ASSESSMENT OF THE VARITARGET NOZZLE FOR VARIABLE RATE APPLICATION OF LIQUID CROP PROTECTION PRODUCTS

by

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Abstract

Traditionally, growers spray uniform application of pesticides over the target area regardless of variations in pest infestations. In recent years, variable rate application (VRA) technologies have made it possible to apply pesticides in variable rates across the field. In pesticide application, nozzles play a vital role. In general, pesticides are applied using conventional nozzles. Most conventional nozzles vary flow rates only over a 2:1 range when operated within the recommended pressure range due to a fixed spray orifice. Conventional nozzles vary droplet sizes tremendously when there are speed and application rate changes which results in inefficient application. Conventional nozzles have limitations when used for VRA.

A new nozzle called Varitarget nozzle (U.S. Patent No. 5,134,961) was developed and marketed by Bui, (2005) to overcome the limitations with conventional nozzles. Varitarget nozzles have a variable orifice that changes in size in response to pressure changes, allowing varying flow rates with a minimal change in droplet size. Laboratory tests and field tests were conducted to study the performance of Varitarget nozzle. Varitarget black/blue and clear/yellow caps were evaluated in this study.

Lab studies were conducted to measure Varitarget characteristics compared to conventional nozzles. The flow rate ratios of Varitarget nozzle black and clear caps were 12:1 and 10: 1 while the conventional nozzles produced flow rate ratios ranging from only 3:1 to 4:1. The measured flow rate of Varitarget nozzle black and clear caps was similar to that published by the manufacturer upto 40 psi and varied higher after 40 psi. Both Varitarget black and clear cap nozzle was within the standard VMD requirements until 40 psi and showed increasing trend while the conventional nozzles matched the standard VMD requirements. The VT black and clear cap nozzles showed better coverage at higher pressures when compared to conventional nozzles. CV values for VT black and clear capped nozzles were less than 10 % which indicates capability of good uniform distribution. Spray angle of 110 degrees for VT black and clear capped nozzles was consistent over a range of pressures.

Field studies were also conducted to compare the Varitarget to conventional nozzles. In the varying speed study, droplet size varied from 498 to 621 microns with a SD of 47.50 for VT black nozzle and 465 to 599 microns with a SD of 54.08 for VT clear cap nozzle as the speed varied from 4 to 12 mph. In the varying application rate study, The droplet size varied from 432 to 510 microns with a SD of 27.84 for VT black nozzle and 355 to 452 microns with a SD of 39.80 as the application rate varied from 4 to 12 GPA. In both studies, the observed pressure range required for spraying was minimum and varied slightly.

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Last but not least, I would like to thank my parents, who have always been there to celebrate in my accomplishments and comfort me in my sorrows.

Dedication

This thesis is dedicated to my dad, Dr. Sreenivasulu, who has supported me all the way since the beginning of my studies. You have been with me every step of the way, through good times and bad. Thank you for everything.

Abbreviations and Symbols

^{o}C	degree centigrade
dia	Diameter
^{o}F	Fahrenheit
ft	foot
g	gram
gpm	gallons per minute
GPA	gallons per acre
hr	hour
in	inches
kg	kilogram
lb	pounds
m	meter
mm	millimeter
min	minutes
mph	miles per hour
psi	pound per square inch
RPM	revolutions per minute
s	second
Watt	wattage
V	volts
v	velocity (m/s)
CV	coefficient of variation
D/SC	Droplets per square centimeter
DGPS	Differential Global Positioning System
GPS	Global Positioning System
GIS	Geographic Information System
PAC	Percentage Area Coverage (%)

PWM Pulse Width Modulation

RS Relative Span

SD Standard Deviation

VFFN Variable Flow Fan Nozzle

VT Varitarget

VRT Variable Rate Technology

VRA Variable Rate Application

WSP water sensitive papers

CHAPTER 1 - INTRODUCTION

1.1 Background

The application of crop protection products is an important step in the growing of agronomic crops. Traditionally crop protection products are uniformly applied throughout the field without considering spatial variability of weeds. Thornton et al. (1990) proved that the weeds are not distributed uniformly within crop fields. Blumhorst et al. (1990) reported that herbicide application rate varies with soil properties like pH, moisture content, and organic matter. Hence applying the crop protection products uniformly results in over application, wastage, environmental problems, off target drift etc. If herbicides are applied according to spatial variability of weeds, crop production will be improved and herbicide waste will be reduced (Johnson et al. 1995).

In recent years, variable rate application (VRA) technologies make it possible to apply pesticides in variable rates across the field. Variable rate application (VRA) is a process of application designed to reduce the amount of chemical applied and improves efficacy and effectiveness of chemical application through site specific management practices (Vogel et al. 2005). Different VRA spray techniques are used to apply herbicides at various rates.

One VRA technique available is direct injection system. With this system, active ingredient is injected into system downstream of sprayer pump and prior to branching of distribution hoses to the boom section and thereby applying crop protection products at variable rates (Walker and Bansal, 1999). Koo et al. (1987) found that the transportation lag was 20 seconds when there is a step change. Tompkins et al. (1990) found that the transportation lag was from 12 to 26 seconds. Qiu et al. (1998) found that the application errors for direct injection systems were as high as 40%.

Another VRA technique is direct nozzle injection system which is similar to direct injection system. Direct nozzle injection system was developed to reduce the time lag which was a major problem in direct injection system. In this system, active ingredient is injected directly into the nozzle housing. Rockwell and Ayers (1996) found that the average transport lag was 3.8 seconds which was less but found that the distribution of active ingredient to each nozzle was not even. The direct nozzle injection system is complex and requires additional pipeline and plumbing.

Another VRA technique that can vary the application rate real time and on the go is sensor based systems. These systems utilize sensors which are capable of measuring desired properties such as soil properties, crop characteristics, weeds etc on the go (Daniel R. Ess et al, 2000). The measurements are then processed in a computer and a signal is sent to the controller which releases herbicide on the go. The main advantage of this system is that it doesn't require herbicide maps and differential global positioning systems (DGPS). This system requires less herbicide and drift issues are minimal when compared with conventional spraying system. Rangwongkit et al. (2006) found that sensor technology decreases the herbicide quantity by 20.6%. Tian et al. (1999) found that 48% of herbicide saving was observed if 0.5% weed coverage was used as control threshold. Yong Chen et al. (2005) found that there was no chemical drift when chemical is applied on weeds surface. The main limitation of this system is high cost.

Another VRA technique known as pressure based control system which uses same equipment and configuration of a standard field sprayer to vary application rates. (Walker and Bansal, 1999). In this system, the flow rate is varied by varying pressure and the application rate (GPA) is varied. In general, the relationship between pressure and flow rate for a fixed orifice nozzle is given by the following orifice equation (Walker and Bansal, 1999):

$$Q = K\sqrt{P}$$

Where:

Q = Flow rate from nozzle

K = Constant

P = Pressure

The above equation clearly shows that in order to double the flow rate, the pressure must be increased four times for a fixed orifice nozzle. Walker and Bansal, (1999) stated that large pressure changes requires a more expensive pump. Large pressure changes will produce smaller droplets which results in drift and causes environmental problems. Vogel et al. (2005) found that at the point of transition between one treatment rate and another, spikes of output up to two times the prescribed amount occurred resulting in over application and often higher than normal pressure also resulted in drift. The limitations with flow control and fixed orifice nozzles are well recognized.

To overcome the above limitation of flow control, Giles and Combo, (1990) developed pulse width modulation (PMW) for intermittent flow control of conventional fixed orifice spray nozzles. Each nozzle body was equipped with a direct acting, inline solenoid valve, which operates at 10 to 15 Hz (Giles et al. 1996). The system operates under the direction of a computer and an application controller. The variation in flow rate through the nozzle is achieved by controlling the PWM duty cycle (Han et al. 2001). The time the nozzle valve is open compared to total open and closed time is referred to as duty cycle (Giles, 1997). A flow control range of over 10:1 was achieved under constant system pressure with modest changes in droplet diameter and spray pattern (Giles, 1997).

Pierce and Ayers, (2001) found that 65 to 100 % weed control was observed at duty cycles 25 to 100% for post emergence application and 100% weed control at all duty cycles for pre emergence herbicide application. Gopala Pillai et al. (1999) found that the flow rate was in the ratio of 9.5: 1 without a significant change in the spray pattern. Han et al, (2001) found that the flow rate changes due to inaccuracy of pressure controller ranged from 0.5 to 2.2%. Giles et al. (2001) found that the pulsed spray retained 2 to 3 fold more kinetic energy at the same flow rates when compared to pressure variation. Gopala Pillai et al. (1999) found that as the speed increased and duty cycle decreased, spray uniformity decreased considerably along travel direction.

So far we have discussed different variable rate application (VRA) techniques which use a fixed orifice nozzle for spraying herbicides at variable rates. Most farmers currently use fixed orifice nozzles for VRA. Typically fixed orifice nozzles vary flow rates approximately over a 2:1 range when operated within a recommended pressure range. When the nozzle is operated out of its recommended pressure range, there will be a dramatic change in droplet size and uniformity of spray. High pressure results in drift and low pressure results in large droplets. Conventional nozzles with a fixed orifice also have limitations when used for VRA.

A relatively new development in nozzle technology to overcome the limitations of a fixed orifice nozzle is the development of the variable orifice nozzle. Walker and Bansal, (1999) developed a variable orifice nozzle with two thin flat rectangular plates joined along the long sides and along one end. They noted that the flow rate varied proportionately with a change in the fluid pressure. They found that the small spray angle was a limitation.

Womac and Bui, (2002) developed a variable flow fan nozzle (VFFN). To vary the flow rate, droplet size, and create a fan spray, they used a split–end meter plunger in a tapered sleeve which served as a variable orifice. They found that the independent control of liquid flow rate and droplet spectrum was achieved by varying pressure.

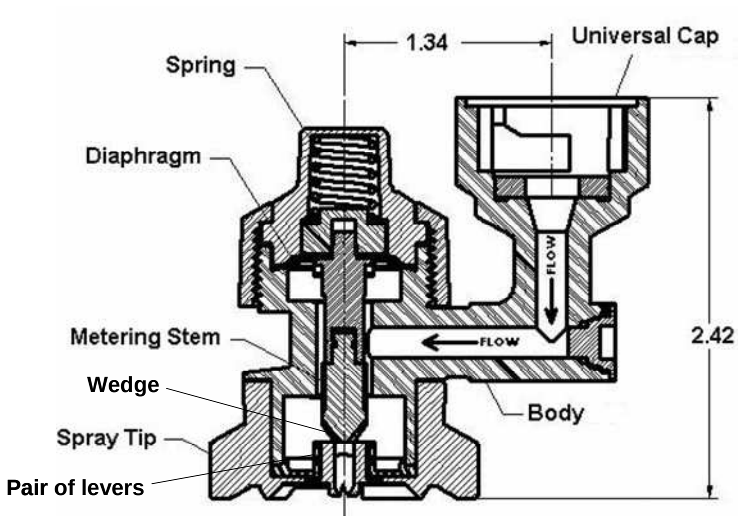
Bui, (2005) developed and marketed the Varitarget nozzle (U.S. Patent No. 5,134,961) that is capable of controlling flow rate and maintaining optimum droplet spectrum over a range of flow control. The Varitarget nozzle has a variable area spray orifice and a variable area pre-orifice. Both orifices will vary during operation allowing for varying flow rates without pressure adjustments, thus keeping the droplet size optimized and spray angle constant over the variation in flow rate. Bui observed that the flow rate varied from 0.15 to 0.80 GPM as the pressure varies from 15 to 50 PSI. He observed that the spray angle is 110^{o} and spray distribution was consistent over the range of flow rate. The response time for the rate change was found to be less than 0.25 seconds.

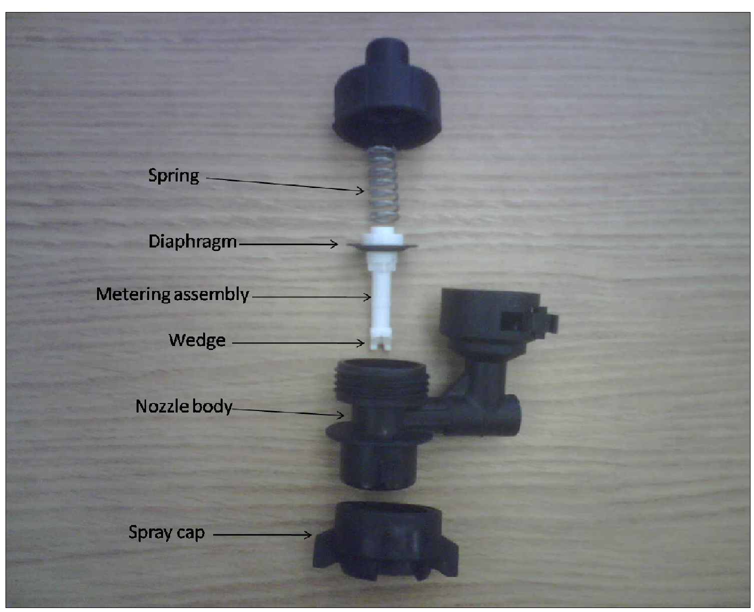
1.2 Varitarget nozzle

1.2.1 Description

The Varitarget nozzle is comprised of a spray tip, metering assembly, diaphragm, spring and a nozzle body (Figure 1.1 and Figure 1.2). The spray tip has a flexible spray orifice, the area of which is controlled by a pair of levers. One end of the metering assembly is a wedge which controls the movement of the pair of levers. The wedge consists of two metering groves at various depths. The other end of the metering assembly is coupled to a diaphragm and a spring (pre orifice). The diaphragm is used to control the movement of the metering assembly through the balance of liquid pressure and spring force. (Bui, 2005)

Figure 1.1 Varitarget nozzle cross sectional view





1.2.2 Spray tip or spray cap description

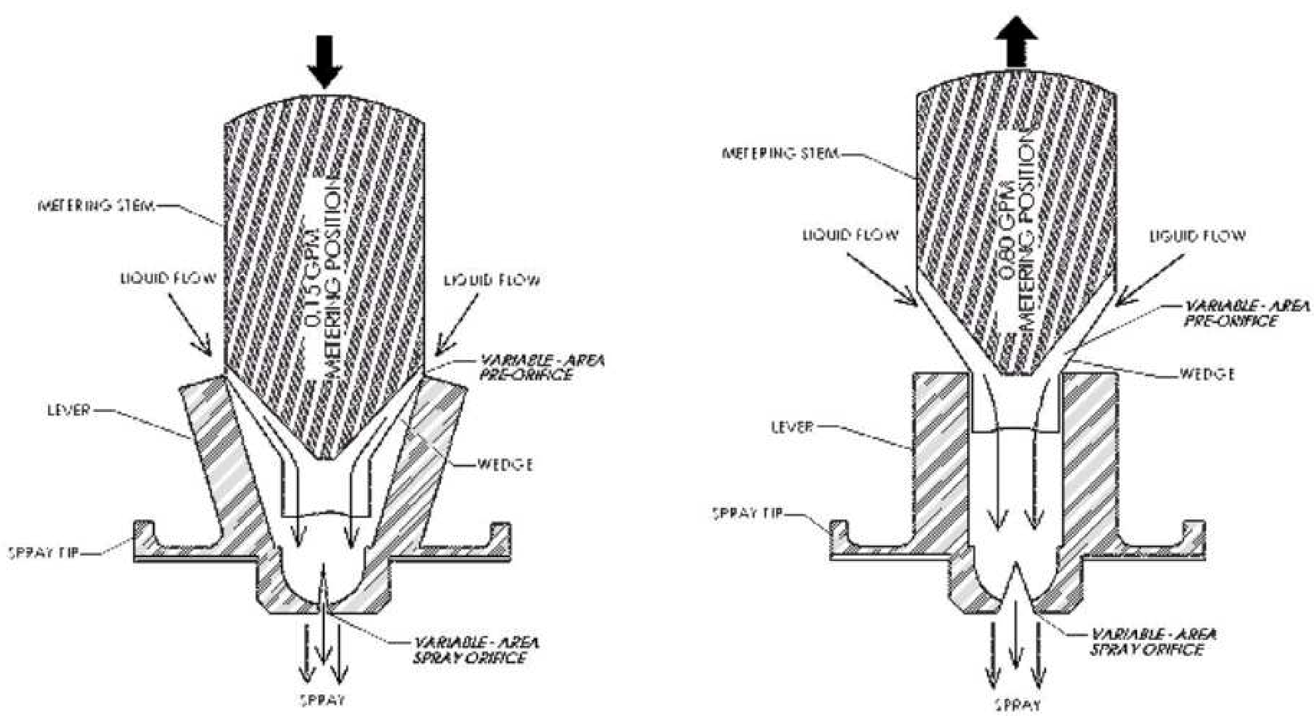
The Varitarget nozzle comes with yellow cap previously named as clear cap (medium droplet spectrum), blue cap previously named as black cap (coarse droplet spectrum), orange cap (fine droplet spectrum), and green cap (very coarse droplet spectrum). In this study I will evaluate the performance of black cap and clear cap.

Important Note: Throughout this study, I will be using the term clear cap for yellow cap and black cap for blue cap because the manufacturer changed the name of the cap colors during the study.

1.2.3 Operation

The pressurized liquid enters the nozzle body, flows through the metering grooves in the metering assembly, and exits at the spray orifice in the spray tip. When the position of the metering assembly varies, the flow rate will also vary. When the liquid pressure is less than the spring force, the metering assembly moves toward the spray orifice and flow rate decreases, and when the liquid pressure is more than the spring force, the metering assembly moves towards pre orifice and flow rate increases (Figure 1.2)(Bui, 2005)

Figure 1.2 description of Varitarget nozzle operation



Source: Bui, 2005

1.3 Hypothesis

Most farmers use conventional nozzles in applying crop protection products for variable rate application (VRA). Conventional fixed orifice nozzles have limitations such as; varying flow rates only over a 2:1 range and large changes in droplet spectrum when pressure, speed and application rate changes occur. My hypothesis is a Varitarget nozzle will perform better while making variable rate application (VRA) by maintaining a uniform droplet size range at various spraying inputs compared to conventional fixed orifice.

1.4 Objectives of this research

This study is to evaluate the performance of the Varitarget nozzle while adjusting various application parameters associated with making variable rate application (VRA). This will be accomplished in laboratory studies by comparing the Varitarget nozzle with six commonly used conventional spray nozzles and in field studies simulating variable rate application (VRA). The following experiments will be used:

Lab studies

1. To compare the measured and reference flow rates of Varitarget nozzle (black and clear caps), XR 8003, XR 11003, TT 11003, AI 11003, Airmix 11003, ULD 12003 at pressures ranging from 10 to 110 psi.
2. To evaluate droplet charecteristics of Varitarget nozzle (black and clear caps), XR 11003, TT 11003, TTI 11003, AI 11003, Airmix 11003, ULD 12003 nozzles at pressures ranging from 10 to 50 psi at a constant speed of 10 mph.
3. To measure the uniformity of spray distribution for Varitarget black and clear capped nozzles at pressures ranging from 15 to 50 psi.
4. To measure the spray width and spray angle for Varitarget black and clear capped nozzles at pressures ranging from 10 to 80 psi.

Field studies

1. To evaluate the droplet spectrum of Varitarget nozzle (black and clear caps) at varying speeds ranging from 4 to 12 mph in increments of 2 mph while maintaining a constant application rate (10 GPA).

2. To evaluate the droplet spectrum of Varitarget nozzle (black and clear caps) at varying application rates ranging from 4 to 12 GPA in increments of 2 GPA while maintaining a constant speed.

CHAPTER 2 - REVIEW OF LITERATURE

2.1 Direct Injection

Direct injection is a technique that can be used for variable rate application to spray active ingredient at a predetermined constant flow rate while varying the active ingredient on the go. This system injects active ingredient down stream of the sprayer pump and prior to branching of the distribution hose to the boom section.

Qiu et al, (1998) developed site specific strategies for applying herbicides based on soil properties and crop yield potential, with a direct-injection applicator. They developed a simulation model using SLAM II to evaluate the performance of a direct injection sprayer used for site-specific application of pre emergence herbicides in corn. The model used the agronomic field data from the university research farm as inputs. They developed a complement of system parameters to reduce application errors. Results from the model were input to GIS software to generate herbicide application rate maps. They found that the application errors for direct injection systems were as high as 40%. They also found that the rate change occurred after as much as 80m of travel past the point of a step change of the input command to the controller.

Anglund and Ayers, (2000) evaluated the field performance of a ground sprayer at constant and variable application rates with both pressure-based and injection sprayer control technology. They found that this produced an accurate application rate within ± 2.25% of the desired rate. They found that in pressure-based variable rate application, the transport lag was 2s due to GPS signal lag and control valve response lag, where as the lag time for the injection-based variable rate application ranged from 15 to 55s due to flow rate of the carrier ingredient. Transportation lag or lag time is the time required to change from one application rate to the other.

2.2 Direct Nozzle Injection

Direct nozzle injection is similar to direct injection. In this case the active ingredient is injected directly into the nozzle housing. Rockwell and Ayers, (1996) studied the spray patterns using coefficient of variation (CV). They found that the direct nozzle injection system did not generate a good spray pattern. They also found that the spray was not delivered uniformly to individual nozzles. They also studied the time lag and found that the time lag was 2.5 seconds.

Rockwell and Ayers, (1996) found that the lag time is significantly reduced when the direct injection nozzle is compared with direct injection. They observed that in direct nozzle injection, proper mixing of active ingredient with the carrier liquid reduced significantly. Direct nozzle injection systems are more expensive than direct injection systems because of additional plumbing required to deliver active ingredient.

2.3 Sensor Based Spraying

Sensor based spraying systems utilize sensors which are capable of measuring desired properties such as soil properties, crop characteristics, weeds, etc., and apply ingredients at varying application rates on the go and real time. Rangwongkit et al. (2006) developed a tractor mounted site-specific, real time herbicide applicator for variable rate herbicide application between sugarcane rows. They used a software based machine vision system for quantified greenness level to actuate the controllers of a sprayer pump system. Pulse width modulation (PWM) was used to vary the application flow rate by adjusting the duty cycle. They found that the error of green color output from image processing was about 0.31% at SD +0.25. The flow rate accuracy was about 91.7%. They found that this technology decreases the herbicide quantity used by 20.6%.

Tian et al. (1999) developed and tested an automatic sprayer controlled by a real time machine vision system. Multiple video images were used to cover the target area. Individual nozzles were controlled separately to increase accuracy. They identified weed infestation zones (10 in × 13 in) and tested to evaluate the effectiveness and performance under varying field conditions. They found that 48% of herbicide saving was observed if 0.5% weed coverage was used as control threshold.

Yong et al. (2005) developed and tested an agricultural robot which could cut the weeds and spray chemicals onto weeds automatically. The robot consists of a digital video camera, two robotic arms, four wheels, a computer, and a radio controller. They found that less chemical is needed when chemicals were applied onto cut weeds directly. They found that there was no chemical drift when chemical is applied onto the weeds' cut surface.

2.4 Pulse Width Modulation (PWM)

PWM flow control has been used for variable rate herbicide application. In this system, the chemical and carrier are pre-mixed in a single container, and the nozzle flow is modulated by intermittent operation of an electrically driven solenoid valve coupled to the inlet of the spray nozzle (Han et al. 2001). Variation in flow rate through the nozzle is achieved by controlling the PWM duty cycle.

Giles et al. (1990) developed a new variable rate application technique which is referred to as pulse width modulation (PMW) which varies nozzle flow by intermittent operation of an electrical solenoid valve attached to the spray nozzle body. By cycling the valve open and closed, the flow rate through the nozzle is controlled in an analogous on/off manner. The valve is cycled by means of an electrical signal consisting of a square wave of variable duty cycle and frequency. The nozzle can be pulsed at a selected frequency and the duty cycle is varied over the range of operational limits to provide the desired flow rate. They observed a 3:1 flow rate change as they varied the duty cycle at different valve actuation frequencies. They also found that the spray pattern remained unchanged though the flow rate changed considerably with changes in the duty cycle.

Gopala Pillai et al. (1999) tested a pulse width modulation system for site-specific herbicide applications. The system has a flow rate in the ratio of up to 9.5 to 1 without a significant change in the spray pattern. They observed that the droplet spectrum remained constant for duty cycles 50% and 100% but changed significantly at 10% duty cycle. Response delay was small and suitable for high-speed herbicide applications. As travel speed increased and duty cycle decreased, spray deposition uniformity along the direction of travel decreased substantially. They suggested that for high speed applications, it would be desirable to modify the controller for higher valve frequencies compared to the current 10 Hz frequency.

Han et al. (2001) modified and tested a commercial sprayer with 25 individual nozzles on a 60-ft sprayer boom for variable rate application. The sprayer consisted of pulse-width modulation (PWM) solenoids, a pressure controller, and a nozzle control system interfaced to a computer. The system used high-resolution prescription maps derived from aerial images. They found that the flow rate changes due to inaccuracy of the pressure controller ranged from 0.5 to 2.2 %. They also found that the flow rate control errors for valves ranged from –15 to 12% when a single flow rate calibration curve was used.

D.K. Giles (2001) investigated the relationship between droplet size and velocity, cumulative momentum and kinetic energy of spray clouds from fan nozzles operating at different flow rates by changing pressure and pulse width modulation flow control. They also tested the spray cloud dynamics for flow control using conventional and pulsed with modulation techniques. Laser doppler analysis was used to investigate the size and dynamics of spray clouds from nozzles operating continuously and intermittently. They found that the pulsing retained more droplet velocity and kinetic energy within spray. They also found pulsed spray retained 2 to 3 fold more kinetic energy at same flow rates when compared to pressure variation.

Pierce and Ayers, (2001) tested the pulse width modulation technology and its effectiveness on weed control from herbicides. They found that the nozzle flow rate variation along the boom was less than 2%. The nozzle flow rate was approximately proportional to the duty cycle setting with an error of 4% from the theoretical uniform spray pattern along the boom. They observed a range in weed control of 65 to 100% at duty cycle settings of 25 to 100% for post emergence herbicide application. Weed control of nearly 100% was observed in pre emergence herbicide application at all duty cycles.

2.5 Variable Rate Orifice Nozzle

A relatively new development in nozzle technology is the development of a variable orifice nozzle. A variable orifice adjusts orifice size during operation to obtain various flow rates. This design provide for variable flow rate while keeping the droplet size optimized and sprays angle constant.

Walker and Bansal, (1999) developed and tested a variable-orifice nozzle for variable rate application. The nozzle is designed such that the nozzle orifice changes as the fluid pressure changes. They used two thin flat rectangular plates joined along the long sides and along one end. Water is forced between two plates at high pressure so that the pressure deforms the plates, thereby allowing water to come much like fan spray. Spray was discharged through the opened end. Flow rate depended on the width of the nozzle, plate thickness, water pressure, metal strength properties, and shape of the tip. They noted that the discharged flow rate linearly increased as hydraulic pressure increased. They also found that a small spray fan angle was a limitation and noted that this nozzle could be used for aerial application.

Womac and Bui, (2002) developed a variable flow fan nozzle (VFFN) for variable rate chemical application. A split end meter plunger in a tapered sleeve served as a variable orifice that varied the flow rate and droplet size and created a fan spray. The fan spray exited at a right angle to the plane of the slit. They tested three VFFN prototypes with spray angles of 50^0, 70^0, and 90^0. They found that the VFFN spray angle equaled the taper angle of the nozzle sleeve at a line pressure of 40 psi. They observed turndown ratio (flow rate) for the 90^0 prototype to be 13 to 1 at certain parameters. Turndown ratio is the ratio of maximum flow rate to that of minimum flow rate. By adjusting the control pressure from 60 to 20 psi, the droplet spectrum DV0.1, Dv0.5, and Dv0.9 values were varied from 58 to 190 microns, 141 to 522 microns, and 300 to 850 microns, respectively. They found that the independent control of liquid flow rate and droplet size spectrum was achieved by separately varying line pressure and control pressure.

Bui, (2005) developed and marketed a new nozzle with flow rate and droplet size control capability. The design has a combination of a variable-area pre-orifice and a variable-area spray orifice with both orifices varying flow during operation to obtain a variety of flow rates while keeping the droplet sizes optimized and sprays angle constant. They observed that the flow rate varied from .15 to .80 gpm, VMD of droplets varies from 425 to 325 microns for systemic pesticides and from 240 to 200 microns for contact pesticides as the pressure varies from 15 to

50 psi. They observed that the spray angle is 110^{o} and spray distribution was consistent over the range of flow rate. The response time to rate changes is less than 0.25s.

2.5 Problems with conventional spraying systems and fixed orifice nozzle

For many years, fixed orifice (conventional) nozzles have been and are continuing to be used for spraying crop protection products. Fixed orifice conventional nozzles have problems when there are application rate changes, pressure changes and during speed changes.

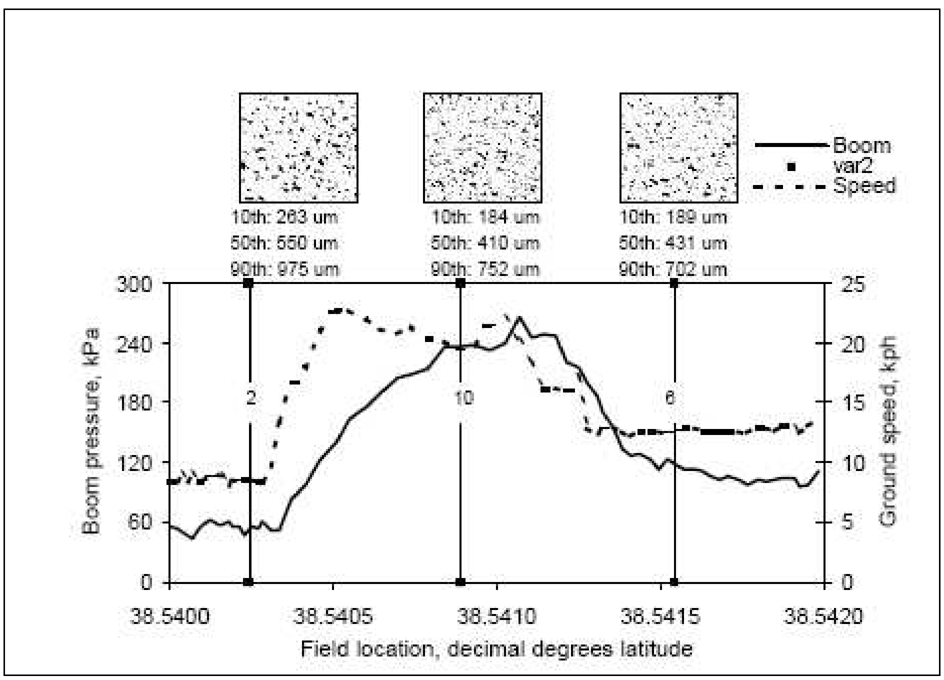
Vogel et al. (2005) constructed and tested a commercially available VRA sprayer with a Raven SCS 440 sprayer controller, Compaq Ipaq 3850 with Farmworks Farm Site Mate Software, and a Trimble AgGPS 132 using Coast Guard correction. The sprayer was calibrated to center the 1.5 to 2.8m transition zone between grid cells with different herbicide rates. They found that the fast close valve which was used for automatic product shut-off resulted in as much as a 40 GPA over application. They also found that at the point of transition between one treatment rate and another, spikes of output as much as two times the prescribed amount occurred resulting in over application and often higher than normal pressure resulting in drift. They summarized that the fixed orifice nozzles were a constraint for variable rate application.

Ruixiu Sui et al. (2003) interfaced a John Deere 4700 sprayer with a MidTech TASC 6300 variable rate, three-channel, spray control system. Thirty-seven XR Teejet 8004VS spray nozzles were spaced at 1.7 ft interval along the boom. They measured the dynamic response of the system. They found that the average delay time was 38.3 seconds and an average rise time was 65.9 seconds. They also found that the response time varied with the speed but the product of speed and response time remained almost constant. They also found that the system took time to achieve constant application rate when the application rate varied from high to low than when it varied from low to high.

Giles and Downey, (2001) evaluated the spray deposition applications for conventional pressure based spray systems and pulse width modulation system at varying speed and varying application rates. They used Case Tyler WT Patriot sprayer equipped with AIM Navigator GPS system, Mid-Tech TASC-6000 spray rate controller and AIM command blended pulse spray actuator systems. In the varying speed study, the deposition was tested at speeds ranging from 3 to 14 mph with a target application rate at 7GPA. With varying application rate study, the ground speed was maintained constant at 12 mph and the application rate prescription was changed from 5, 30 and 15 gpa at south, middle and north areas of field respectively. For the pressure based spraying systems, TT 11003 and TT 11010 nozzles were used for variable speed and variable application rates studies respectively.

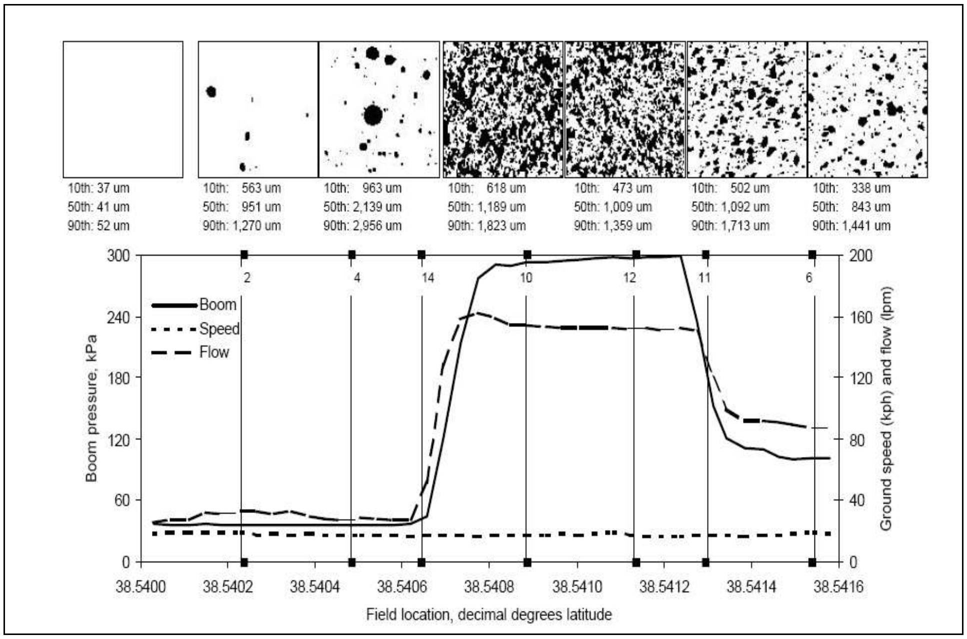
Results with the conventional pressure based spraying systems showed that at varying speed conditions, there was less area covered and low ground speed resulted in lower pressure. It was also found that the 4:1 range of speed control exceeded the suggested pressure operating range of the nozzles resulting in application rate errors as the field was being treated (Figure 2.1). With the varying application rate study, they found that the pressure varied largely which results in varying droplet spectrum (Figure 2.2).

Figure 2.1 Pressure flow control system study with constant application rate, variable speed with TT 11003 nozzles



Source: Giles and Downey, (2001)

Figure 2.2 Pressure flow control system study with varying application rate, constant speed with TT 11010 nozzles



Source: Giles and Downey, (2001)

CHAPTER 3 - LAB STUDIES – METHODS AND MATERIALS

3.1 Spray Track Machine

A spray track machine was designed and fabricated to simulate actual field spraying conditions to facilitate multiple treatments and replications. The spray track has an aluminum bar 24 ft long which is supported on two tripods (Figure 3.1). The aluminum bar can be adjusted to different heights. The spray track machine has an electric motor and chain driven sprayer boom (Figure 3.2). The electric motor is equipped with three sprockets that drive a chain to propel the sprayer boom along the aluminum bar at 5, 10, 15 mph. The electric motor is controlled by a switch which can direct the sprayer boom in a forward or reverse direction along the aluminum bar. The electric motor is equipped with a brake to stop the spray boom at the end of track. The sprayer boom has two nozzle bodies spaced 20 inches apart (Figure 3.3). Coupled to the nozzle bodies are battery operated fast acting solenoid valves (Figure 3.4). The solenoid valves are remotely controlled to activate the nozzles. A digital pressure gauge was used to monitor pressure (Figure 3.5). This spray track machine will be used in the flow rate measurement study, the droplet study and in the spray pattern analysis study.

Figure 3.1 Spray track machine

Figure 3.2 Electric motor and chain assembly

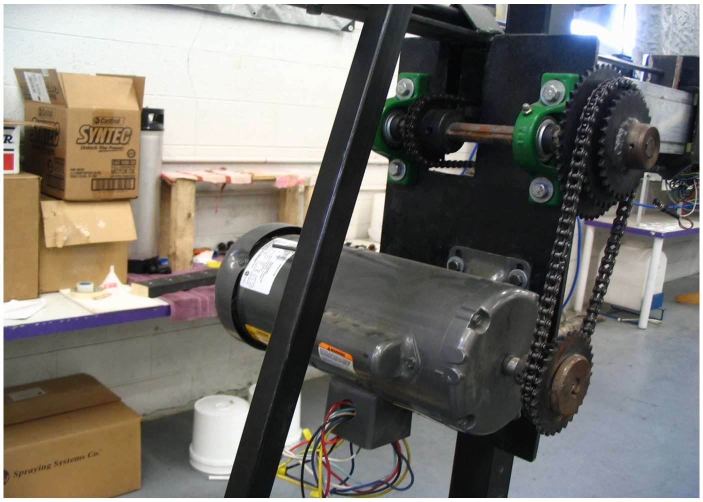


Figure 3.3 Sprayer boom

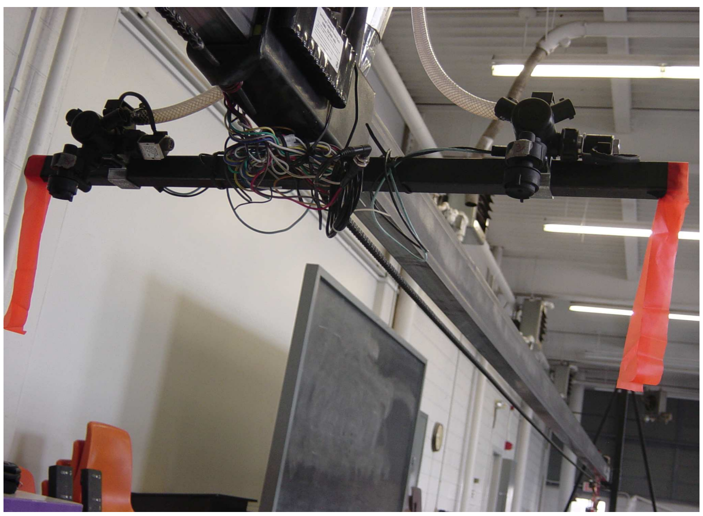


Figure 3.4 Solenoid valve and Varitarget nozzle

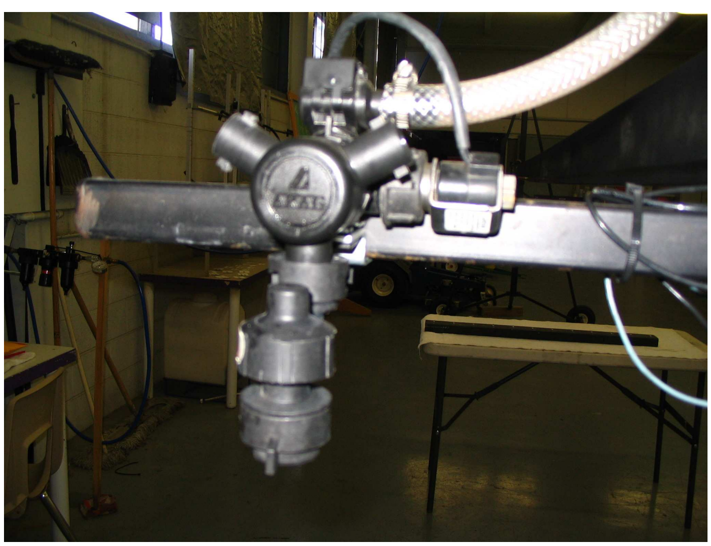


Figure 3.5 Digital pressure gauge

3.2 Flow Rate Measurement Study

Accurate nozzle flow rate is important for efficient and effective crop protection applications. As flow rate changes so will the amount of material being applied. Nozzle orifice size and spray pressure are key features affecting the flow rate through nozzles.

A study was designed to measure the flow rates comparing six conventional fixed orifice nozzle designs and two newly designed variable flow rate orifice nozzles. Flow rates of each nozzle were measured at pressures ranging from 10 psi to 110 psi at increments of 5 psi. The nozzles were selected based on different design configurations. The XR 8003, XR 11003, TT 11003, AI 11003 (Spraying Systems Co.), Airmix 11003 (Greenleaf Technologies), ULD 12003 (Hypro) nozzles were selected as conventional fixed orifice designed nozzles. Varitarget black and clear capped nozzles (Delavan AgSpray) were the variable rate designed nozzles.

3.2.1 Statistical design of experiment

For all the nozzle treatments, pressure was held constant, eight nozzle treatments were randomized, and flow rates were measured. Both the pressure and nozzle treatments were randomized at each replication. Three replications were done for each nozzle treatment.

3.2.2 Procedure

This study was performed in the spray laboratory (Seaton 142) at Kansas State University utilizing the sprayer boom on the spray track machine in stationary mode. For this study, one nozzle body was used.

Water in a 5 gallon pressurized steel container was used to measure the flow rates (Figure 3.6). The container was equipped with a 130 psi pop-off safety valve to allow for the high pressure treatments. The container has an air adapter connected to the pressure regulator (Figure 3.7) which was connected to an air compressor which supplied the required pressure to complete each treatment. The container has a spray adapter which is connected to the nozzle body through a spray hose. The desired pressure was set using the pressure regulator and was monitored using a DPG500 digital pressure guage. The desired nozzle was fastened to the nozzle body of sprayer boom. A calibration container was placed under the nozzle such that all of the spray from the nozzle is collected in the container. On pressing the remote control button, the nozzle starts spraying. Spray was collected in the calibration container for 15 seconds. Time was monitored using a stop clock. The calibration container and liquid was then weighed using an Ohaus CS - 2000 compact scale (Figure 3.8). The resulting weight obtained was recorded as grams per 15 seconds. The grams per 15 seconds was then converted to gallons per minute and recorded as the flow rate obtained from each nozzle

Figure 3.6 Five gallon pressurized steel container with spray adapter and air adapter

Figure 3.7 Pressure relugator, scale used for flow rate measurements study

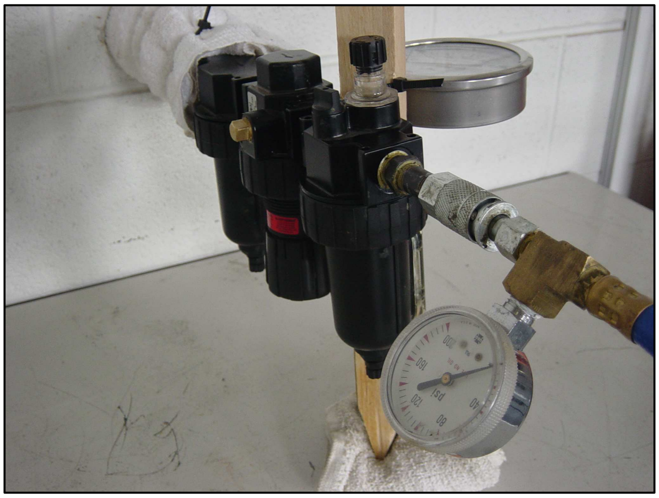
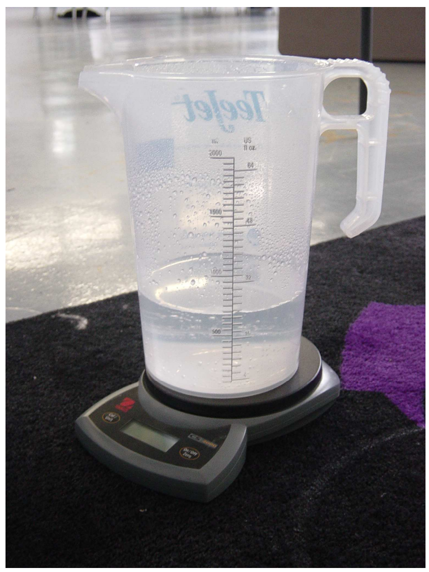


Figure 3.8 Scale used for measuring flow rates



The flow rates obtained for all treatments from the three replications were averaged. Statistical analyses of the data were conducted with SAS 9.1 (SAS, 2003). The model used was General Linear Model (GLM) procedure to analyze flow rate measurements by nozzle at various pressures. The LS Means for each nozzle were tested and used to report the differences (alpha = 0.05) found for each nozzle treatments at various pressures.

3.3 Droplet Measurement Studies

The importance of droplet size information in spraying crop protection products has increased considerably in recent years. Too small droplets generally provide a good coverage but can drift away to other crops (Wolf, 2004). Too large droplets results in reduced coverage but are not likely to drift. The goal is to select the nozzle that produces droplets that gives good coverage while keeping drift to a minimum.

A study was planned to measure the critical droplet characteristics from several spray nozzles. The characteristics measured were VD0.1, VMD, VD0.9, percentage area coverage (PAC), droplets per square centimeter (D/SC), relative span (RS). Droplet characteristics of conventional nozzles with fixed orifice design and a new variable rate application (VRA) designed nozzles were compared. Eight nozzles were selected based on different design configurations. XR 11003, TT 11003, TTI 11003(Spraying Systems Co.,), AI 11003, Airmix 11003 (Greenleaf Technologies), ULD 12003 (Hypro) nozzles were selected as conventional fixed orifice designed nozzles. Varitarget black and clear capped nozzles (Delavan Ag Spray) were selected under variable rate designed nozzles.

In this study the droplet characteristics of each nozzle were studied at pressures ranging from 10 psi to 50 psi at increments of 10 psi and at a constant speed of 10 mph. Droplet scan software was used for the analysis of droplet characteristics on water sensitive papers (WSP) (Syngetna, 2002). One limitation of droplet scan software is that it becomes less ineffective in studies of this type above 10 GPA. Based on this limitation, the pressures for each nozzle treatment were also limited to a maximum of 50 psi so that the application rate of each nozzle doesn’t exceed 10 GPA.

3.3.1 Statistical design of experiment

For all the nozzle treatments, pressure was held constant and eight nozzle treatments were randomized and droplets were measured. Both the pressure and nozzle treatments were randomized at each replication. Three replications were done for each nozzle treatment.

3.3.2 Procedure

This study was performed in the spray laboratory (Seaton 142) at Kansas State University utilizing the spray track machine (Figure 3.1). The spray track machine was described earlier. For this study, the 10 mph speed was chosen. The sprayer boom has two nozzle bodies spaced 20 inches apart that are controlled by a solenoid valve which was operated by a battery operated remote control. Pressure for each treatment was created using air compressor which is located in laboratory. The desired pressure was regulated by the pressure regulator and was monitored using a DPG500 digital pressure guage. Water was used in this study to measure the droplet spectrum. Water was placed in the 0.52 gallon high pressure (140 psi) spray bottles (Figure 3.9) and attached to the spray boom to complete the trials.

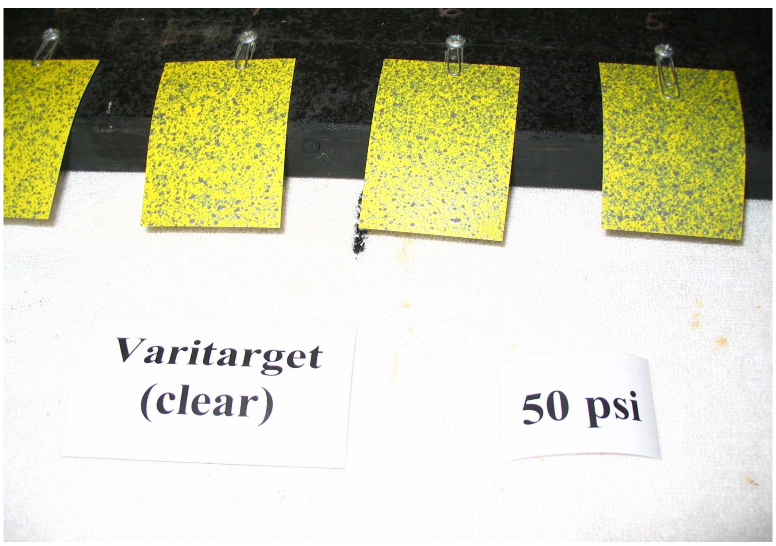
Figure 3.9 High pressure spray bottle used in study

Water sensitive paper (WSP) was used as collectors for droplets. A total of twelve water sensitive papers were clipped on a wooden board. The wooden board was then placed on a table and was placed under the aluminum bar (Figure 3.10). The height of the aluminum bar was adjusted so that the distance between the nozzle and the water sensitive papers was 18 inches.

The cards were placed on the wooden block in a numerical order under the aluminum bar. For each treatment, the selected nozzle and pressure was chosen. The remote control activated the spray boom and the boom was passed over the water sensitive papers (Figure 3.11). After drying the water sensitive papers were placed in a pre labeled sealable bags. To prevent contamination from high humidity, a desiccant pack was placed in each bag to prevent the papers from absorbing additional water. After all treatments and replications were completed, the prelabeled sealeable bags were stored for later analysis.

Figure 3.10 Wooden board and table placed under the aluminum bar of spray track machine

Figure 3.11 Water sensitive cards after spraying



3.3.4 Analysis

Droplet Scan TM version 2.3 (WRK of Arkansas, Lonoke, AR; and WRK of Oklahoma, Stallwater, OK; Devore Systems, Inc., Manhattan, KS) was used to analyze the water sensitive papers. Droplet Scan TM has been tested as a reliable source of predicting droplet stain characteristics when compared to other card reading methods (Hoffman, 2004). Water sensitive cards were placed on the bed of scanner in a order as collected. The droplet scan software performs a high resolution scan of each card in the order kept on the scan bed. Once the scanning is complete, the data is written to the disk as a droplet list file (DLF) file. The droplet scan software generated composite results VD0.1, VMD, VD0.9, percentage area coverage (PAC) and number of droplets on each card. All these data were copied to Microsoft Excel and the information was used to calculate droplets per square centimeter and relative span (RS). Relative span is a measure of the range of droplet sizes in the mid eighty percent of the droplet size spectrum (I.W.Krik, 2003).The relative span (RS) was calculated as follows (Womac et al., 2002)

$$RS = \frac{(VD0.9 - VD0.1)}{VMD}$$

Where:

RS is relative span

VD0.9 is the diameter for which 90% of volume is contained in smaller particles

VD0.1 is the diameter for which 10% of volume is contained in smaller particles

VMD is volume mean diameter

The VMD, percentage area coverage (PAC), droplets per square centimeter (D/SC), relative span (RS) obtained for the eight different nozzles at different pressures from three replications were averaged.

Statistical analyses were conducted for D/SC and PAC using SAS 9.1 (SAS, 2003). The model used was general linear model (GLM) procedure to analyze droplet characteristics by nozzle at various pressures. The LS means for each nozzle were tested and used to report the differences (alpha = 0.05) found for each nozzle treatments at various pressures.

The VMD was analyzed by comparing average VMD obtained from each nozzle tested to that of the measured VMD ranges based on manufacturers' droplet sizing charts. The droplet categories and color codes are based on the ASABE Standard S-572 (Table 3.1). RS was analyzed by comparing the average RS values obtained from different nozzles. The closer the RS value to one, the more uniform the droplet size distribution which indicates a smaller variance from the maximum droplet size (VD0.9) to the minimum droplet size (VD0.1) (Denesowych, 2005)

Table 3.1 ASABE standard S-572 droplet classification

Droplet Category	Color	Symbol	VMD (micron)
Very Fine	red	VF	< 150
Fine	orange	F	150-250
Medium	yellow	M	250-350
Coarse	blue	C	350-450
Very coarse	green	VC	450-550
Extremely coarse	white	XC	>550

3.4 Spray Pattern Studies

A uniform spray pattern along the sprayer boom is important for achieving a good distribution of crop protection product across the field. The spray pattern includes spray angle and spray distribution along the sprayer boom. Nozzle spacing, spray angle, and spray height determine the spray area. A nozzle spacing of 20 inches, spray height of 14-20 inches, spray angle of 110 degrees are considered optimal for broadcast applications. (Bui, 2005).

A study was designed to measure the uniformity of spray distribution (Figure 3.12) and spray angle (Figure 3.15) for Varitarget black and clear capped nozzles. The uniformity of liquid distribution was measured using coefficient of variation (CV). The CV is a statistical method for determining spray uniformity of nozzles across the spray boom. The lower the CV value the better the distribution quality. (Spraying Systems Co, 1999). For this study, the CV's of each nozzle were measured at pressures of 15, 20, 30, 40, 50 psi. Three replications were done for each nozzle treatment. The spray angle was calculated by measuring the width of each nozzle at pressures ranging from 10 psi to 80 psi. Two replications were done for each nozzle treatment.

3.4.1 Uniformity of Spray Distribution

3.4.1.1 Procedure

This study was performed in the spray laboratory (Seaton 142) at Kansas State University utilizing a spray table. The spray table is shown in Figure 3.12. The spray table was built by Dr. Wolf (KSU). The spray table is a big tool box equipped with an electric pump, pressure regulator, and booms. The boom has three, 4-position, rotating nozzle bodies. The nozzle bodies are spaced 20 inches apart. The boom is clamped in position using boom rods. The boom has two pressure gauges at the left and right sections of the boom to monitor pressure. Boom control valves are used to control the flow and pressure.

Figure 3.12 Spray Table

3.4.1.2 Operation

A pattern check (40×30 inches) manufactured by Redball, LLC was used to collect and measure the spray pattern. The pattern check is shown in Figure 3.13. The pattern check consists of twenty-three 2-inch wide and 3.5 cm deep uniformly positioned V-shaped gutters. The pattern check was placed on the top of the box base and boom height was adjusted by adjusting boom clamps so that the nozzle was approximately 18 inches above pattern check.

Figure 3.13 Pattern check used for measuring uniformity of spray distribution

The desired nozzles were affixed to the three nozzle bodies. The system was primed by switching the pump to the 'ON' position. Boom control valves were adjusted to a setting so that the desired pressure was developed in the system. Once the desired pressure was maintained and the nozzle was spraying, the pattern check was centered and placed horizontally under the nozzles (Figure3.14). The pattern check was placed for 30 seconds at pressures of 15 and 20 psi and for 15 seconds at pressures of 30, 40 and 50 psi. The pattern check was tilted vertically and the height of the water collected in the twenty-three V-shaped gutters was measured using a ruler. The water in the pattern check was then dumped back into the tool box and additional treatments were completed. The heights obtained from the twenty-three V-shaped gutters for black and clear cap nozzles at different pressures from three replications were averaged. Using an Excel spreadsheet, the average, standard deviation and coefficient of variation (CV) were calculated. CV is calculated using the following formula (Krishnan et al. 2001)

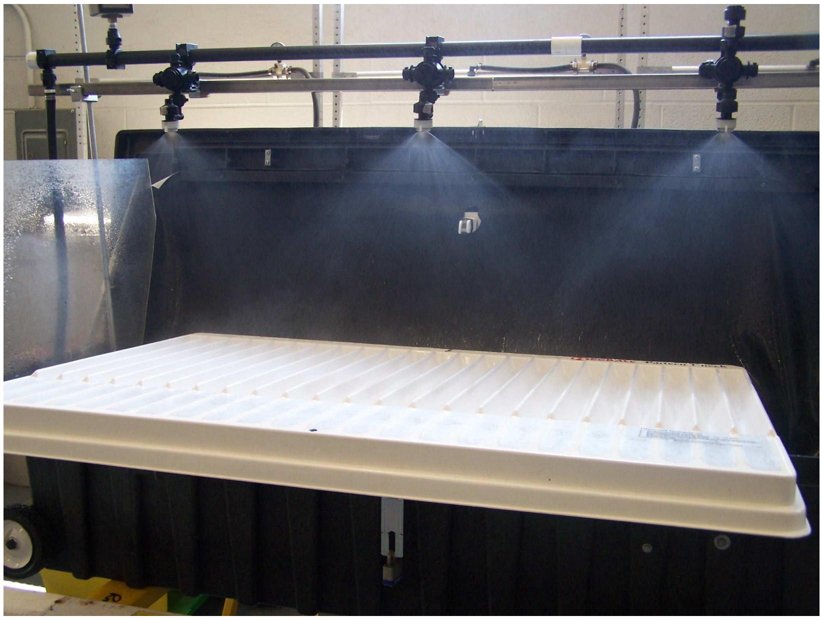
$$CV = \mathrm{S} / \bar{x}$$

Where:

$\bar{x}$ = Average volume of twenty- three V-shaped gutters

S = Standard deviation of the volumes of the total number V shaped gutters within the target area for a test.

Figure 3.14 Pattern check placed on the spray table while spraying



3.4.2 Spray Width and Spray Angle

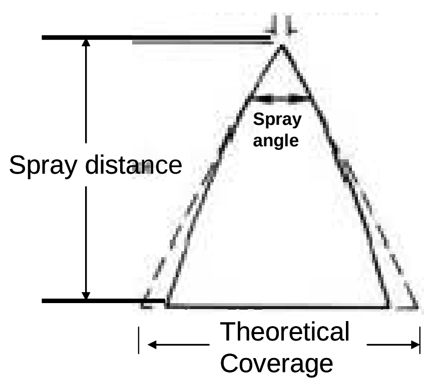
The effective spray width and spray angle of Varitarget black and clear capped nozzles was measured utilizing the spray track machine. One nozzle body of the sprayer boom was used for this study. Two pattern checks manufactured by Redball, LLC were joined together and placed under the nozzle at a height of 19 inches as shown in Figure 3.15. The pattern checks were positioned under the nozzle such that the center of the nozzle matches the center of the pattern check (Figure 3.16).

.Figure 3.15 Two pattern checks attached and placed under the nozzle boom to measure spray width

Figure 3.16 Pattern check was placed such that the center of the nozzle matches the center of pattern checks

Water was placed in the 0.52 gallon high pressure spray bottles and attached to the spray boom. The desired pressure was set using the pressure regulator and was monitored using a DPG500 digital pressure guage. The nozzle was fastened to the nozzle body of the sprayer boom. Spray from the nozzle was collected for 30 seconds at pressures of 10 to 30 psi and 15 seconds at pressures of 40 to 80 psi. The pattern check was tilted vertically and the width of the spray collected in the V-shaped gutters was measured using a ruler. Each measurement was repeated two times. The width obtained for black and clear cap nozzles at different pressures from two replications were averaged. The spray angle was calculated using spray coverage calculator from AutoJet Technologies website (http://www.autojet.com/techcenter/coverage_calculator.asp) (Figure3.17) and was cross checked with simple trigonometric equations.

Figure 3.17 Schematic diagram of measurement of spray angle



CHAPTER 4 - FIELD STUDIES – METHODS AND MATERIALS

4.1 Evaluation of Droplet Characteristics at Varying Speeds

Crop protection product manufacturers are beginning to recommend droplet sizes for specific applications on their labels. The applicator has to control the droplet size category created by the sprayer during application. In general, spray rate controllers are used to maintain a constant application rate (GPA) despite changes in speed. If we change the speed, the rate controller has to adjust flow rate to maintain a constant application rate (GPA). The relation between application rate, flow rate and nozzle spacing is given by

$$\text{Application rate (GPA)} = \frac{Flowrate(gal/\min)\times Speed(mph)\times Nozzlespacing(inches)}{5490}$$

There are two ways in which the nozzle flow rate can be changed, either by changing operating pressure or orifice size (Bretthauer, 2004). In the case of conventional nozzles, the orifice size is fixed and the droplet sizes vary tremendously as the pressure changes. Thus, conventional nozzles have limitations when speed changes. The Varitarget nozzle has an orifice that changes its size in response to pressure changes, allowing it to provide a wide range of flow rates with a minimal change in droplet size. The data to support this characteristic would be useful for the application industry as we seek ways to make variable rate applications in a more efficient and safe manner.

A study was planned to measure droplet characteristics of Varitarget black and clear capped nozzles at various spraying speeds ranging from 4 mph to 12 mph at increments of 2 mph. The treatments were planned to deliver a constant spray volume of 10 gallons per acre (GPA). Each nozzle treatment was replicated three times at the different speeds.

This study was done on 06/01/07 from 10:00 AM to 2:00 PM in the parking lot at Bill Snyder Family Football Stadium located on Kimball Avenue, Manhattan, KS. The study area is shown in Figure 4.1 A Kubota (M 9000) tractor (Kubota Corporation) was used for spraying. A commercially available pressure-based sprayer was used in this project. The sprayer was attached to the tractor as shown in Figure 4.2. The sprayer was equipped with a 150 gallon tank and 25 ft three section boom. The sprayer boom has 15, three-position nozzle bodies spaced at 20 inches. A Ravan SCS 440 automatic sprayer controller was used to set and maintain the desired application volume. The Ravan SSC 440 consists of a computer based control console, a speed sensor, a turbine type flow meter, a motorized control valve and three section boom controls. The console was mounted in the tractor cab. The radar speed sensor was mounted to the frame of sprayer. The standard butterfly control valve, boom control valves and flow meter were installed on sprayer according to factory specifications.

F**igure 4.1 The study area for field studies**

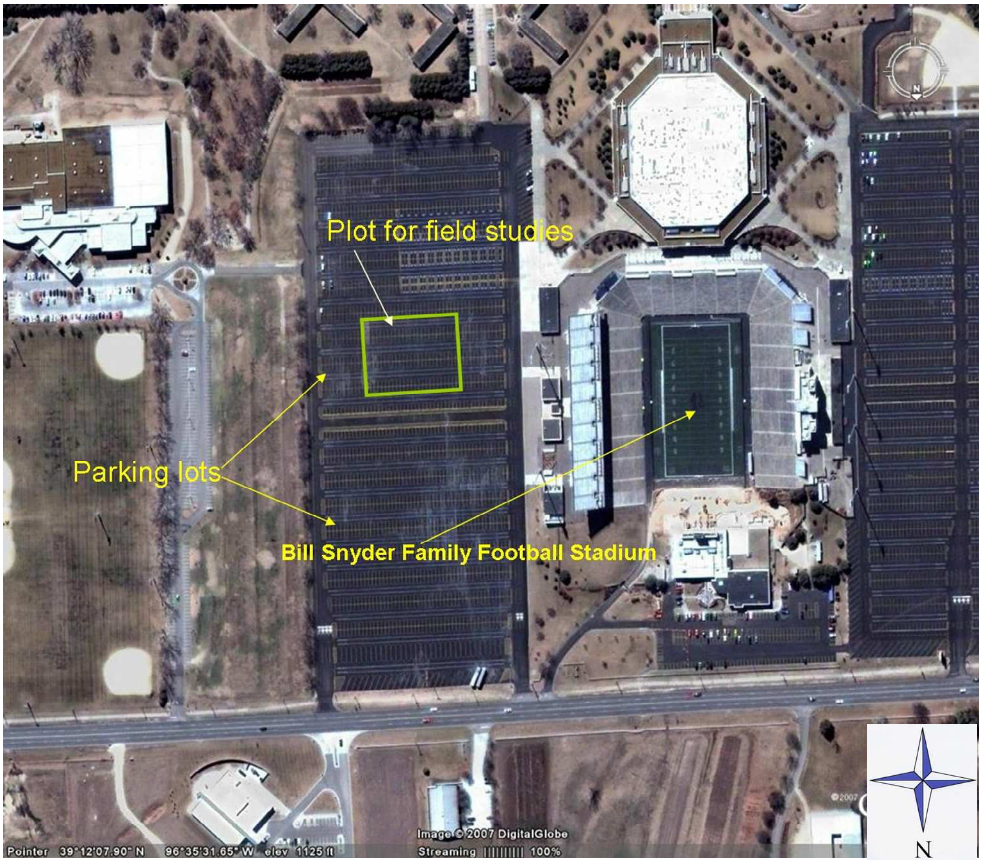


Figure 4.2 Sprayer with 25ft boom attached to the tractor and ready for spraying

4.1.1 Operation

The sprayer tank was filled with water and the Varitarget nozzle caps were affixed to the nozzle bodies on the sprayer boom. Four wooden blocks were placed under the left and right booms and 2 wooden blocks were placed on the middle boom as shown in Figure 4.2. The wooden blocks were placed in such a way that the sprayer will be driven in the direction of wind through out all the treatments. The height of the sprayer boom was adjusted to be 20 inches above the wooden blocks. Water sensitive papers were affixed to the paper clips on the wooden blocks. The Raven SCS 440 was programmed to deliver 10 GPA for all treatments (Target GPA). Prior to driving the sprayer through the test course, the sprayer was driven to determine the gear and throttle setting to maintain the proper speed while keeping the rpm's reasonable to run the pump. Once the desired speed was maintained, the boom sections are turned on and sprayer was driven across the test area spraying on the water sensitive papers as shown in Figure 4.3. The temperature, wind speed, relative humidity during each treatment are given in Table 4.1 The actual GPA delivered during the treatment, pressure required to complete the treatment, engine RPM generated at different speeds are given in Table 4.2. Each treatment was replicated three times and all the treatments were randomised. The water sensitive papers were allowed to dry for some time and then placed in prelabeled-sealable bags for preservation. Because of a high humidity risk, a desiccant pack was placed in each bag to prevent the paper from absorbing additional water. After all treatments and replications were completed, the prelabeled sealable bags were placed in envelopes and stored for later analysis using DropletScan™.

Figure 4.3 Sprayer spraying on water sensitive cards

Table 4.1 Temperature, wind speed, relative humidity at each speed for Varitarget black and clear capped nozzle

black cap			
Speed (mph)	**Temp (°F)**	**RH (%)**	**Wind Speed (mph)**
4	77.00	58.50	7.33
6	77.33	56.00	5.13
8	77.00	58.33	4.70
10	79.00	58.00	3.13
12	77.00	57.67	4.53
clear cap			
Speed (mph)	**Temp (°F)**	**RH (%)**	**Wind Speed (mph)**
4	79.00	54.67	1.90
6	79.00	57.67	3.93
8	79.33	57.67	5.63
10	78.67	56.00	3.93
12	80.00	58.67	4.90

Table 4.2 Application rate delivered, pressure while spraying and engine RPM at each speed for Varitarget black and clear capped nozzle

black cap			
Speed (mph)	**GPA delivered**	**PSI @ Spraying**	**RPM**
4	9.67	27.33	2100
6	10.00	25.67	1600
8	10.00	26.67	2100
10	10.00	30.67	1700
12	10.00	30.67	2100
clear cap			
Speed (mph)	**GPA delivered**	**PSI @ Spraying**	**RPM**
4	9.67	26.00	2100
6	10.00	24.67	1600
8	10.00	29.33	2100
10	10.00	30.00	1700
12	10.67	33.33	2100

4.1.2 Analysis

Droplet Scan™ version 2.3 (WRK of Arkansas, Lonoke, AR; and WRK of Oklahoma, Stallwater, OK; Devore Systems, Inc., Manhattan, KS) was used to analyze the water sensitive papers. Similar procedure as used in section 3.3.4 to get VD0.1, VMD, VD0.9, PAC, D/SC, RS values was used in this study also.

Statistical analyses were conducted for D/SC, PAC using SAS 9.1 (SAS, 2003). The model used was general linear model (GLM) procedure to analyze droplet characteristics by nozzle at various pressures. The LS means for each nozzle were tested and used to report the differences (alpha = 0.05) found for each nozzle treatments at various speeds.

RS was analyzed by comparing the average RS values obtained from the two nozzles. The VMD was analyzed by comparing average VMD obtained from each nozzle to that of the measured VMD ranges based on manufacturers' droplet sizing charts. The droplet categories and color ranges from VF to XC are from the ASABE standard S-572 (Table 3.1)

4.2 Evaluation of Droplet Characteristics at Varying Application rates (GPA)

Varying application rates of crop protection products has the potential to improve both agronomic and environmental aspects of crop production. The application rate of the field sprayer is given by

$$\text{Application rate} = \frac{Flowrate(gal/\min)\times Speed(mph)\times Nozzlespacing(inches)}{5490}$$

From the above formula, changing application rate can be achieved by changing sprayer travel speed or by changing flow rate from the nozzles. In the case of conventional nozzles, changes in speed or changes in nozzle flow rate results in drastic change in droplet spectrum. Varitarget nozzle is a nozzle that is designed to maintain the same droplet spectrum despite the change in speed or change in flow rate. The Varitarget nozzle must be evaluated for its droplet spectrum at varying application rates.

A study was planned to measure droplet characteristics of Varitarget black and clear capped nozzles at various application rates ranging from 4 to 12 GPA at increments of 2 GPA. Each nozzle treatment was replicated three times.

This study was done on 06/06/07 from 1:45 PM to 5:00 PM in parking lots of Bill Snyder Family Football Stadium located on Kimball Avenue, Manhattan, KS. Kubota tractor and sprayer, Raven automatic rate controller and other settings which were used in the varying speed study was used in this study also. The descriptions of tractor and rate controller and other settings are given in section 4.1.

4.2.1 Operation

The same procedure used in the varying speed study (section 4.1) was used to lay wooden blocks and place water sensitive papers. The Raven SCS 440 was programmed to deliver the desired GPA. Prior to driving the sprayer through the test course, the sprayer was driven to maintain the required GPA. Once the desired GPA was maintained, the sprayer was then driven over the wooden blocks and sprayed on the water sensitive cards as shown in Figure 4.3 The temperature, wind speed, relative humidity during each treatment is given in Table 4.3 The sprayer traveling speed during the treatment, pressure required to complete the treatment is given in Table 4.4 The water sensitive cards are allowed to dry and then placed in prelabeled sealable bags for preservation. Because of high humidity and potential contamination, a desiccant pack was placed in each bag to prevent the paper from absorbing additional water. After all treatments and replications were completed, the pre labeled sealable bags were placed in envelopes and stored for later analysis.

Table 4.3 Temperature, wind speed and relative humidity at each speed for Varitarget black and clear capped nozzle

Black Cap			
GPA	**Temp (^oF)**	**RH (%)**	**Wind Speed (mph)**
4	86.67	24.33	2.47
6	87.33	23.33	3.03
8	88.33	23.33	1.37
10	86.67	24.33	1.50
12	87.67	23.67	3.20
Clear Cap			
GPA	**Temp (^oF)**	**RH (%)**	**Wind Speed (mph)**
4	90.00	26.67	2.03
6	90.33	24.33	2.00
8	88.00	24.33	2.83
10	88.33	24.67	1.60
12	88.33	26.33	1.87

Table 4.4 Speed of the tractor and pressure while spraying at each application rate for Varitarget black and clear capped nozzle

Black Cap		
GPA	**Driven Speed (mph)**	**PSI @ Spraying**
4	7.90	19.33
6	7.60	23.00
8	7.70	22.00
10	7.70	22.00
12	7.63	25.00
Clear Cap		
GPA	**Driven Speed (mph)**	**PSI @ Spraying**
4	7.97	23.67
6	7.67	23.00
8	7.70	24.33
10	7.80	28.00
12	7.70	29.33

4.2.2 Analysis

Similar analysis procedure that was used for the ‘varying speed’ study (section 4.1.2) to evaluate VMD, PAC, D/SC and RS was used in this study.

CHAPTER 5 - RESULTS AND DISCUSSIONS – LAB STUDIES

5.1 Flow Rate Measurement Study

Flow rate measurements of the Varitarget nozzle (black and clear caps) along with six conventional nozzles at different pressures ranging from 10 to 110 psi were compared. The results are presented in Table 5.1. Significant differences in flow rates were found among the compared nozzle treatments.

Table 5.1 Flow rates of eight nozzles at different pressures

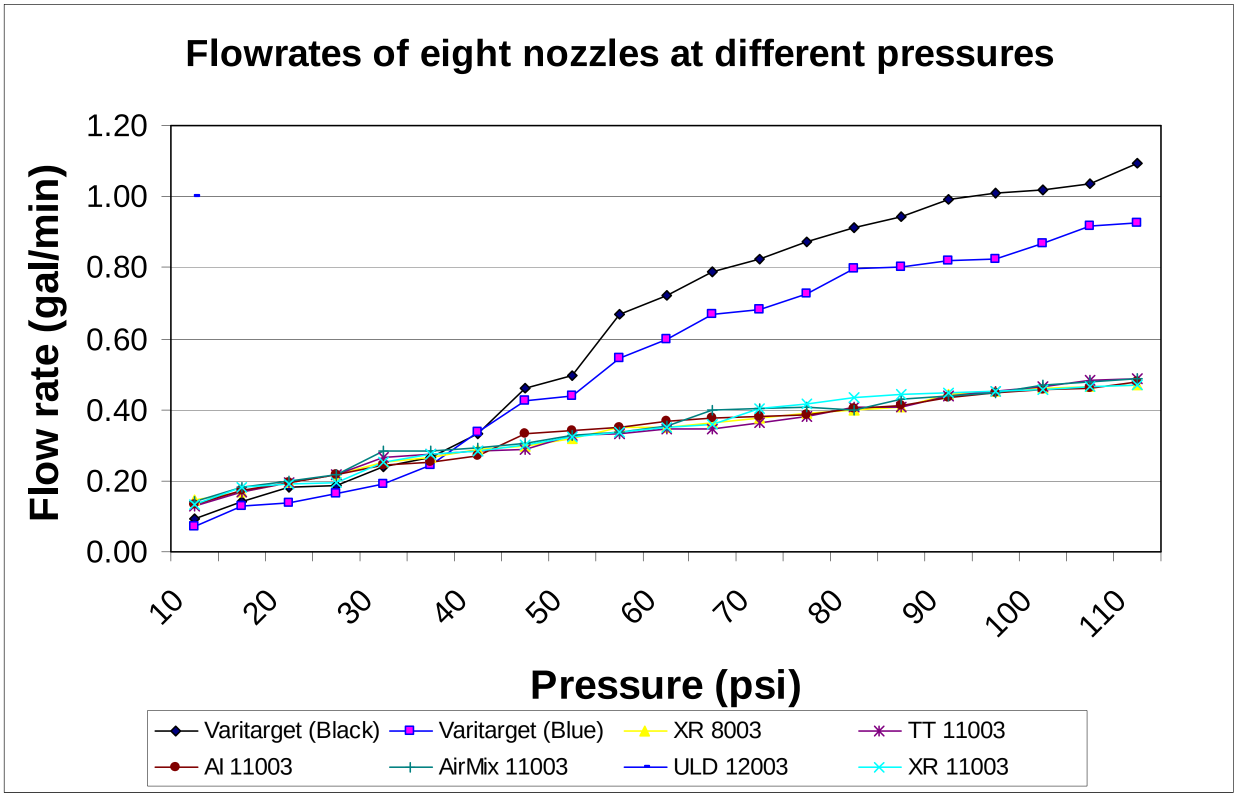
Pressure (psi)	Flow rate (gal/min)							
	VT black	VT clear	XR 8003	XR 11003	TT 1003	AI 11003	AM 11003	ULD 12003
10	0.09^{d}	0.07^{e}	0.14^{a}	0.13^{abc}	0.12^{bc}	0.13^{abc}	0.14^{ab}	0.11^{c}
15	0.14^{c}	0.13^{c}	0.17^{ab}	0.18^{ab}	0.16^{b}	0.17^{ab}	0.18^{ab}	0.18^{a}
20	0.18^{c}	0.13^{d}	0.19^{bc}	0.19^{bc}	0.19^{bc}	0.19^{bc}	0.20^{ab}	0.21^{a}
25	0.18^{cd}	0.16^{d}	0.21^{ab}	0.19^{bc}	0.21^{ab}	0.21^{ab}	0.21^{ab}	0.22^{a}
30	0.23^{c}	0.19^{d}	0.25^{bc}	0.25^{bc}	0.26^{ab}	0.24^{bc}	0.28^{a}	0.25^{bc}
35	0.26^{abc}	0.24^{c}	0.26^{abc}	0.27^{ab}	0.27^{ab}	0.25^{bc}	0.28^{a}	0.25^{bc}
40*	0.33^{ab}	0.33^{a}	0.28^{c}	0.28^{c}	0.28^{c}	0.27^{c}	0.29^{bc}	0.27^{c}
45	0.45^{a}	0.42^{b}	0.29^{ef}	0.29^{ef}	0.28^{f}	0.33^{c}	0.30^{de}	0.31^{d}
50	0.49^{a}	0.43^{b}	0.31^{cd}	0.32^{cd}	0.32^{cd}	0.34^{c}	0.32^{cd}	0.32^{cd}
55	0.67^{a}	0.54^{b}	0.35^{cd}	0.33^{de}	0.33^{e}	0.35^{cd}	0.33^{cd}	0.35^{c}
60	0.72^{a}	0.59^{b}	0.35^{c}	0.34^{c}	0.34^{c}	0.36^{c}	0.35^{c}	0.36^{c}
65	0.78^{a}	0.66^{b}	0.36^{ed}	0.35^{ed}	0.34^{e}	0.37^{d}	0.40^{c}	0.37^{d}
70	0.82^{a}	0.68^{b}	0.37^{cd}	0.40^{c}	0.36^{d}	0.38^{cd}	0.40^{c}	0.38^{cd}
75	0.87^{a}	0.72^{b}	0.38^{cd}	0.41^{c}	0.38^{d}	0.38^{cd}	0.40^{cd}	0.40^{cd}
80	0.91^{a}	0.79^{b}	0.39^{de}	0.43^{c}	0.40^{d}	0.40^{de}	0.40^{de}	0.38^{e}
85	0.94^{a}	0.80^{b}	0.40^{c}	0.44^{c}	0.40^{c}	0.41^{c}	0.42^{c}	0.42^{c}
90	0.99^{a}	0.81^{b}	0.44^{c}	0.44^{c}	0.44^{c}	0.43^{c}	0.43^{c}	0.44^{c}
95	1.0^{a}	0.82^{b}	0.45^{c}	0.45^{c}	0.45^{c}	0.44^{c}	0.44^{c}	0.45^{c}
100	1.01^{a}	0.86^{b}	0.46^{c}	0.45^{c}	0.46^{c}	0.45^{c}	0.47^{c}	0.45^{c}
105	1.03^{a}	0.91^{b}	0.46^{c}	0.46^{c}	0.48^{c}	0.46^{c}	0.47^{c}	0.47^{c}
110	1.09^{a}	0.92^{b}	0.46^{c}	0.47^{c}	0.48^{c}	0.47^{c}	0.48^{c}	0.48^{c}

Means with same letters are not significantly different

*** Factory rated flow rate for each fixed orifice nozzle at 40 psi should be equal to 0.30gpm. Also seen in Table 5.2.**

Flow rates of Varitarget black and clear nozzles varied from 0.09 to 1.09 gal/min and 0.07 to 0.92 gal/min as pressure varied from 10 psi to 110 psi. Flow rates of XR 8003 varied from 0.14 to 0.46 gal/min, XR 11003 varied from 0.13 to 0.47 gal/min, TT 11003 varied from 0.12 to 0.48 gal/min, AI 11003 varied from 0.13 to 0.47 gal/min, Airmix 11003 varied from 0.14 to 0.48 gal/min, ULD 12003 varied from 0.11 to 0.48 gal/min as the pressure varied from 10 to 110 psi. Figure 5.1 compares the average flow rates obtained by eight different nozzles. It was observed that the flow rates of Varitarget black and clear nozzles were similar to the flow rates of other nozzles until 40 psi and varied significantly higher after 40 psi.

Figure 5.1 Flow rate measurements of eight nozzles at different pressures



Differences were found when evaluating the measured flow rate and comparing it to the calibrated flow rate which was based on the published nozzle manufacturers' flow rate charts. The manufacturers' flow rate charts for each nozzle is presented in Table 5.2

Table 5.2 Manufacturers flow rates for each nozzle

Varitarget (black)		Varitarget (clear)		XR 8003		XR 11003	
Pressure	flow rate	Pressure	flow rate	Pressure	flow rate	Pressure	flow rate
16	0.15	15	0.1	15	0.18	15	0.18
25	0.2	27	0.15	20	0.21	20	0.21
32	0.3	30	0.2	30	0.26	30	0.26
35	0.4	32	0.25	40	0.3	40	0.3
38	0.5	34	0.3	50	0.34	50	0.34
41	0.6	38	0.4	60	0.37	60	0.37
44	0.7	42	0.5				
47	0.8	47	0.6				
60	1	55	0.7				
65	1.2	65	0.8				
85	1.5	90	1				
		100	1.2				
TT 11003		**AI 11003**		**Air Mix 11003**		**ULD 12003**	
Pressure	**flow rate**	**Pressure**	**flow rate**	**Pressure**	**flow rate**	**Pressure**	**flow rate**
15	0.18	30	0.26	15	0.18	15	0.18
20	0.21	40	0.3	20	0.21	20	0.21
30	0.26	50	0.34	30	0.26	30	0.26
40	0.3	60	0.37	40	0.3	40	0.3
50	0.34	70	0.4	50	0.34	50	0.34
60	0.37	80	0.42	60	0.37	60	0.37
75	0.41	90	0.45	80	0.42	70	0.4
90	0.45	100	0.47	90	0.45	80	0.42
						90	0.45
						100	0.47
						115	0.51

The published manufactures flow rates for Varitarget black nozzle varied from 0.15 to 1.5 gal/ min as the pressure varied from 16 to 85 psi. The actual measured flow rates of Varitarget black nozzle were close to that of manufactures' flow rates until 40 psi and varied after 40 psi. (Figure 5.2) The maximum flow rate obtained in our study was 1.09 gal/min at 110 psi. According to manufacturer, this nozzle should achieve 1.09 gal/ min at 60 psi.

The published manufactures flow rates for Varitarget clear nozzle varied from 0.1 to 1.2 gal/ min as the pressure varied from 15 to 100 psi. The actual measured flow rates of Varitarget clear nozzle were relatively close to that of manufactures published flow rate chart until 40 psi and varied a little after 50 psi (Figure 5.3). The maximum flow rate obtained in our study was 0.92

gal/min at 110 psi. According to manufacturer, this nozzle should achieve 0.92 gal/ min at 90 psi.

Figure 5.2 Measured flow rate and manufacturers published flow rate of Varitarget black nozzle

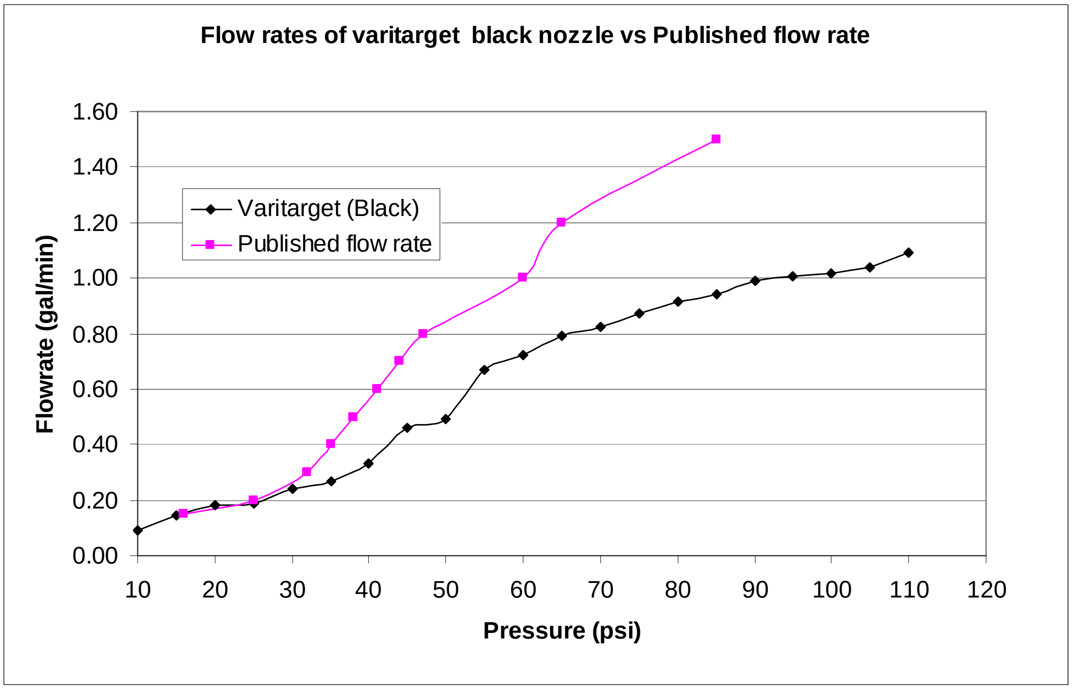
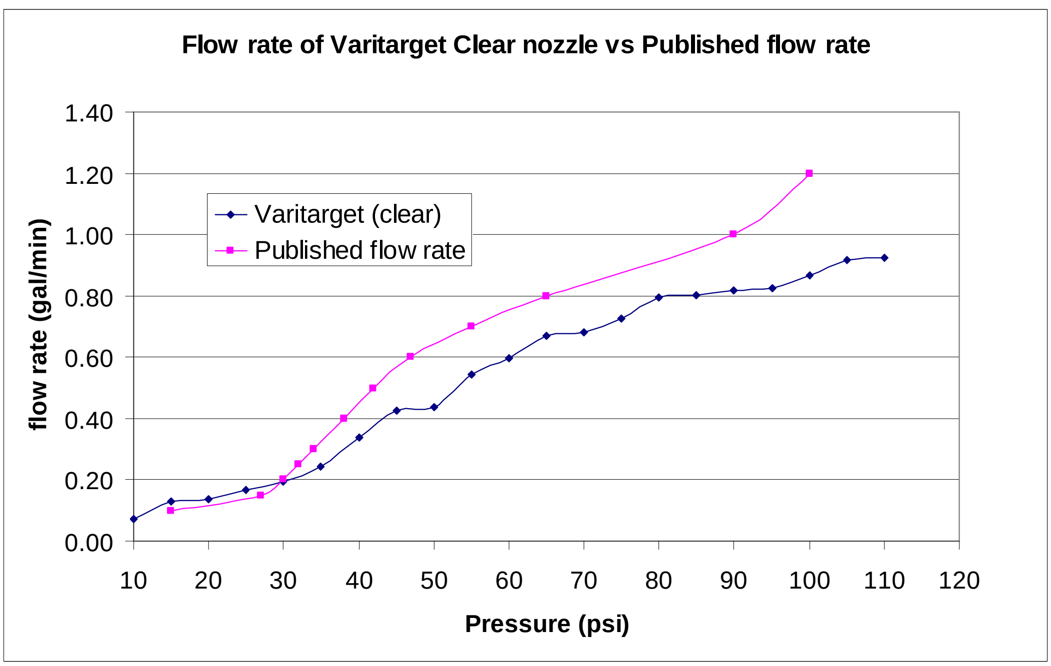
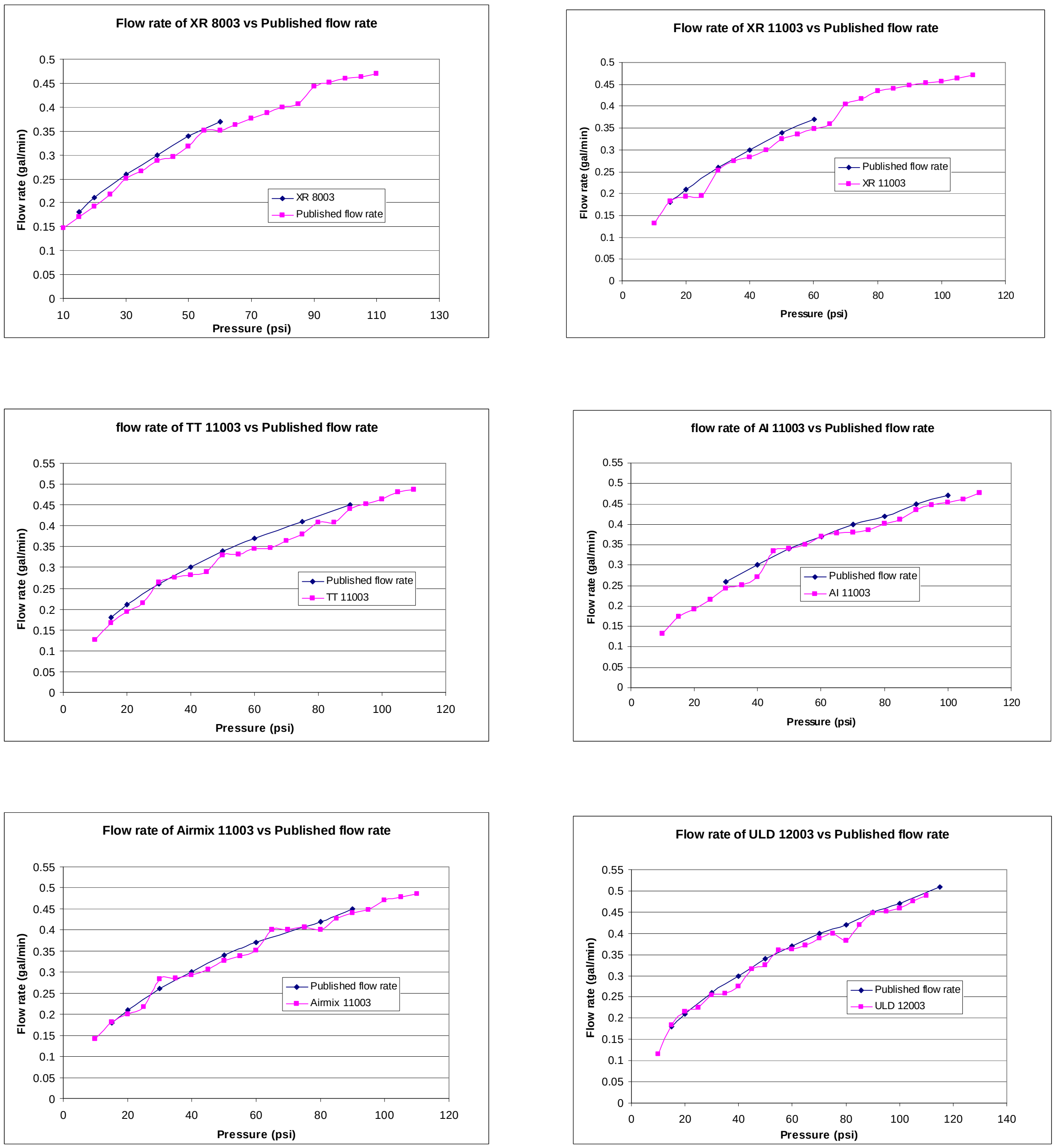


Figure 5.3 Measured flow rate and manufacturers published flow rate of Varitarget clear nozzle



The actual measured flow rates of XR 8003, XR 11003, TT 11003, AI 11003, Airmix 11003, and ULD 12003 nozzles proved to be close to that of the nozzle manufactures published flow rates. Figure 5.4 shows the manufactures' flow rates and actual measured flow rates for each of the six different nozzles.

Figure 5.4 Measured flow rate and manufacturers published flow rate for six conventional nozzles at different pressures



Differences were found when evaluating the turndown ratios of flow rates. Turn down ratio is the ratio between measured maximum and minimum flow rates (Womac et al., 2002). There was a significant difference observed between Varitarget (black and clear caps) and remaining six nozzles. The turndown ratio of Varitarget black and clear capped nozzles were13:1 and 10:1 respectively. The turn down ratio of XR 8003 was 3.2:1, XR 11003 was 3.5:1, TT 11003 was 4:1, AI 11003 was 3.61, Airmix 11003 was 3.42:1, and ULD 12003 was 4.36:1 respectively.

5.2 Droplet Measurement Studies

Droplet characteristics of Varitarget (black and clear caps), XR 11003, TT 11003, TTI 11003, AI 11003, Airmix 11003 and ULD 12003 were analyzed and compared at pressures ranging from 10 to 50 psi at increments of 10 psi and at a constant speed of 10 mph. DropletScan™ was used to measure and compare the droplet characteristics such as VMD, percentage area coverage (PAC), droplets per square centimeter (D/SC), relative span (RS). A copy of Droplet scan software report is attached in the Appendix A

Using water sensitive paper as the collector, significant differences were found among the compared nozzle treatments. The measured VMD, standard VMD range and droplets sizing/color for each nozzle at pressures ranging from 10 to 50 psi are presented in Table 5.3

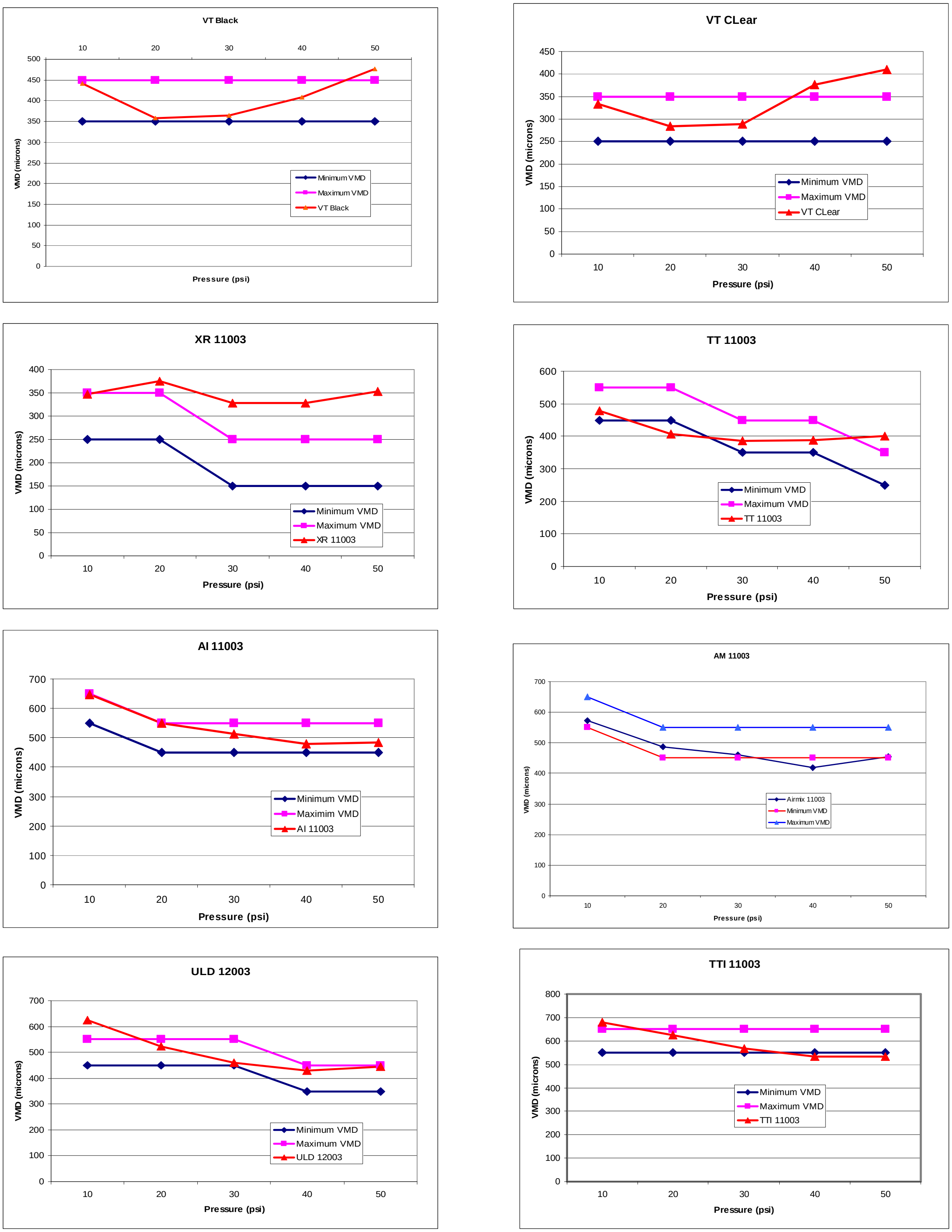
An interesting comparison was found when evaluating the measured VMD obtained from DropletScan ™ and comparing it to the standard droplet spectra of individual nozzles which was based on the nozzle manufacturers' droplet sizing charts and the ASABE S-572 droplet spectra classification system (Table 3.1).The measured VMD (359 to 476 microns) for VT black nozzle was within the standard VMD range until 40 psi and showed an increasing trend after 40 psi. The measured VMD (284 to 410 microns) for VT clear nozzle was within the standard VMD range until 30 psi and showed an increasing trend after 30 psi. The measured VMD (327 to 353 microns) for XR 11003 nozzle was not within the standard VMD range at all pressures tested. The measured VMD (387 to 478 microns) for TT 11003 nozzle was within the standard VMD range at 10, 30 and 40 psi and was out of standard VMD range at 20 and 50 psi. The measured VMD (480 to 647 microns) for AI 11003 nozzle was not within the standard VMD range at all pressures. The measured VMD (419 to 573 microns) for AM 11003 was within the standard VMD range at all pressures. The measured VMD (431 to 624 microns) for ULD 12003 nozzle was out of the standard VMD range at 10 psi and within standard VMD range at remaining pressures. The measured VMD (532 to 681 microns) for TTI 11003 nozzle was out of the standard VMD range at 10, 40, 50 psi and within standard VMD range at 20 and 30 psi. The measured VMD for TTI 11003 nozzle showed an decreasing trend as the pressures increased. Figure 5.5 shows the measured VMD and Standard VMD range for each nozzle at different pressures.

Table 5.3 VMD, Droplet size/color and VMD range for eight nozzles at different pressures

Treatment	PSI	VMD	Droplet size/color	VMD range (Microns)*	
VT Black	10	442	Coarse	350	450
	20	359	Coarse	350	450
	30	365	Coarse	350	450
	40	408	Coarse	350	450
	50	476	Coarse	350	450
VT Clear	10	334	Medium	250	350
	20	284	Medium	250	350
	30	289	Medium	250	350
	40	377	Medium	250	350
	50	410	Medium	250	350
XR 11003	10	347	Medium	250	350
	20	375	Medium	250	350
	30	328	Fine	150	250
	40	327	Fine	150	250
	50	353	Fine	150	250
TT 11003	10	478	Very Coarse	450	550
	20	408	Very Coarse	450	550
	30	387	Coarse	350	450
	40	389	Coarse	350	450
	50	401	Medium	250	350
AI 11003	10	647	Extra Coarse	550	650
	20	548	Very Coarse	450	550
	30	514	Very Coarse	450	550
	40	480	Very Coarse	450	550
	50	484	Very Coarse	450	550
AM11003	10	573	Extra Coarse	550	650
	20	486	Very Coarse	450	550
	30	461	Very Coarse	450	550
	40	419	Very Coarse	450	550
	50	456	Very Coarse	450	550
TTI 11003	10	681	Exta Coarse	550	650
	20	626	Exta Coarse	550	650
	30	566	Exta Coarse	550	650
	40	534	Exta Coarse	550	650
	50	532	Exta Coarse	550	650
ULD 12003	10	624	Very Coarse	450	550
	20	523	Very Coarse	450	550
	30	461	Very Coarse	450	550
	40	431	Coarse	350	450
	50	444	Coarse	350	450

*** Minimum and maximum VMD range as per ASABE S-572 droplet spectra classification system for each nozzle**

Figure 5.5 Measured VMD and standard VMD range for each nozzle at different pressures



A critical indicator for good nozzle performance would be represented by percentage area coverage (PAC). Higher PAC indicates potential for more material on target with potential for better pest control. The PAC for VT black and clear capped nozzle ranged from 3.5 to 27.1% and 3.1to 26.6% as the pressure varied from 10 psi to 50 psi. The PAC for XR 11003 ranged from 5.9 to 18.6%, TT 11003 from 4.1 to 15.2%, AI 11003 from 5.1 to 12.1%, Airmix 11003 from 4.9 to 15.9%, ULD from 5.5 to 14.5% and TTI from 2.7 to 9.0% as pressure varied from 10 to 50 psi. VT black and clear capped nozzles have higher PAC followed by XR 11003, TT 11003, Airmix 11003, ULD 12003, AI 11003, TTI 11003.

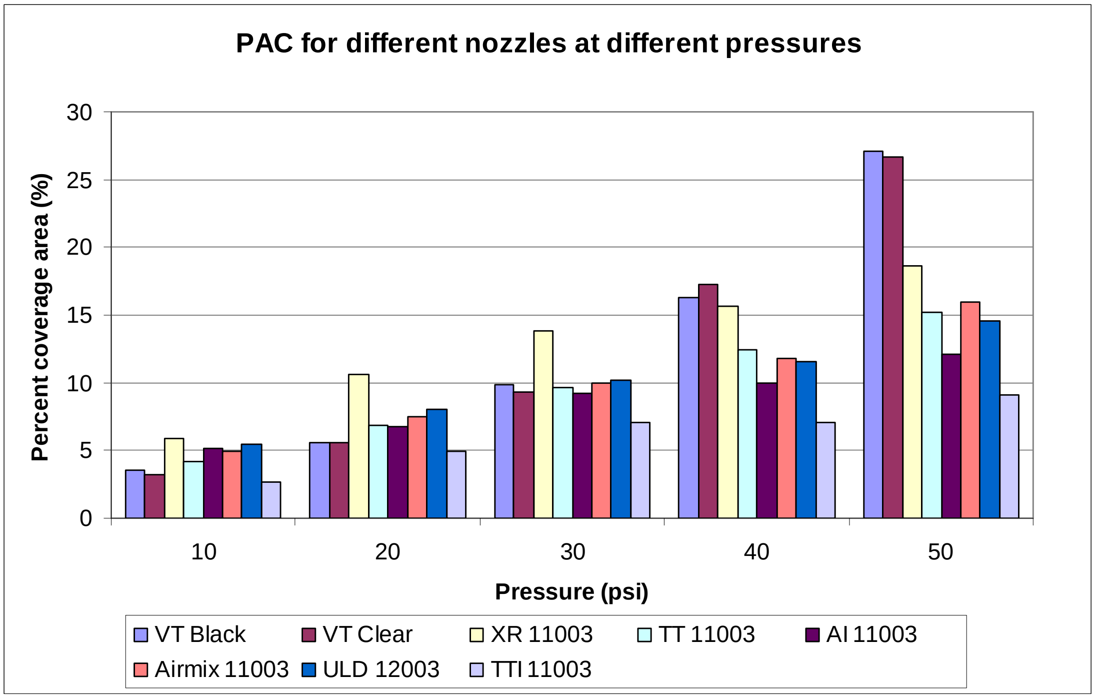
The statistical analysis results of PAC for the eight nozzles treatments at different pressures are reported in Table 5.4. PAC for TTI 11003 was the lowest among all the nozzles at different pressures. There was no significant difference observed among the nozzles until 40 psi. At 50 psi, VT black and clear capped nozzles significantly differed from other nozzles. (Figure 5.6)

Table 5.4 Percentage area coverage for eight nozzles at different pressures

Treatment	10 psi	20 psi	30 psi	40 psi	50 psi
VT black	3.5^{cd}	5.5^{d}	9.8^{b}	16.2^{ab}	27.1^{a}
VT clear	3.1^{de}	5.5^{d}	9.3^{bc}	17.2^{a}	26.6^{a}
XR 11003	5.9^{a}	10.6^{a}	13.8^{a}	15.6^{b}	18.6^{b}
TT 11003	4.1^{c}	6.8^{c}	9.6^{b}	12.4^{c}	15.2^{cd}
AI 11003	5.1^{b}	6.7^{c}	9.1^{bc}	9.9^{d}	12.1^{de}
Airmix 11003	4.9^{b}	7.5^{bc}	9.9^{b}	11.7^{c}	15.9^{bc}
ULD 12003	5.5^{ab}	8.0^{b}	10.2^{b}	11.5^{c}	14.5^{cd}
TTI 11003	2.7^{e}	4.9^{d}	7.1^{c}	7.1^{e}	9.0^{e}

Means with same letter are not significantly different

Figure 5.6 Percentage area coverage for eight nozzles at different pressures



Another good indicator of good nozzle performance is the number of droplets placed on the target. DropletScan ™ reports the number of droplets counted in the area scanned. Thus transforming the number of droplets into droplets per square centimeter (D/SC) provides a basis for comparison. D/SC for VT black and clear capped nozzles ranged from 17 to 264 D/SC and 34 to 328 D/SC as pressure varied from 10 to 50 psi. D/SC for XR 11003 ranged from 54 to 221 D/SC, TT 11003 from 17 to 125 D/SC, AI 11003 from 13 to 57 D/SC, Airmix 11003 from 14 to 105 D/SC, ULD from 12 to 75 D/SC and TTI from 6 to 31 D/SC (Table 5.5).

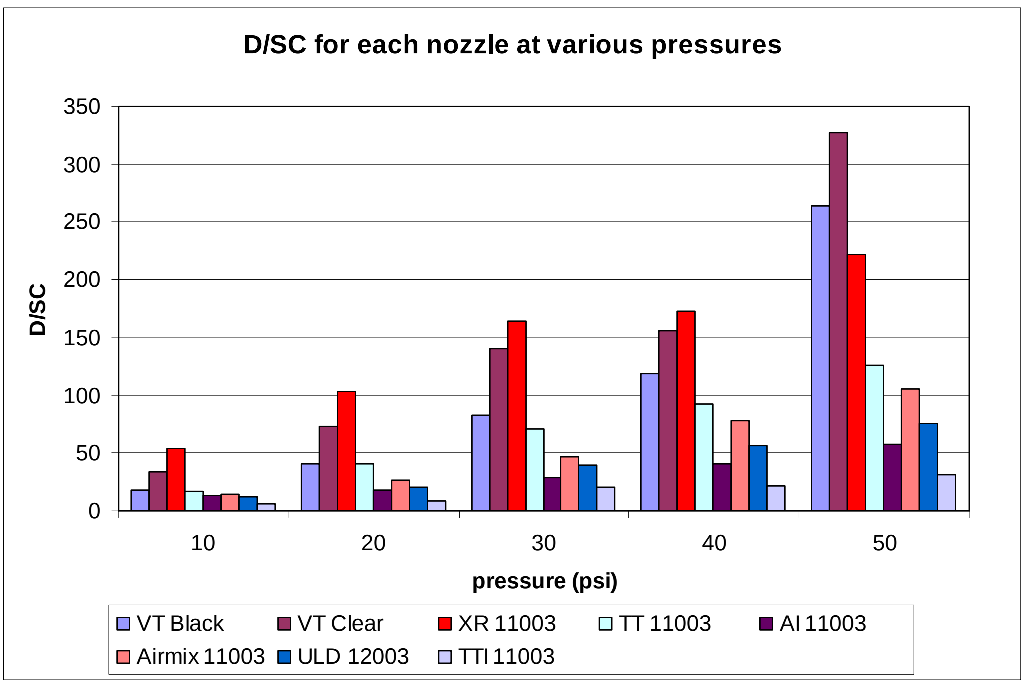
The statistical analysis results of D/SC for eight nozzles treatments at different pressures are reported in Table 5.5. At 10, 20, 30, 40 psi, the XR 11003 nozzle placed most droplets with 54, 103,164,173 D/SC. At 50 psi VT clear capped nozzle placed most droplets with 328 D/SC. At all pressures, TTI 11003 placed least number of droplets. All nozzle treatments were not significantly different at 10 and 20 psi with the exception of XR 11003. As the pressure increased from 30 to 50 psi, VT black, VT clear and XR 11003 nozzles produced significantly higher D/SC to that of TT 11003, AI 11003, Airmix 11003, ULD 12003 and TTI 11003 nozzles (Figure 5.7)

Table 5.5 Droplets per Square centimeter for eight nozzles at different pressures

Treatment	10 psi	20 psi	30 psi	40 psi	50 psi
VT black	17[c]	41[c]	82[c]	119[c]	264[b]
VT clear	34[b]	73[b]	140[b]	156[b]	328[a]
XR 11003	54[a]	103[a]	164[a]	173[a]	221[b]
TT 11003	17[c]	41[c]	90[c]	92[d]	125[c]
AI 11003	13[c]	18[d]	29[de]	41[f]	57[ed]
Airmix 11003	13[c]	26[d]	46[d]	78[d]	105[cd]
ULD 12003	12[c]	21[d]	39[de]	57[e]	75[cde]
TTI 11003	6[c]	8[e]	20[e]	21[g]	31[e]

Means with same letter are not significantly different

Figure 5.7 Droplets per Square centimeter for eight nozzles at different pressures



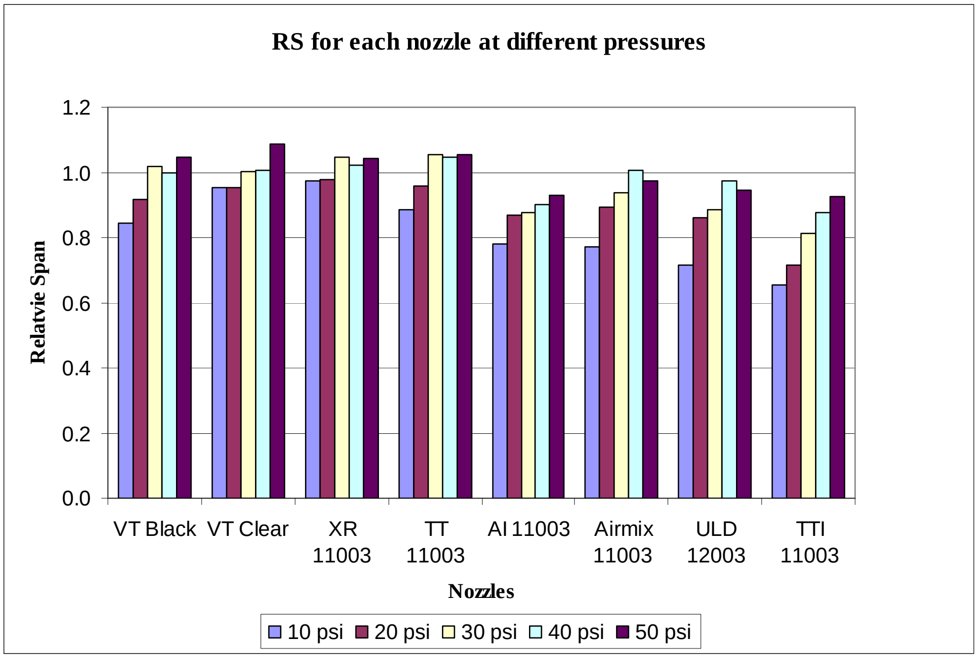
The results of RS are presented in Table 5.6. The RS for Varitarget black and clear capped nozzles ranged from 0.845 to 1.047 and 0.954 to 1.085 as the pressure increased from 10 psi to 50 psi. The RS for XR 11003 ranged from 0.973 to 1.044, TT 11003 from 0.882 to 1.056, Airmix 11003 from 0.772 to 0.974, AI 11003 from 0.778 to 0.93, ULD 12003 from 0.716 to 0.946, TTI 11003 from 0.653 to 0.927 as the pressure varied from 10 psi to 50 psi. (Figure 5.7) The RS gradually increased for all the nozzles as the pressure increased.

It was observed that the RS for TTI 11003, AI 11003, Airmix 11003 and ULD 12003 nozzles (manufactured to produce bigger droplets) was less than 1. The minimum RS observed was 0.653 for ULD 12003 at 10 psi and maximum RS was 0.975 for TTI 11003 at 40 psi. The RS for VT black cap, VT clear cap, XR 11003, TT 11003 nozzles (manufactured to produce smaller droplets) was around 1. The minimum RS observed was 0.883 for TT 11003 at 10 psi and maximum RS was 1.087 for VT clear capped nozzle at 50 psi. (Figure 5.8)

Table 5.6 Relative Span of the eight nozzles at different pressures

Treatment	10 psi	20 psi	30 psi	40 psi	50 psi
VT black	0.845	0.718	1.019	0.999	1.047
VT Clear	0.954	0.952	1.000	1.006	1.085
XR 11003	0.973	0.979	1.044	1.02	1.044
TT 11003	0.882	0.958	1.055	1.046	1.056
AI 11003	0.778	0.868	0.878	0.901	0.93
Airmix 11003	0.772	0.890	0.938	0.0075	0.974
ULD 12003	0.716	0.860	0.885	0.9757	0.946
TTI 11003	0.653	0.713	0.811	0.8749	0.927

Figure 5.8 Relative span for the eight different nozzles at different pressures



5.3 Spray Pattern Studies

The coefficient of variation (CV) and spray angle of the Varitarget black and clear capped nozzles were measured. CV values up to 10 % are considered as acceptable coverage (Huseyin Guler et al., 2006). The CV was measured at pressures ranging from 15 psi to 40 psi and the spray angle was measured at pressures ranging from 10 psi to 80 psi. The results of CV for Varitarget black and clear capped nozzles are presented in Table 5.7 and Table 5.8. The results of spray angle are presented in Table 5.9

Table 5.7 Height of spray in inches in each collector at different pressures and CV values for Varitarget black capped nozzle

Troughs	Pressure			
	15 PSI	20PSI	30 PSI	40PSi
1	2.4	2.7	2.9	3.5
2	2.4	2.9	3.1	3.7
3	2.7	3.1	3.1	3.8
4	3.2	3.4	3.2	3.9
5	3.1	3.3	3.3	4.0
6	2.8	3.1	3.3	4.0
7	2.8	3.2	3.4	4.0
8	3.0	3.2	3.5	4.0
9	3.1	3.2	3.5	3.9
10	2.8	3.0	3.3	3.8
11	2.6	3.0	3.3	3.8
12	2.6	3.2	3.4	3.9
13	2.7	3.4	3.2	3.6
14	2.9	3.4	3.1	3.4
15	3.0	3.4	3.2	3.6
16	3.0	3.3	3.1	3.7
17	2.7	3.0	3.1	3.8
18	2.9	2.9	3.0	3.9
19	2.9	2.8	2.9	3.9
20	2.5	2.9	2.9	3.7
21	2.3	2.8	2.8	3.6
22	2.3	2.5	2.8	3.5
23	2.3	2.5	2.7	3.4
MEAN	2.74	3.05	3.13	3.76
STDEV	0.27	0.27	0.22	0.18
CV	**10.0**	**8.8**	**7.2**	**4.9**

*** Refer to discussion from section 3.4.1.2 for calculating CV**

Table 5.8 Height of spray in inches in each collector at different pressures and CV values for Varitarget clear capped nozzle

	Pressure			
Troughs	**15 psi**	**20 psi**	**30 psi**	**40 psi**
1	2.3	2.4	2.3	3.5
2	2.3	2.5	2.4	3.8
3	2.4	2.6	2.4	3.8
4	2.8	2.7	2.4	3.9
5	2.8	2.8	2.4	3.9
6	2.7	2.8	2.4	3.8
7	2.6	2.8	2.4	3.9
8	2.6	2.8	2.4	4.0
9	2.6	2.9	2.4	4.0
10	2.7	2.8	2.4	4.0
11	2.8	2.8	2.4	4.0
12	2.6	2.8	2.5	4.0
13	2.3	2.5	2.5	4.0
14	2.4	2.6	2.5	3.9
15	2.6	2.8	2.5	3.9
16	2.6	2.6	2.4	3.8
17	2.4	2.5	2.5	3.7
18	2.4	2.6	2.5	3.8
19	2.5	2.7	2.4	3.8
20	2.7	2.9	2.4	3.7
21	2.7	2.9	2.3	3.6
22	2.5	2.6	2.3	3.5
23	2.3	2.4	2.2	3.5
MEAN	2.54	2.68	2.41	3.81
STDEV	0.17	0.15	0.08	0.17
CV	**6.6**	**5.7**	**3.4**	**4.5**

*** Refer to discussion from section 3.4.1.2 for calculating CV**

Table 5.9 Spray width, and spray angle for VT black and VT clear capped nozzles measured at spray height of 19 inches

VT Black Capped Nozzle			VT Clear Capped Nozzle		
PSI	Width[a](inches)	Angle[b]	PSI	Width (inches)	Angle
10	51	107	10	42	96
20	54	110	20	45	100
30	54	110	30	54	110
40	54	110	40	54	110
50	54	110	50	54	110
60	54	110	60	54	110
70	56	112	70	54	110
80	58	114	80	54	110

a. width was measured using ruler

b. spray angle was calculated using spray coverage calculator from AutoJet Technologies website

5.3.1 Uniformity of spray pattern

The CV values of VT black capped nozzle varied from 10 to 4.9% as the pressure varied from 15 psi to 40 psi. (Table 5.7). The highest CV of 10% was observed at 15 psi and least CV of 4.9% was observed at 40 psi. It was observed that the CV decreased as the pressure increased from 15 psi to 40 psi.

The CV values of VT clear capped nozzle varied from 6.6 to 4.5% as the pressure varied from 15 psi to 40 psi. (Table 5.8). The highest CV of 6.6% was observed at 15 psi and lowest CV of 3.4% was observed at 30 psi. It was observed that the CV decreased as the pressure increased until 30 psi and the CV increased at 40 psi.

5.3.2 Spray width and spray angle

The spray width for VT black capped nozzle ranged from 51 to 58 inches as the pressure varied from 10 to 80 psi. The spray angle varied from 107 to 114 degrees as the pressure varied from 10 to 80 psi.. The spray angle was 107 at 10 psi, stood constant at 110 degrees from 20 to 60 psi, increased to 112 and 114 degrees at pressures of 70 and 80 psi.

The spray width for VT clear capped nozzle ranged from 42 to 54 inches as the pressure varied from 10 to 80 psi. The spray angle varied from 96 to 110 degrees as the pressure varied from 10 to 80 psi The spray angle was 96 degrees at 10 psi, 100 degrees at 20 psi and was constant at 110 degrees for the remaining pressures.

CHAPTER 6 - RESULTS AND DISCUSSIONS – FIELD STUDIES

6.1 Evaluating droplet characteristics at varying speeds

Droplet characteristics of Varitarget black and clear capped nozzles were analyzed and compared at speeds ranging from 4 to 12 mph in increments of 2 mph. DropletScan™ was used to measure and compare the droplet characteristics such as VMD, percentage area coverage (PAC), droplets per square centimeter (D/SC), relative span (RS).

The critical measured droplet statistics and standard comparisons based on nozzle manufacturers droplet sizing charts and the ASABE S-572 droplet spectra classification system (Table 3.1) for each nozzle at speeds ranging from 4 to 12 mph are presented in Table 6.1. The measured VMD for Varitarget black capped nozzle ranged from 621 to 498 microns with a standard deviation (SD) of 47.50 as the speed varied from 4 to 12 mph. The measured VMD for VT black capped nozzle was not within the standard VMD range for coarse droplet spectrum (350 to 450 microns) (Figure 6.1). What we can conclude from the data is that the measured VMD for the VT black capped nozzle was within standard VMD range for very coarse droplet spectrum (450 to 550 microns). The measured VMD for the Varitarget clear capped nozzle ranged from 599 to 465 with a SD of 54.08 as the speed varied from 4 to 12 mph. The measured VMD for the VT clear capped nozzle was not within the standard VMD range for medium droplet spectrum (250 to 350 microns) (Figure 6.2). What we can conclude is the measured VMD for VT clear capped nozzle was within standard VMD range for coarse droplet spectrum (350 to 450 microns). (Table 3.1)

Table 6.1 VD 0.1, VMD, VD 0.9, PAC, Droplets/SqCm, Relative Span, Droplet spectrum, VMD range for Varitarget black and clear capped nozzle at speeds ranging from 4 mph to 12 mph

VT Black										
Speed	**Pressure**	**VD 0.1**	**VMD**	**VD 0.9**	**PAC**	**D/SC**	**RS**	**Droplet size/color**	**VMD range (Microns)**	
4	27.33	318	621	871	37^{a}	71^{a}	1.94	**Coarse**	**350**	**450**
6	25.67	303	527	743	23.9^{b}	69^{a}	1.72	**Coarse**	**350**	**450**
8	26.67	280	498	701	19.9^{b}	68^{a}	1.75	**Coarse**	**350**	**450**
10	30.67	283	518	730	21.6^{b}	77^{a}	1.80	**Coarse**	**350**	**450**
12	30.67	299	532	756	23.5^{b}	108^{b}	1.74	**Coarse**	**350**	**450**
			SD=47.50							

VT Clear										
Speed	**Pressure**	**VD 0.1**	**VMD**	**VD 0.9**	**PAC**	**D/SC**	**RS**	**Droplet size/color**	**VMD range (Microns)**	
4	26	326	599	847	36.6^{a}	91^{b}	1.83	**Medium**	**250**	**350**
6	24.67	265	496	705	24.0^{b}	92^{b}	1.85	**Medium**	**250**	**350**
8	29.33	255	472	685	23.5^{b}	89^{b}	1.82	**Medium**	**250**	**350**
10	30	242	465	679	22.0^{b}	104^{ab}	1.88	**Medium**	**250**	**350**
12	33	274	519	750	27.8^{b}	125^{a}	1.85	**Medium**	**250**	**350**
			SD = 54.08							

Means with same letter are not significantly different

Figure 6.1 Measured VMD and the ASABE standard (minimum and maximum) VMD range for Varitarget black capped nozzle at various speeds

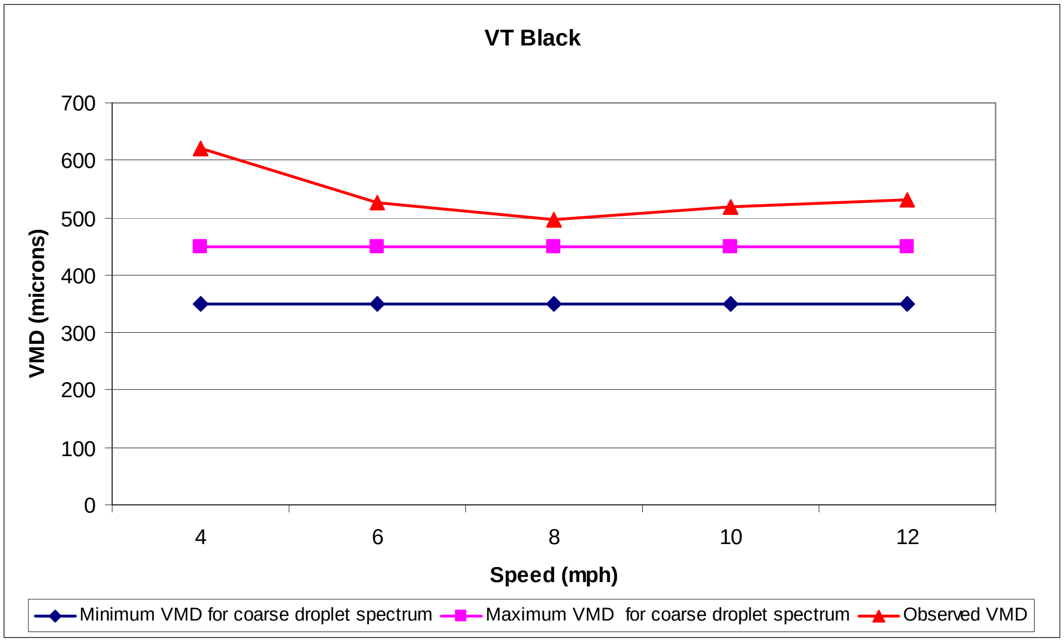
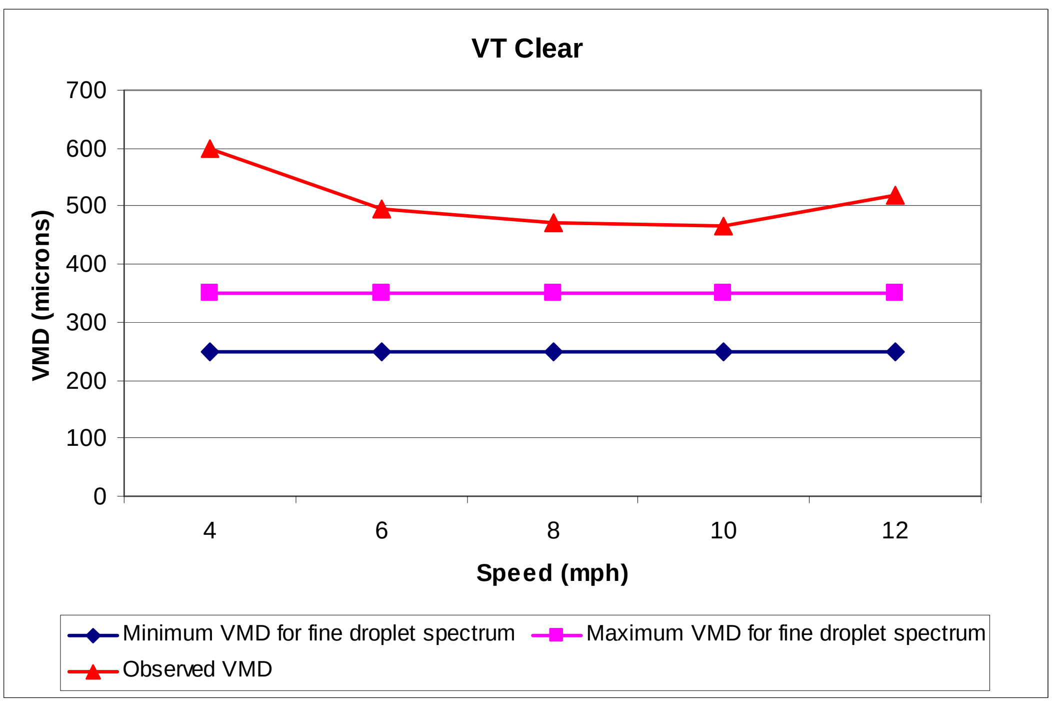
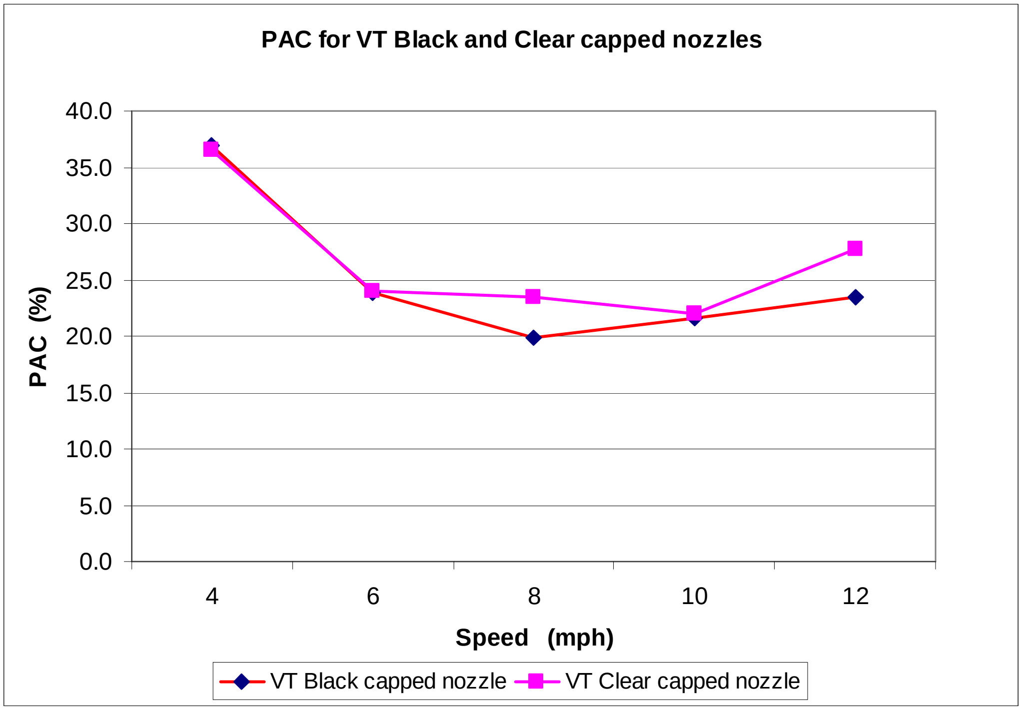


Figure 6.2 Measured VMD range and the ASABE standard (minimum and maximum) VMD range for Varitarget clear capped nozzle at various speeds



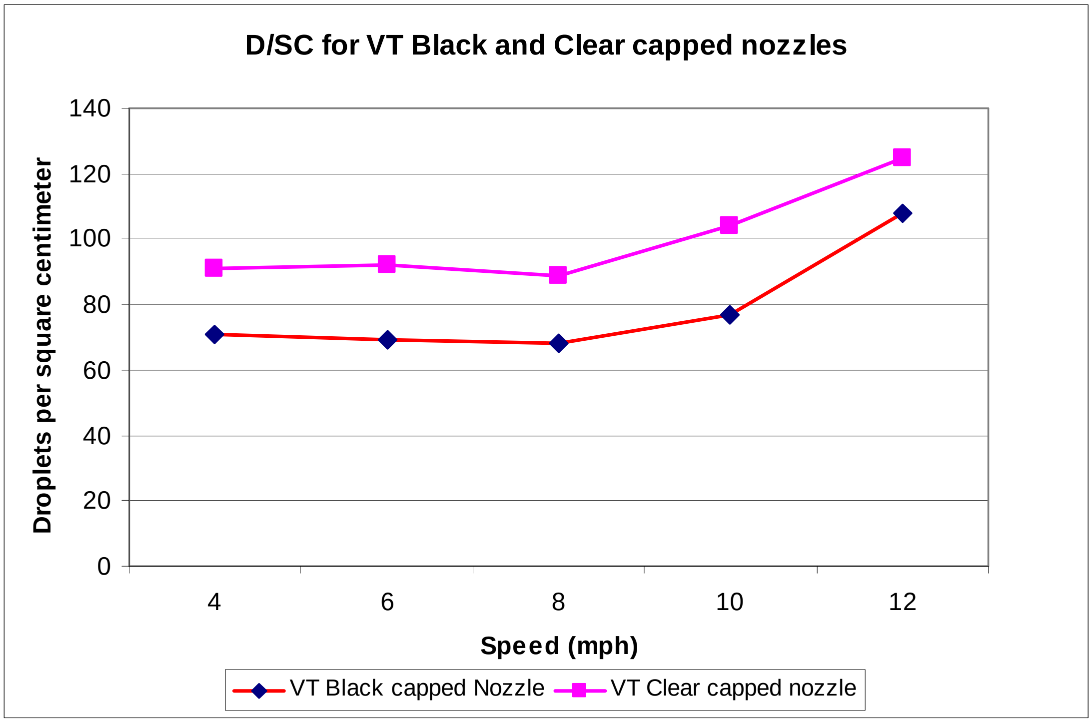
The results of PAC are presented in Table 6.1. The PAC for VT black capped nozzles ranged from 21.6 to 37.5% as the speed varied from 4 to 12 mph. The PAC for VT clear capped nozzles ranged from 22.0 to 36.6% as the speed varied from 4 to 12 mph. The PAC for Varitarget black capped nozzle at 4 mph varied significantly higher from the remaining speeds. The PAC for Varitarget clear capped nozzle at 4 mph varied significantly higher from the remaining speeds. It was observed that both the nozzles have similar PAC. (Figure 6.3)

Figure 6.3 Percentage area coverage for Varitarget black and clear capped nozzles



The results of D/SC are shown in Table 6.1 D/SC for VT black capped nozzle ranged from 71 to 108 D/SC as speed varied from 4 to 12 mph. D/SC for VT clear capped nozzle ranged from 91 to 125 D/SC as speed varied from 4 to 12 mph. The D/SC for Varitarget black capped nozzle at 12 mph varied significantly higher from the remaining speeds. The D/SC for Varitarget clear capped nozzle at 10 and 12 mph varied significantly higher from the remaining speeds. The D/SC for the Varitarget clear capped nozzle was higher than the D/SC for Varitarget black capped nozzle at each treatment speed.(Figure 6.4).

Figure 6.4 Droplet per square centimeter for Varitarget black and clear capped nozzles



The results of RS are presented in Table 6.1The RS for Varitarget black capped nozzle ranged from 1.72 to 1.94 as the speed varied from 4 mph to 12 mph. The RS for Varitarget clear capped nozzle ranged from 1.82 to 1.85 as the speed varied from 4 mph to 12 mph. It is observed that there is not much variation among the RS values for both the nozzles.

6.2 Evaluation of Droplet characteristics at various application rates

Droplet characteristics of Varitarget black and clear capped nozzles were analyzed and compared for variable application rates ranging from 4 to 12 GPA in increments of 2 GPA. DropletScan™ was used to measure and compare the droplet characteristics such as VD 0.1, VMD, VD 0.9, percentage area coverage (PAC), droplets per square centimeter (D/SC), and relative span (RS).

The measured VMD, standard VMD range based on the nozzle manufacturers droplet sizing charts and the ASABE S-572 droplet spectra classification system, droplets sizing/color for each nozzle at application rates ranging from 4 to 12 GPA are presented in Table 6.2. The measured VMD for Varitarget black capped nozzle ranged from 432 to 510 microns with a SD of

27.84 as the application rate varied from 4 to 12 GPA. The measured VMD for VT black capped nozzle was within the standard VMD range at 4 GPA and was not within the standard VMD range at remaining application rates for coarse droplet spectrum (Figure.6.5). From the Figure we can conclude that the measured VMD for VT black capped nozzle was within standard VMD range for very coarse droplet spectrum. The measured VMD for Varitarget clear capped nozzle ranged from 355 to 452 with a SD of 39.80 as the application rate varied from 4 to 12 GPA. The measured VMD for VT clear capped nozzle was not within the standard VMD range for medium droplet spectrum (Figure 6.6). From the Figure we can conclude that the measured VMD for VT clear capped nozzle was within standard VMD range for coarse droplet spectrum (table 3.1).

Table 6.2 VD 01, VMD, VD 09, PAC, Droplets/SqCm, Relative Span, Droplet spectrum, VMD range for Varitarget black and clear capped nozzle at application rates ranging from 4 GPA to 12 GPA at increments of 2 GPA

GPA	Pressure	VD 0.1	VMD	VD 0.9	PAC	D/SC	RS	Droplet size/color	VMD range (Microns)	
4	19.33	233	432	596	8.9[b]	39[b]	1.84	**Coarse**	**350**	**450**
6	23.00	249	479	699	20.2[a]	68[a]	1.90	**Coarse**	**350**	**450**
8	22.00	236	469	673	18.7[a]	72[a]	1.96	**Coarse**	**350**	**450**
10	22.00	233	470	682	17.9[a]	65[a]	1.97	**Coarse**	**350**	**450**
12	25.00	258	510	734	22.9[a]	71[a]	1.93	**Coarse**	**350**	**450**
			SD = 27.84							

VT Clear										
GPA	**Pressure**	**VD 0.1**	**VMD**	**VD 0.9**	**PAC**	**D/SC**	**RS**	**Droplet size/color**	**VMD range (Microns)**	
4	23.67	197	355	542	11.2[b]	67[b]	1.78	**Medium**	**250**	**350**
6	23.00	237	427	630	18.5[a]	107[a]	1.78	**Medium**	**250**	**350**
8	24.33	215	419	620	18.3[a]	86[b]	1.92	**Medium**	**250**	**350**
10	28.00	221	452	655	22.8[a]	110[a]	2.00	**Medium**	**250**	**350**
12	29.33	222	452	672	23.3[a]	149[a]	1.99	**Medium**	**250**	**350**
			SD = 39.80							

Means with same letter are not significantly different

Figure 6.5 Measured VMD range and the ASABE standard (minimum and maximum) VMD range for Varitarget black capped nozzle at various application rates

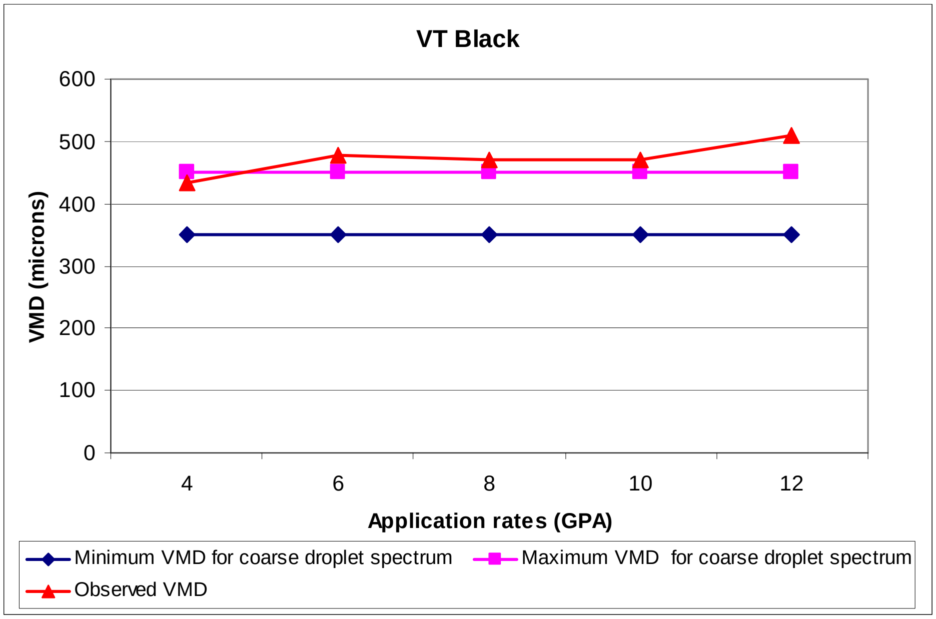
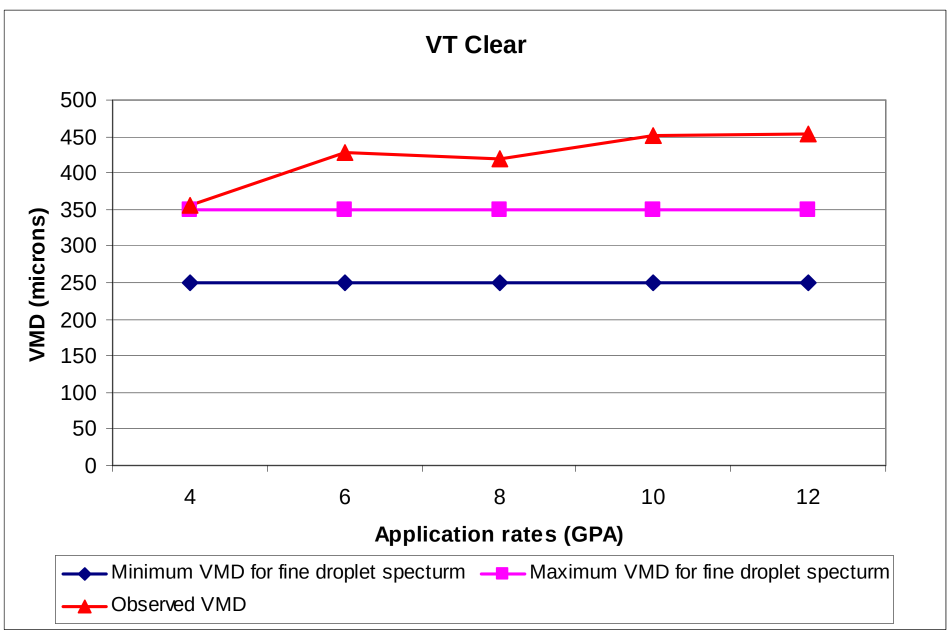


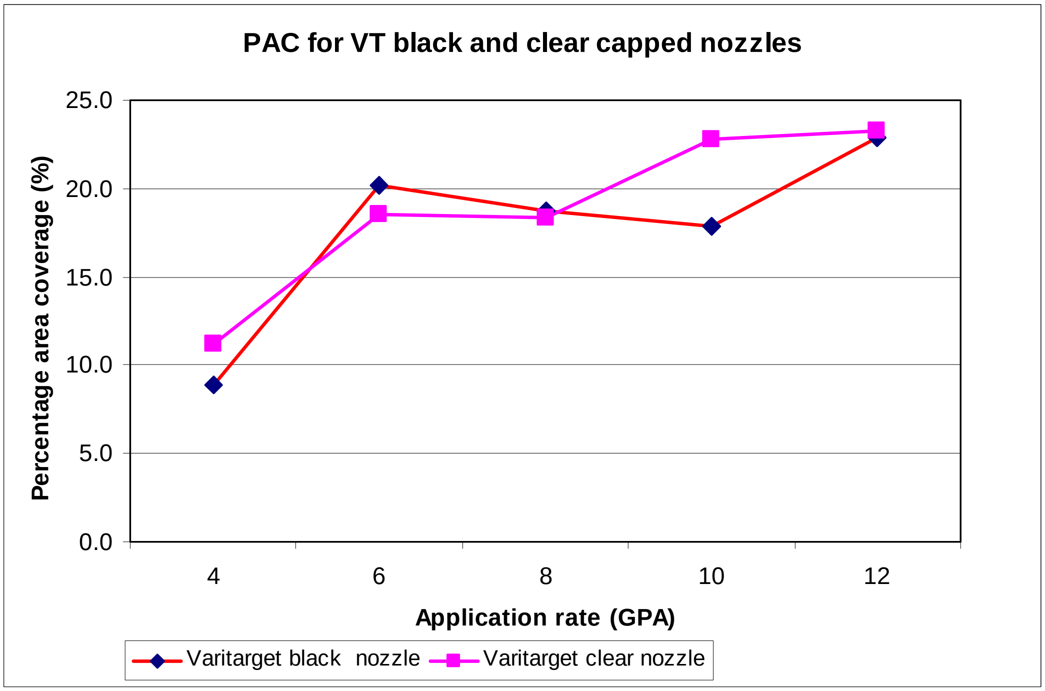
Figure 6.6 Measured VMD range and the ASABE standard (minimum and maximum) VMD range for Varitarget clear capped nozzle at various application rates



The results of PAC are presented in Table 6.2. The PAC for VT black capped nozzles ranged from 8.9 to 22.9% as the application rate varied from 4 to 12 GPA. The PAC for VT clear capped nozzles ranged from 11.2 to 23.3% as the application rate varied from 4 to 12 GPA. The

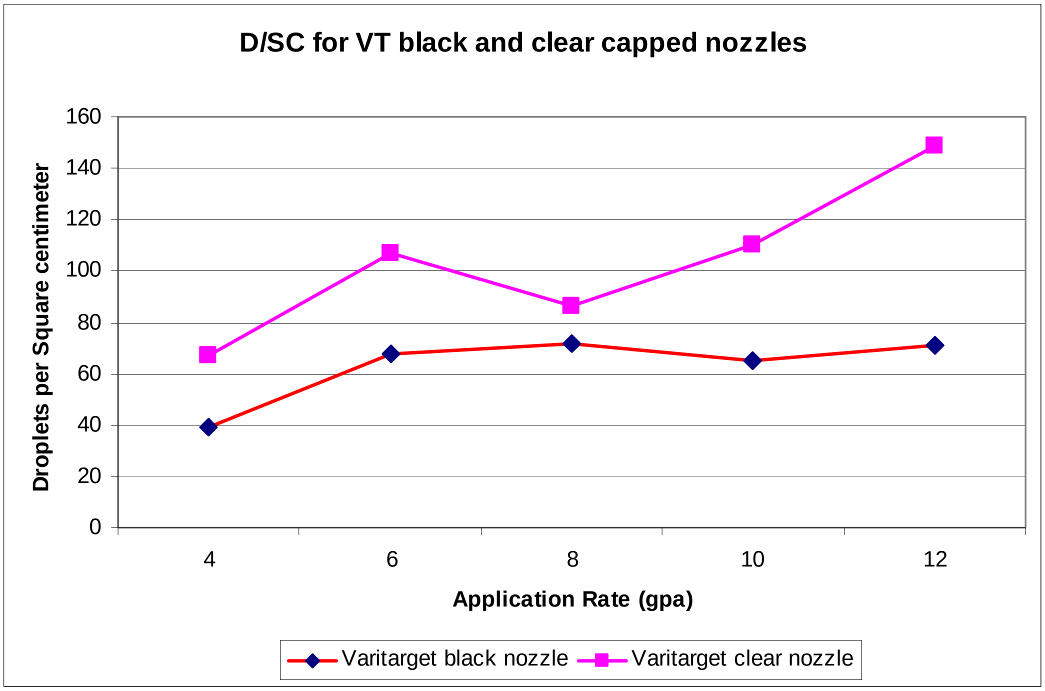
PAC for both the nozzles was similar (Figure 6.7). The PAC for Varitarget black capped nozzle at application rate 4 GPA varied significantly lower from the remaining application rates. The PAC for Varitarget clear capped nozzle at application rate 4 GPA varied significantly lower from the remaining application rates.

Figure 6.7 Percentage area coverage for Varitarget black and clear capped nozzles at different application rates



The results of D/SC for Varitarget black and clear capped nozzles are presented in Table 6.2. D/SC for VT black capped nozzle ranged from 39 to 71 D/SC as application rate varied from 4 to 12 GPA. D/SC for VT clear capped nozzle ranged from 67 to 149 D/SC as application rate varied from 4 to 12 GPA. The D/SC for Varitarget black capped nozzle at application rate 4 GPA varied significantly lower from the remaining application rates. The D/SC for Varitarget clear capped nozzle at application rate 4 GPA varied significantly lower from the remaining application rates. The D/SC for Varitarget clear capped nozzle was higher when compared to the D/SC for Varitarget black capped nozzle (Figure 6.8).

Figure 6.8 Droplets per square centimeter for Varitarget black and clear capped nozzles at different application rates



The results of RS for Varitarget black and clear capped nozzles are presented in Table 6.2. The RS values for Varitarget black nozzle ranged from 1.84 to 1.93 as the application rates varied from 4 to 12 GPA. The RS for Varitarget clear capped nozzle ranged from 1.78 to 1.99 as the application rates varied from 4 to 12 GPA. It is observed that the Varitarget clear capped nozzle has higher RS values as compared to that of Varitarget black nozzles.

CHAPTER 7 - CONCLUSIONS

7.1 Lab Studies

7.1.1 Flow rate measurements

Flow rates of eight different nozzles were measured at pressures ranging from 10 psi to 110 psi at increments of 5 psi. The flow rates of all nozzles were similar up to 40 psi with the VT black and clear capped nozzles having significantly higher flow above 40 psi.

When compared to the manufacturers published flow rates, both the Varitarget nozzles were similar up to 40 psi but were higher after 40 psi while the conventional nozzle flow rates were similar to that of their respective manufacturers published flow rate charts throughout the complete test range.

The turndown ratio of the Varitarget black and clear capped nozzles were 12:1 and 10: 1 while the other nozzles produced a turndown ratio of 3:1 to 4:1. A significant difference was observed between Varitarget nozzles and conventional nozzles. The higher ratio for the VT black and clear capped nozzles is desirable when considering variable rate application.

7.1.2 Droplet measurement studies

Droplet characteristics of eight different nozzles at pressures ranging from 10 psi to 50 psi were analyzed. The measured VMD for VT (black and clear) capped nozzles was within standard VMD ranges until 40 psi and showed an increasing trend after 40 psi. The measured VMD for XR 11003 nozzle did not match the standard VMD range. The measured VMD for ULD 11003, TT 11003, AI 11003, TTI 11003 was within the standard VMD ranges.

PAC for VT (black and clear) capped nozzles varied tremendously with the increase in pressure when compared to the remaining nozzles. VT black and clear capped nozzles were significantly different to the other nozzles after 30 psi. VT black and clear capped nozzles showed a better coverage at higher pressures when compared to conventional nozzles.

D/SC for VT (black and clear) capped nozzles, XR 11003 nozzles increased tremendously with the increase in pressure. D/SC for VT black, VT clear, XR 11003 nozzles was significantly different to that of remaining nozzles at all pressures.

The RS for VT (black and clear) capped nozzles was near one. With one being the goal, then the VT black and clear capped nozzle are considered to have a uniform droplet size distribution. The RS for Airmix 11003, ULD 11003, TTI 11003, AI 11003 nozzles was below one and not as quite as uniform.

7.1.3 Spray pattern studies

7.1.3.1 Uniformity of Spray distribution

The CV for the VT black capped nozzle decreased as the pressure increased from 15 to 40 psi. The CV values were observed less than 10% as the pressure varied. Thus, the VT black nozzle has a very good uniformity of distribution. All the CV values were less than 10 % and the VT clear nozzle has a very good uniformity of distribution.

7.1.3.2 Spray width and spay angle

The spray angle for VT black and clear capped nozzles was 110 degrees and consistent as pressure varied from 30 to 80 psi. The spray angle was less than 110 degrees at lower pressure of 10 and 20 psi.

7.2 Field Studies

7.2.1 Evaluation of droplet characteristics at different speeds

Droplet characteristics of Varitarget black and clear capped nozzles were analyzed at speeds ranging from 4 mph to 12 mph at increments of 2 mph. Treatments were designed to be compared at a constant GPA of 10 GPA.

The measured VMD for VT black and clear capped nozzles was not within the standard VMD range for coarse and medium droplet spectrum respectively. In each case the droplets were larger. The PAC for both Varitarget black and clear capped nozzles varied significantly higher at 12 mph to that of remaining speeds. The D/SC for both Varitarget black and clear capped nozzles varied significantly higher at 12 mph to that of remaining speeds. The D/SC for Varitarget clear capped nozzle was higher when compared to the D/SC for Varitarget black capped nozzle.

7.2.2 Evaluation of droplet characteristics at different application rates

Droplet characteristics of Varitarget black and clear capped nozzles were analyzed at application rates ranging from 4 to 12 GPA at increments of 2 GPA. The measured VMD for VT black capped nozzle was within the standard VMD range at 4 GPA and was not within the standard VMD range at remaining application rates for coarse droplet spectrum. The measured VMD for the VT clear capped nozzle was not within the standard VMD range for medium droplet spectrum. Instead it was observed that the measured VMD for VT black and clear capped nozzles was within the standard VMD range for very coarse and coarse droplet spectrum respectively. The PAC for both Varitarget black and clear capped nozzles was significantly different at application rate 12 GPA to that of remaining application rates. The D/SC for Varitarget black and clear capped nozzle at application rate 4 GPA varied significantly from the remaining application rates.

7.3 Observed differences between conventional nozzles and the Varitarget nozzles in this study

7.3.1 Varitarget nozzle

It was observed that as the speed varied from 4 to 12 mph, the pressure required for spraying (observed on the pressure gauge located on the boom) ranged from 25.67 to 30.67 psi with a SD of 2.32 for Varitarget black nozzle and 24.67 to 33.33 psi with a SD of 2.81 for Varitarget clear nozzle. The RPM required by the tractor ranged from 2100 to 1600 as speed varied from 4 to 12 mph for both Varitarget black and clear capped nozzle.

It is also observed that at a ground speed of 7.9 mph and as the application rate varied from 4 to 12 GPA, the pressure required for spraying ranged from 19.33 to 25.0 psi with a SD of 2.04 for Varitarget black nozzle and 23.67 to 29.33 psi with a SD of 4.0 for Varitarget clear nozzle.

It is also observed that the droplet size varied from 498 to 621 microns with a SD of 47.50 for VT black nozzle and 465 to 599 microns with a SD of 54.08 for VT clear cap nozzle as the speed varied from 4 to 12 mph. The droplet size varied from 432 to 510 microns with a SD of 27.84 for VT black nozzle and 355 to 452 microns with a SD of 39.80 as the application rate varied from 4 to 12 GPA.

7.3.2 Conventional nozzle

It is observed from the conventional nozzle charts that there will be tremendous change in pressure when speed is varied to maintain same application rate. It is also observed that there will be a large change in pressure when application rates were changed at a constant speed. Giles and Downey, (2001) evaluated the performance of pressure based system with conventional nozzle and reported that the pressure varied higher when there are speed changes and application rate changes. They also reported that large pressure variation results in a variation of droplet spectrum which results in inefficient application. The conventional nozzle has its own limitations when used for Variable rate application.

The rule of thumb can be used here for conventional nozzles:

1. To double the flow rate from a fixed orifice, the pressure needs to be increased four times.
2. To double the speed, the pressure needs to be increased four times when using fixed orifice to maintain required flow rate.

CHAPTER 8 - FUTURE RECOMMENDATIONS

1. In this study, droplet scan software was used to measure the spray droplets characteristics. It was noticed that the VMD was typically higher than the published standard droplet spectra of individual nozzles. I would recommend to check the VMD values using other methods such as laser based optical techniques and see if the VMD values vary in a similar way.

2. In this study the speed and application rate were changed manually keeping the cards at a constant place. I would recommend using GIS made maps of speed and application rate changes and see how the droplet charecteristics vary on the go.

3. I would also recommend studying the transportation lag when there are speed and application rate changes.

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Appendix A - A copy of DropletScan™ Software report

Preview Window

Zoom In   Zoom Out   Previous Page   Next Page   Go To Page   1/8

Report generated by DropletScan, a product of WRK and DSI.
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Prasad -Research
Seaton 142
2007 -Feb

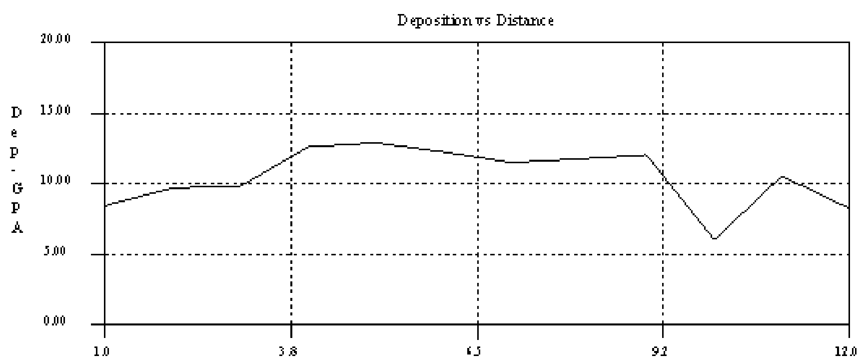
Material: water
Number of Nozzles: 2
Nozzle Pres. (PSI): 10
Flow Rate at 40 PSI (GPM): 0
Nozzle Type: VARITARGET BLACK
Spread Factors Equation
SF = 1.6333 + 0.0009*D + 0.0000*D*D

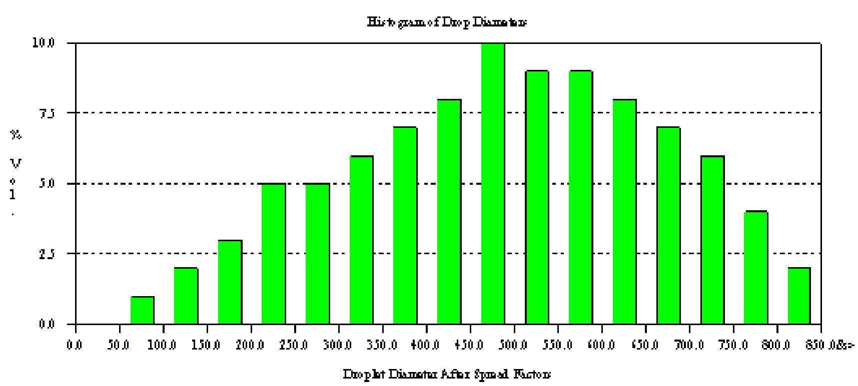
Composite results
VMD = 494
VD(0.1) = 224
VD(0.9) = 726
GPA = 10.51

% Area Coverage = 29.1

Run ID: 50-1
Time:
Target Rate (GPA):
Target Swath (Ft):
Application Height (Ft):
Number of Passes:
Ground Speed (MPH):

Wind Velocity (MPH):
Wind Direction(deg.):
Cross Wind (MPH):
Temperature (F):
Humidity (%):





1

Preview Window

Zoom In Zoom Out Previous Page Next Page Go To Page 2/8

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File: C:\droplet scan data old dell\2007 Data\Prasad Research\Lab study\REP 1\50 PSI\50-1.dlf 3/8/2007 4:25:17 PM

Prasad -Research
Seaton 142
2007 -Feb

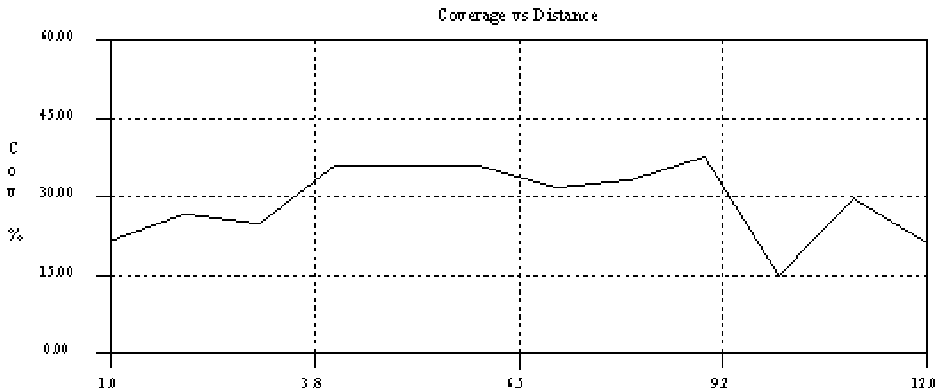
Material: water
Number of Nozzles: 2
Nozzle Pres. (PSI): 10
Flow Rate at 40 PSI (GPM): 0
Nozzle Type: VARITARGET BLACK
Spread Factors Equation
SF = 1.6333 + 0.0009*D + 0.0000*D*D

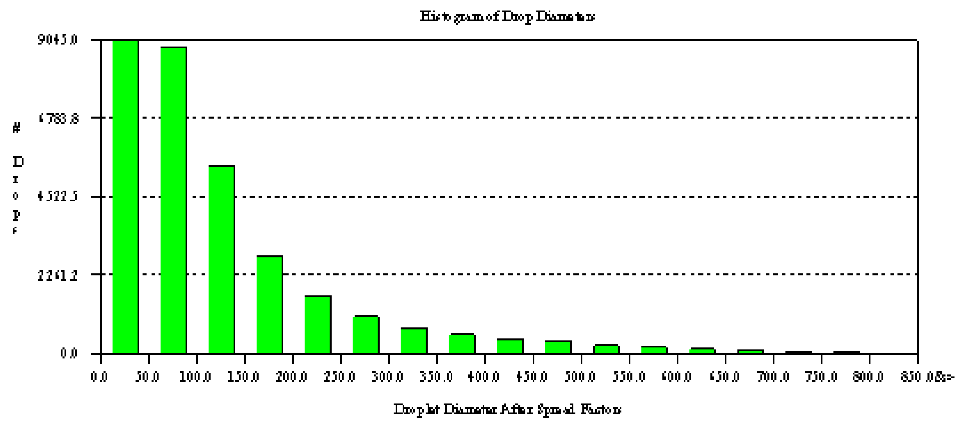
Composite results
VMD = 494
VD(0.1) = 224
VD(0.9) = 726
GPA = 10.51

% Area Coverage = 29.1

Run ID: 50-1
Time:
Target Rate (GPA):
Target Swath (Ft):
Application Height (Ft):
Number of Passes:
Ground Speed (MPH):

Wind Velocity (MPH):
Wind Direction(deg.):
Cross Wind (MPH):
Temperature (F):
Humidity (%):





2

DropletScanReport V1.1

Preview Window

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Report generated by DropletScan, a product of WRK and DSI.
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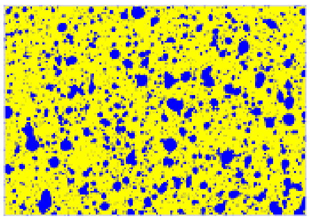
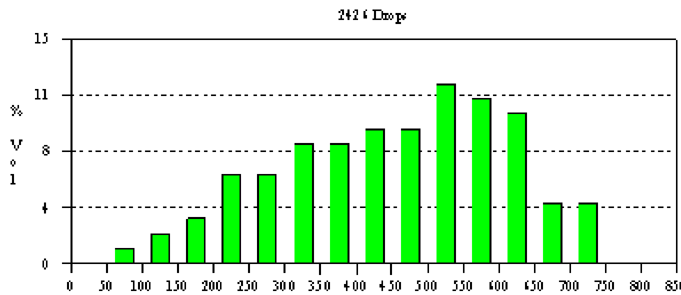
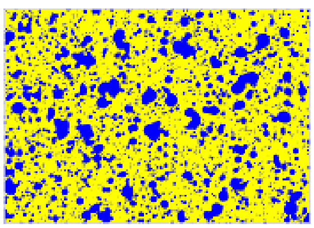
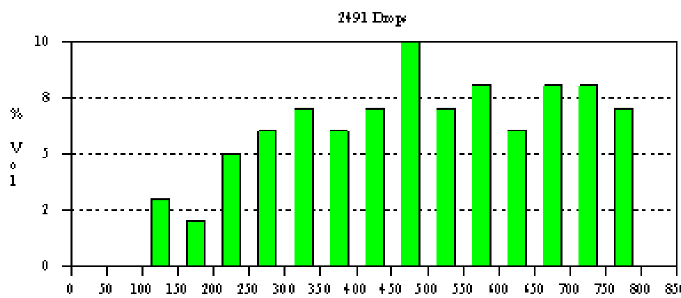
1.0 with 8.45 GPA & VMD = 461



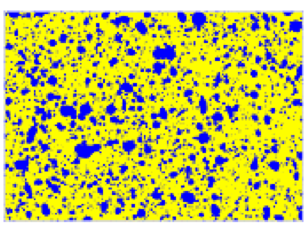


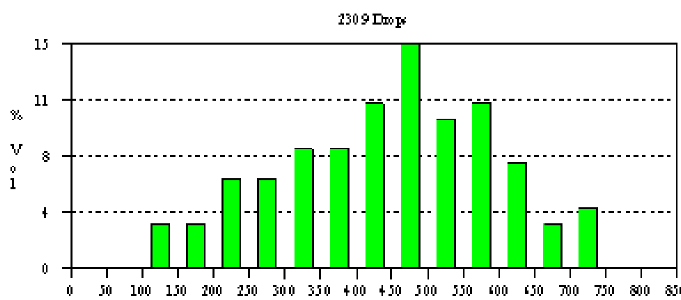
2.0 with 9.72 GPA & VMD = 492



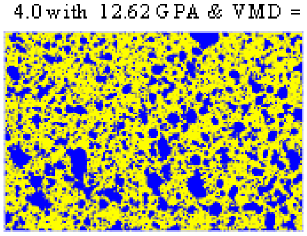


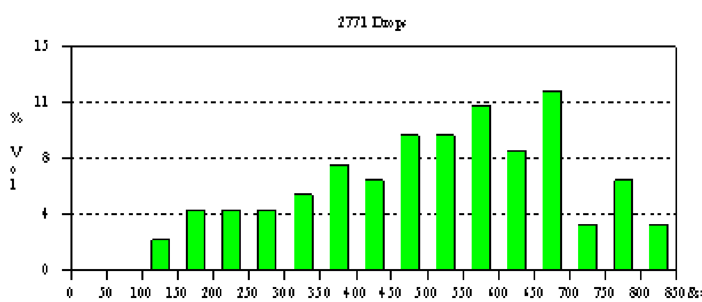
3.0 with 9.84 GPA & VMD = 456





4.0 with 12.62 GPA & VMD = 517





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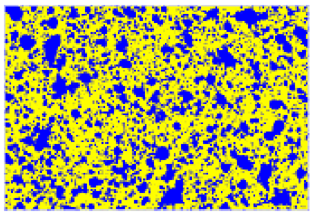
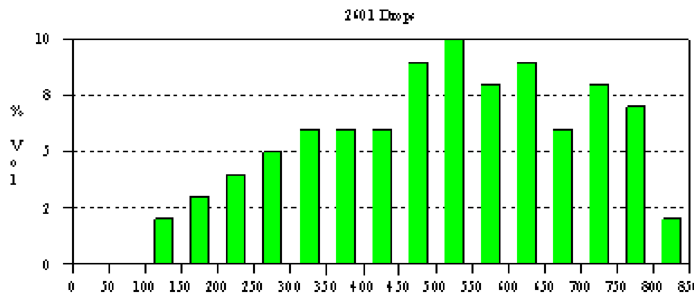
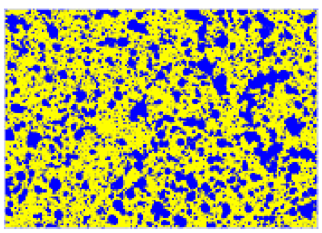
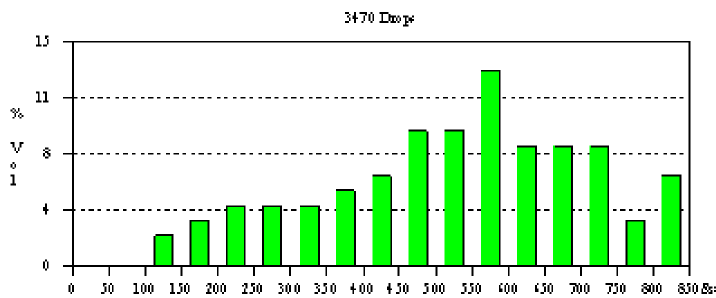
5.0 with 12.93 GPA & VMD = 519



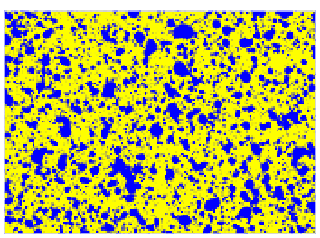


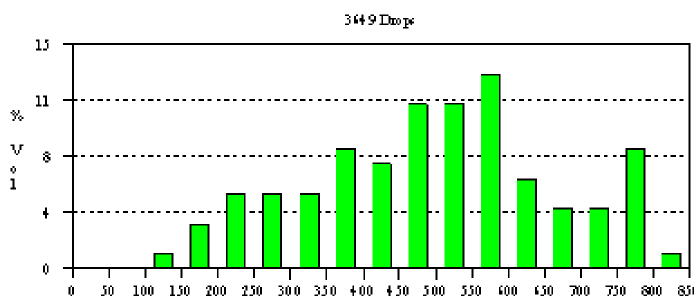
6.0 with 12.27 GPA & VMD = 541



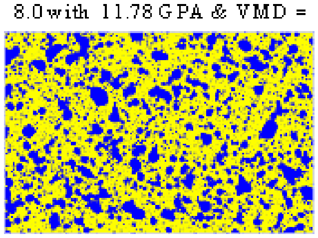


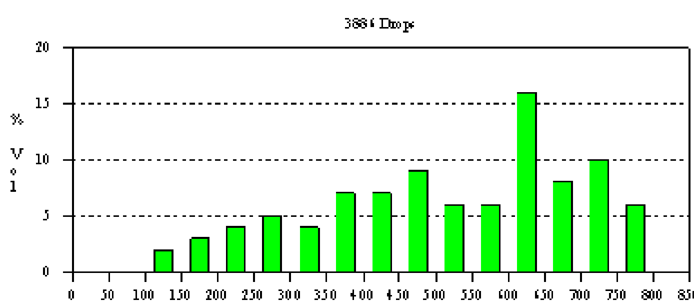
7.0 with 11.53 GPA & VMD = 501





8.0 with 11.78 GPA & VMD = 543





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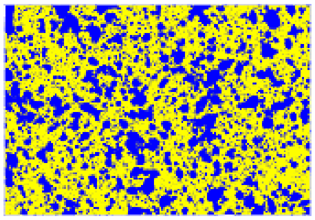
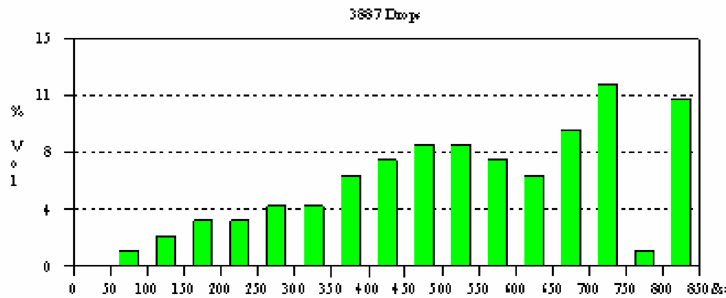
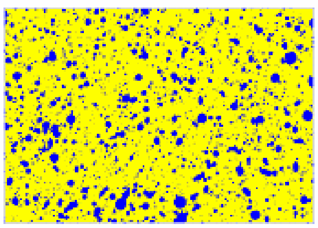
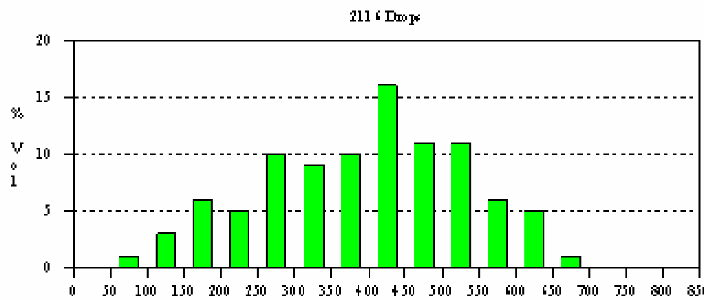
9.0 with 12.05 GPA & VMD = 542



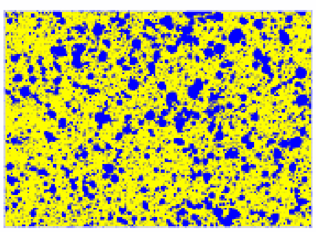


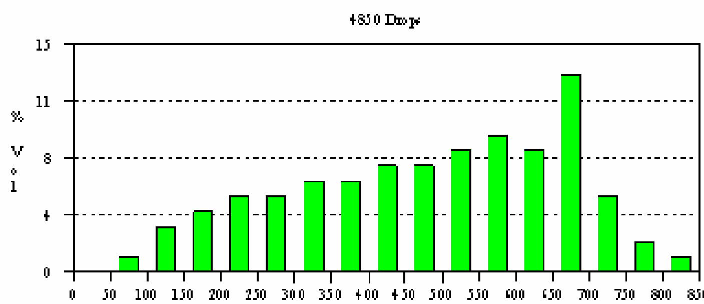
10.0 with 6.05 GPA & VMD = 407





11.0 with 10.56 GPA & VMD = 506





12.0 with 8.26 GPA & VMD = 398