PRECISION AGRICULTURE

Implementing Site-Specific Management:

Sprayer Technology – Controlling Application Rate On-The-Go

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Introduction

For many years, the main challenge of crop chemical application has been *control*. Early on, the primary concern was control of the pest, whether weed, insect, or disease. As crop producers began to experience tight profit margins, increased control of application rates to reduce the waste of a costly input became a major concern. More recently, environmental awareness, regulatory scrutiny of crop production operations, and the appearance of genetically modified crops (e.g., Roundup Ready soybeans) have made the control of pesticide placement (i.e., hit the target, prevent drift) even more important. Add to this the advent of site-specific management in which the rates of crop production inputs, including pesticides, are varied throughout the field in response to crop, soil, and pest variability. Now, crop producers need to have it all — effective pest control, site-specific application rate control, and minimal environmental impact. The demands on chemical application systems stand at unprecedented levels.

For years, recommended application rates for soil-applied herbicides have varied based on soil texture and/or organic matter content. Soil pH and cation exchange capacity (CEC) can also affect crop response and the degree of weed control resulting from herbicide application. Often, labeled rates of products will vary two- to three-fold depending on these soil properties. With the current trend toward post-emergence herbicide application, field scouting to identify variability in weed infestation has provided a basis for site-specific treatment. Whether the strategy is for pre- or post-emergence application, recommended herbicide rates can vary markedly over the extent of a single field.

Various methods have been, and are being, implemented to address the demands placed upon chemical applicators. One recent advancement has been the advent of variable rate application systems. These systems, responding to variable rate application maps, have the potential to improve the efficiency and effectiveness of chemical application through site-specific treatment. In order to understand the potential of variable-rate systems to improve chemical application, it is necessary to understand just how these systems operate. This publication describes the fundamentals of the construction and function of spraying systems, from simple fixed-rate units to state-of-the-art variable-rate systems.

Spraying System Fundamentals

A basic field spraying system typically consists of the following components: a tank to hold a mixture of active chemical ingredient(s) and water; a centrifugal pump; a pressure gauge; throttling valves; a shut-off valve; a boom; nozzles; and the plumbing necessary to connect the components. Figure 1 illustrates a simple field spraying system.

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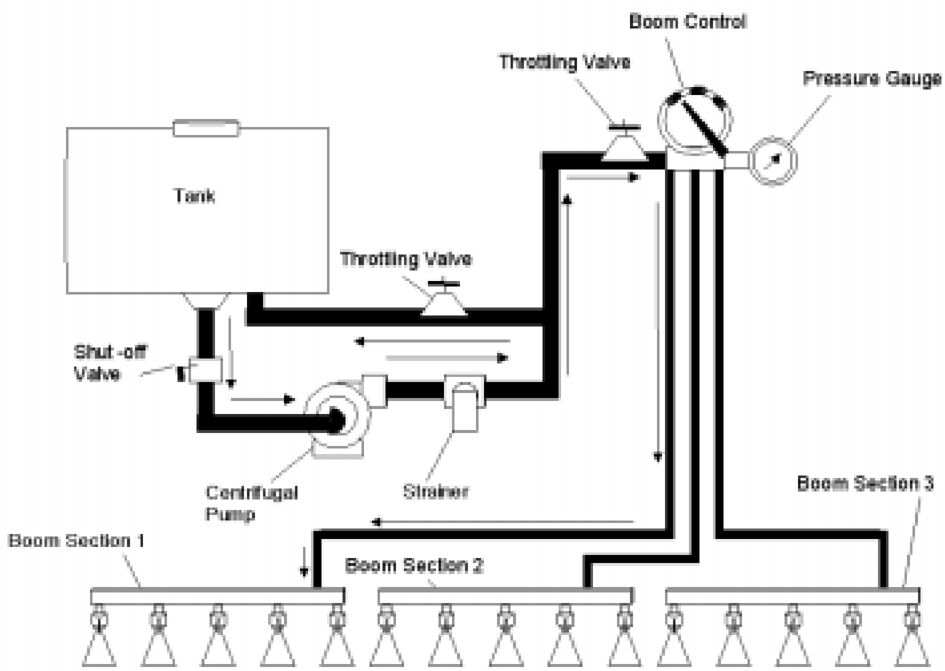

Figure 1. *Illustration of a conventional field spraying system.*

The application rate of a field sprayer such as the one depicted in Figure 1 can be described by the following formula:

$$R\ (gpa) = \frac{Q\ (gpm) \times 5{,}940}{S\ (mph) \times W\ (in)}$$

where:

R = application rate (gallons per acre or gpa)

Q = flow from a nozzle (gallons per minute or gpm)

S = sprayer travel speed (miles per hour or mph)

W = nozzle spacing (inches)

5,940 = unit conversion constant

This formula helps to clarify important relationships. For instance, if nozzle spacing is fixed (which it almost always is), there are only two ways to change application rate with conventional sprayer technology:

1) change the sprayer travel speed (*S*) or
2) change the flow rate from the nozzles (*Q*).
Changing nozzle flowrate has traditionally been accomplished by either changing nozzles or changing system pressure. Let's examine the implications of these strategies.

Changing travel speed to change application rate

Changing travel speed (while holding system pressure constant) is a fast way to make relatively large changes in application rate. Since sprayer pumps are often driven by the engine of the spray vehicle, travel speed changes are accomplished by changing transmission gear selections, not engine speed. (Keeping engine speed nearly constant minimizes variation in nozzle output.) Changing from one gear to the next will often result in application rate changes exceeding 10% (due to travel speed changes of 10% or more). Therefore, changing travel speed is typically restricted to coarse adjustment of application rate. Upward travel speed adjustments are typically limited to about 25%. This is due to the need for spray boom stability (to maintain a stable relationship between discharge point on boom and target to ensure precise coverage), especially with wide booms of 80 feet or more.

Commercial applicators, often operating with the largest category of spray boom, have another compelling reason to maintain travel speeds —

productivity. Since field capacity (acres per hour) is directly related to travel speed within a field, any significant lowering of travel speed to accomplish a rate change costs time and money.

Changing nozzle flow rate to change application rate

Pressure is related to the resistance to fluid flow in a hydraulic system such as a liquid sprayer . For a given flow rate, a nozzle with a small orifice will produce greater system pressures than a nozzle with a large orifice. The greater the flow rate to the nozzle, the greater the pressure buildup within the system for a given orifice. Seen another way, the greater the pressure developed within a spraying system, the greater the flow rate from a nozzle. The relationship between pressure and flow rate in an application system is expressed by the formula:

$$\frac{Q_2}{Q_1} = \sqrt{\frac{p_2}{p_1}} \quad \text{or} \quad Q_2 = Q_1\sqrt{\frac{p_2}{p_1}}$$

where:

Q_1 = flow rate at pressure p_1
p_1 = calibrated operating pressure
Q_2 = desired flow rate at pressure p_2
p_2 = adjusted (new) operating pressure

The formula can be used to show that a large change in pressure is necessary to produce any meaningful change in flow rate. Large pressure changes can produce a number of challenges for sprayer operators as will be discussed in the next few pages.

Valves can be used in spraying systems to throttle the output from a pump. When pump output is throttled, both system pressure and nozzle flow are reduced. A valve that controls the amount of flow in a tank return line can also regulate system pressure and flow. By restricting flow in the return line, more flow is directed to the spray boom and system pressure increases.

Flow control valves can be adjusted manually or electrically. The simplest pressure regulation valves are manually adjusted by an operator as directed by a pressure gauge reading. Electrically-actuated valves can be far removed from a tractor or sprayer cab, enhancing the ease of adjustment and the flexibility in system design. A sprayer controller can operate these more complex valves automatically. However, many such valves are slow acting, taking a number of seconds to adjust from fully-open to fully-closed positions.

Some large commercial-grade sprayers are equipped with spray system pumps driven hydraulically at variable speeds. Pump output is directly controlled by varying the speed of a hydraulic motor used to drive the pump. Flow from the pump controls nozzle flow and the resulting application rates produced by such spraying systems.

The change in application rate resulting from a change in system pressure is normally limited to about 10% for a given nozzle arrangement. This limit results from the need to maintain a consistent droplet size distribution and spray pattern characteristics to reduce spray drift potential and/or ensure appropriate coverage which is critical with some crop protection chemicals.

System pressure not only affects the flow rate from a nozzle, but the size of droplets produced by the nozzle, as well. While there is no nozzle capable of producing droplets of a single size, the general rule is that **higher pressures** will produce a greater *proportion* of **smaller droplets** from a nozzle. A typical measure of droplet size distribution is the volume median diameter (VMD) (see Glossary for additional information). As illustrated in Figure 2, increasing system pressure can greatly reduce the size of spray droplets produced by a nozzle. A greater proportion of smaller droplets can improve spray coverage of target pests, but can also increase the risk of spray drift.

Changing nozzles to change application rate

One can vary the flow rating at a given pressure, spray angle, spray pattern, droplet size distribution, and a host of other characteristics simply by changing sprayer nozzles.

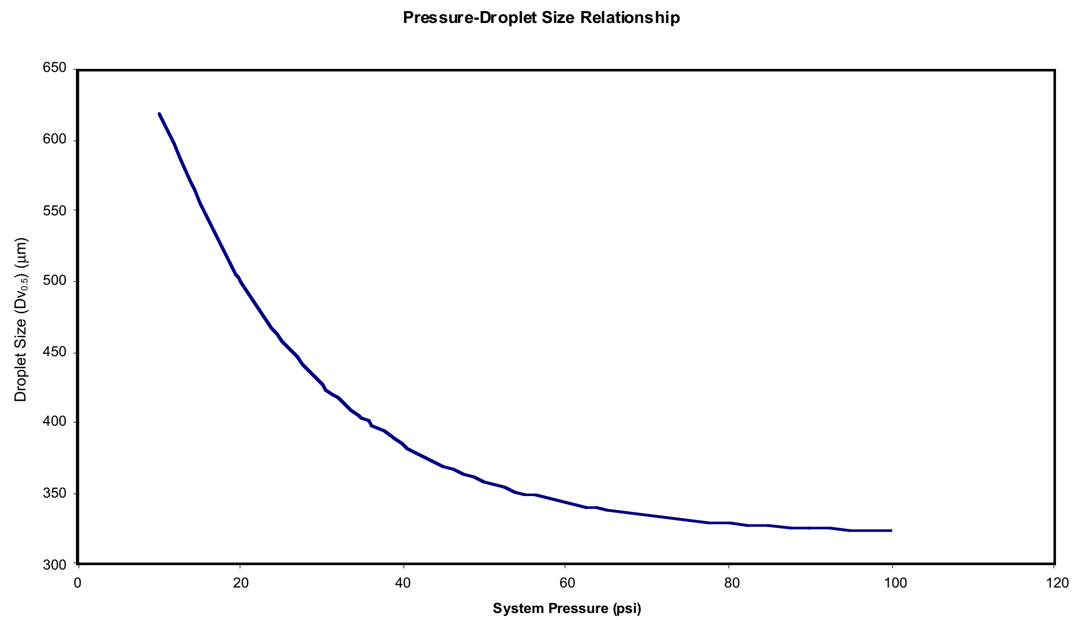

***Figure 2**. Relationship between system pressure and droplet size produced by a spray nozzle.*

However, for conventional boom-type sprayers with fixed, single nozzles, this is the most time-consuming strategy for changing application rate. This process is typically undertaken as a maintenance procedure before spraying season or when there is evidence of uneven nozzle discharge across the width of a spray boom. Technologies such as the multiple nozzle body assembly shown in Figure 3 have been developed to speed the process of changing nozzles, but for these particular devices, the operator must still manually switch between nozzles by rotating the nozzle body assembly.

So, for conventional spraying systems, if the necessary change in application rate is less than 10%, changing system pressure is often a satisfactory solution. If the change is greater than 10%, but less than 25%, changing travel speed is the recommended solution. If changes of greater than 25% are necessary, different nozzles are typically recommended. Changing pressure is as easy as changing a valve setting. Changing travel speed is as easy as shifting gears. However, changing nozzles on a conventional sprayer can be a time-consuming task. Therefore, for practical purposes, conventional spraying systems are limited to in-field changes in application rate of 25% or less.

As expressed earlier, the demands on spraying systems are increasing. Not just rate change, but on-the-go, precise changes to either maintain a fixed application rate under varying conditions or to accomplish variable rate applications. It is not unusual for recommended chemical application rates to vary by a factor of two or more as soil

***Figure 3.** Illustration of a nozzle body that can accommodate multiple sprayer nozzles*

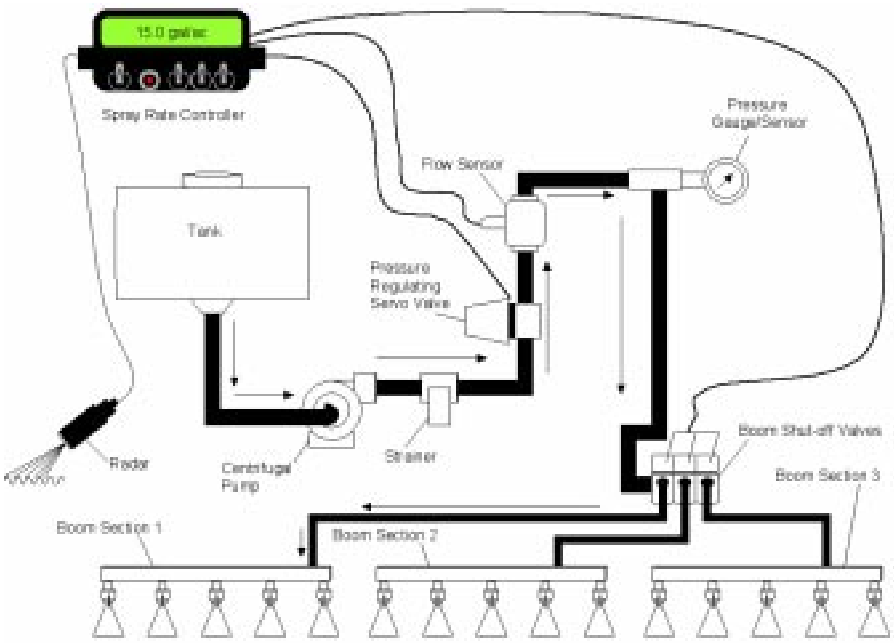

Figure 4. *Illustration of a spraying system that incorporates pressure-based control of application rate.*

texture, organic matter, or weed density vary across a field. Conventional spraying systems that rely on manual speed, pressure, or nozzle changes are limited in their ability to quickly and precisely respond to large rate changes in the field. The following section describes automatic sprayer rate control systems starting with those that control rates within a narrow range and ending with those that can produce wide ranges of application rates (without reducing productivity in the field). What follows is a discussion of automatic sprayer control systems.

Systems for Automating Control of Chemical Application Rate

Pressure-Based Control Systems

For years, the state of the art in controlled crop chemical application has been pressure-based control systems that permit the operator to change travel speed in the field without changing the application rate produced by a sprayer. (The goal has been to apply and maintain a consistent rate over an entire field with tank-mix methods.) Such systems monitor travel speed and use a controller to adjust system pressure or flow rate to maintain a constant application rate. If the calculated rate is higher than the desired rate, system pressure is reduced to reduce flow rate. If the calculated rate is lower than the desired rate, system pressure is increased to increase flowrate. Application rate is maintained by the controller through the use of a pressure regulating servo valve (Fig. 4).

As discussed earlier, using changes in pressure to make large changes in nozzle flow is problematic. In order to make large changes in the flow rate from a nozzle simply by changing pressure, the pressure change must be quite large. The pressure-flow formula introduced earlier can be rearranged to make this quite clear.

$$p_2 = p_1 \text{x} \left(\frac{Q_2}{Q_1} \right)^2$$

where:

Q_1 = flow rate at pressure p_1
p_1 = calibrated operating pressure
Q_2 = desired flow rate at pressure p_2
p_2 = adjusted (new) operating pressure

Example

Let's say that you were spraying at a speed of 8 miles per hour, the system was operating at 40 pounds per square inch (psi), and the flow from each nozzle was 0.2 gallons per minute (gpm). You need to slow down to 4 miles per hour as you approach the end of a pass. In order to maintain the same application rate, the flow from each nozzle must be reduced by half, however the change in system pressure needed is more significant. In fact, using the pressure-flow formula, it can be shown that the pressure would need to be reduced to 10 psi:

$$p_2 = 40\,\frac{lb}{in^2}\,\text{x}\left(\frac{0.1\,gpm}{0.2\,gpm}\right)^2 = 10\,\frac{lb}{in^2}\ \text{(or psi)}$$

Unfortunately, the pattern produced by a typical nozzle at 10 psi would be markedly different from the original. Spray angle would be reduced (as shown in Figure 5) and droplet size distribution would be affected. Reduced spray angle could produce gaps in spray coverage. The greater proportion of large droplets produced at the greatly reduced system pressure could reduce the level of leaf coverage.

In response to this situation, nozzle manufacturers have developed *extended range nozzles*. According to one manufacturer, such nozzles can operate effectively at pressures ranging from 15 to 90 psi, a major improvement in performance when compared to conventional nozzle technology. However, the range of pressures (6:1) produces a range of nozzle flow rates of less than 2.5 to 1. This range of flow rate variation is enough to help with problems encountered during turns and travel speed changes in the field, but not enough to fully accommodate variable rate applications based on soil or weed variability.

In addition to the effects on spray angle and droplet size distribution resulting from large changes in pressure (at least with standard nozzles), there is a problem — the slowness of response with motorized valves which can take seconds to change pressure over a significant range. In a field situation, a sprayer can travel quite a distance in this time. In one second, a sprayer travels about 1.5 feet for every mile per hour of travel speed. For a sprayer traveling at 15 miles per hour, each second of delay causes an area over 22 feet long and as wide as the spray boom to receive an incorrect rate of chemical application.

Automatic Nozzle Selection

A variation on pressure-based sprayer control has been developed by Midwest Technologies, Inc.*

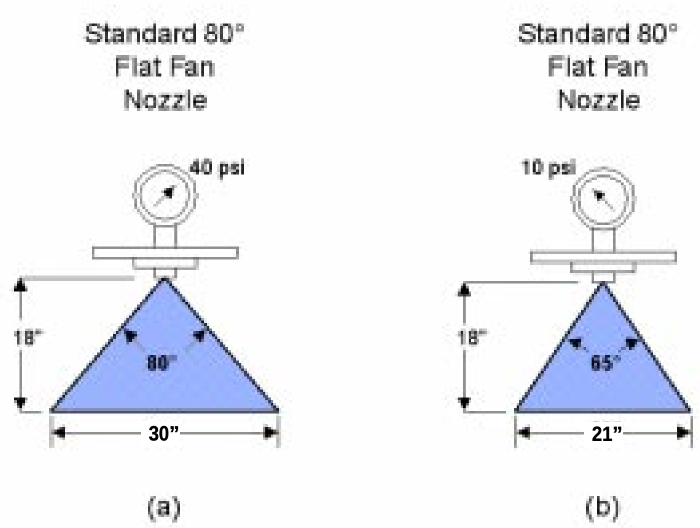

Figure 5. *Spray pattern from a nozzle operating at (a) 40 psi and the same nozzle at (b) 10 psi.*

(Springfield, IL). The "Auto Tip Control" (ATC) system can switch among three nozzles at each discharge point along a spray boom. The system automatically selects the nozzles used based on site-specific application rates, measured travel speed, and user-specified pressure limits. Single nozzles or combinations of three nozzles can be automatically selected to provide an ***application rate range*** (or ***flow control range***) of 9 to 1 at a given pressure.

Nozzles must be sized to permit smooth transitions between flow rates as different combinations are selected by the system. The user specifies minimum and maximum pressure switch points between which the system will operate. The system responds to increasing flow demands by increasing pressure until the maximum pressure switch point is reached. At that time, the next larger set (or combination) of nozzles is selected. The system responds to decreasing flow demands by reducing pressure until the minimum pressure switch point is reached. The system then switches to the next smaller set (or combination) of nozzles.

Example

An ATC-equipped sprayer is accelerating past 10 miles per hour in the field. The system is operating at an application rate of 40 gpa. The minimum pressure switch point has been set at 10 psi and the maximum pressure switch point is 40 psi. "Flood jet" nozzle sets are spaced 60 inches apart along the spray boom. The following table provides flow data for the nozzle combinations that can be selected by the sprayer:

At 10 miles per hour, with the "A" nozzles selected, the system would be operating at 40 psi and a flow rate of 4 gpm in order to produce the desired 40 gpa application rate:

Nozzle(s)	Rated Capacity at 10 psi (gpm)	Rated Capacity at 40 psi (gpm)
A	2	4
B	4	8
A + B	6	12
C	12	24
A + B + C	18	36

As the sprayer speed exceeds 10 miles per hour, the maximum pressure switch point will be exceeded and the system will automatically switch to the next larger set of nozzles, "B," which will then operate within the pressure range of 10 to 40 psi. If system pressure reaches 40 psi with the "B" nozzles selected, the "A" nozzles will then be turned on as well. If sprayer speed continues to increase, this process can continue until the "A," "B," and "C" nozzles at each discharge point on the sprayer boom are all operating at 40 psi.

$$R\,(gpa) = \frac{Q\,(gpm) \;\text{x}\; 5{,}940}{S\,(mph) \;\text{x}\; W\,(in)} = \frac{4 \;\text{x}\; 5{,}940}{10 \;\text{x}\; 60} = 40 \text{ gpa}$$

The ATC system provides the user a wide range of application rates that are produced on-the-go. However, care must be taken to specify nozzle combinations that will function properly over the actual range of operator-specified pressures (up to 100 psi). Improper selection can produce poor system performance during nozzle switching as well as the potential for excessive spray drift or poor spray coverage.

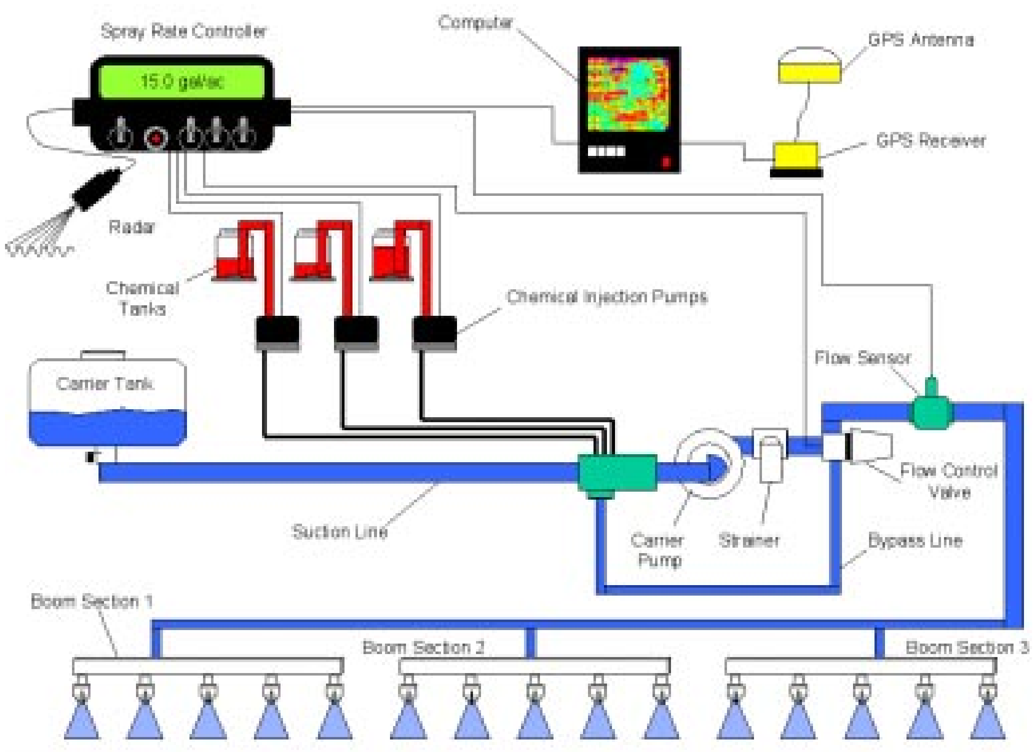

Figure 6. *Illustration of a spraying system that incorporates chemical injection technology.*

Chemical Injection

In response to some of the challenges resulting from the use of pressure-based variable rate application systems, alternatives have been developed.

Traditionally, sprayers have been used to apply chemical solutions or suspensions from a large common tank to which chemicals are added and mixed with water prior to application. This strategy assumes that the same product(s) will be applied to all or part of a field. An alternative to tank mixing is ***chemical injection***, where chemicals are added just before they enter the nozzles. Chemical injection systems are equipped with a large tank that contains a carrier (almost always water) and one or more small tanks that contain chemical products. Each chemical tank is coupled with an independently controlled injection pump that can be used to meter chemical into a carrier stream that is directed toward a spray boom. In the most basic chemical injection sprayers, the flow rate of carrier is fixed while the injection rates of chemical(s) are varied to accommodate variations in ground speed. More sophisticated systems permit variable rate application of a number of products carried onboard a sprayer that can be selected and varied as directed by a digital application map. (See SSM-2-W, “Implementing Site-Specific Management: Map- versus Sensor-Based Variable Rate Application,” for additional information on map-based application systems.) Figure 6 is an illustration of a chemical injection sprayer that can dispense three chemical products independently. There are commercially available systems that can handle six or more chemicals.

Chemical injection spraying systems eliminate problems associated with large amounts of leftover tank mix and can reduce worker exposure to chemicals associated with tank mixing. They also permit the independent control of multiple chemical products in one trip through a field. While the chemical injection concept has significant advantages over conventional spraying systems, the primary disadvantage of such systems to date has been the long transport delay, or lag, between chemical injection pump(s) and discharge at the boom. Systems that use conventional "plumbing" arrangements (in which the injector and boom are separated by long distances of tubing) can take a number of seconds to transport a chemical mixture from an injection pump to the boom. This situation can be especially troublesome when variable-rate applications require frequent application rate changes. Chemical injection systems that control both carrier and chemical flow rates have been designed to increase the speed with which systems can respond to changes in application rates.

Summary

Conventional spraying systems have limitations that keep them from being able to fulfill all of the goals of todays chemical applicator. Variable rate spraying systems offer the potential to do a better job of controlling pests while at the same time improving both rate and placement control. Other challenges such as controlling drift still remain, but are being addressed by a new generation of technologies that will be discussed in the next installment of this "Implementing Site-Specific Management" publication series.

Glossary

Drop(let) Size Distribution: as all spray nozzles produce spray patterns composed of droplets of varying sizes, this term refers to the proportions of droplet sizes within a certain range; typically determined with sophisticated detection and measurement systems for a specific sprayer nozzle under controlled operating and environmental conditions; often expressed in terms of median droplet size (measured in micrometers (µm)). [See Volume Median Diameter]

Flow Control Range: often expressed as a ratio (e.g., 8:1), it is the range of output from a spray nozzle at a given pressure with the lowest effective output assigned a value of one, and the greatest output described as maximum flow rate/minimum flow rate.

Sprayer controller: an electronic device used to adjust product application rates on the go, based on user directions or digital application rate maps.

Volume Median Diameter (VMD; $D_{v0.5}$): a measure of the droplet size distribution discharged by a nozzle; expressed as the droplet size (diameter) for which 50% of the total volume (or mass) of liquid sprayed is made up of droplets with diameters larger than the median value, and 50% smaller than the median value.

Related Publications

The following publications provide information about other aspects of chemical application and site-specific management:

A detailed discussion of variable-rate application equipment can be found in the Purdue University Cooperative Extension publication:

SSM-2-W, "Implementing Site-Specific Management: Map- versus Sensor-Based Variable Rate Application"

An entry in the "Site-Specific Management Guidelines" series published by the Potash & Phosphate Institute (PPI) also contains valuable information about spraying systems:

SSMG-7, "Variable Rate Equipment — Technology for Weed Control," D. Humburg

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