzles were used on the boom and plastic tank of 200 l for chemical storage. The HTP pump receives power from a kerosene engine with

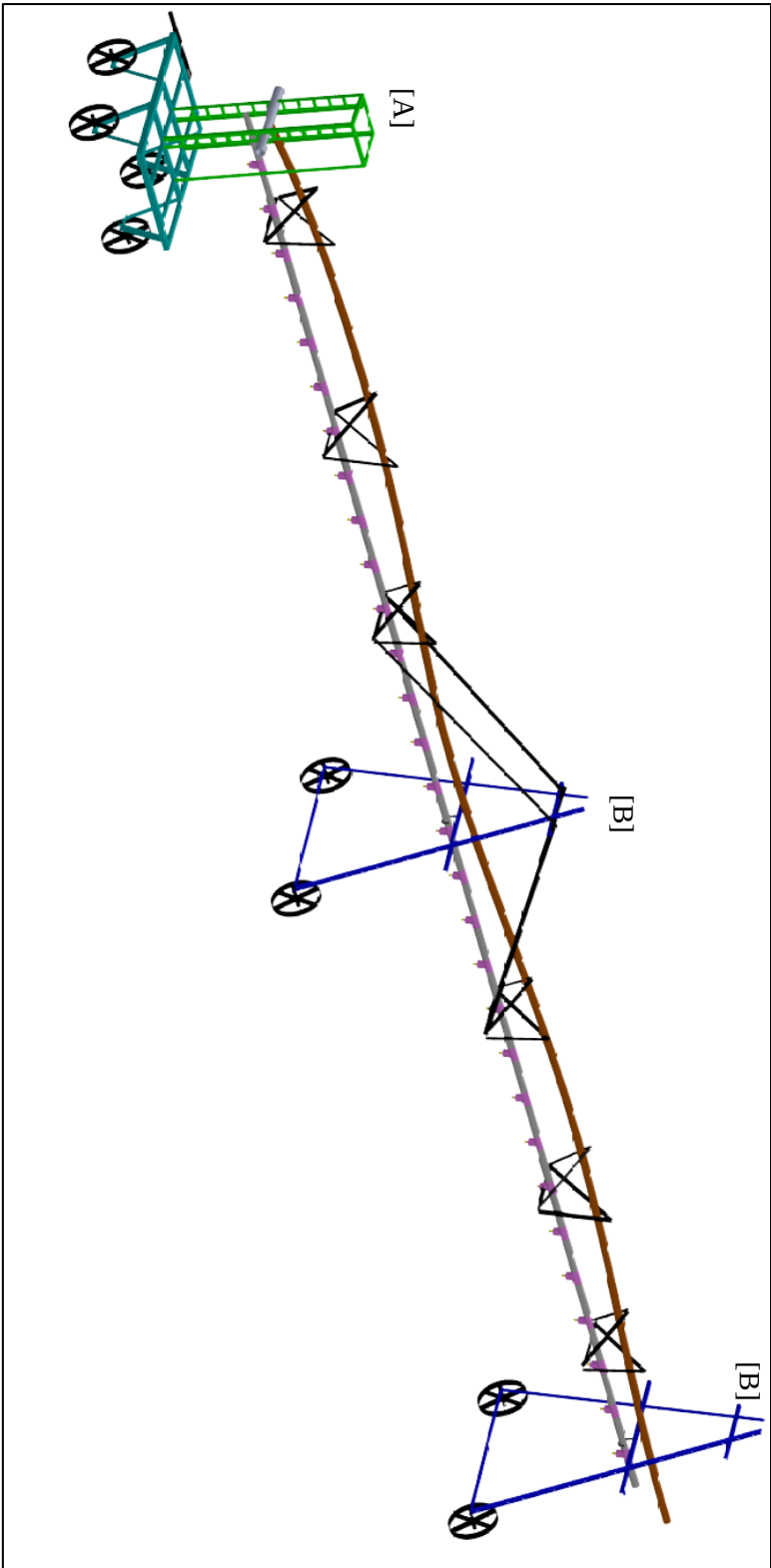
PTO shaft. The chemical is delivered to boom structure with the help of delivery pipe. Boom support structure is provided with wheels to be easily pulled in the field. For pulling of boom support structure one end trolley have facility of handle and other end is pulled with the help of plastic rope connected to bottom side of triangle structure.

Table 3.4 Different parameters of developed power sprayer of soybean crop

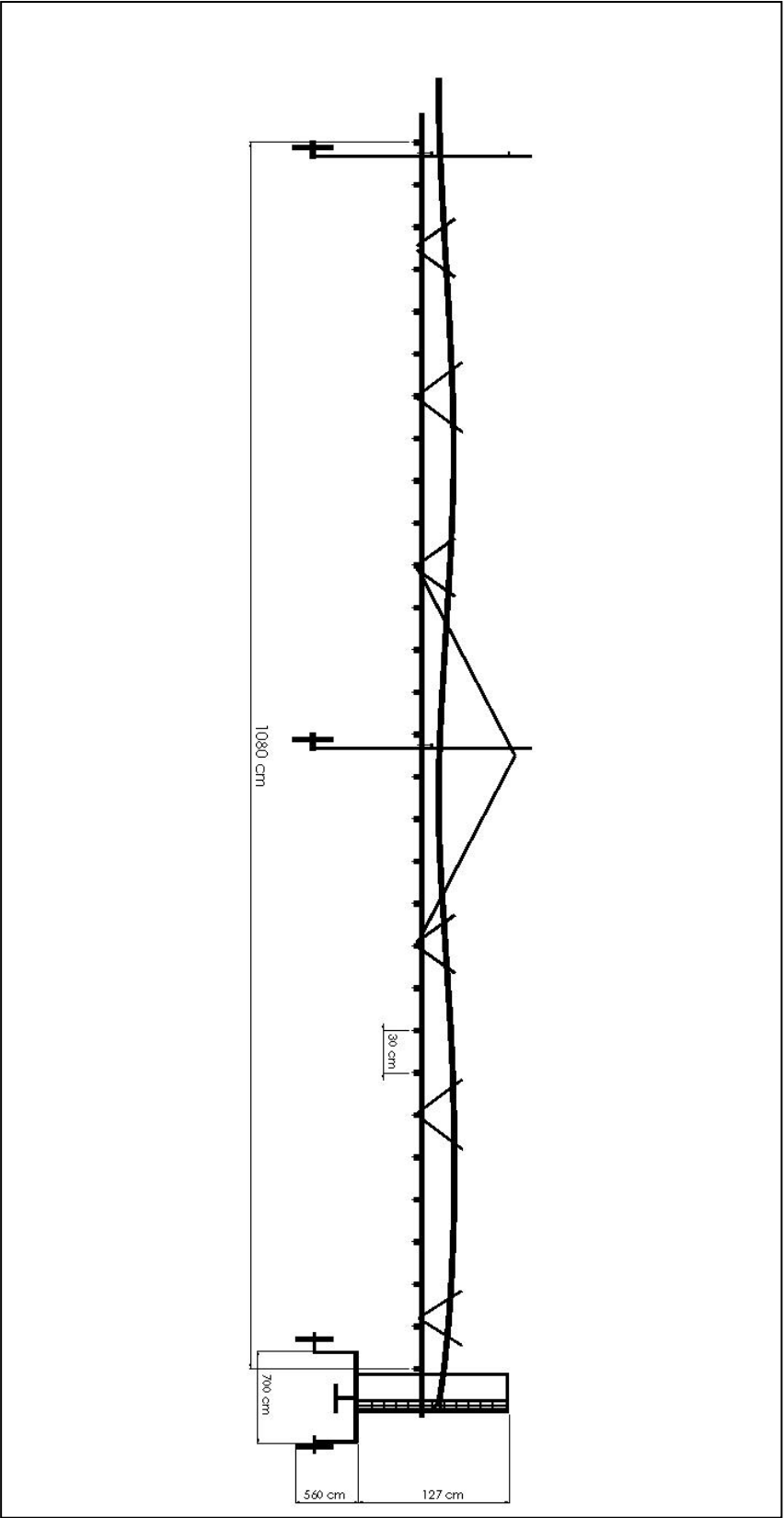
S. No.	Parameters	Values
Boom support structure		
1.	Number of nozzles on boom	36
2.	Nozzle spacing on boom, cm	30
3.	Height of boom from ground	Adjustable
4.	Type of nozzles	Hollow cone
5.	Delivery pipe diameter, cm	0.85
6.	Length of delivery pipe, m	50
Chemical storage cum power unit		
7.	Type of pump	Horizontal Triplex Piston
8.	Pump power, kW	3.73 – 5.96
9.	Pump speed, rpm	800 – 1000
10.	Pump operating pressure, k Pa	100 – 5000
11.	Engine power, kW	2.2
12.	Engine speed, rpm	3000
13.	Pesticide tank capacity, l	200

3.11 Computer aided design of power sprayer

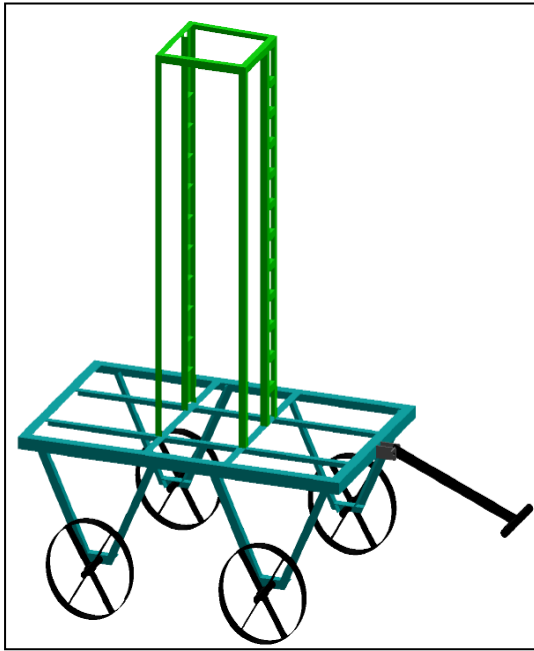
Computer aided design of machine (boom support span, chemical storage cum power unit) was made with solid work 2020 software are shown in fig. 3.11 to 3.12.



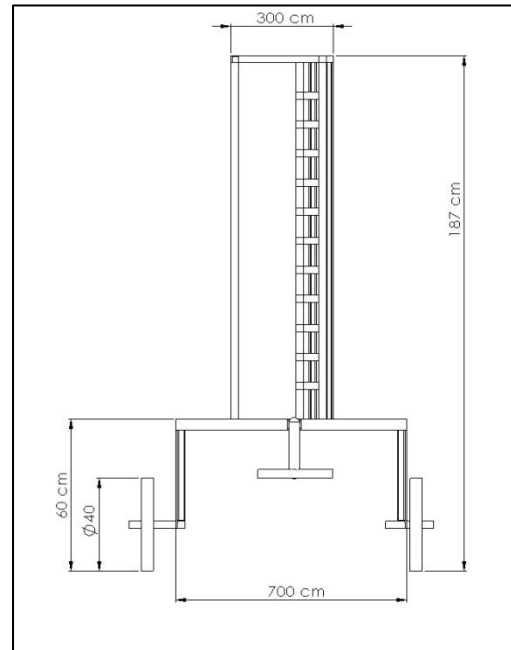
(a) Isometric view of boom support span



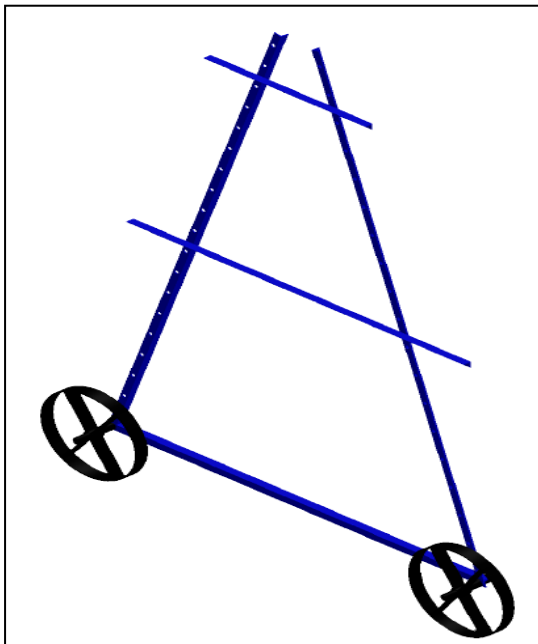
(b) Line diagram of boom support span



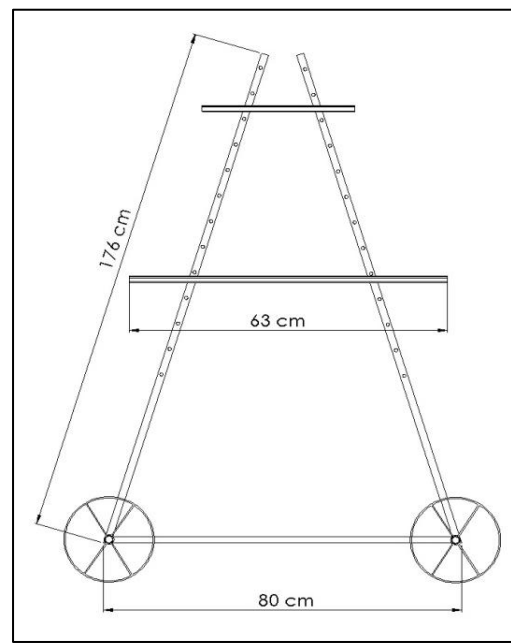
(c) Elongated view of component [A]



(d) Line diagram of component [A]



(e) Elongated view of component [B]



(f) Line diagram of component [B]

Fig 3.12 Isometric view of boom support span

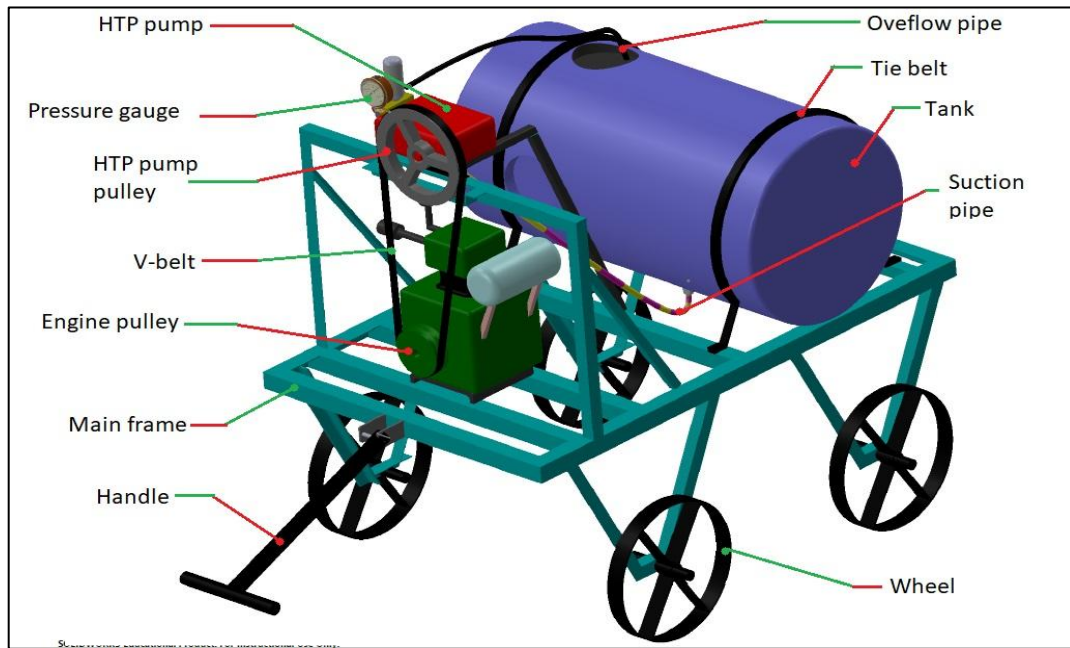


Fig 3.13 Isometric view of boom support span

3.12 Actual View of Developed Power Sprayer

Actual view of fabricated machine is shown in fig 3.13 and fig 3.14.



Fig 3.14 Actual view of boom support span



Fig 3.15 Actual view of chemical storage cum power unit

3.13 Field Test

The field size, test duration, spray pressure, swath, discharge, speed of operation, field capacity and other relevant information were taken. The field test were conducted on 0.40 ha trial field at IGKV campus.

3.13.1 Application rate of boom

The application rate of sprayer was calculated by measuring the volume of liquid for cover the test plot. Following equation was used to calculate application rate

$$\text{Application rate (l ha}^{-1}\text{)} = \frac{\text{Volume of liquid sprayed}}{\text{Area of test plot}} \quad (3.25)$$

3.13.2 Field capacity of the sprayer

3.13.2.1 Theoretical field capacity

Theoretical field capacity was calculated by

$$\text{Theoretical Field capacity} = \frac{\text{speed} \times \text{boom width}}{10} \times 100 \quad (3.26)$$



Fig 3.16 Field test of developed machine

3.13.2.2 Actual field capacity

For calculating actual field capacity the time consumed for real work and that lost for other activities such as turning, filling of tank were taken into consideration. The time required for actual operation and time lost measured by stopwatch. Actual field capacity was calculated by

$$\text{Actual field capacity} = \frac{A}{T_{\text{total}}} \quad (3.27)$$

$$\text{Total time} = \text{time for turning} + \text{time for refilling} + \text{time for actual work} \quad (3.28)$$

Where,

A = area covered, ha;

T_{total} = total time taken, hour;

3.13.2.3 Field efficiency

Field efficiency is the ratio of actual field capacity to the theoretical field capacity, field efficiency is expressed in percent, (Sahay, 1971). Accordingly field efficiency was worked out using following relation;

$$\text{Field efficiency} = \frac{\text{Actual Field capacity}}{\text{Theoretical field capacity}} \times 100 \quad (3.29)$$

3.14 Sample Collection for Droplet Size

Glossy papers were used to collect droplet data. Liquid was mixed thoroughly with blue dye so that, spots can be easily analyzed. These papers were analyzed by using computer image analyzer (Fiji) application. The computer program consist of custom plug-in which process the uploaded image and gives the numbers of spots on image.

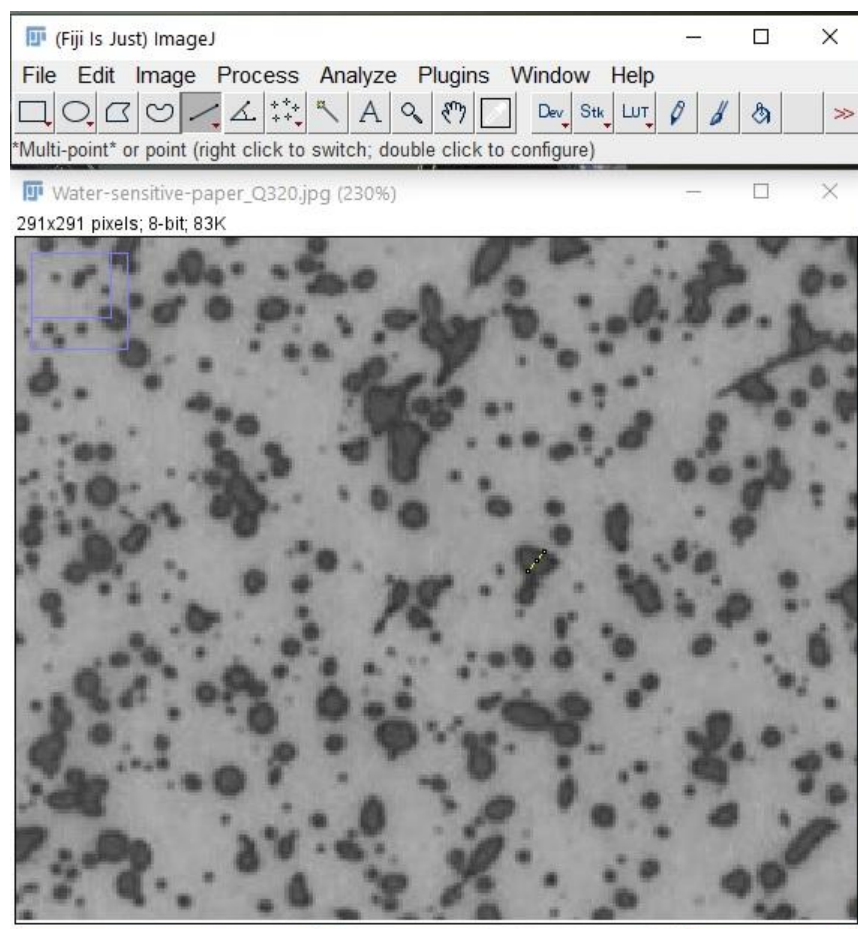


Fig 3.17 Image analyzer application window

The sample tags were scanned with scanner and cropped with no background. To encounter any type of foreign stains or dots, that the accuracy of counting can be maintained. The glossy paper of size 2 cm x 5 cm were taken and putted on random place under each test plot, and tags were fixed as they facing upwards.

After taking samples each tag was analyzed using Fiji application software for droplet diameter and number of droplets.

3.15 Fuel Consumption

The consumption of fuel affects the cost of operating machine. Generally the fuel consumption is measured in l h^{-1} or l ha^{-1} . The fuel consumed in this power sprayer was measured by “*Topping-Up Method*”.

Initially the engine tank was filled to top of its neck and then the sprayer was operated at the field and then the fuel used for topping up was measured by using beaker. In this way the fuel used to that time taken and area covered was determined.

3.16 Cost Economics of Developed Sprayer

Cost of spraying operation performed for all the treatments was calculated on the basis of prevalent input cost and price used for fabrication of the machine, rental wages of operator and labour. The cost of operation of machine was calculated in the two sections as fixed cost and variable costs. Fixed cost is independent of variable cost, and variable cost depends upon the work amount.

3.16.1 Fixed cost

(a) Depreciation

This cost reflects the reduction in value of a machine with use (wear) and time (obsolescence). While actual depreciation would depend on the sale price of the machine after its use.

The following expression based on the straight line method was used to calculate the depreciation (IS: 9164 -1979).

$$D = \frac{P-S}{L \times H} \quad (3.30)$$

Where

D = Depreciation cost, Rs h⁻¹;

P = Initial cost of the machine, Rs;

S = Salvage value of the machine, usually taken as 10% of the initial investment of the machine Rs;

L = Expected useful life period of the machine, years;

H = Number of working hours per year.

(b) Interest

Interest on investment in a farm machine is a legitimate cost, since money spent in buying a machine cannot be used for other productive enterprises. Annual charges of interest should be calculated on the basis of the actual rate of interest payable. The rate of interest should reflect the prevailing rates (12%) (IS:1964-1979). The interest on investment was calculated by using formula given below.

$$I = \frac{P-S}{2} \times \frac{i}{H} \quad (3.31)$$

Where,

I = Interest on investment, Rs h⁻¹

P = Capital cost of machine, Rs.

S = Salvage value of machine, Rs.

H = Number of working hours per year

i = Rate of interest (usually it is assumed as 12 %)

(c) Taxes and insurance

It is taken as 2% of the initial cost of the machine per year. Insurance cost is taken based on the actual payment to the insurance (IS:9164-1979).

(d) Housing cost

Housing cost was calculated on the basis of prevailing rates of locality, it is generally taken as 1.5% of initial cost of the machine per year (IS: 9164-1979).

3.16.2 Variable cost

(a) Repair and maintenance

Repair and maintenance costs are necessary to keep a machine in perfect working condition due to wear, part failure, renewal of tyre and tube and accidents. The repair and maintenance costs shall be calculated as 5 to 10% of the initial cost of the machine per year (Sahay, 1971).

(b) Fuel cost

Fuel consumption depends on the size of the power unit and cost of actual fuel consumption was calculated as shown.

$$\text{Fuel cost (Rs h}^{-1}\text{)} = \text{Quantity of fuel consumed per hour (l h}^{-1}\text{)} \times \text{Cost of fuel (Rs lit}^{-1}\text{)} \quad (3.32)$$

(c) Lubricants

Charges for lubricants should be taken as actual consumption but roughly cost of lubricating oil was taken as 30 % of fuel cost (Sahay, 1971).

$$\text{Oil cost} = 30\% \times \text{Quantity of fuel consumed per hour (Rs h}^{-1}\text{)} \text{ (l h}^{-1}\text{)} \times \text{Cost of fuel (Rs lit}^{-1}\text{)} \quad (3.33)$$

(d) Operator wages

It was calculated as per actual wages of operator per hour as on prevalent time.

3.16.3 Total cost of operation of developed power sprayer

By summing the total fixed cost and variable cost we got the total cost of spraying per hour was carried as shown below.

$$\text{Total cost per hour} = \text{Fixed cost per hour} + \text{Variable cost per hour} \quad (3.34)$$

$$\text{Cost of spraying operation (Rs ha}^{-1}\text{)} = \frac{\text{Total cost Rs h}^{-1}}{\text{Effective field capacity}} \quad (3.35)$$

3.16.4 Break-even point

Break-even point of machine was calculated by following equation (Sharma and Mukesh, 2008).

$$\text{BEP} = \frac{\text{AFC}}{\text{CH} - \text{OC}} \quad (3.36)$$

Where,

BEP = Break-even point, h yr⁻¹;

AFC = Annual fixed cost of machine, Rs y⁻¹;

OC = Operating cost, Rs y⁻¹; and

CH = Custom hiring charge, Rs y⁻¹ = (OC + 25 % over head).

3.16.5 Payback period:

Payback period of developed sprayer was calculated by following equation (Sharma and Mukesh, 2008).

$$\text{PBP} = \frac{\text{P}}{\text{ANP}} \quad (3.37)$$

Where,

PBP = Payback period, year;

P = Initial cost of machine, Rs; and

ANP = Average net annual profit, Rs y^{-1} ,

$$ANP = (CH - OC) \times AU \quad (3.38)$$

$$AU = AA \times EC \quad (3.39)$$

Where,

AA = Average annual use, h y^{-1} and

EC = Effective capacity of machine, ha h^{-1} .

RESULTS AND DISCUSSION

This chapter deals with the results obtained during the experiments and research work. The results pertaining to laboratory test performance of both nozzles for pesticide application at different heights and pressure have been described and discussed.

4.1 Laboratory Testing of Components of Soybean Power Sprayer

Prior to operation in the field, power sprayer for soybean was tested in laboratory to ensure proper working of all the components. In the laboratory, the performance of different nozzle types was tested for their uniformity, category of droplet, swath width, discharge etc.

4.1.1 Selection of nozzles

As the first step, the nozzles for project work were chosen as per market availability because for boom sprayer the numbers of nozzles were much more required for this sprayer. In this way, flat fan and hollow cone nozzles were selected for laboratory evaluation. These nozzles are easily available in Chhattisgarh. Both the nozzles are generally used for of agricultural sprayers. Testing of nozzles for pesticide application was conducted with respect to different independent and dependent parameters. Statistical analysis viz. Factorial complete randomized design was used and level of significance was taken as 5%.

4.1.2 Uniformity of spray distribution

Uniformity of spray nozzles were tested under patternator. Uniformity test gives idea about the quantity of liquid distributed over the area under spray pattern. So both the nozzles were tested at different pressures and heights. The liquid collected from all the measuring tubes were noted and data were analyzed in MS excel to find the variability of quantity of liquid. The uniformity data are depicted in the graphs as shown in Fig. 4.1 to 4.9.

A good nozzle should precisely distribute equal amount of liquid in each channels. Variability in the distribution should be low and so it should make a flat distribution pattern and also it should have a bigger covering area. In actual, the nozzle makes a higher concentration of liquid to the centre channels.

4.1.2.1 Spray liquid distribution of Hollow cone nozzle (N_1)

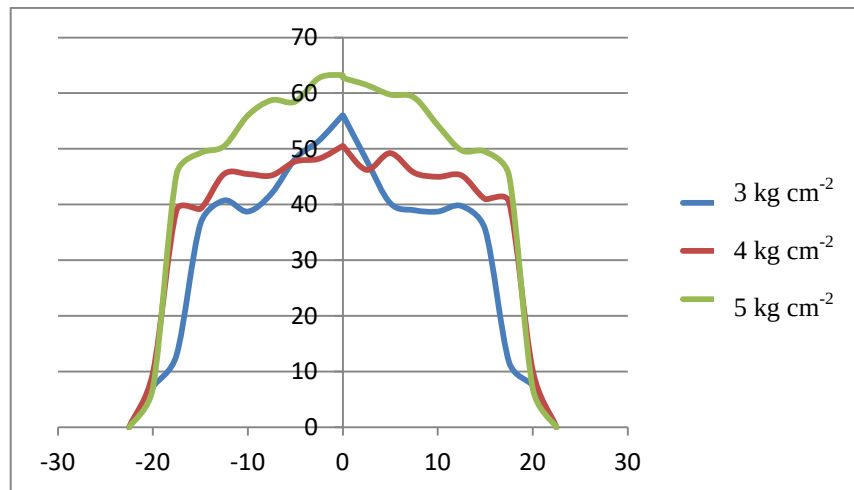


Fig.4.1 Hollow cone nozzle (N_1) volumetric distribution of liquid due to different operating pressures at 25 cm height

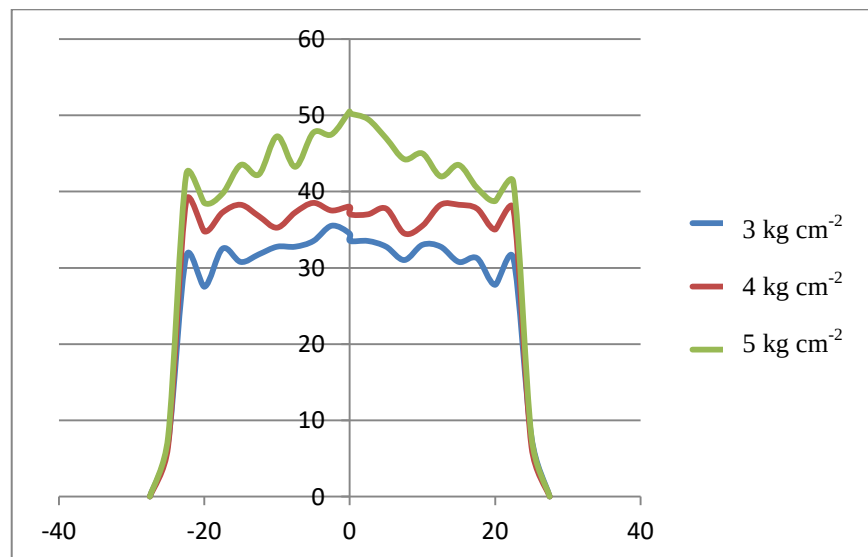


Fig.4.2 Hollow cone nozzle (N_1) volumetric distribution of liquid due to different operating pressures at 35 cm height

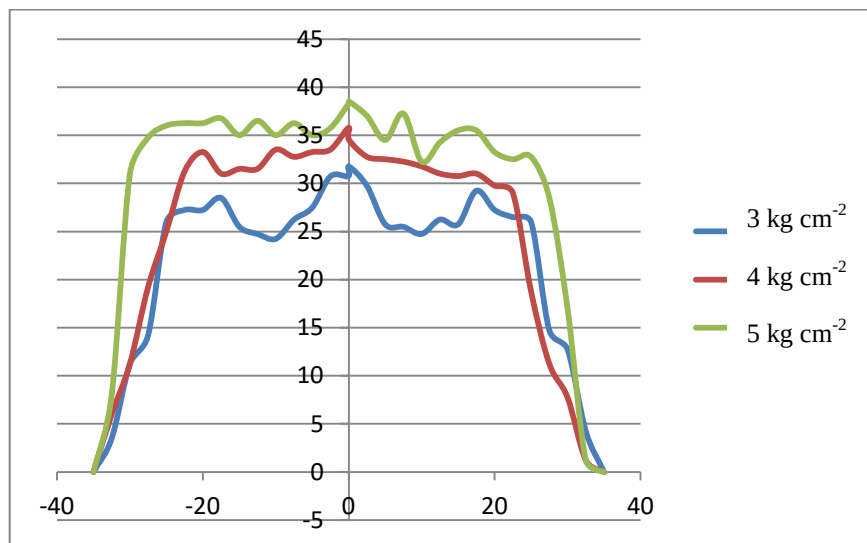


Fig. 4.3 Hollow cone nozzle (N_1) volumetric distribution of liquid due to different operating pressures at 45 cm height

From the above figures it was found that the nozzle distributes larger amount of liquid at central channels and comparatively lower in corner channels. The swath width was getting larger as the pressure was increased but the discharge was also increased with it, which led to more wastage of spray liquid.

Also the more pressure cause to smaller droplets caused more drift. By analyzing all graphs it was found that at a pressure of 4 kg cm^{-2} the nozzle was making more equally concentrated pattern by yielding an optimum discharge.

At pressure of 4 kg cm^{-2} the hollow cone nozzle was making most uniform spray and also has minimum coefficient of variation. When pressure was increased discharge of nozzle also increased simultaneously, this led to increase in wastage of liquid.

On the other hand when pressure was decreased to 3 kg cm^{-2} , coefficient of uniformity was also increased so the hollow cone nozzle working at 4 kg cm^{-2} was chosen as best.

4.1.2.2 Spray liquid distribution of Flat fan nozzle (N_2)

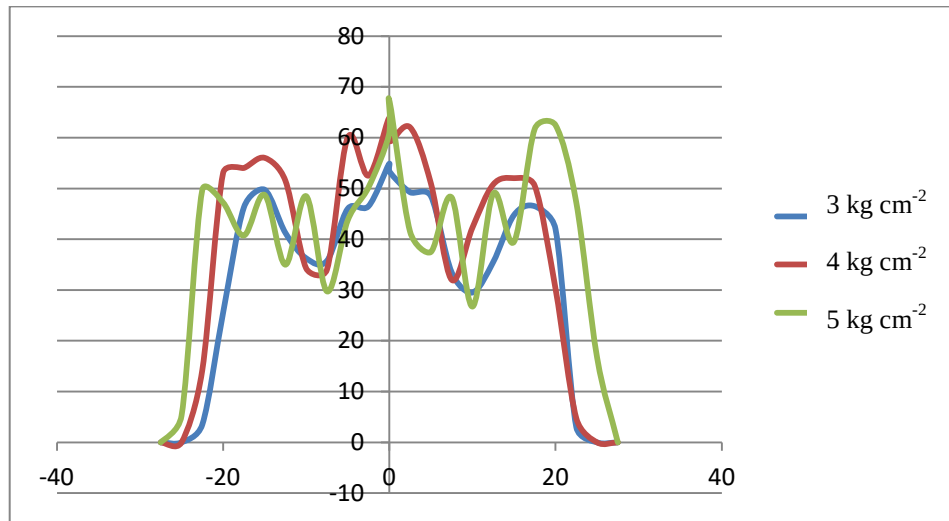


Fig. 4.4 Flat fan nozzle (N_2) volumetric distribution of liquid due to different operating pressures at 25 cm height

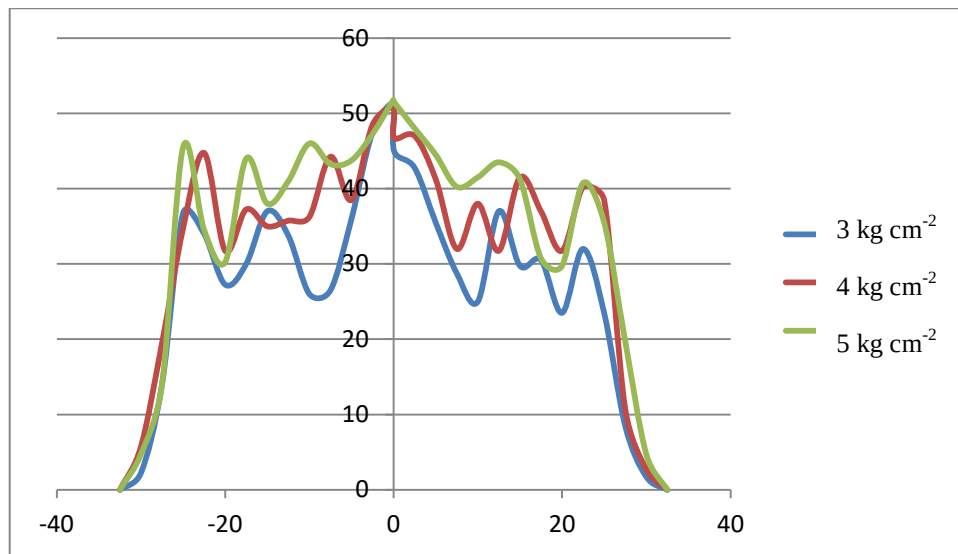


Fig. 4.5 Flat fan nozzle (N_2) volumetric distribution of liquid due to different operating pressures at 35 cm height

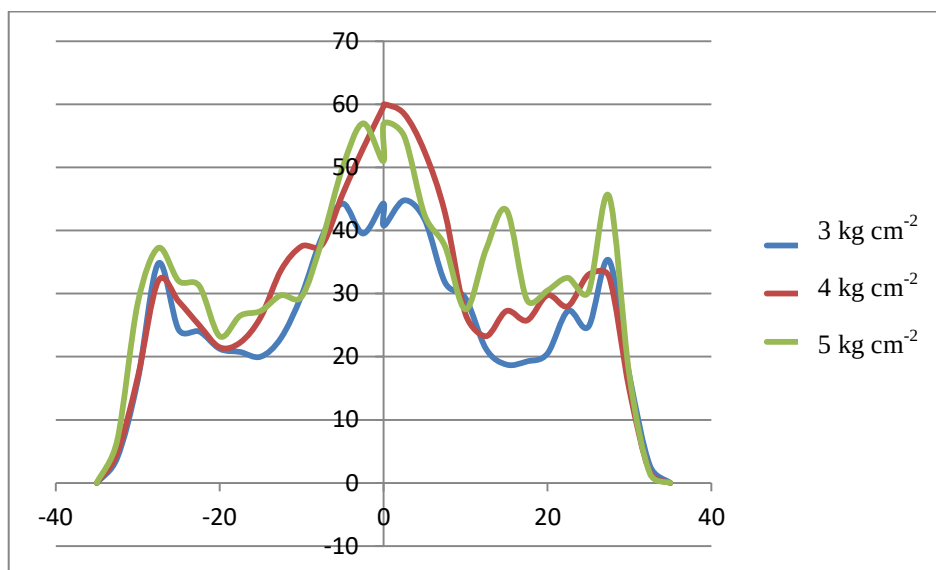


Fig. 4.6 Flat fan nozzle (N₂) volumetric distribution of liquid due to different operating pressures at 45 cm height

According to Fig.4.4 to Fig.4.6 it can be seen that the concentration made by flat fan nozzle had so much inequality which was not suited for uniform spraying. These distributions also confirm that central channels get more concentration than others. The performance of nozzle was tested under 3 pressures viz. 3 kg cm⁻², 4 kg cm⁻² and 5 kg cm⁻² and all the data collected were shown by the trend lines on the graph.

When the height of nozzle was increased, more flat distribution was achieved but at more height the spray angle got reduced. When pressure was increased on hollow cone from 3 kg cm⁻² to 4 kg cm⁻², the number of evenly liquid distribution channels was increased. On the other hand, when pressure was increased from 4 kg cm⁻² to 5 kg cm⁻², the flatness of distribution curve got again disturbed.

4.1.3 Effect of nozzle height, nozzle type and pressure on coefficient of variation

One of the most important requirements on agricultural sprayer is to produce uniform distribution of the applied chemical on the target area. A series of laboratory measurements were conducted to examine the spray uniformity

distribution. In total, 18 combinations of nozzle type, height and pressure were tested corresponding with 72 measurements for N₁- Hollow cone nozzle, N₂-Flat fan nozzle.

Table 4.1 Effect of nozzle type and nozzle height on coefficient of variation

Treatment	CV, %
N ₁ H ₁	5.17
N ₁ H ₂	4.47
N ₁ H ₃	7.29
N ₂ H ₁	18.26
N ₂ H ₂	18.56
N ₂ H ₃	18.84
C.D.	0.040
SE(d)	0.019
SE(m)	0.013

The ANOVA table for interaction (N×H) between nozzle type (N) and nozzle height (H) is shown in Appendix-B which indicates that there is significant difference at 5% level. The low value of coefficient of variation represents an indication for good uniformity distribution.

From the Table 4.1 it was observed that among different interactions (N×H), between nozzle type and nozzle height, treatment N₁H₂ gave the best uniformity distribution (4.47%), followed by N₁H₁ (5.17%) and N₁H₃ (7.29%). The coefficient of variation is tolerated up to 11% and uniformity of distribution over this limit is declared as in-sufficient.

The value of coefficient of variation of N₂ at all the respective heights of H₁, H₂ and H₃ were found greater than 11%. The details of coefficient of variation of interaction between nozzle type and nozzle height is presented in Table 4.1.

Table 4.2 Effect of nozzle types and pressure on coefficient of variation.

Treatment	CV
N ₁ P ₁	5.55
N ₁ P ₂	5.62
N ₁ P ₃	5.76
N ₂ P ₁	17.47
N ₂ P ₂	18.43
N ₂ P ₃	19.75
C.D.	0.040
SE(d)	0.019
SE(m)	0.013

The ANOVA Table for interaction between nozzles type and pressures was found to be significant at 5% level (Appendix-B). This is probably due to the behavior of the nozzles of different spray angles. The values of coefficient of variation in percentage (CV, %) were 5.55% for N₁P₁ followed by 5.62% and 5.76% for N₁P₂, N₁P₃ respectively. The selection of nozzle may reduce the losses of spray dose and gives good distribution pattern as reflected in the values of coefficient of variation.

The interaction between the type of nozzle and the nozzle pressure indicated that with increasing pressure, the spray pattern also increases. The critical difference was found to be 0.040 between the treatment of different nozzle type and pressure. Details of coefficient of variation of interaction between nozzle type and pressure are presented in Table 4.2.

Table 4.3 Effect of interaction between nozzle type, nozzle height and the nozzle pressure on the coefficient of variation.

Treatment	CV, %
N ₁ H ₁ P ₁	4.44

N ₁ H ₁ P ₂	5.99
N ₁ H ₁ P ₃	5.08
N ₁ H ₂ P ₁	5.13
N ₁ H ₂ P ₂	4.04
N ₁ H ₂ P ₃	4.26
N ₁ H ₃ P ₁	7.10
N ₁ H ₃ P ₂	6.84
N ₁ H ₃ P ₃	7.95
N ₂ H ₁ P ₁	14.50
N ₂ H ₁ P ₂	17.16
N ₂ H ₁ P ₃	23.13
N ₂ H ₂ P ₁	22.71
N ₂ H ₂ P ₂	16.80
N ₂ H ₂ P ₃	16.17
N ₂ H ₃ P ₁	15.22
N ₂ H ₃ P ₂	21.35
N ₂ H ₃ P ₃	19.95
C.D.	0.069
SE(d)	0.033
SE(m)	0.023

• N ₁ - Hollow cone	• P ₁ - 3 kg cm ⁻²	• H ₁ - 25 cm
• N ₂ - Flat Fan	• P ₂ - 4 kg cm ⁻²	• H ₂ - 35 cm
	• P ₃ - 5 kg cm ⁻²	• H ₃ - 45 cm

The effect of interaction of nozzle type, nozzle height and pressure were also investigated. The interaction among these three factors was found to affect the results of spray distribution. The critical difference between the treatment of different nozzle type, height and pressure was found to be 0.069.

The flat fan nozzle had given coefficient of variation much higher as compared to hollow cone nozzle. In the case of hollow cone nozzle the distribution of liquid to each channel was almost equal to adjacent channels. But in the case of flat fan nozzle there was much disruption in distribution of liquid.

Analyzing the results as shown in Table 4.3, it was found that under hollow cone nozzle, with the treatment combination ($N_1H_2P_2$) makes most uniform distribution as indicated with the least value of coefficient of variation (4.44%) among its different treatments.

On the other hand, under flat fan nozzle with treatment combination ($N_2H_1P_1$) resulted in the most uniform distribution with the least value of coefficient of variation (14.50%). The analysis of variance is shown in Appendix-B, it reveals that there are significant differences at 5% level due to the effect of different nozzle type, height and pressure. Details of interaction between nozzle type, height and pressure are presented in Table 4.3.

4.1.4 Effect of nozzle type, pressure and height on spray angle and swath

width

To measure the swath width and spray angle of the tested nozzles, the inline spray patternator was used. Another important nozzle performance parameter that defines the correct nozzle spacing, overlap and height of the application is the spray angle. The angle of the spray depends on the nozzle type, height and operating pressure. To analyze the spray angle and swath width, a series of laboratory measurements were performed. Total 18 combinations of nozzle type, height and pressures were performed. The results revealed that when the pressure increases swath width and angle also increases but at 45 cm height swath width gradually tends to remain constant.

Table 4.4: Effect of nozzle height on spray angle and swath width.

Treatment	Spray angle, °	Swath width, cm
N_1H_1	65.23	32

N ₁ H ₂	86.47	43
N ₁ H ₃	79.03	52
N ₂ H ₁	80.06	42
N ₂ H ₂	72.79	51.6
N ₂ H ₃	62.85	55
C.D.	6.896	0.607
SE(d)	3.282	0.289
SE(m)	2.320	0.204

As shown by the results of interaction, it is evident that combination of nozzle type and nozzle height affects spray angle significantly at 5% level as shown in Appendix-C. After the analysis of data, it was found that when height was increased from 25 to 35 cm, the angle of spray varied from 65.23° to 86.47° for hollow cone nozzle, and decreased from 80.06° to 72.79° for flat fan nozzle. When height was further increased from 35 cm to 45 cm a gradual decrease in spray angle for hollow cone nozzle was reported. The effect on spray angle of both nozzles (hollow cone and flat fan) at different heights and pressures are shown in Fig 4.7 and Fig 4.8.

Table 4.5: Effect on spray angle and swath width due to pressure.

Treatment	Spray angle, °	Swath width, cm
N ₁ P ₁	69.984	35
N ₁ P ₂	81.507	44
N ₁ P ₃	73.002	37
N ₂ P ₁	77.319	40
N ₂ P ₂	80.06	42
N ₂ P ₃	83.974	45
C.D.	N/A	0.607
SE(d)	3.282	0.289

SE(m)

2.320

0.204

Table 4.6: Effect on spray angle and swath width due to nozzle type, height and pressure.

Treatment	Spray angle, °	Swath width, cm
N ₁ H ₁ P ₁	72.5	37.5
N ₁ H ₁ P ₂	80.5	38.5
N ₁ H ₁ P ₃	75.5	39
N ₁ H ₂ P ₁	95.5	53.5
N ₁ H ₂ P ₂	86.5	43.5
N ₁ H ₂ P ₃	99.5	50
N ₁ H ₃ P ₁	124	62
N ₁ H ₃ P ₂	121	61
N ₁ H ₃ P ₃	115.5	59.5
N ₂ H ₁ P ₁	82.5	40
N ₂ H ₁ P ₂	86	45.5
N ₂ H ₁ P ₃	100.5	52
N ₂ H ₂ P ₁	94	54.5
N ₂ H ₂ P ₂	97	55.5
N ₂ H ₂ P ₃	105.5	56
N ₂ H ₃ P ₁	110.5	55
N ₂ H ₃ P ₂	115	62.5
N ₂ H ₃ P ₃	111	60
C.D.	N/S	1.051
SE(d)	5.684	0.500
SE(m)	4.019	0.354
• N ₁ - Hollow cone	• P ₁ - 3 kg cm ⁻²	• H ₁ - 25 cm

- N₂- Flat Fan
- P₂- 4 kg cm⁻²
- H₂- 35 cm
- P₃- 5 kg cm⁻²
- H₃- 45 cm

The results as shown in the ANOVA, it was found that the interaction of nozzle pressure makes a significant effect on the spray angle and also on the swath width at 5% level of significance. When pressure gradually increased, the swath width also increased proportionality. Details of effects of interactions of nozzle type, height and pressure on spray angle and swath width are shown in Appendix-C and Appendix-D respectively.

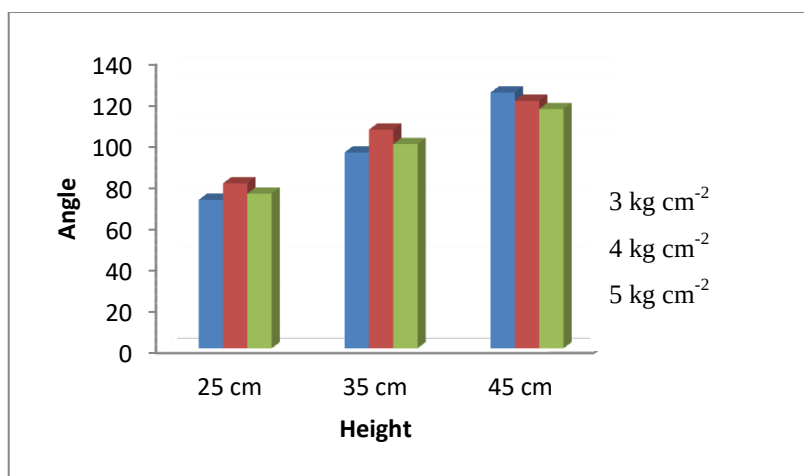


Fig.4.7: Effect of different pressures and heights on spray angle of Hollow cone nozzle (N₁).

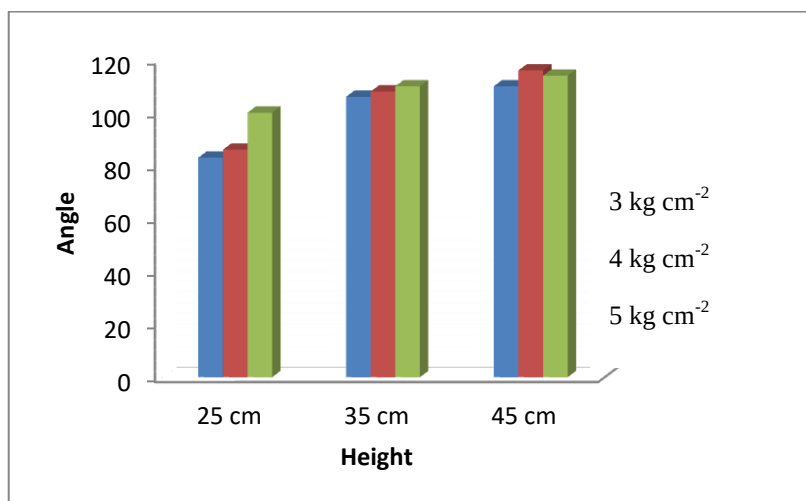


Fig.4.8: Effect of different pressures and heights on spray angle of Flat fan nozzle (N₂).

As shown in Fig. 4.9, when the height is increased swath width also increased. As the height on nozzle increased from 25 cm to 35 cm swath width increased from 32 to 43 cm and 42 to 51.6 cm for nozzle N_1 and N_2 respectively. In case when height further increased from 35 cm to 45 cm, the swath width also increases from 43 to 52 cm and 51.6 to 55 cm for N_1 and N_2 respectively. The Fig. 4.9 and Fig. 4.10 shows the details about increase in swath width due to different pressure and height.

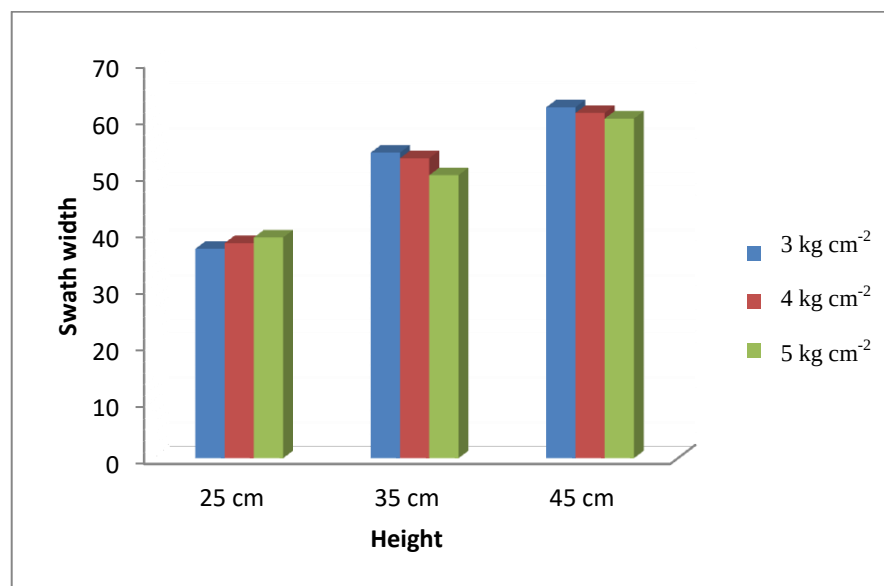


Fig. 4.9: Effect of pressure and height on Swath width of Hollow cone nozzle (N_1).

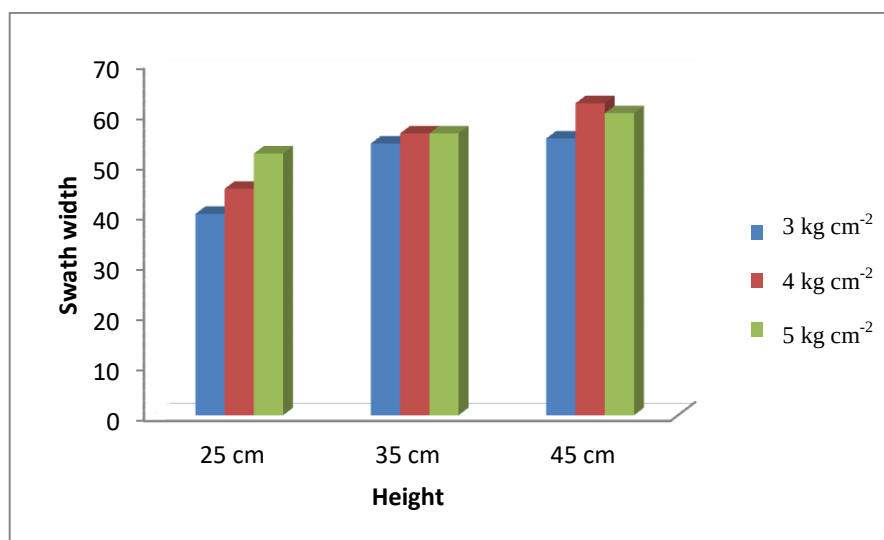


Fig. 4.10: Effect of pressure and height on Swath width of Flat fan nozzle (N_2).

4.1.4.1 Spray angle

To sum up the above results, it was revealed that the hollow cone nozzle resulted in biggest spray angle 124° at H_3 and P_1 combination ($N_1H_3P_1$). Also the H_3 and P_2 combination ($N_2H_3P_2$) resulted in the largest swath width of 62.5 cm.

The results presented in ANOVA table it was found that interaction between nozzle type with height and pressure individually makes a significant effect on spray angle but could not effect significantly when interaction between nozzle type, height and pressure is taken in combination.

4.1.4.2 Swath width

By analysis of ANOVA of interaction of nozzle type, height and pressure it reveals that the height and pressure makes a significant effect on swath width significantly as well as individually.

Both the combination of $N_1H_3P_1$ and $N_2H_3P_2$ are good in terms of spray angle and swath width but it can be seen that the swath made by individual nozzle at these pressure height combinations are more than double of the nozzle spacing between two adjacent nozzles which led to excessive overlapping of spray pattern.

So the combination ($N_1H_2P_2$) which had good performance at uniformity distribution is chosen as best as it also had optimum discharge.

4.2 Effect of Pressure on Discharge Rate

The spray liquid was collected in plastic bag and then it was measured with the help of marked beaker and data was analyzed at 5% level of significance. Discharge amount of liquid were measured and data were noted at 3 kg cm^{-2} , 4 kg cm^{-2} and 5 kg cm^{-2} each for 1 minute.

The results are presented in Table 4.7. It showed that when the pressure was increased discharge also increased proportionately.

Table 4.7 Effect of nozzle type and pressure on average discharge on nozzle

Treatment	Discharge, ml min ⁻¹
N ₁ P ₁	650.5
N ₁ P ₂	744.5
N ₁ P ₃	900.5
N ₂ P ₁	771.25
N ₂ P ₂	908
N ₂ P ₃	957.25
C.D.	6.060
SE(d)	3.022
SE(m)	2.137

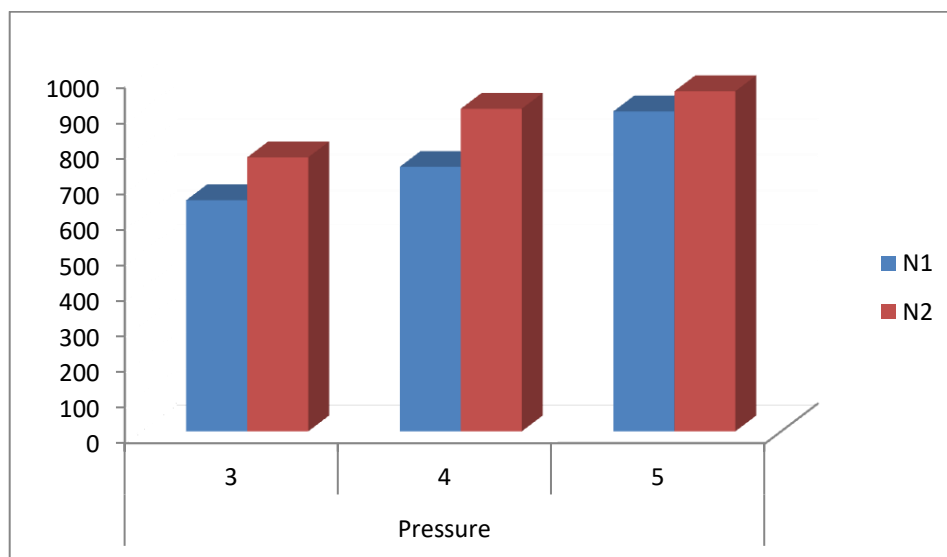


Fig. 4.11: Effect of different pressure on nozzle discharge.

As shown in Table 4.7, when pressure was increased from 3 kg cm⁻² to 4 kg cm⁻² and thereafter 5 kg cm⁻², the discharge of nozzle N₁ varied from 650.5 ml min⁻¹ to 900.5 ml min⁻¹. In the like way discharge of nozzle N₂ varied from 771.25 ml min⁻¹ to 957.25 ml min⁻¹ which indicated that discharge of nozzle was directly

proportional to pressure. So for controlling the application rate of chemical liquid in the field the pressure can be adjusted accordingly.

The discharge performance of combination $N_1H_2P_2$ was taken in account so that, in boom sprayer it should be necessary that every nozzle get good pressure and fluctuation in the pressure can't effect the spraying operation. Also the pressure P_2 was making good discharge that fulfilling agitation requirement of tank with using optimum spray discharge. As shown in the ANOVA table (Appendix-E), It was found that the interaction between nozzle type and pressure had a significant effect on nozzle discharge.

4.3 Effect of Nozzle Type, Height and Pressure on Average Droplet Size

Table 4.8 effect of nozzle type, height and pressure on average droplet size

Treatment	Average size (μm)
$N_1H_1P_1$	126.28
$N_1H_1P_2$	135.14
$N_1H_1P_3$	157.28
$N_1H_2P_1$	171.39
$N_1H_2P_2$	168.34
$N_1H_2P_3$	167.70
$N_1H_3P_1$	170.97
$N_1H_3P_2$	176.95
$N_1H_3P_3$	189.08
$N_2H_1P_1$	255.49
$N_2H_1P_2$	258.16
$N_2H_1P_3$	279.35
$N_2H_2P_1$	269.83
$N_2H_2P_2$	262.94

	N ₂ H ₂ P ₃	268.74
	N ₂ H ₃ P ₁	214.66
	N ₂ H ₃ P ₂	253.33
	N ₂ H ₃ P ₃	204.27
	C.D.	3.581
	SE(d)	1.704
	SE(m)	1.205
•	N ₁ - Hollow cone	• P ₁ - 3 kg cm ⁻² • H ₁ - 25 cm
•	N ₂ - Flat Fan	• P ₂ - 4 kg cm ⁻² • H ₂ - 35 cm
		• P ₃ - 5 kg cm ⁻² • H ₃ - 45 cm

Sample tags were collected during testing and analyzed with the help of computer software (Fiji). According to usage of insecticide and pesticide, droplet size should be in the range of 100-200 μ m.

Table 4.8, presented here depicts the average size of droplet made by both nozzles at different height and pressure combinations. The pressure and height were found to be significantly affecting the droplet parameters.

Smallest average size of droplet was found to be 126.28 μ m made by $N_1H_1P_1$ combination and largest droplet size was found to be 279.35 μ m at $N_2H_1P_3$ combination. But the average size of droplet made by nozzle N_1 and N_2 reported during testing were 162.56 μ m and 251.86 μ m respectively.

The treatment combination $N_1H_2P_2$ had average droplet size of 168.34 μ m. The details about interaction of nozzle type, height and pressure are given in Appendix-F.

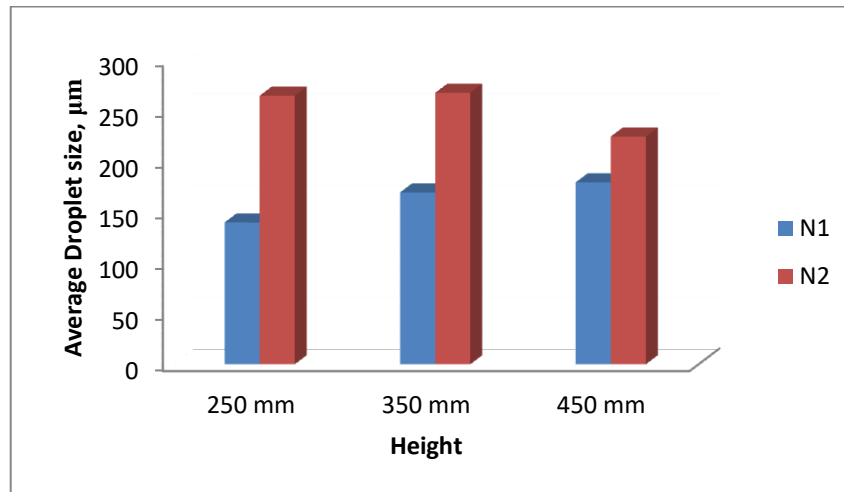


Fig. 4.12: Effect of nozzle type and height on droplet size.

4.4 Measurement of Droplets Deposition

The developed power sprayer was run at 36 hollow cone nozzles after considering laboratory evaluation. Hollow cone nozzle N_1 was operated with 35 cm height and 4 kg cm^{-2} pressure. The droplet deposition samples were taken on glossy paper and were analyzed in computer software (Fiji) for counting the total number of droplets. The numbers of droplets counted are given in the Table 4.9.

Table 4.9: Average number of droplets at pre determined pulling speed

Sample	Number of droplets cm^{-2}
Tag-1	43.54
Tag-2	40.33
Tag-3	49.05
Average droplets	44.30

4.5 Measurement of spray overlapping

The results revealed that, 36 nozzles were forming 11.23 m swath at the height of 35 cm and pressure 4 kg cm^{-2} . At this pressure the hollow cone nozzle

was producing the individual swath of 43.5 cm and had overlap of 13.5 cm. Thus the overlap was calculated as 45 %.

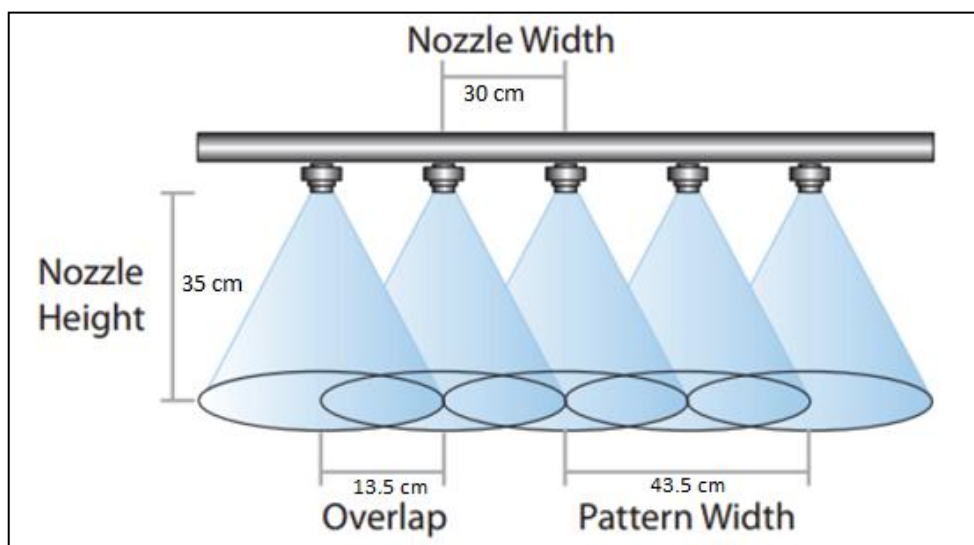


Fig. 4.13 Spray overlaps of boom sprayer

4.6 Spray application rate of developed boom sprayer

Discharge rate of developed power sprayer was recorded during the field test. The power sprayer was run until the test plot considered was covered. The chemical tank was fully filled with liquid. The quantity of liquid sprayed during operation was 458 liter on 0.40 ha of land; it showed that the sprayer yielded the application rate of 1146 l ha^{-1} at the operating pressure of 4 kg cm^{-2} .

4.7 Evaluation of Field Capacity Of Sprayer

4.7.1 Theoretical field capacity

By using the equation 3.26 (section 3.9.2.1), theoretical field capacity of developed power sprayer was calculated at different pulling speed of operator and it is presented in Table 4.10.

Table 4.10: Effects of different pulling speed on theoretical field capacity of

sprayer.

Speed, km h^{-1}	TFC, ha h^{-1}
---------------------------	-------------------------

1.8	2.021
1.26	1.414
0.9	1.01

4.7.2 Effective field capacity

Effective field capacity was worked out using equation 3.27 (section 3.9.2.2). According to actual field performance the effective field capacity was calculated to be 1.10 ha h⁻¹, 0.928 ha h⁻¹ and 0.64 ha h⁻¹ at 1.8 km h⁻¹, 1.26 km h⁻¹ and 0.9 km h⁻¹ pulling speed respectively.

4.7.3 Field efficiency

The field speed of developed power sprayer for soybean crop was calculated by using equation 3.29 (section 3.9.2.3). The efficiency of sprayer was calculated as 54.4%, 65.6% and 63.3% at the speed of 1.8 km h⁻¹, 1.26 km h⁻¹ and 0.9 km h⁻¹ respectively. The values of various parameters (Effective field capacity and field efficiency) based on field observations were worked out and are presented in Table 4.11.

Table 4.11: Total time taken during spraying operation at different pulling speed

S. No.	Operations	Pulling speed		
		1.8 km h ⁻¹	1.26 km h ⁻¹	0.9 km h ⁻¹
1	Turning, h	0.3	0.33	0.46
2	Refilling + Adjustment, h	0.06	0.003	0.05
3	Miscellaneous, h	0.03	0.01	0.01
4	Total time of operation, h	0.90	1.077	1.54
5	Effective field capacity (ha h ⁻¹)	1.10	0.928	0.64
6	Field Efficiency, %	54.4%	65.6%	63.3%

4.8 Fuel consumption of power sprayer

Fuel consumption of power sprayer for soybean crop was measured is given in Table 4.12.

Table 4.12 Average fuel consumption

Replication	Fuel consumption, l h ⁻¹
R ₁	0.603
R ₂	0.610
R ₃	0.624
Average consumption	0.608

4.9 Cost Estimation of Developed Machine

4.9.1 Operational cost of machine

The cost of developed power sprayer for soybean crop was worked out to be Rs. 40000. The cost of operation was found to be Rs. 283.99 and fixed cost was estimated as Rs. 24.8.

Details about both fixed and variable cost is shown in the Table 4.13. As the efficiency of machine was about 65.6% so the estimated total cost of spraying was Rs. 406.89. Distribution of various costs for operation of power sprayer is shown in Fig. 4.14.

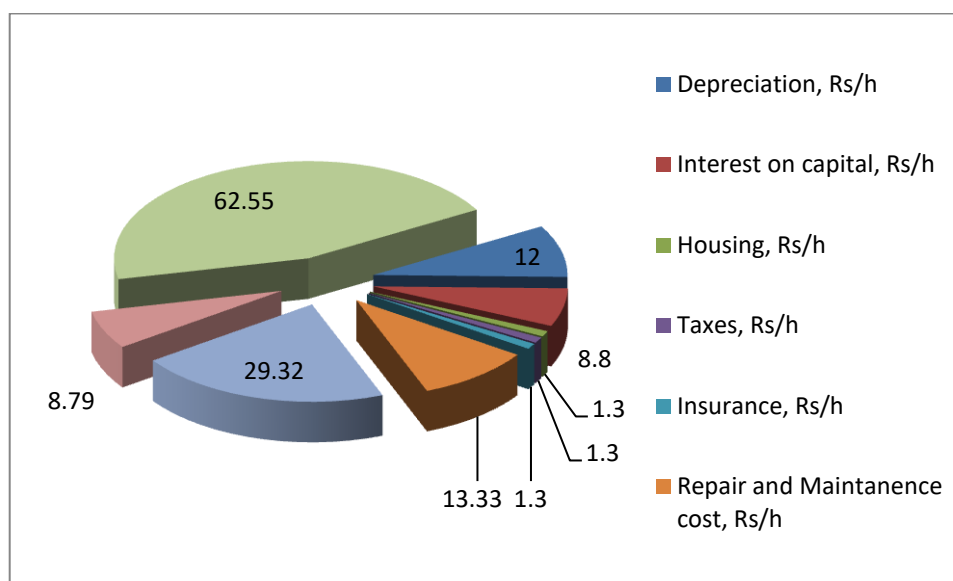


Fig. 4.14 Distribution of cost of operation of power sprayer

Table 4.13 Details of fixed and variable cost (in Rs.)

S. No.	Particulars	Power sprayer for soybean crop
A	Fixed cost Rs h ⁻¹	
1	Cost of developed machine, Rs.	40000.00
2	Life of the machine (year)	10
3	Annual use (working hour per year)	300.00
4	Salvage value, (10% of initial cost)	4000.00
5	Depreciation, Rs. h ⁻¹	12
6	Interest on investment , @12% per annum	8.8
7	Housing cost, insurance and taxes each @1% of the initial cost, Rs. h ⁻¹	4
Total	Fixed cost Rs. h ⁻¹	24.8
B	Variable cost Rs. h ⁻¹	
1	Fuel cost Rs. h ⁻¹	29.32
2	Lubrication cost Rs. h ⁻¹ , (@30% of fuel cost)	8.79
3	Repair and maintenance cost (@ 10% of initial cost), Rs. h ⁻¹	13.33
4	Insecticide, (70g ha ⁻¹)	170.00
5	Wages of 2 operators (@Rs.180 for 8 h)	62.55
Total	Variable cost, Rs. h ⁻¹	283.99
(A+B)	Total Cost (Fixed + Variable), (Rs. h ⁻¹)	308.79
	Total cost of spraying with power sprayer, (Rs. ha ⁻¹)	415.02

4.9.2 Break-even point

Break-even point was worked out using equation 3.36 (section 3.16.4).

$$\text{BEP} = \frac{\text{AFC}}{\text{CH} - \text{OC}}$$

$$\text{AFC} = 24.8 \times 300 = \text{Rs.}7440 \text{ year}^{-1}$$

$$\text{CH} = \text{OC} + 25\% \text{ over head;}$$

$$= 308.79 + 77.1957 = \text{Rs.}385.98 \text{ year}^{-1}$$

$$\text{OC} = \text{Rs. } 308.79 \text{ h}^{-1}$$

$$\text{BEP} = \frac{7440}{385.98 - 308.79} = \text{Rs.}96.39 \text{ year}^{-1}$$

The break-even point was worked out to be Rs. 96.39 year⁻¹. Break-even point is the point at which the total cost incurred is balanced by total gain or benefit accrued by use of power sprayer on custom hiring basis.

4.9.3 Pay-back period

Pay-back period was worked out using equation 3.37 (section 3.16.5).

$$\text{PBP} = \frac{P}{\text{ANP}}$$

$$P = \text{Initial cost of machine} = \text{Rs.}40,000$$

$$\text{ANP} = (\text{CH} - \text{OC}) \times \text{AU}$$

$$= (385.98 - 308.79) \times 300$$

$$= 23,157 \text{ year}^{-1}$$

Hence,

$$\text{PBP} = \frac{40000}{23157} = 1.72 \text{ years}$$

The pay-back period for spraying operation using power sprayer was worked out to be Rs.1.72 years. The pay-back period refers to the amount of time taken to recover the cost of investment using developed power sprayer as compared to that procured on custom hiring basis. Thus here the pay-back period is very short (1.72 years) when the cost of operation of developed power sprayer was compared with that used on custom hiring basis. It seems to be an attractive proposition to use developed power sprayer for spraying operation as compared to that obtained on custom hiring basis for spraying operation of soybean crop.

SUMMARY AND CONCLUSIONS

Summary

Soybean [*Glycine max.* (L.) Merrill] is known as a miracle crop, as it is major source of protein (40%), vitamins and edible oil (20%) containing major essential amino acids. It contributes to edible oil requirement of country. Reduction in soybean yield affects the economy of the country as well as farmer. Spraying is an important operation to protect plants from insects and pests. Insects and pests deals great reduction up to 33% (Singh and Singh, 1992) in yield, so timely operation of spraying in the field is of utmost importance. The problem faced by the soybean farmers is mostly at its leafy stage wherein due to vigorous growth, the plant canopy covers whole growing area and the spray operator hesitates entering in the field due to fear of snakes and scorpions etc.

There are various types of single and multi nozzle sprayers are available but all sprayers need entry of operator in the field, most of Indian farmers cannot afford tractor operated boom sprayers due to poor economic status.

Therefore there is good scope and need of such sprayer that allows spray without or minimal entry of operator in the field. In order to fulfill the requirement of such sprayer, a study was under taken entitled “Development of power sprayer for soybean crop” with the following objectives:

1. To develop a power sprayer for soybean crop.
2. To conduct a performance evaluation studies on developed power sprayer.
3. To estimate cost of spraying of developed sprayer.

Keeping in view above objectives, a power sprayer for soybean crop was developed at SVCAET, IGKV, Raipur. The developed sprayer was working satisfactorily and efficiently in the field. It was found to possess good expected life and reduced cost of operation as compared to other sprayers or those procured on

custom hiring basis. One of the advantages of this developed sprayer is that it does not need very skilled operator and do not need high maintenance charges.

Purpose of developing the sprayer was to achieve a very long range of coverage with minimum entry in the field, also to maintain uniformity in spraying throughout the entire range. The developed sprayer consists of a boom support structure and a chemical storage cum power unit to deliver the spray liquid from outside the field. The boom support structure can be operated by two persons. The boom support structure need to be pulled parallel to the field bund/path. This machine is useful for spraying throughout all the growth stages of soybean. It can serve spray operation for all types of liquid as pesticides and insecticides.

Besides fabrication of boom support structure and a chemical storage cum power unit, the selection of appropriate type of nozzle is crucial in the development of power sprayer. Performance evaluations of nozzles were conducted for selection of the best nozzle in the laboratory of SVCAET, IGKV, Raipur. Each nozzle was tested at different heights (25 cm, 35 cm and 45 cm) and pressures (3 kg cm⁻², 4 kg cm⁻² and 5 kg cm⁻²). Comparison was also made on various parameters like uniformity of volumetric distribution, spray angle, swath width, droplet size, droplet density and discharge. Performance of developed sprayer under field condition was also tested like field capacity, field efficiency, fuel consumption and cost of operation. Finally the economic viability of developed power sprayer was also judged using parameters such as break-even point, pay-back period etc.

Conclusion

After laboratory evaluation the machine best combination of nozzle type, nozzle height and liquid pressure was selected and field evaluation was carried out in the ground of IGKV Raipur. Based on the laboratory analysis and field evaluation, the following points emerged:

1. The most uniform volumetric distribution for hollow cone nozzle (N₁) was found under the combination of 4 kg cm⁻² pressure with 35 cm nozzle height at patternator. The coefficient of variation (CV) of distribution was

4.04%. On the other hand most uniform volumetric distribution for flat fan nozzle (N_2) was found under the combination of 3 kg cm^{-2} pressure with 25 cm nozzle height at patternator. The coefficient of variation (CV) of distribution was 14.50 %.

2. It was observed that increase in nozzle height from 25 cm to 35 cm resulted in increase of the spray angle. The spray angle increased from 72.5° to 99.5° for N_1 , and 82.5° to 105.5° for nozzle N_2 respectively. When nozzle height is further increased from 35 cm to 45 cm the spray angle also increased from 99.5° to 115.5° for N_1 and 105.5° to 111° for N_2 .
3. With increase in nozzle height from 25 cm to 45 cm, the maximum swath width was increased from 37.5 cm to 62 cm and 40 cm to 62.5 cm for nozzle N_1 and N_2 respectively. At nozzle to nozzle spacing of 30 cm, the sprayer gave 45% spray overlapping.
4. Average droplet size received with 35 cm height and 4 kg cm^{-2} was $168.34 \mu\text{m}$ which is within the range of effective droplet size (G.A. Mathew (1992)).
5. Field efficiency was found 54.4%, 65.6% and 63.3% at the speed of 1.8 km h^{-1} , 1.26 km h^{-1} and 0.9 km h^{-1} respectively. Total cost of operation of sprayer was calculated to be Rs. 415.02 ha^{-1} .

Suggestion for Future Work

1. Design of engine carrier trolley can be improved to reduce the vibration of trolley.
2. Provision for easy turning of machine may be improved.
3. As per availability finer nozzle may be selected to maintain application rate.

REFERENCE

- Alms. 1987. *Organo Metalics*, 11(2): 116-127.
- Anonymous. 2002. Pesticide information. *Technical Bulletin*. 42(1).
- Anibude, 2016. Development of and Animal Drawn Hydraulic Boom Sprayer. *American Journal of Engineering Research (AJER)* E-ISSN: 2320-0847 P-ISSN:2320-0936. 5(2):222-228.
- Bharatbhai, 2017. Automatic Agriculture Pesticide Spraying Vehicle. *International Journal of Engineering Development and Research* (www.ijedr.org). 5(4). 2321-9939.
- Bindra, O.S., Singh, H. 1977. *Pesticide Application Equipment*. 2nd edition, 66 Janpath, New Delhi, Oxford and IBH Publishing Co., 27-42.
- Bouse, L.F., Carlton, J.B., Wilzand Doneal, H. 1994. Droplet size distribution of animal drawn hydraulic boom sprayer. *Agri J. Engg. Res.* 5:229-18.
- Butts, T.R., Luck, J.D., Fritz, B.K., Hoffmann, W.C. and Kruger, G.R. 2019. Evaluation of spray pattern uniformity using three unique analyses as impacted by nozzle, pressure, and pulse- width modulation duty cycle. *Pest Management Science*. 75(7): 1875-1886.
- Cerruto, E., Aglieco, C., Failla, S. and Manetto, G. 2013. Parameters influencing deposit estimation when using water sensitive papers. *J. Agrill. Engg.* 9
- Chen, Y., Zhu, H., Ozkan, H.E., Derksen, R.C. and Krause, C.R. 2013. Spray drift and off-target loss reductions with precision air-assisted sprayer *Trans. Of ASABE*. 56(6):1273-1281.
- Ciba-Geigy Limited. 1985. Water-sensitive paper for monitoring spray distribution. Ciba-Geigy Application Services. Publ.No. AG 8.11/19374 XYe. Basle, Switzerland.
- Costa, L.L., Ferreira, M.C., Campos, H.B.N., Carvalho, G.G.F., Barbosa, J.C. 2015. The mixture sprayed by hydraulic and centrifugal energy nozzles for the control of Asian soybean rust. *Acta Scientiarum: agronomy*. 37(4):425-433.
- Derksen, R.C., Breth, D.I. 1994. Orchard air-carrier sprayer application accuracy and spray coverage evaluations, *Applied Engineering in Agriculture*. 10(4): 463-470.

- Di Prinzio, A., Behmer, S., Magdalena, J.C. and Chersicla, G. 2010. Effect of pressure on the quality of pesticide application in orchards. *Chilean Journal of Agricultural Research*, 70(4):674-678.
- Ennis, W.B. and Williamson, R.E. 1963 Influence of Droplet Size on Effectiveness of Low-Volume Herbicidal Sprays, Cambridge University Press. 11(1):67-72.
- Fritz, B.K., Hoffmann, W.C., Bonds, J.A.S. and Farooq, M. 2011. Volumetric collection efficiency and droplet sizing accuracy of rotary impactors. *Trans. Of ASABE*. 54(1):57-63.
- Fritz, B.K., Clint, H.W., Wolf, R.E., Bretthauer, Scott, and Bagley, W.E., 2012. Measurement and classification methods using the ASAE S572.1 reference nozzles. *J. Plant Protection Research*. 52(4).
- Giles, D.K., Akesson, N.B., Yates, W.E. 2008. Pesticide Application Technology: Research and Development and the Growth of the Industry, ASABE, 51(2); 397-403.(doi:10.13031/2013.24377)
- Hall, F.R. 1993. Application of plantation crops. *Application Technology for crop protection*. Edited by G.A.Mathews and E.W.Hilsop. CAB International, U.K. pp:187-194.
- Jain, S.C. and Philip, G. 2009. Farm machinery- An approach; 1st ed., Standard publishers distributors, Delhi, 115-116.
- Jaybhaye, P.R., Shinde, P.B., Asewar, B.V. 2015. Response of soybean to sowing dates and spacing under rainfed condition. *International Journal of Tropical Agriculture*. 33(2); 748-750.
- Johnston, D.R. 1973. Insecticide concentration for ultra-low volume crop spray application. *Pesticide Science*. 4:77-82.
- Koszel, M. 2009. Influence of fan flat nozzles wear degree on drop tracks size. *Research in Agricultural Engineering*. 55(2): 39-44.
- Kruckeberg, J.P., Hanna, H.M., Steward, B.L. and Darr, M.J. 2012. The relative accuracy of DRIFTSIM when used as a real-time spray drift predictor. *Trans. Of the ASABE*. 55(3):1159-1165.
- Kumar, T., Tomar, S.P.S., Bhadauria, N.K.S., Singh, P., Badauria, N.S. 2019. Efficacy of insecticides against major insect-pests of soybean in arid region at central India, *International J. Chemical Studies* 2019; 7(2): 13-18

- Kumbhare, D.N., Singh, V., Waghmare, P., Ansari, A., Tiwari, V. and Gorle, R.D. 2016. Fabrication of automatic pesticides spraying machine. IRJET. 3(4).
- Mathew, V.J., Des, S.K., Das, D.K., Pradhan, S.C. 1992. Development and testing of power tiller operated boom sprayer. AMA. 23(4): 25-27.
- Matthews G.A. 2004. How was the pesticide applied? Crop Protection. 23, 651-653.
- May, K.R. 1950. The measurement of airborne droplets by the magnesium oxide method. Journal of Scientific Instruments 27(5):128.
- Nuytens, D. 2007. Drift from Field Crop Sprayers: The influence of Spray Application Technology Determined Using Indirect Drift Assessment Means. Ph.D. Thesis, KU Leuven, Leuven, Belgium.
- Ozkan, H.E., Zhu, H., Derksen, R.C., Guller, H. and Krause C. 2006. Evaluation of various spraying for effective application of fungicides to control Asian soybean rust. International advances in pesticide application. Aspects of Applied Biology. 77:267-275.
- Pal, S.K., Gupta, S.K.D. 1996. Pesticide Application. In: Training and Fellowships Program International Crops Research Institute for the Semi-Arid Tropics Patancheru, Andhra Pradesh 502324, India. 5-12.
- Panneton, B. and Drummond, A. 1991. Digital image analysis of spray samples. Applied Engineering in Agriculture. 7(2). 273-278.
- Pergher, G., Gubiani, R., Chividino, S.R.S., Dell, D. and Lagazio, C. 1997. Assessment of spray deposition and recycling rate in the vineyard from a new type of air-assisted tunnel sprayer, Crop Protection. 45: 6-14.
- Ruas, J.M.F., Balan, R. and Saab, O.J.G. 2011. Coverage comparison by knapsack sprayers manual and engine powered. Ciencias Agranrias, Londrina, v. 32,n.4,p.1417-1422.
- Sahay, J., 1971. Elements of agricultural engineering., 5th edition, Standard Publishers Distributors.
- Salyani, M., Zhu, H., Sweeb, D.R. and Pai, N. 2013. Assessment of spray distribution with water-sensitive paper. Agric. Eng. Int. CIGR Journal. 15(2): 101-111.
- Sanchavat, H., Chudhary, H., Bhautik, G., Singh, S.N., 2018. Field evaluation of a tractor mounted boom sprayer. Agricultural Engineering Today. 41(4). 2017.

- Singh, G., Kumar, S.S., Dixit, A., Manes, G.S. and Singh, A., 2011. Spray distribution pattern of different sprayers on cotton using droplet analyser. *Journal of Research, SKUAST-J.* 10(1):44-40.
- Singh, S., Manes, G.S. and Sandhar, N.S. 2002. Studies on spray pattern of different nozzles. *J Res Punj Agric University.* 39(3):399-407.
- Sharma, D.N. and Mukesh, S. 2008. *Farm Machinery Design (Principles and Problems)*, 1st Edition, Jain Brothers, New Delhi. P-259.
- Shengde, C., Yubin, L., Zhiyan, Z., Fan, O., Wang, G., Huang, Xi., Deng, Xi. And Cheng, S. 2020. Effect of droplet size parameter on droplet deposition and drift of aerial spraying by using plant protection UAV. *Journal of Agronomy.* 2073-4395.
- Sirmour, A. 2019, Studies on development of tractor drawn herbicide applicator cum planter with seed and fertilizer choke indicator, Ph.D. Thesis. Indira Gandhi Agricultural University. p.1-250.
- Smith, D.B., Burt, E.C. and Lloyd, E.P. 1975. Selection of optimum spray droplet sizes for boll weevil and drift control. *Journal of Economic Entomology*, 68(3).
- Turner, C.R. and Huntington, K.A. 1970. The use of a water sensitive dye for the detection and assessment of small spray droplets. *Journal of Agricultural Engineering Research.* 385-387
- Walk Date, P.J. (1987) A random-walk model for dispersion of heavy particles in turbulent air flow. *Boundary layer meteorology.* 39:175-190.
- Wilson, S., D, Warrel., Romulus, W., Geetha, M., Rodrigues, R., Fu., S.H., Begum, R., Sati, P., Piyasena, K., Bhatiya, M., Brown, P., Jha, P., 2020, Snakebite Mortality in India: A Nationally Representative Mortality Survey, WHO.
- Weidenhoff, J.D. 1991. Spray droplet size as related to disease and insect control on row crops. *Res Bul. 945 Ohio Agric. Exp. Sta., Wooster. OH.*
- Xu, L., Zhu, H., Ozkan, H.E. and Thistle, H.W. 2010. Evaporation rate and development of wetted are of water droplets with and without surfactant at different locations on waxy leaf surfaces. *Journals of Biosystem Engineering.* 106(1). 58-67.
- Yadav, N.K., Tiwari, G.S. and Meena, S.S. 2020. Estimation of the cost economics of developed wheel operated sprayer. *The Pharma Innovation Journal.* SP-09:198-199.

- Zaman, Q.U., Salyani, M. 2004. Effects of foliage density and ground speed on ultrasonic measurement of citrus tree volume, *Applied Engineering in Agriculture*, vol. 20(2): 173-178.
- Zhu, H., Salyani, M. and Fox, R.D. 2011. Computers and Electronics in Agriculture. 76(1). 38-43.

APPENDIX

APPENDIX-A

Table-A1: Volumetric distribution data of nozzle N1 (Hollow cone) at 25 cm height and 3 kg cm⁻².

Nozzle name : N1(Hollow Cone)									
Pressure: 3 kg cm ⁻²							CV, %: 4.44		
Amount of water collected, ml									
Distance from centre		R1		R2		R3		R4	
(mm)		L	R	L	R	L	R	L	R
0		55	54	56	58	57	58	56	54
25		51	54	53	50	52	42	50	46
50		44	40	48	41	53	38	48	42
75		41	39	40	39	41	40	46	38
100		40	38	39	39	37	38	39	40
125		42	40	41	41	42	39	38	39
150		35	36	35	36	36	36	40	34
175		14	12	11	10	14	13	13	12
200		8	7	6	7	7	8	8	8

Table-A2: Volumetric distribution data of nozzle N1 (Hollow cone) at 25 cm height and 4 kg cm⁻².

Nozzle name : N1(Hollow Cone)									
Pressure: 4 kg/cm ⁻²							CV, %:	5.99	
Amount of water collected, ml									
Distance from centre	R1		R2		R3		R4		
(mm)	L	R	L	R	L	R	L	R	
0	50	48	51	50	51	53	50	51	

25	49	47	49	46	46	43	49	49
50	48	44	41	50	52	51	50	52
75	46	48	50	47	42	43	43	45
100	43	41	42	46	48	48	49	45
125	49	51	45	41	46	45	42	44
150	40	41	41	40	36	42	40	41
175	41	39	39	43	38	39	38	41
200	8	9	11	10	10	11	10	11

Table-A3: Volumetric distribution data of nozzle N1 (Hollow cone) at 25 cm height and 5 kg cm⁻².

Nozzle name : N1(Hollow Cone)								
Pressure: 5 kg cm ⁻²						CV, %: 5.089		
Amount of water collected, ml								
Distance from centre	R1		R2		R3		R4	
(mm)	L	R	L	R	L	R	L	R
0	64	63	62	61	64	62	63	65
25	60	64	65	67	66	54	60	61
50	58	60	61	60	60	60	55	59
75	57	62	59	58	63	59	56	58
100	55	50	57	52	59	59	53	56
125	53	51	48	50	51	49	50	49
150	50	51	46	45	52	50	49	52
175	44	47	48	43	41	40	49	51
200	5	8	7	6	8	9	8	5

Table-A4: Volumetric distribution data of nozzle N1(Hollow cone) at 35 cm height and 3 kg cm⁻².

Nozzle name : N1(Hollow Cone)									
Pressure: 3 kg cm ⁻²						CV, %:		5.089	
Amount of water collected, ml									
Distance from centre	R1		R2		R3		R4		
(mm)	L	R	L	R	L	R	L	R	
0	34	35	35	33	34	32	35	34	
25	34	33	33	32	38	30	37	39	
50	35	34	32	35	35	32	32	30	
75	30	31	31	29	39	31	31	33	
100	35	32	30	32	33	38	33	30	
125	30	33	31	32	31	34	35	32	
150	33	31	29	29	31	29	30	34	
175	32	31	34	32	33	30	31	32	
200	28	29	26	27	28	26	28	29	
225	33	32	30	32	29	30	34	31	
250	7	8	8	8	7	8	6	7	

Table-A5: Volumetric distribution data of nozzle N1 (Hollow cone) at 35 cm height and 4 kg cm⁻².

Nozzle name : N1(Hollow Cone)									
Pressure: 4 kg cm ⁻²						CV,%:		5.089	
Amount of water collected, ml									
Distance from centre	R1		R2		R3		R4		
(mm)	L	R	L	R	L	R	L	R	
0	39	40	40	38	38	36	35	34	
25	38	36	39	38	37	37	36	37	
50	39	38	37	36	38	39	40	38	

75	37	37	37	30	39	37	36	34
100	37	38	39	31	34	36	31	37
125	35	39	35	38	39	37	38	39
150	38	36	39	40	38	38	38	39
175	37	39	38	36	34	38	40	38
200	30	34	36	35	35	34	38	37
225	39	38	40	38	40	38	36	37
250	6	7	8	6	7	6	5	7

Table-A6: Volumetric distribution data of nozzle N1 (Hollow cone) at 35 cm height and 5 kg cm⁻².

Nozzle name : N1(Hollow Cone)								
Pressure: 5 kg cm ⁻²						CV, %: 5.089		
Amount of water collected, ml								
Distance from centre	R1		R2		R3		R4	
(mm)	L	R	L	R	L	R	L	R
0	49	50	52	49	50	52	51	50
25	49	48	46	50	49	50	46	50
50	46	45	50	49	48	46	47	48
75	49	48	41	42	42	43	41	44
100	47	46	47	47	48	46	47	41
125	45	46	42	40	40	41	42	41
150	38	40	47	48	45	43	44	43
175	42	41	40	39	38	42	39	40
200	36	39	38	36	40	39	40	41
225	42	38	41	40	42	40	44	47
250	9	8	7	9	7	8	8	6

Table-A8: Volumetric distribution data of nozzle N1 (Hollow cone) at 45 cm height and 4 kg cm⁻².

Nozzle name : N1(Hollow Cone)		
Pressure: 4 kg cm⁻²	CV,%:	5.089
Amount of water collected, ml		

Distance from centre (mm)	R1		R2		R3		R4	
	L	R	L	R	L	R	L	R
0	38	36	37	38	35	32	33	32
25	31	33	37	35	33	32	33	31
50	31	32	34	36	32	32	36	30
75	32	34	36	34	34	31	29	30
100	36	32	32	31	35	30	31	34
125	35	33	30	30	32	28	29	33
150	32	30	31	32	35	30	28	31
175	31	29	30	29	32	32	31	34
200	36	32	34	29	31	29	32	29
225	30	25	31	31	32	30	32	30
250	25	15	20	17	21	19	34	24
275	13	11	19	9	22	13	23	12
300	9	9	13	4	13	10	10	8
325	6	0	5	0	7	5	6	0

Table-A9: Volumetric distribution data of nozzle N1 (Hollow cone) at 45 cm height and 5 kg cm⁻².

Nozzle name : N1(Hollow Cone)									
Pressure: 5 kg cm ⁻²							CV,%:	5.089	
Amount of water collected, ml									
Distance from centre	R1		R2		R3		R4		
(mm)	L	R	L	R	L	R	L	R	
0	32	35	39	41	40	39	42	39	
25	37	36	38	32	35	41	33	39	
50	38	33	35	35	37	38	30	32	

75	38	36	38	39	36	40	33	34
100	35	31	33	38	38	30	34	30
125	33	34	36	39	39	29	38	35
150	37	34	35	38	35	31	33	39
175	38	32	35	37	35	33	39	40
200	37	30	36	34	36	35	36	34
225	34	32	36	37	39	29	36	32
250	36	35	36	34	33	28	39	34
275	34	33	32	23	34	28	39	30
300	36	28	29	11	30	16	29	13
325	5	0	8	0	10	5	9	0

Table-A10: Volumetric distribution data of nozzle N2 (Flat Fan) at 25 cm height and 3 kg cm⁻².

Nozzle name : N2(Flat Fan)								
Pressure: 3kg cm ⁻²						CV, %: 5.089		
Amount of water collected, ml								
Distance from centre	R1		R2		R3		R4	
(mm)	L	R	L	R	L	R	L	R
0	53	54	55	53	56	49	55	57
25	52	50	53	49	41	59	40	39
50	48	40	47	43	40	56	49	55
75	32	30	28	34	41	32	42	38
100	34	38	35	24	37	32	39	24
125	32	33	53	28	42	51	38	30
150	50	52	56	45	36	34	57	48

Distance from centre (mm)	R1		R2		R3		R4	
	L	R	L	R	L	R	L	R
0	70	72	48	74	64	62	60	60
25	27	52	71	33	59	42	44	39
50	68	25	24	29	57	31	26	65
75	25	65	40	58	27	35	27	35
100	44	30	57	23	59	26	34	28
125	33	51	28	47	29	49	50	49
150	50	31	46	52	52	50	47	25
175	22	66	54	55	23	58	64	68
200	67	58	45	49	32	76	45	67
225	65	25	65	45	35	54	34	65
250	8	14	6	15	0	20	7	18

Table-A13: Volumetric distribution data of nozzle N2 (Flat Fan) at 35 cm height and 3 kg cm^{-2} .

Nozzle name : N2(Flat Fan)									
Pressure: 3 kg cm ⁻²						CV, %:		5.089	
Amount of water collected, ml									
Distance from centre		R1		R2		R3		R4	
(mm)		L	R	L	R	L	R	L	R
0		58	44	35	55	58	47	54	34
25		34	54	56	23	55	39	45	55
50		40	34	32	47	40	38	32	23
75		30	31	26	29	29	22	21	33
100		23	25	21	32	27	23	33	20
125		33	40	46	32	31	44	25	32

150	33	24	29	29	56	21	30	45
175	32	25	34	32	20	33	34	32
200	28	29	26	27	27	20	28	18
225	33	32	45	30	31	42	27	24
250	34	32	26	21	42	18	45	23
275	8	4	17	4	15	6	16	20
300	3	0	2	0	4	2	0	5

Table-A14: Volumetric distribution data of nozzle N2 (Flat Fan) at 35 cm height
and 4 kg cm⁻².

Nozzle name : N2(Flat Fan)								
Pressure: 4 kg cm ⁻²						CV, %: 5.089		
Amount of water collected, ml								
Distance from centre	R1		R2		R3		R4	
(mm)	L	R	L	R	L	R	L	R
0	39	54	60	38	52	55	52	40
25	45	36	39	56	54	37	56	59
50	39	38	57	36	38	53	20	38
75	54	37	37	30	50	37	36	24
100	37	58	39	31	19	36	50	27
125	35	26	35	38	45	24	28	39
150	26	40	39	40	38	47	37	39
175	37	36	38	36	34	38	40	38
200	30	34	36	35	23	21	38	37
225	46	38	40	38	42	38	51	47
250	35	36	40	36	39	46	25	36

275	23	10	19	11	17	11	19	11
300	8	3	4	0	2	4	9	4

Table-A15: Volumetric distribution data of nozzle N2 (Flat Fan) at 35 cm height and 5 kg cm⁻².

Nozzle name : N2(Flat Fan)								
Pressure: 5 kg cm ⁻²					CV,%: 5.089			
Amount of water collected, ml								
Distance from centre	R1		R2		R3		R4	
(mm)	L	R	L	R	L	R	L	R
0	49	50	52	39	50	62	56	55
25	48	42	46	50	49	50	46	50
50	46	45	50	39	58	46	21	48
75	49	48	41	42	42	43	41	28
100	47	46	47	40	43	27	47	53
125	45	46	42	40	36	51	41	37
150	48	40	27	48	33	23	44	54
175	42	41	40	27	38	32	56	23
200	22	23	23	36	53	39	23	21
225	27	36	34	40	42	40	35	47
250	45	37	56	46	36	25	45	34
275	15	23	14	26	15	7	12	23
300	3	7	2	8	6	0	8	4

Table-A16: Volumetric distribution data of nozzle N2 (Flat Fan) at 45 cm height and 3 kg cm⁻².

Nozzle name : N2(Flat Fan)

Pressure: 3 kg cm ⁻²						CV,%:		5.089	
Amount of water collected, ml									
Distance from centre	R1		R2		R3		R4		
(mm)	L	R	L	R	L	R	L	R	
0	54	42	39	39	43	40	41	42	
25	35	45	40	46	41	41	42	47	
50	42	40	44	41	45	43	46	43	
75	37	24	38	42	43	37	38	24	
100	29	30	34	25	23	26	33	36	
125	18	20	22	21	27	19	25	25	
150	24	21	15	15	28	22	13	17	
175	19	19	16	28	21	18	27	12	
200	15	29	21	17	28	22	21	14	
225	25	32	17	23	24	27	30	27	
250	30	31	26	29	16	15	25	24	
275	36	30	35	32	34	44	34	35	
300	16	13	22	25	12	13	15	17	
325	4	0	5	3	4	4	3	4	

Table-A17: Volumetric distribution data of nozzle N2 (Flat Fan) at 45 cm height and 4 kg cm⁻².

Nozzle name : N2(Flat Fan)									
Pressure: 4 kg cm ⁻²						CV, %: 5.089			
Amount of water collected, ml									
Distance from centre (mm)	R1		R2		R3		R4		
	L	R	L	R	L	R	L	R	
0	60	58	58	57	62	60	58		65

25	57	64	53	61	58	54	44	55
50	42	58	46	49	52	49	43	54
75	54	34	28	47	43	44	26	46
100	39	30	57	25	23	26	31	26
125	34	20	22	21	47	19	32	33
150	24	21	15	35	38	22	28	31
175	19	19	16	28	33	18	21	38
200	15	29	21	35	28	26	22	29
225	25	32	17	23	24	27	34	30
250	30	31	26	38	16	25	43	38
275	36	35	35	32	34	44	23	20
300	17	13	22	25	12	13	16	8
325	4	0	5	3	4	4	6	0

Table-A18: Volumetric distribution data of nozzle N2 (Flat Fan) at 45 cm height and 5 kg cm⁻².

Nozzle name : N2(Flat Fan)								
Pressure: 5 kg cm ⁻²						CV, %:		5.089
Amount of water collected, ml								
Distance from centre (mm)	R1		R2		R3		R4	
	L	R	L	R	L	R	L	R
0	54	58	43	63	53	48	54	59
25	56	53	58	51	54	52	60	64
50	59	50	35	39	56	49	50	32
75	48	41	38	39	25	16	43	54
100	25	18	33	38	26	24	34	30
125	23	34	36	34	22	45	38	35

150	16	32	25	38	35	64	33	39
175	38	21	21	37	36	33	11	25
200	27	30	27	34	13	35	26	23
225	34	32	36	37	39	29	16	32
250	30	35	36	34	33	28	29	24
275	44	33	37	45	34	48	34	56
300	36	28	19	11	30	16	29	13
325	5	2	6	0	9	4	7	0

Appendix- B

ANOVA table of interaction on nozzle type, height and pressure on CV%.

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
N	1	1,501.71	1,501.71	1,402,734.43	0.00
H	2	17.47	8.73	8,160.47	0.00
N X H	2	9.55	4.77	4,460.28	0.00
P	2	9.30	4.65	4,346.52	0.00
N X P	2	6.40	3.20	2,990.15	0.00
H X P	4	90.76	22.69	21,194.92	0.00
N X H X P	4	71.09	17.77	16,602.14	0.00
Error	18	0.019	0.001		
Total	35	1,706.32			

Appendix-C

ANOVA table of interaction of nozzle type, height and pressure on spray angle.

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
N	1	16.00	16.00	0.49	0.49
H	2	6,633.38	3,316.69	102.75	0.00

N X H	2	729.50	364.75	11.30	0.00
P	2	168.72	84.36	2.61	0.10
N X P	2	256.50	128.25	3.97	0.03
H X P	4	246.77	61.69	1.91	0.15
N X H X P	4	111.00	27.75	0.86	0.50
Error	18	581.00	32.27		
Total	35	8,742.88			

Appendix-D

ANOVA of interaction of nozzle type, height and pressure on swath width

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
N	1	78.02	78.02	312.11	0.00
H	2	1,988.38	994.19	3,976.77	0.00
N X H	2	126.05	63.02	252.11	0.00
P	2	43.55	21.77	87.11	0.00
N X P	2	89.55	44.77	179.11	0.00
H X P	4	73.77	18.44	73.77	0.00
N X H X P	4	23.11	5.77	23.11	0.00
Error	18	4.50	0.25		
Total	35	2,426.97			

Appendix-E

ANOVA of interaction of nozzle type, height and pressure on discharge.

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
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N	1	207,905.014	207,905.014	3,793.823	0.00000
H	2	86.083	43.042	0.785	0.46107
N X H	2	346.361	173.181	3.160	0.05036
P	2	570,864.000	285,432.000	5,208.525	0.00000
N X P	2	30,418.111	15,209.056	277.533	0.00000
H X P	4	46.917	11.729	0.214	0.92953
N X H X P	4	338.139	84.535	1.543	0.20301
Error	54	2,959.250	54.801		
Total	71	812,963.875			

Appendix- F

ANOVA of interaction nozzle type, height and pressure on average droplet size.

Source of Variation	DF	Sum of Squares	Mean Squares	F-Calculated	Significance
N	1	71,759.393	71,759.393	24,707.829	0.00000
H	2	2,154.225	1,077.113	370.866	0.00000
N X H	2	9,866.978	4,933.489	1,698.674	0.00000
P	2	623.282	311.641	107.303	0.00000
N X P	2	523.123	261.561	90.060	0.00000
H X P	4	2,238.227	559.557	192.664	0.00000
N X H X P	4	1,402.262	350.566	120.705	0.00000
Error	18	52.278	2.904		
Total	35	88,619.769			

RESUME

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