

**DESIGN DEVELOPMENT AND PERFORMANCE  
EVALUATION OF TRACTOR MOUNTED HYDRAULIC  
BOOM SPRAYER FOR COTTON CROP**

**वैश्विक कृषि मशीनरी एवं प्रौद्योगिकी विद्यापीठ, उदयपुर,  
राजस्थान**

BY

**BABASAHEB SUKHADEO GHOLAP**

**THESIS**

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MAHARANA PRATAP UNIVERSITY OF AGRICULTURE AND TECHNOLOGY  
UDAIPUR-313 001 (RAJASTHAN)**

**MAHARANA PRATAP UNIVERSITY OF AGRICULTURE AND TECHNOLOGY,  
UDAIPUR  
COLLEGE OF TECHNOLOGY AND ENGINEERING, UDAIPUR**

Dated: 21/09/2011

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This is to certify that this thesis entitled “**Design development and performance evaluation of tractor mounted hydraulic boom sprayer for cotton crop**” submitted for the degree of **Master of Engineering** in Agricultural Engineering in the subject of **Farm Machinery and Power Engineering** embodies bonafide research work carried out by **Mr. Babasaheb Sukhadeo Gholap** under my guidance and supervision and that no part of this thesis has been submitted for any other degree. The assistance and help received during the course of investigation have been fully acknowledged. The draft of the thesis was also approved by the advisory committee on 21 June 2011.

**Dr. Ravi Mathur**  
Major Advisor

**Dr. G. S. Tiwari**  
**Head**  
Deptt. of Farm Machinery and Power  
Engineering

**Dr. N. S. Rathore**  
**DEAN**  
College of Technology and Engineering  
Udaipur

**MAHARANA PRATAP UNIVERSITY OF AGRICULTURE AND TECHNOLOGY,  
UDAIPUR  
COLLEGE OF TECHNOLOGY AND ENGINEERING, UDAIPUR**

Dated: 07/01/2012

**CERTIFICATE-III**

This is to certify that this thesis entitled “**Design development and performance evaluation of tractor mounted hydraulic boom sprayer for cotton crop**” submitted by **Mr. Babasaheb Sukhadeo Gholap** to Maharana Pratap University of Agriculture & Technology, Udaipur, in partial fulfillment of the requirements for the degree of **Master of Engineering** in Agricultural Engineering in the subject of **Farm Machinery and Power Engineering**, after recommendation by the external examiner was defended by the candidate before the following members of the examination committee. The performance of the candidate in the oral examination on his thesis has been found satisfactory; we therefore, recommend that the thesis be approved.

**Dr. Ravi Mathur**  
Major Advisor

**Dr. A. K. Mehta**  
Advisor

**Dr. S. K. Jain**  
Advisor

**Dr. G. P. Sharma**  
DRI Nominee  
(In place of Dr. P. K. Singh)

Dean, C.T.A.E  
**Dr. N. S. Rathore**

**Dr. G. S. Tiwari**  
**Head**  
Department of FMPE

Approved  
Director Resident Instruction

**MAHARANA PRATAP UNIVERSITY OF AGRICULTURE AND TECHNOLOGY,  
UDAIPUR**

**COLLEGE OF TECHNOLOGY AND ENGINEERING, UDAIPUR**

Dated: /01/2012

## **CERTIFICATE – IV**

**This is to certify that Mr. Babasaheb Sukhadeo Gholap student of Master of Engineering in Agriculture Engineering in the subject of Farm Machinery And Power Engineering, Department of Farm Machinery And Power Engineering has made all corrections/modifications in the thesis entitled “Design development and performance evaluation of tractor mounted hydraulic boom sprayer for cotton crop” which were suggested by the external examiner and the advisory committee in the oral examination held on 07/01/2012 the final copies of the thesis duly bound and corrected were submitted on**

**/ 01/2012**

**Dr. Ravi Mathur**

Major Advisor

**Dr. G. S. Tiwari**

**Head**

Deptt. of Farm Machinery and power  
Engineering

**Dr. N. S. Rathore**

**Dean**

College of Technology and Engineering,

Udaipur

## ABSTRACT

Cotton farming is a popular agribusiness in India. It is one of the principal commercial crops in India with 11 million ha cultivated area which is largest in the world. India is second largest producer of cotton in the world though the yield is only 300 kg/ha as against the world average of 558 kg/ha, due to poor control of insect pest and dry land farming conditions. A major reason for such a pesticide loss is use of inefficient spraying machines, which are unable to maintain specified nozzle pressure, nozzle discharge, nozzle height that affects spray pattern, droplet size, spray uniformity etc.

The principle of working of the tractor mounted boom sprayer is to move the spray liquid to the individual nozzles along the boom. The pump is driven by the PTO shaft of the tractor and the sprayer unit sucks the chemical and discharges it through the spray boom or through the discharge line consisting of a delivery hose and spray guns. A 12-m tractor mounted boom sprayer was modified and developed considering the various deficiencies in the components of the existing boom sprayer. In order to develop new hydraulic boom sprayer, initially the performance of the existing boom sprayer was evaluated. The modifications were done in the some component of the boom sprayer for structural stability and new folding arrangement.

The developed boom sprayer was tested in a laboratory in terms of liquid distribution, droplet size, droplet density and uniformity coefficient for four levels of nozzle discharge (0.45, 0.70, 0.90 and 1.35 l/min) and nozzle pressure (278.5, 413.7, 551.6 and 689.5 kPa). The deposition of droplet was taken at top, middle and bottom position of the plant and on upper and lower leaf surface. More liquid distribution was observed within  $\pm 20$  per cent of the total mean value. Droplet size (VMD) ranged from 155.44 to 181.55  $\mu\text{m}$ , droplet density (DD) from 17 to 29 drops/cm<sup>2</sup> and uniformity coefficient (UC) from 0.99 to 1.23 for the developed boom sprayer at nozzle discharge rate 0.90 l/min and nozzle pressure 689.5 kPa. Further uniform distribution obtained for entire 12 m length of boom. These were close to recommended values for effective pest control on crops.

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# CHAPTER I

## INTRODUCTION

### 1.1 Background

The world's population is continuously increasing, especially in many developing countries. To feed and clothe these people, food crop yields need to be increased and more natural fibers need to be produced. Continuous growing world population and an increased pressure on the available area to cultivate crop, demands for a more intensive agriculture.

Cotton is one of the principal commercial crops of India, with 11 mha cultivated area (largest in the world). India is second largest producer of cotton in the world. The yield is only 300 kg /ha as against the world average of 558 kg/ha. This is due to poor control of insect pest and dry land farming conditions. Cotton plays an important role in the national economy providing large employment in the farm marketing and processing sectors. Although, there has been a significant growth in production, productivity and quality of Indian cotton during the last 50 years, it is way below the average world productivity and far below the general quality requirements (Anonymous, 2010).

India accounts for 21 per cent of the world cotton production 4.9 Million tonnes out of 23.2 Million tonnes of world production during 2008-09. Cotton yield has increased from 278 kg/ha to 567 kg/ha during 2000-01 to 2007-08 as shown in Table 1.2.

The country accounts for a little over 21 per cent of the global cotton production in the year 2008-09 (Table 1.1). Much of this success owes itself to the introduction of Bt cotton in 2002 prior to which cotton production suffered huge losses due to its susceptibility to insect pests. Among the insects cotton bollworms are the most serious pests of cotton in India causing annual losses of at least US\$ 300 million. The cotton bollworm complex comprises American bollworm, also called 'false America bollworm' or 'old world bollworm' pink bollworm, spiny bollworm and spotted bollworm. *Spodoptera litura*, the leaf worm, is mainly a foliage feeder but it also damages cotton bolls. Insecticides valued at US\$ 660 million are used annually on all crops in India, of which about half are used on cotton alone (Manjunath, 2004). The cost of 21,500 metric tonnes (active ingredient) of insecticides used on cotton in India in 2001 was US\$340 million. Further, the most destructive cotton pest, *Helicoverpa armigera*, is known to have developed resistance against most of the recommended insecticides (Ramasubramanyam, 2004) forcing farmers to apply as many as 10-16 sprays. Incorporating insect resistance pest has thus, been the most important objective of cotton improvement efforts in India (Anonymous, 2010).

**Table 1.1 World production and consumption of cotton in the year 2008-09**

| Country       | Production<br>(million tonnes) | Consumption<br>(million tonnes) |
|---------------|--------------------------------|---------------------------------|
| China         | 7.8                            | 9.9                             |
| India         | 4.9                            | 3.9                             |
| United state  | 2.8                            | 0.8                             |
| Pakistan      | 2.0                            | 2.5                             |
| Uzbekistan    | 1.0                            | 0.2                             |
| Brazil        | 1.2                            | 0.9                             |
| Turkey        | 0.4                            | 1.1                             |
| Rest of world | 3.1                            | 4.8                             |
| Total         | 23.2                           | 24.1                            |

Source: Cotton Incorporated, 2009.

**Table 1.2 Area, Production and productivity of cotton in India during last six decades**

| Year    | Area in lakhha | Production in lakhbales of<br>170 kgs | Yield kg/ha |
|---------|----------------|---------------------------------------|-------------|
| 1950-51 | 56.48          | 30.62                                 | 92          |
| 1960-61 | 76.78          | 56.41                                 | 124         |
| 1970-71 | 76.05          | 47.63                                 | 106         |
| 1980-81 | 78.24          | 78.6                                  | 170         |
| 1990-91 | 74.39          | 117                                   | 267         |
| 2000-01 | 85.76          | 140                                   | 278         |
| 2006-07 | 91.44          | 280                                   | 521         |
| 2007-08 | 94.39          | 315                                   | 567         |

Source: Cotton Advisory Board (2008-2009), India.

Cotton crop is grown in semi arid regions of the country. More than sixty per cent production is contributed by three states alone namely Gujarat, Maharashtra and Andhra Pradesh. The area of cultivation of cotton in various states of India is shown in Table 1.3. the table also depicts state wise cotton production during last five years. Cotton sowing is in progress in all the cotton growing states but the pace of area coverage is slow.

**Table 1.3 State wise cotton production during the last five years**

| State | Production | Productivity | Area, lakh |
|-------|------------|--------------|------------|
|-------|------------|--------------|------------|

|                | (million bales) |             | (million bales) |             | ha           |
|----------------|-----------------|-------------|-----------------|-------------|--------------|
|                | 2001-2002       | 2002-2007 * | 2001-2002       | 2002-2007   | 2001-2007**  |
| Punjab         | <b>0.9</b>      | <b>2.4</b>  | <b>262</b>      | <b>630</b>  | <b>4.52</b>  |
| Haryana        | 0.5             | 1.6         | 153             | 569         | 5.62         |
| Rajasthan      | <b>0.7</b>      | <b>0.9</b>  | <b>343</b>      | <b>416</b>  | <b>3.44</b>  |
| Gujarat        | <b>3.25</b>     | <b>11.0</b> | <b>328</b>      | <b>743</b>  | <b>16.47</b> |
| Maharashtra    | <b>3.42</b>     | <b>6.0</b>  | <b>195</b>      | <b>320</b>  | <b>27.66</b> |
| Madhya Pradesh | 2.0             | 2.1         | 546             | 539         | 5.91         |
| Andhra Pradesh | 2.67            | 4.3         | 454             | 667         | 8.37         |
| Karnataka      | 0.7             | 0.8         | 201             | 367         | 3.13         |
| Tamil Nadu     | 0.5             | 0.5         | 425             | 669         | 1.03         |
| Others         | 0.08            | 0.2         |                 |             | 0.51         |
| <b>Total</b>   | <b>14.8</b>     | <b>29.8</b> | <b>2907</b>     | <b>4920</b> | <b>76.66</b> |

Source: All India Coordinated Cotton Improvement Project (AICCIP) 2007-08, Annual Report

\*Average production (million bales)

\*\*Average area (lakh ha)

## 1.2 Rationale

Efficient distribution of chemical agents is highly correlated with the uniformity of spray coverage in the canopy. Irregularities in the spray pattern are mainly created by pressure variation in the hydraulic equipment, misalignment of spray nozzles, drift and spray boom vibrations. Pressure variations in the hydraulic equipment (with respect to the spray liquid) and misarranged spray nozzles have to do with the technical state of the sprayer. Wind moves a pesticide through the air, during or after application, to a site other than the intended site of the application. In the field of spraying, this phenomenon is called drift. Affecting the droplets reduces the effect of drift. This involves adjusting their shape and size or charging the droplets and the crop or accompanying the droplets with a vertical air stream. The latter is known as air assisted spraying. Positioning the spray boom closer to the crop reduces the effect of the wind (Nation, 1982). However, in order to avoid damage to the missing crop a stable spray boom must be guaranteed. Increasing the boom stability improves the homogeneity and raises the efficiency of the chemicals.

## 1.3 Pesticide

Pesticides are critical inputs for crop production worldwide and are expected to continue to play a major role for the future to protect most of the crop systems from the infestation of insect-pests and disease. A large volume of pesticide is used in crop protection; however its application on different crops is highly inefficient. Misapplication, evaporation, leaf runoff and drift during the process of spraying, results in loss of a major portion of these chemicals. The unused and lost portion of pesticides, which may be to the extent of 90 per cent of the applied chemical, not only results in economic loss but it also pollutes air, water and soil.

Pesticide application is a complex process and the magnitude and uniformity of spray deposition are mainly influenced by target canopy characteristics, type of spray equipment and mode of operation and properties of spray chemical. Uniform distribution and deposition of chemical spray from top to bottom of plant canopy and on the underside of the leaves is of utmost importance for effective control of pests. Incorporation air-assistance in the spraying system improves the deposition uniformity in the entire plant or tree canopy structure. Spray deposition on the lower part of plant leaves, where most of the pests harbour, also improves in air-assisted spray application. The deposition of spray droplets, requirement of air volume in air-assisted spraying system and pesticide application rates are mainly influenced by canopy characteristics, like, leaf area index and leaf area density.

The efficacy of pesticides in the insect control is mainly influenced by the amount of chemical used in a unit area of target, deposit of the chemical on the area and percentage of the target area receiving the pesticides. The above factors viz., dose, distribution and coverage are dependent on the type of application viz. high volume, low volume and ultra volume sprays. However, each method of spraying has its own merits and demerits.

#### **1.4 Application of Pesticide by Hydraulic Boom Sprayer**

The most common method of applying pesticides to the field crops in more developed and relatively wealthy agricultural regions of the world is with hydraulic boom sprayers. These machines, although variable in size, are basically simple in design. Their main features have changed little over the last fifty years. However, numerous detail changes have been made in more recent times so that the equipment available today is more reliable and potentially safer and more efficient in use.

To be efficient, all the pesticide application equipments have to be used to apply maximum proportion of the agrochemicals emitted to the intended target is difficult to achieve with sprayer (Hislop, 1987). Optimal timing can often be achieved by good management and taking advantage of the high work rates possible with powered sprayers.

As the length of boom increases boom movement also increases. Previous studies showed that horizontal and vertical movements of boom affect the uniformity of the spray. To ensure the effectiveness of the chemicals, they must be distributed accurately. This requires a stable spray boom. The longer booms are generally trailed behind tractors which will increase length of tractor sprayer assembly which in turn increases turning radius of the assembly.

The growing world trade requires uniform technical regulations, concerning the performance of pesticide sprayers. This also includes common guidelines for testing application techniques. European and International Standards help to ensure a high level of state of the art of sprayers and lead to uniform criteria for the evaluation of spraying systems concerning working quality, operator safety and environmental protection. International and European standardization is conducted by the International Organization for Standardization (ISO) and the European Committee for Standardization (CEN). Therefore it is necessary to design hydraulic boom sprayer which fulfills CEN standards (Herbst, 2002).

Spray nozzles used for broadcast spraying do not deliver a uniform quantity of material over the width of the spray pattern. The distribution pattern is determined by nozzle design, nozzle wear, nozzle clogging and pressure at the nozzle. When numbers of nozzles are spaced on the boom, the individual nozzle spray pattern must overlap to obtain uniform distribution over the entire boom length. Nozzle manufacturers recommend a boom height for each particular nozzle and nozzle spacing. Improper boom height will result in uneven distribution patterns. Anything that changes boom height such as rolling land that causes the boom to tilt and undulated land that causes the boom to bounce up and down as well as forward and backward will affect the distribution pattern. Pressure may also affect distribution pattern. The tests conducted at the Prairie Agricultural Machinery Institute in Canada resulted in poor distribution at a pressure of 1.36 kg/cm<sup>2</sup>. The actual application varied by more than 40 per cent above and below the recommended application rate. However, when the pressure was increased to 2.72 kg/cm<sup>2</sup>, a good distribution pattern was obtained. Boom height should be checked and varied for uniform distribution (Nalavade, 2008).

Experimental work and simulation studies pointed out that undesired spray boom motions give rise to an uneven spray deposition pattern, resulting in under and over application of spray deposits ranging from 0 to 800 per cent of the desired spray distribution. Increasing the boom stability improves the homogeneity and raises the efficiency of the chemicals (Nation, 1978).

Wastage of pesticides and poor pest control give rise to loss of yield in field crops. The existing boom sprayers manufactured by manufacturers are not scientifically defined. Due to improper design and operation leads to uneven uniformity of spray pattern. To improve uniformity of spray, the spray distribution along the swath width should be uniform. To achieve this scientific

and efficient spray boom system must be designed. It is therefore necessary to undertake research work to design and develop a boom sprayer for cotton crop and test the same in the laboratory.

In India, very few research studies have been done on boom sprayers for annual field crops. In view of the above discussion a research study was undertaken to design and develop tractor mounted hydraulic boom sprayer for cotton crop and evaluate its performance in the laboratory.

In the light of the above, a project work was undertaken with the following objectives:

- i. To test the existing tractor mounted hydraulic boom sprayer in the laboratory.
- ii. To design and develop a spray boom for uniform spray application.
- iii. To evaluate the performance of developed spray boom in the laboratory.

## CHAPTER II

### REVIEW OF LITERATURE

This chapter gives brief information regarding review of work done on the various areas on cotton crop and boom sprayer. An attempt has been made to review the related areas. The literature surveyed includes pest and disease on cotton, cotton yield, yield losses, crop protection techniques, pesticide use, crop protection equipments and tractor mounted boom sprayer and spray boom design.

#### 2.1 Important Insects, Pests and Diseases on Cotton

Anonymous (2002) quoted various insects, pests and diseases of the cotton plant. The plant is affected by as many as 21 pests. Pests infecting plants before flowering are jassids, aphids, thrips, whitefly and mealy bug etc. and pests' attacking the plant after it has commenced producing buds, flowers and bolls are Spotted bollworm, American bollworm and Pink bollworm etc. The important diseases on cotton are wilt, black arm which affect the American cotton and dahlia which affect desi cotton. Other diseases are grey mildew, rust, root knot etc.

Puttarudriah (1983) described various pests and their features. They are listed in table 2.1

**Table 2.1 Features of important pests on cotton**

| S. No. | Pests   | Features   |
|--------|---|--|
| 1      | Aphid (Aphid gossypii)                                  | Appears in colonies on the tender portion of plants, yellow in colour, affected leaves curl.   |
| 2      | Jassid (Amrasca biguttula)                              | Small greenish leaf hopper found on the underside of the leaves turn yellow and start curling.   |
| 3      | Whitefly (Bemesia tabaci)                               | Small, white dot like insect suck the sap.   |
| 4      | Spotted bollworm (Earias vitteulla and earias insulana) | Small brown caterpillar bore into top shoots before boll formation and later in to green bolls, the top shoots droop down and attacked bolls are shaded.   |
| 5      | American bollworm (Heliothis armiger)                   | Adult brownish yellow coloured, the caterpillar is green with longitudinal streaks and damages the bolls by feeding. The special feature of this bollworm is that it keeps half of its body outside and head end inside. |

#### 2.2 Chemical Control of Cotton Pests

Matthews (1994) quoted that pests are controlled by using various chemicals such as fungicides, insecticides most commonly used for cotton includes foret (10%), Dimethoate (0.03%), Phosphamidon (0.2%), Endosulphan (0.06%), Monocrotophos (0.6%) etc. but it depends on the type of pests infesting the crop. For control of diseases, seeds are treated with organomecurials like agrason, cerson etc. and crop is sprayed with bordeaux mixture, zireb, copper oxychloride (0.25%) and carbendyazim etc.

He further emphasizes that successful chemical controls of cotton insect pest depends not only on the correct choice of insecticides but also on using the appropriate equipment and application technique.

### 2.3 Cotton Yield

Anonymous (2008), reported that Indian cottonseed yields dramatically increased since 2002-03. The average yield from 2003-04 to 2006-07 jumped by more than 50 per cent compared to its level over the previous period (1990-91 to 2002-03). Indian ginning output increased in the recent years due to improvisation of ginning technology. Table 2.2 shows the cotton yields in India for last few years.

**Table 2.2 Cotton yields in India**

| Year of growing          | 1990-2000 | 2000-2007 | 2007 |
|--------------------------|-----------|-----------|------|
| Seed cotton yield, t/ha  | 0.71      | 0.99      | 1.02 |
| Cotton fiber yield, t/ha | 0.30      | 0.43      | 0.52 |
| Ginning output, per cent | 42        | 44        | 51   |

*Source:* UNCTAD secretariat [Data: ICAC (fiber yields) and FAO (seed yields)]

### 2.4 Yield Losses

Mathews (1979) reported that the pest were chief competitors of the crops on the earth. They transmit diseases to human and animals. They included insects, fungi, bacteria, viruses, weeds, nematodes, rodents and birds. He reported that about one third of the agricultural production in the world was annually lost due to pest.

Oerke *et al.*, (1994) reported that production losses due to pests, diseases and weeds was 15 per cent, 14 per cent and 13 per cent on the average for the main cereals and potatoes, in the absence of control measures. When compared with potential yields, the loss reduction was roughly about 70 per cent equally distributed between pests, diseases and weeds.

Oerke *et al.*, (1995) estimated the average losses in 8 major crops. They claimed that 42 per cent of attainable production was lost as a result of pests, varying from 28 per cent in Europe and 31 per cent in North America to just below 50 per cent in Asia and Africa.

Oerke and Dehne (1997) concluded that worldwide production of most crops increased due to control measures. The efficacy of crop protection practices was calculated as the percentage of potential losses prevented by control. The efficacy was found highest in cotton (55 per cent), and 34 to 38 per cent in the food crops like rice, wheat and maize. The efficacy of actual crop protection was 61, 44 and 38 per cent in North America, Oceania and all other region respectively. The efficacy of actual crop protection worldwide was only 40 per cent.

Gommes (1999) analyzed the effect of technology and management trends, innovation, policy and extreme factors and weather on agricultural yields. He concluded that weather is the main factor affecting the agricultural production. According to him, the agricultural production systems such as production, harvest, storage, transportation etc. was affected by weather both directly and indirectly through diseases, pests, damage to infrastructure, etc.

## **2.5 Crop Protection Techniques**

Mathews (1979) had classified plant protection techniques into mainly five methods viz. cultural, physical and mechanical control, biological control, chemical control and integrated pest management.

## **2.6 Pesticide Use**

Bache and Johnstone (1992) stated that different droplet sizes had different dispersal characteristics and were subjected to complex macro and micro-climatic interactions in pesticide application.

Derksen and Breth (1994) reported that appropriate timing of pesticide application was critical for controlling pest problems and reducing pesticide use. Proper pesticide application resulted from the proper timing of application, selection of equipment, spray formulation and calibration. The quality of application was important to effectiveness of an application.

Tjaart (1999) reported that use of herbicides increased, pesticides use was still increasing, whereas use of insecticide decreased. He concluded that the countries having high-income with subsidized agricultural system (France, Netherlands, United kingdom, United states, Japan) or countries that produce commodities such as cotton, fruit and vegetables used high amount of pesticides.

Gerd and Yongfan (2005) reported that overall annual pesticide use in Asia was estimated close to 5, 00,000 tonnes valued at US\$ 8.3 billion. Further he concluded that trend of pesticides use was increasing in Asia, while worldwide it was stagnant.

Anonymous (2006), World Watch Institute reported the use of pesticides worldwide increased from 0.49 kg/ha in 1961 to 2 kg/ha in 2004.

Balsari *et al.*, (2008) developed a prototype sprayer which automatically adapted spray and air distribution according to the characteristics of the target, to the level of crop disease and the environmental conditions. In order to identify the characteristics of the canopy target, in terms of size and density, a Crop Identification System (CIS) based on ultrasonic sensors, was studied. The test confirmed the CIS suitability to detect in time the features of the target to be sprayed and enabled the adequate regulation of spraying parameters

Bode *et al.*, (1983) reported about the new and improved ground application technology, which increased application efficiency while protecting the environment. The technology advance included direct injection, on-board application, handling and control systems, Air-Assisted Sprayers, electrostatic spraying, and nozzle development for precise application of fertilizers and pesticides with minimal impact on the environment.

## **2.7 Crop Protection Equipments**

Matthews and Thronhill (1994) classified pesticide application equipments as: Manually carried equipments and mechanically powered equipments

Anonymous (2006) reported about the Pest Management Regulatory Agency. They classified pesticide applications equipments as ground sprayers, application for solid formulations, aerial sprayer, fumigation equipments, foggers and chemigation.

## **2.8 Tractor Mounted Boom Sprayers**

Combella (1982) reported that the boom sprayer was developed in the 1880 in France and the United States of America and was first used in Australia in the early 1900. These early units were horse-drawn, using hollow cone nozzles and utilizing a ground drive positive displacement pump (metered sprayer). Later developments were seen for pump, power source, tank capacity and boom length. Flat fan nozzles were introduced in 1940. He further mentioned developments in fiberglass tanks, more efficient pumps, more durable and lighter spray lines, self-leveling booms and even some electrostatic components.

Rutherford (1985) enlisted the advantages of the boom and hydraulic nozzle system. The advantages were in terms of

### *Effectiveness*

The farmers are satisfied with the performance of their sprayers using this system.

### *Versatility*

Versatility of the boom and nozzle system makes the sprayer more popular among the farmers.

### *Efficiency*

The boom and nozzle system produces reliable results.

### *Fast*

Farmers can treat their field using this system within specified time.

### *Safety*

This system produced minimal risk to the operator, bystanders and the environment.

Jones (2006) has described components of mechanized boom sprayer. Most of the boom sprayers were operated by tractors and power is transmitted to the pump from PTO shaft. The components of boom sprayer were tank, pump, spray boom, nozzles, filters and control system

Padmanathan and kathirvel (2007) developed a power tiller operated rear mounted boom sprayer for spraying cotton and other crops planted in rows and to produce uniform spray pattern using minimum amount of spray materials. Test was carried out on the developed sprayer both in laboratory and in the field. The spray boom consisted of sixteen hollow cone nozzles, placed 40 cm apart with a swath width of 3.2 m and forward speed of 2 km/h. The effective field capacity of the sprayer was 0.72 ha/h. The performance of the power tiller operated boom sprayer was satisfactory at a pressure of 3 kg /cm<sup>2</sup> and was adopted by the farmers for spraying cotton crop and other row crops

Nalavade *et al.*, (2008) developed a tractor mounted wide spray boom for increased efficiency. A 15-m tractor mounted spray boom was developed considering the stresses acting on the boom structure. It was tested in the laboratory and in the field to evaluate its performance. The developed spray boom's performance was compared with existing 9-m spray boom developed by a local manufacturer. Further, both spray booms were evaluated from the economic point of view. Statistical analysis showed that there was no significant variation in spray uniformity within a field for all the test trials. A 15-m spray boom was found to be more economical than the existing 9-m spray boom.

## **2.9 Spray Boom Design**

Nation (1978) reported that a better boom stability can make a substantial contribution to higher working rates by reducing the likelihood of the boom tips striking the ground. This facilitated use of so that either larger boom or higher forward speed during spraying.

Cowling (1980) studied the boom design from the manufacturing point of view. He developed a boom structure outline by assuming standard truss specifications. He also discussed some of the components about fabrication of boom as material, method of fabrication, hinges and joints.

Hodge *et al.*, (1980) reported that the boom should be designed such that the time required for pack up and unpack as well as for raising and lowering is minimum.

Nation (1980) reported that the boom moments such as rolling, yawing affected the spray distribution. Further he concluded that, with a stiff, rigid boom an increase in boom height at one side is usually accomplished by a corresponding decrease in height at other side, caused by rolling of the sprayer.

Behncken (1983) enlisted some of the considerations required for boom construction. He studied the various aspects for the construction of boom sprayer in terms of construction material, boom size, boom folding and boom height adjustment.

## **2.10 Factors Affecting Spraying**

### **2.10.1 Quantity of spray**

Fulton (1965) found that in many situations, volume of the spray fluid of the protective fungicide reduced, with equal or even better efficiency in disease control, provided the dose per unit area on the basis of active ingredient is not lowered.

Johnston (1970) stated that when suitable droplet size was selected, droplet density can be calculated from the graph developed from following relationship.

$$N = \frac{60 \times 100^3 \times Q}{\pi \times d^3}$$

Where,

N = Mean number of droplets falling on square centimeter area.

d = Droplet diameter,  $\mu\text{m}$

Q = Volume of spray, l/h

### **2.10.2 Spray nozzles**

Mathews (1979) classified the nozzles according to the form of energy employed to break up bulk liquid into droplets and to project the resultant spray droplets to the intended target. The

different categories of energy used are hydraulic energy, gaseous energy, centrifugal energy, kinetic energy, thermal energy and electro-dynamic energy.

Hall (1991) reported that height, plant distance, shape growth patterns, and expertise of the operator to match the application with the target geometry were the vital factors determining the efficiency of spray application process. Accurate control of travel speed and adjustment of liquid and air flow to the foliar target were critical for any efficient application. The factors responsible for effective spraying were mainly droplet size, droplet density and spray drift.

### 2.10.3 Droplet size

Weidennhoff (1991) classified the pesticide sprays according to droplet size. This is presented in Table 2.3. He considered pesticide spray, droplet diameter and size distribution was of great importance. Usually droplet size present in VMD, which means Volume Median Diameter that is representative sample of the droplets of spray which divided spray into two equal part so that one half of the volume contains droplet smaller than a droplet whose diameter is VMD and other half of volume contains large droplets. NMD means Number Median Diameter, which divided the spray into two equal parts by number without reference of the volume. Because the VMD and NMD is affected by the proportion of large and small droplets, respectively, the ratio between these two parameters is often an indication of the range of sizes, thus more uniform the size of the droplet, the nearer ratio to one. This is known as uniformity coefficient. Therefore uniformity coefficient is the ratio VMD / NMD.

**Table 2.3 Droplet size classification**

| VMD of droplets , $\mu\text{m}$ | Droplet size classification |
|---------------------------------|-----------------------------|
| < 50                            | Aerosol                     |
| 51 – 100                        | Mist                        |
| 101 -200                        | Fine spray                  |
| 201 -400                        | Medium spray                |
| > 400                           | Coarse spray                |

Willson *et al.*, (1963) conducted an exhaustive study on effect of different droplet sizes on the effective disease control. He found that spray droplets with 500  $\mu\text{m}$  VMD was not effective for good disease control as those with the 100 – 400  $\mu\text{m}$  VMD. For spray applications of fungicide, insecticide or herbicide, he considered droplet range as shown in Table 2.4.

Bode *et al.*, (1983) quoted a spectrum of droplet sizes between 150 and 300  $\mu\text{m}$  for herbicides application for tractor mounted sprayers.

**Table 2.4 Droplet range for application/pest control**

| <b>Application</b>                 | <b>Droplet Category</b> | <b>Approximate VMD Range,<br/>µm</b> |
|------------------------------------|-------------------------|--------------------------------------|
| <b>Fungicide</b>                   |                         |                                      |
| foliar protective or curative      | Medium                  | 226-325                              |
| <b>Insecticide</b>                 |                         |                                      |
| foliar contact or stomach poison   | Medium                  | 226-325                              |
| foliar systemic                    | Coarse                  | 326-400                              |
| soil-applied systemic              | Coarse                  | 326-400                              |
|                                    | Very Coarse             | 401-500                              |
|                                    | Extremely Coarse        | >500                                 |
| <b>Herbicide</b>                   |                         |                                      |
| foliar/post emergent contact       | Medium                  | 226-325                              |
| foliar/post emergent systemic      | Coarse                  | 326-400                              |
| soil-applied/pre-emergent systemic | Coarse                  | 326-400                              |
|                                    | Very Coarse             | 401-500                              |
|                                    | Extremely Coarse        | >500                                 |

Source: ASAE Standard S572 FEB04; American Society of Agricultural and Biological Engineers, St. Joseph, MI; (2009).

Johnston (1973) used one droplet per sq. mm as the droplet density criterion for control of red scale *aconidiella aurantii* on citrus. The criterion was considered so that the deposited droplets (100 µm) should be sufficient to give high probability of a direct hit on the scale insect.

Alms, (1987) studied the effect of the spray droplet size and distribution of drops containing uniform droplets of 120, 145 and 200 µm. This contained with 0.075 per cent Bifenthrin 2E were deposited on leaf (177 cm<sup>2</sup>) in distribution ranging from 0 – 182 drops/cm<sup>2</sup>. It was found that egg deposition was reduced to 80 per cent with 41 drops/cm<sup>2</sup> of 120 µm or 18 drops/cm<sup>2</sup> of 200 µm. The droplet density of 41 drops/cm<sup>2</sup> of 120 µm corresponded to 3.7 l/ha and 18 drops/cm<sup>2</sup> of 200 µm corresponded to 7.5 l/ha. They concluded that droplets of 120 µm were more efficient in pesticide.

Anonymous (2002) studied the adequacy of density using ultra low volume sprays. They recommended that an average of 15-20 droplets per sq. cm was adequate for controlling most of the insects and pests. The study also reported the results of spray deposition with conventional sprayer and found that pesticides deposition was greater on the upper surface of the leaves than the lower surface. Outside deposition was found bigger than inside canopy deposition. The center of canopy received about half the quantity of spray deposited at the outside of the tree.

It was concluded from review that the droplet density, 15-25 drops/cm<sup>2</sup>, droplet size 150-250 μm and uniformity coefficient 0.75 to 1.5 offered effective pest control in the crops. In view to eliminate the pest from the crop, the spray should reach deep into the canopy underside of the leaf. The concept of air assisted spraying coming into existence because it increases the deposition and reduces the drift up to 50 per cent. Further to increase deposition deep into the canopy and to reduce the drift to great extent, an air assisted spraying technique is being developed.

## CHAPTER V

### SUMMARY AND CONCLUSIONS

The world's population is continuously increasing, especially in many developing countries. To feed and clothe these peoples, food crop yields need to be increased and more natural fibers need to be produced. Continuous growing world population and an increased pressure on the available area to cultivate crop, demand for a more intensive agriculture.

Cotton plays an important role in the national economy providing large employment in the farm marketing and processing sectors. It is one of the principal commercial crops in India, with 11 million ha cultivated area which is largest in the world. India is second largest producer of cotton in the world. The cotton yield in India is only 300 kg /ha as against the world average of 558 kg/ha due to poor control of insect pest and dry land farming conditions.. Although, there has been a significant growth in production, productivity and quality of Indian cotton during the last 50 years, it is way below the average world productivity and far below the general quality requirements.

Boom sprayers are hydraulic equipments used for pesticide application in field crops. As the length of boom increases boom movement also increases. Previous studies showed that horizontal and vertical movements of boom affect the uniformity of the spray. To ensure the effectiveness of the chemicals, they must be distributed accurately. This requires a stable spray boom. The longer booms are generally trailed behind tractors which will increase length of tractor sprayer assembly which in turn increases turning radius of assembly.

Wastage of pesticides and poor pest control give rise to loss of yield in field crops. The existing boom sprayers manufactured by manufacturers are not scientifically defined. Due to improper design and operation leads to uneven uniformity of spray pattern. To improve uniformity of spray, the spray distribution along the swath width should be uniform. To achieve this scientific and efficient spray boom system must be designed. It is therefore necessary to undertake research work to design and develop a boom sprayer for cotton crops and test the same in the laboratory.

In India, very few research studies have been done on boom sprayers for annual field crops. In view of all above discussion and facts, a research study was undertaken to Design development and performance evaluation of tractor mounted hydraulic boom sprayer for cotton crop, with the following objectives:

1. To test the existing tractor mounted hydraulic boom sprayer in the laboratory.
2. To design and develop a spray boom for uniform spray application.
3. To evaluate the performance of developed spray boom in the laboratory

In order to develop new hydraulic boom sprayer, initially the performance of the existing boom sprayer was evaluated in the laboratory. Its liquid distribution, flow rate of the pump, discharge and pressure measurement of nozzles and spray deposition was measured. In addition design deficiencies of the various components of the sprayer were identified and necessary modifications were incorporated. For the existing boom sprayer droplet size (VMD), droplet density (DD) and uniformity coefficient (UC) ranged from 130.9 to 206.39  $\mu\text{m}$ , 11 to 27 drops/cm<sup>2</sup> and 1.18 to 1.31 respectively for the three plant position. On the basis of data collected during laboratory test for the various parameters it was revealed that developed sprayer was better than existing sprayer for the cotton crop.

The performance of the developed boom sprayer was evaluated in the laboratory for dependent and independent variables. For the laboratory evaluation cotton plants were raised in the polythene bags. The sprayer was operated on the plant canopy at forward speed of 2.5 km/hr. The laboratory experiment was conducted to study the different experimental variables on spray penetration deep into the canopy. Independent variables included four levels of nozzle discharge as 0.45, 0.70, 0.90 and 1.35 l/min and four levels of nozzle pressure as 278.5, 413.7, 551.6 and 689.5 kPa. Dependent variables were Droplet size ( $\mu\text{m}$ ), Droplet density (drops/cm<sup>2</sup>) and Uniformity coefficient.

To facilitate the evaluation of the spray penetration into the plant canopy, the deposition of the droplets were observed at top, middle and bottom position of plant canopy and on upper and lower leaf surface. At each position the glossy paper were stapled at three locations to observe the deposition of droplets. Image pro, the electronic imaging programme was used as an analyzer for analysis of glossy paper.

The performance of the developed boom sprayer increased and its droplet size (VMD), droplet density (DD) and uniformity coefficient (UC) ranged from 155.44 to 181.55  $\mu\text{m}$ , 17 to 29 drops/cm<sup>2</sup> and 0.99 to 1.23 respectively for the three plant position

On the basis of the results obtained from the laboratory performance evaluation the following conclusions were drawn:

## **Conclusions**

- 1) The liquid distribution under of the developed boom sprayer improved and more distribution was within the  $\pm 20$  per cent of total mean value.

- 2) The mean discharge and pressure of developed boom sprayer increased by 49 per cent and 184.4 per cent compared to the existing boom sprayer respectively.
- 3) The discharge and pressure of the developed boom sprayer was nearly uniform in all nozzles.
- 4) Droplet size (VMD), droplet density (DD) and uniformity coefficient (UC) ranged from 130.9 to 206.39  $\mu\text{m}$ , 11 to 27 drops/ $\text{cm}^2$  and 1.18 to 1.31 respectively for the three plant position in existing boom sprayer.
- 5) Droplet size (VMD), droplet density (DD) and uniformity coefficient (UC) ranged from 155.44 to 181.55  $\mu\text{m}$ , 17 to 29 drops/ $\text{cm}^2$  and 0.99 to 1.23 respectively for the three plant position in the developed boom sprayer for effective pest control on cotton crop.

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## APPENDIX I

### Plant parameters at different stages of plant growth

| S.No. | Plant parameter   | Age of plant (DAT) |
|-------|---|--------------------|
|       |   | 85                 |
| 1     | Average total number of leaves per plant  | 380.7              |
| 2     | Leaf area index   | 3.0                |
| 3     | Average height of plant, cm   | 101.4              |
| 4     | Average width of plant, cm  | 95.1               |
| 5     | Average length of leaf, cm  | 14.8               |
| 6     | Average width of leaf, cm   | 10.2               |
| 7     | Total area of single leaf, cm <sup>2</sup>  | 150.9              |
| 8     | Total vegetative area of single plant considering both leaf surfaces (upper and lower), cm <sup>2</sup> | 1,14,000           |

Crop-cotton

DAT=Days after transplanting

Cotton= Varsity NH-44

## APPENDIX II

### Specifications of the testing instruments

#### i. Spray scanner

Make- Advanced agricultural machinery system (AAMS), Belgium

Aluminium rails-

Length- 3200 mm

Number- 9

Width- 420 mm

Spray scanner

Channel length- 1500 mm

Channel width- 100 mm

Number of channels- 8

Power (rechargeable battery- 12 V: 15 Ah

Transmission- electric motor 12 V

Weight- 57.5 kg

#### ii. Pump tester

Make-Advanced agricultural machinery system (AAMS), Belgium

Maximum pressure- 1600 kPa

Maximum flow rate- 800 l/min

Maximum supply voltage- 14 V DC

#### iii. Pressure gauge tester

Make- Advanced agricultural machinery system (AAMS), Belgium

Maximum pressure- 2500 kPa

Reference pressure gauge- diameter 160 mm

Quick coupling-1/2"

Test manometer-1/4", 3/8" and 1/2".

#### iv. AAMS Pressure gauge

Make- Advanced agricultural machinery system (AAMS), Belgium

Maximum pressure- 1600 kPa

Measuring container- 2 l with graduation 20 ml.

### APPENDIX III

#### CRD ANOVA TABLE

##### I Existing Boom sprayer

Discharge rates (D1, D2, D3 and D4) – 0.45, 0.70, 0.90 and 1.35 l/min

Pressures (P1, P2, P3 and P4) – 278.5, 413.7, 551.6 and 689.5 kPa

**Table 1 Volume median diameter (VMD)**

| S.No. | SOURCE | DF  | SS        | MS        | F          | SE(m) | CD5%  | CD1%  |
|-------|--------|-----|-----------|-----------|------------|-------|-------|-------|
| 1.    | Treat. | 95  | 504461.62 | 5310.1223 | 479.867**  | 1.921 | 5.357 | 7.067 |
| 2.    | A      | 3   | 39599.6   | 13199.9   | 1192.850** | 0.392 | 1.094 | 1.443 |
| 3.    | B      | 3   | 34780.5   | 11593.5   | 1047.684** | 0.392 | 1.094 | 1.443 |
| 4.    | C      | 5   | 14823.8   | 2964.76   | 267.920**  | 0.480 | 1.339 | 1.767 |
| 5.    | AxB    | 9   | 149541    | 16615.6   | 1501.526** | 0.784 | 2.187 | 2.885 |
| 6.    | AxC    | 15  | 82400.9   | 5493.4    | 496.429**  | 0.960 | 2.679 | 3.534 |
| 7.    | BxC    | 15  | 60533.4   | 4035.56   | 364.687**  | 0.960 | 2.679 | 3.534 |
| 8.    | AxBxC  | 45  | 122783    | 2728.51   | 246.571**  | 1.921 | 5.357 | 7.067 |
| 9.    | Error  | 192 | 2124.64   | 11.0658   |            |       |       |       |

\*\* Significant at 1% level

GM = 190.411 CV = 1.75

**Table 2 Uniformity coefficient (UC)**

| S.No. | SOURCE | DF  | SS        | MS         | F         | SE(m) | CD5%  | CD1%  |
|-------|--------|-----|-----------|------------|-----------|-------|-------|-------|
| 1.    | Treat. | 95  | 22.907194 | 0.24112836 | 105.220** | 0.028 | 0.077 | 0.102 |
| 2.    | A      | 3   | 1.60962   | 0.53654    | 234.126** | 0.006 | 0.016 | 0.021 |
| 3.    | B      | 3   | 0.227953  | 0.0759843  | 33.157**  | 0.006 | 0.016 | 0.021 |
| 4.    | C      | 5   | 1.16508   | 0.233016   | 101.680** | 0.007 | 0.019 | 0.025 |
| 5.    | AxB    | 9   | 6.76909   | 0.752121   | 328.198** | 0.011 | 0.031 | 0.042 |
| 6.    | AxC    | 15  | 2.60284   | 0.173523   | 75.719**  | 0.014 | 0.039 | 0.051 |
| 7.    | BxC    | 15  | 3.22811   | 0.215207   | 93.909**  | 0.014 | 0.039 | 0.051 |
| 8.    | AxBxC  | 45  | 7.3045    | 0.162322   | 70.832**  | 0.028 | 0.077 | 0.102 |
| 9.    | Error  | 192 | 0.44      | 0.00229167 |           |       |       |       |

\*\* Significant at 1% level

GM = 1.385 CV = 3.46

**Table 3 Droplet density (DD)**



|    |        |     |           |           |         |       |       |       |
|----|--------|-----|-----------|-----------|---------|-------|-------|-------|
| 1. | Treat. | 95  | 4634.0799 | 48.779788 | 3.611** | 2.122 | 5.919 | 7.808 |
| 2. | A      | 3   | 119.177   | 39.7257   | 2.941** | 0.433 | 1.208 | 1.594 |
| 3. | B      | 3   | 56.8715   | 18.9572   | 1.404** | 0.433 | 1.208 | 1.594 |
| 4. | C      | 5   | 83.7257   | 16.7451   | 1.240** | 0.530 | 1.480 | 1.952 |
| 5. | AxB    | 9   | 1077.86   | 119.763   | 8.867** | 0.866 | 2.416 | 3.188 |
| 6. | AxC    | 15  | 772.594   | 51.5063   | 3.813** | 1.061 | 2.959 | 3.904 |
| 7. | BxC    | 15  | 448.733   | 29.9155   | 2.215** | 1.061 | 2.959 | 3.904 |
| 8. | AxBxC  | 45  | 2075.11   | 46.1137   | 3.414** | 2.122 | 5.919 | 7.808 |
| 9. | Error  | 192 | 2593.33   | 13.5069   |         |       |       |       |

\*\* Significant at 1 % level

GM = 19.767 CV = 18.59