Review Article

HERBICIDE APPLICATION METHODOLOGIES: INFLUENCE OF NOZZLE SELECTION, DROPLET SIZE AND SPRAY DRIFT ON EFFECTIVE SPRAYING – A REVIEW

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ABSTRACT

Chemical weed control in agriculture has become a more popular method, because of its ease, efficiency and effectiveness in controlling weeds. In cropping situations, herbicides are applied by low pressure agricultural sprayers. Nozzle is a sprayer component, used to obtain the spray atomization. The nozzle, spray tip, multiple nozzle boom, pressure regulation and sprayer calibration are the essential components of any spray-application technology. Decision making and selection of nozzle is most important, as it should develop a desired spray pattern. Droplet size smaller than 150 microns poses a most serious drift hazard problem. The right nozzle for spraying produces desired spray pattern as well as reduces spray drift. Simultaneously, spray uniformity will be achieved at 50 to 100% overlapping of the nozzle spacing. The standard flat fan nozzles are recommended for broadcast application, likewise even flat fan nozzles are recommended for band-application. But, the floodjet and other nozzles are selected based on the product being used and spray pattern desired. The shape and accuracy of a spray pattern can become faulty over a time and nozzle should be replaced if the flow exceeds its factory rating by 10%. Nozzles wear rate is influenced by pesticide formulation, nozzle type, orifice material and capacity, and sprayer operating pressure. Ceramic, hardened-stainless steel, stainless steel or plastic-based nozzle tips are recommended over brass tips for prolonged usages. Hence, all the parameters including nozzle selection, droplet size, spray drift and nozzle set-up should be taken care-of to achieve effective herbicide application.

INTRODUCTION

Problem of weeds and methods of controlling them have been with farmer since the early days of agriculture. The relatively labour-intensive and less effective methods of weed control are replaced by the improved weed management techniques such as cultural, mechanical, chemical and biological weed control methods. Out of all control methods, growing labour scarcity and increasing cost of manual weeding, makes chemical weed control as a popular method because of their cost-effectiveness and higher weed control efficiency (Choudhury *et al.,* 2016). Herbicides are chemicals, which are designed to kill or control the unwanted plants (weeds) in cropping or non-cropping situations. Herbicide efficacy and crop tolerance depend on inherent species sensitivity to herbicide and size of the weed or crop at application. In order to successfully use herbicides, their application must be accurate and uniform (Miller and Bellinder, 2001). In agriculture, herbicides are applied as pre-planting, pre-emergence and post-emergence depending on the crop and weed situation in the field. Herbicides can be applied by a variety of means including boom sprayers, aerial sprayers, misters, blanket wipers, rope wick applicators, weed seekers, back-pack sprayers and broadcasting of granular formations (Peltzer, 2016; Choudhury *et al.,* 2016). But, most of the herbicides used in cropping situations are applied in the form of liquid; where the formulations are mixed with water. This type of water mixed herbicides are usually applied by boom sprayers, misters, hand operated sprayers, foot-operated sprayers, wick applicators, drizzle applicators, gun sprayers and back-pack sprayers.

Nozzle is one of the most important spray components, which are used to atomize the spray liquid. Application of herbicide in a single nozzle lance may lead to complex and difficult spray operation, because of extremity in achieving the straight swath with appropriate overlapping. Furthermore, side swinging of the single nozzle may result in over or under dose application of the chemicals. This problem can effectively be tackled by using multiple nozzle boom sprayers. The most essential components of any spray-application technology are nozzles and spray tip, multiple nozzle booms, pressure regulation and sprayer calibration (Miller and Bellinder, 2001). However, the nozzle is a primary factor in determining the amount of spray applied to targeted area, application uniformity, targeted surface coverage and spray drift (Klein and Kruger, 2011). A perfect nozzle-pressure combination should maximize spray efficiency by increasing deposition and transfer lethal dose to the target, while minimizing residues, off-target losses such as spray drift and user exposure (Smith *et al.,* 2000; Nuyttens *et al.,* 2007; Nuyttens *et al.,* 2009a). The droplet size and velocity distribution, the spray pattern, the entrained air characteristics, the spray sheet structure and the structure of individual droplets are such spray parameters which influence efficiency of application of system (Miller and Butler Ellis, 2000). By considering all these factors, it is important to select a correct nozzle at correct operational parameters for any successful spraying operations.

Nozzle selection

Nozzle selection is the most important decision. The selected nozzle should develop desired spray pattern (Klein and Kruger, 2011; Sumner, 2012). The proper selection of a nozzle type and size is essential for effective herbicide application. A nozzle breaks the spray liquid into droplets to form a spray pattern and simultaneously propel the droplets in proper direction. It also determines the amount of spray volume at particular operating pressure, travel speed and spacing (Grisso *et al.,* 2013; Slocombe and Sharda, 2015). The main types of applicators available are hydraulic nozzles, twin fluid nozzles, controlled droplet applicators, air induction nozzles and air assisted nozzles. Each nozzle type has its own specific characteristics and capabilities, which are designed to use for certain type of application. In general, do not select the nozzle that requires a nozzle screen smaller than 50 mesh. Nozzles requiring 80–100 mesh screens clog too easily (Klein and Kruger, 2011). The nozzle types commonly used in low pressure agricultural sprayers are flat-fan, even flat-fan, floodjet, cone nozzles, air induction (AI), drift reducing (DG) and others (Klein and Kruger, 2011; Grisso *et al.,* 2013; Slocombe and Sharda, 2015). However, the nozzles that are mostly used for application of agricultural chemicals are flat-fan, even flat-fan, and cone nozzle (Phillips, 2010; Sumner, 2012).

Fan nozzles

Fan nozzles are the most common type of nozzles used in agriculture. These nozzles are widely used for spraying of both band and broadcast application of herbicides. These nozzles produce a tapered-edge, flat-fan spray pattern. However, they are categorized into standard flat-fan, even (E) flat-fan, low-pressure flat-fan and extended-range (XR) flat-fan (Table 1). Some special types are also available, such as off-center (OC) flat-fan, and twin-orifice (TJ) flat-fan (Slocombe and Sharda, 2015). The angle of spray determines the swath width and the nozzle height for overlapping. Different spray angle fan nozzles are available in market. The most common spray angles are 65, 73, 80 and 110 degrees (Klein and Kruger, 2011). The recommended spray height at standard nozzle spacing for broad cast spraying is given in table 1.

Table 1. Recommended spray height at standard nozzle spacing for broad cast spraying

Spray angle (degrees)	Spray height (inches)			
	20-inch spacing overlap		30-inch spacing overlap	
	50%	100%	50%	100%
65	22 – 24	NR	NR	NR
73	20 - 22	NR	29 - 31	NR
80	17 – 19	26 – 28	26 – 28	37 – 39
100	10 – 12	15 – 17	14 – 18	25 – 27

NR = Not Recommended (Source: Klein and Kruger, 2011; Grisso *et al.,* 2013; Slocombe and Sharda, 2015).

Nozzle nomenclature

Flat-fan nozzles are usually designated by four to five digit number (Spraying Systems Co.). First number represents the spray angle and remaining numbers signifies the discharge rate at rated pressure. Some additional designations are: BR – brass material, SS – stainless steel, HS – hardened stainless steel, VP – polymer with color coding, VK – ceramic with color coding, VH – hardened stainless steel with color coding, VS – stainless steel with color coding. For example, the 11004VS nozzle made of stainless steel with Visiflo color has 110-degree spray angle and will apply 0.4 gallons per minute (gpm) at the rated pressure of 40 psi. However, some fan nozzles are also identified by LF or LF-R, which reflects the standard and extended-range fan nozzles. First number represents the spray angle followed by a dash and then discharge rate at rated pressure. For example, an LF 80-5R is an extended-range nozzle with an 80-degree spray angle that will apply 0.5 gpm at the rated pressure of 40 psi (Klein and Kruger, 2011).

a) Flood nozzles

Flood nozzles are used to apply the chemicals where clogging is a potential problem and it produces the large droplets at pressure 10 to 25 psi (Figure 1). These nozzles are specially used for soil-incorporated herbicides, pre-emergence without contact herbicides and with spray attachments mounted on tillage implements (Slocombe and Sharda, 2015). The nozzle spacing, orientation and spray release height should be set for 100 percent overlap. The best suited nozzle spacing for flood nozzles is 30-40 inches, at which nozzles produces best spray patterns. Spray pattern is mostly dependent on the pressure regulations as compared to the fan nozzles. However, the spray pattern uniformity will not be same as in the case with the fan nozzles. A special attention should always be taken for nozzle orientation and correct overlap. A combined effect of precision and uniformity of extended-range flat-fan spray nozzles can be obtained by the new Turbo flood nozzles (with pre-orifice and turbulence chambers). Usually these nozzles are recommended for soil applications, particularly when applying tank-mix combinations of fertilizers and herbicides.

Nozzle nomenclature

Spraying Systems Co. designates the flood nozzles as TF or TK. The value following the letters is the flow rate divided by 10 at a rated pressure of 10 psi. For example, TK-SS2 and D-2 are flood nozzles that apply 0.2 gpm at 10 psi (Slocombe and Sharda, 2015).

b) Hollow-Cone Nozzles

The general usage of hollow-cone nozzles (Figure 1) are in application of insecticides or fungicides to field crops. However, with special attention in some cases these nozzles are also used for herbicide application.

c) Full-Cone Nozzles

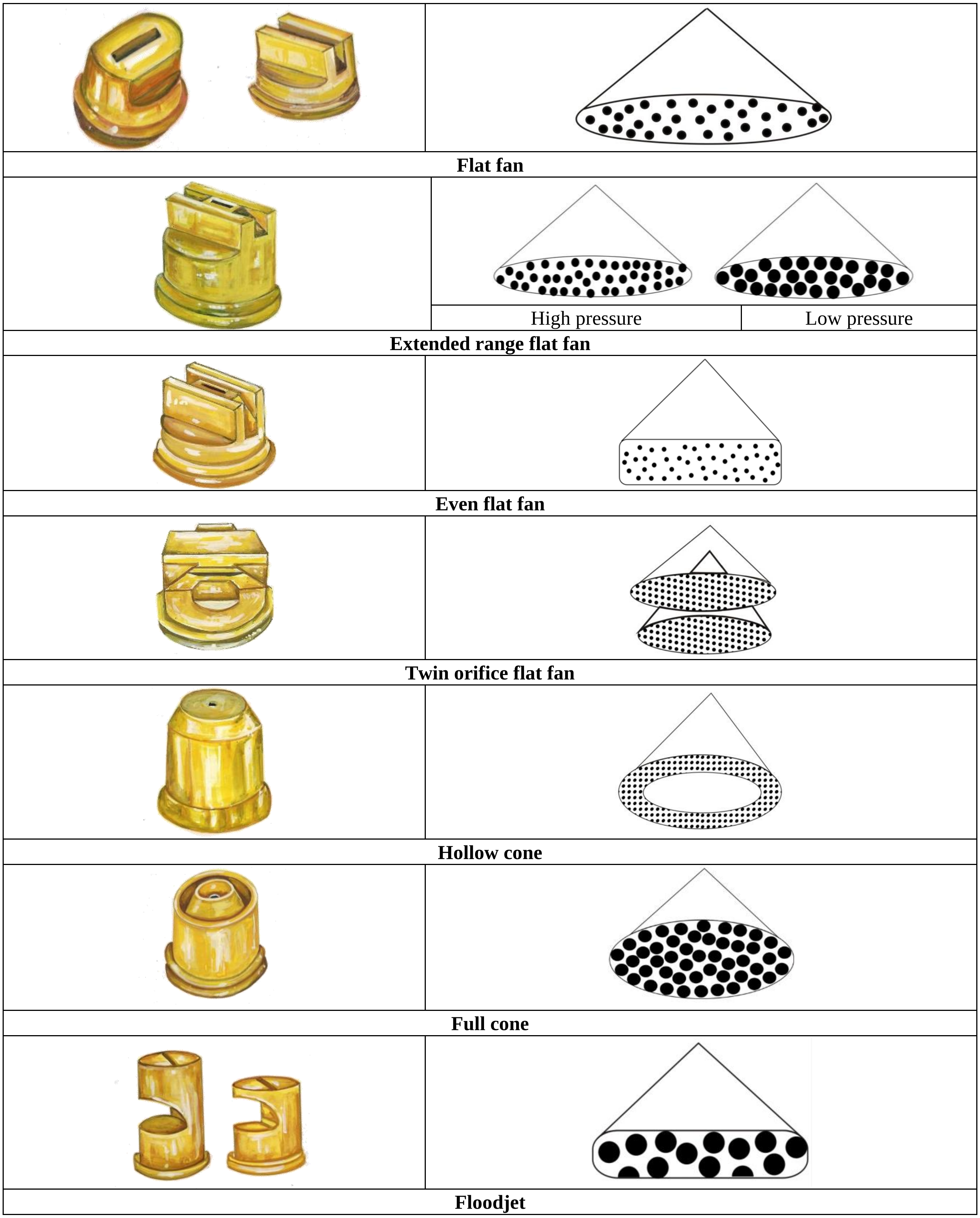
Wide-angle, full-cone nozzles produce large droplets (Figure 1) and are recommended for soil-incorporated herbicides, operate at pressures between 15 psi and 40 psi.

In general, flat fan nozzles are commonly used nozzle in agriculture. But, it cannot be used blindly for all type of herbicide application without considering the operating parameters. This is because of standard flat-fan nozzles are not recommended for banded application of herbicides, due to: these nozzles required overlapping to achieve uniformity. Overlapping within a row crop will cause losing of the spray among the rows or strips. If the nozzles are used without the overlapping the uniformity may not be achieved (Hassen *et al.,* 2013). Moreover, the banded spraying is more economical than broadcast spraying (Nigar *et al.,* 2011) because of its minimized specific targeted area, reduced use of chemical on a specific portion of the field. The same as been reported by the Spraying System Co. (2011) and they suggested using even flat-fan nozzles for banded application (Vern and Elton, 2004). But, the floodjet and other nozzles are used based on the product being used and spray pattern desired (Table 2).

Table 2. Different types of hydraulic nozzle of boom sprayers for herbicide application

Spray pattern	Nozzle type	Common use	Operating pressure (kPa)	Droplet size D (v,0.5) µm	Remarks
Flat fan	Standard	Herbicides	200-400	Fine–medium <144-340	Mainly used for broad scale spraying.
Flat fan	Low pressure	Broad-leaved weed or pre-emergence herbicides	100-250	Medium-coarse 236-403	Large droplets result in less drift. Good control of broad-leaved weeds.
Flat fan	Extended range	Herbicides	100-400	Fine-coarse <144-403	Designed to operate over a large pressure range. Droplet size between standard and low pressure nozzles.
Flat fan	Air induction	Herbicides and fungicides	200-800	Coarse-extremely coarse 341-502	Large droplets result in less drift but have relatively good coverage. Good application on broad leaves.
Flat fan	Air assist (twin fluid)	Herbicides and fungicides	200-600	Medium-coarse 236-403	Ability to change droplet size by changing air pressure.
Flat fan	Twin	Post-emergence herbicides, fungicides	250-400	Fine <144-235	One fan is angled ~30° forwards and the second is angled ~30° back for better leaf coverage.
Flat fan	Wide angle	Banding between rows	150-400	Fine <144-235	Two outlets project either side of the nozzle to produce one wide angle fan
Flat fan	Flooding	High volume pre-emergence herbicides	100-250	Coarse 341-403	Large droplets result in less drift. High volume application.
Even fan	Standard	Banding between rows	150-250	Medium 236-340	Produce a uniform distribution across the fan pattern.
Hollow cone	Whirl	Herbicides	100-400	Fine-coarse <144-403	To apply both pre-emergence and post-emergence herbicides. Large passageway minimizes clogging.
Solid/ Full cone	Full	Pre-emergence herbicides	100-300	Coarse 341-403	Large droplets result in less drift

(Source: Peltzer. 2016. Department of Agriculture and Food, Govt. of Western Australia)



(Source: Grisso *et al.*, 2013; Slocombe and Sharda, 2015)

Fig. 1. Hydraulic nozzles used in low pressure agricultural sprayers

Wang *et al.* (1995) reported that, the nozzle performance is measured by spray uniformity of volumetric distribution. The shape and accuracy of a spray pattern can become faulty over a time and the nozzle should be replaced if the flow exceeds its factory rating by 10% (Sehsah and Baily, 2013). The main aim of the correct nozzle function is to get the least coefficient of variation (CV). New spray nozzles generally have 6% CV, producing a uniform spray distribution when properly overlapped. But the CV may go up to 35 to 57% in worn out and damaged nozzles (Phillips, 2010). Thus, leads to higher discharge rate with erratic spray and non-uniformity of the herbicide application. The wear rate of nozzles is influenced by pesticide formulation, nozzle type, orifice material and capacity and sprayer operating pressure (Sehsah and Baily, 2013). The most common orifice materials used in nozzle manufacturing are brass, nylon, stainless steel, hardened stainless steel, tungsten carbide, thermoplastic and ceramic (Klein and Kruger, 2011; Grisso *et al.,* 2013). Most commonly in boom sprayers, the brass tip nozzles were used for many years. But brass is very susceptible to wear easily. The Manufacturers recommend brass nozzles should be replaced for every one-to-two years. The farmers who were using this type of nozzles for a longer period were affected negatively (Beard, 1999). Hence, it is better to measure the life of nozzle in hours of use rather than in years (Table 3) and change the nozzles accordingly. Nozzles made from hard materials cost more initially, but the cost will be recovered from their long lasting properties (Slocombe and Sharda, 2015). To minimize the mechanical damage to spray nozzles clean their tip with soft brush or blown by compressed air.

Table 3. Different materials used for nozzles manufacturing

Tip material	Remarks	Nozzle life
Ceramic	Superior wear life and are highly resistant to abrasive and corrosive chemicals	20-100 times the life of brass
Hardened - stainless steel	Very good wear life and good durability and resistance to chemicals	8-15 times the life of brass
Stainless steel	Good wear life, excellent resistance to chemicals, and a durable orifice	4-6 times the life of brass
Polymer (plastic)	Good wear life and resistance to chemicals, but the orifice can be damaged if not cleaned properly	2-3 times the life of brass
Brass	Poor wear life and are susceptible to corrosion	1 wear life

(Source: Beard, 1999; Phillips, 2010)

Nozzle influence on droplet size and spray drift

Droplet size is the diameter of an individual spray droplet and measured in microns (micrometers, μ). It is one of the most influential factors in spraying system, which affects crop coverage, biological efficacy of the applied herbicide and spray drift risk (Bird *et al.,* 1996; Ozkan *et al.,* 1997; Carlsen *et al.,* 2006; Nuyttens *et al.,* 2007). Applicators must understand the principles of droplet size to select nozzles that provide adequate coverage, yet have sufficient drift reduction properties (Pringnitz *et al.,* 2001). Nozzles have a wide range of droplet sizes, which are usually summarized through statistically. In droplet size terminology, Dv0.1 means that the volume of 10% of the droplets is smaller than the size indicated on the nozzle. Spray patterns contains range of non-uniform droplet sizes. To indicate a particular average droplet diameters within a spray VMD is been used. The volume median diameter (VMD), also known as Dv5.0, indicates the percentage difference between smaller and larger droplets (Phillips, 2010; Grisso *et al.,* 2013). A typical standard for spray nozzle droplet size and measurement classification was devised by the British Crop Protection Council (BCPC) and American Society of Agricultural Engineers (Table.4) (McCloskey *et al.,* 2012; Grisso *et al.,* 2013; Slocombe and Sharda, 2015). This system will be very useful in comparison of droplet sizes between the various nozzle size, operating condition and manufacturer. A trend been practiced by pesticide manufacturers to mention the droplet size categories on pesticide labels to specify the optimum droplet size.

Table 4. Droplet size distribution classification (ASABE Standard S572.1)

Droplet category	Symbol	Color code	VMD range (μ)*
Extremely fine	XF	Purple	< 60
Very fine	VF	Red	61-144
Fine	F	Orange	144-235
Medium	M	Yellow	236-340
Coarse	C	Blue	341-403
Very coarse	VC	Green	404-502
Extremely coarse	XC	White	503-665
Ultra coarse	UC	Black	> 665

*Estimated from sample reference graph in ASABE/ANSI/ASAE Standard S572.1 (Source: McCloskey et al., 2012)

Droplet size smaller than 150 microns poses most serious drift hazard problems and the droplet size 200 microns and larger in size are less likely to be get drifted. Spray droplets smaller than 100 microns gain horizontal trajectory within a short time and get evaporated rapidly. The herbicide in these droplets becomes very small aerosols, which move into the atmosphere and will not fall out until and unless picked by any external media (Slocombe and Sharda, 2015). Further, the spray particles less than 50 microns may retain suspended in the air indefinitely or until they evaporate. Hence, this should be avoided because there is no way to control deposition of very small droplets. Larger droplets retain their momentum for longer period, poses resistance to evaporation to a much greater degree than smaller droplets due to their larger volume (Nuyttens *et al.*, 2009). Thus, the droplets larger than 150 microns are less prone to be get displaced by wind, which can cause drift. Moreover, the size distribution of droplets in agricultural sprays is not homogeneous and depends on the position within the spray nozzle (Chapple and Hall, 1993; Butler Ellis *et al.*, 1997). In conventional boom sprayer's size of droplets are easily changed by changing the nozzle type (Zhu *et al.*, 2004). Further, increasing the spray liquid pressure with most nozzle designs not only results in a finer spray but also increases the velocity of droplets leaving the region of spray formation (Farooq *et al.*, 2001). However, in general, increased initial downward droplet velocity decreases the drift distances (Ozkan, 1998). But, the tendency of drift tends to increase as the spray becomes finer. Consequently, further increase in pressure may not necessary to increase drift, instead it is reduced in some nozzles (Miller and Smith 1997). It is because of the dominance of droplet velocity. The spray drift are not only affected by the operational parameters, they are also affected by environmental factors and the sprayer being used. The factors responsible for spray drift are enlisted below:

a. Environmental factors – wind speed and direction, temperature and relative humidity.

b. Spray characteristics – formulation of the chemical being applied, additives added to the chemical, spray droplet size and evaporation.

c. Equipment and application factors – nozzle type and size, operating pressure, and the height of the spray boom.

A necessary care should be taken to avoid the drift. Some useful tips to be considered to reduce the spray drift are:

- ✓ Increase the droplet size by reducing the pressure. Under reduced flow rate condition, larger nozzles should be used to stay within application rate.
- ✓ Use nozzles of larger capacity and drift reducing nozzles.
- ✓ Lower boom height to reduce drift with proper overlapping for spray coverage.
- ✓ Adjustment of application methodology according to the weather conditions.

Hence, proper selection of the nozzle as well the operational parameters are most important to obtain the effective herbicide application system.

Some researchers recommend selecting the nozzles based on the product being used (Hartzle and Hanna, 2016). It is because of the product being used is a primary factor, which determines the appropriate spray nozzle. In general, most of the herbicide manufacturers mention nozzle type or droplet size classification in their label (Table 5). The recommended nozzle in the label should produce a range of droplet size, while applying the product. Additionally, TeeJet technologies suggest in their user guide manual to consider droplet size as a key factor for nozzle selection to apply different types of herbicides. They are: nozzles with finer droplets are used for post-emergence contact applications, because of its excellent coverage on leaf surfaces; nozzles with mid-range droplets are used for contact and systemic herbicides; nozzles with coarser droplets are used for systemic and pre-emergence herbicides (soil application).

Table 5. Label recommendations for nozzle type, droplet size and carrier volume (GPA).

Product	Nozzle type	Droplet Size	GPA
Liberty (glufosinate)	Flat fan	NS	>10
Cobra (lactofen)	Flat fan, hollow cone	NS	10-20
Reflex (fomesafen)	Flat fan, hollow cone	NS	10-20
Ultra Blazer (acifluorfen)	Flat fan, hollow cone	Medium	10-20
Armezon (topramezone)	NS	NS	>10
Callisto (mesotrione)	Flat fan	Medium to coarse	10-20
Laudis (tembotrione)	NS	Medium to coarse	10-20
Roundup PowerMax (glyphosate)	NS	Use nozzles that avoid generating a fine mist	3-40
Enlist Duo (2,4D + glyphosate)	See label	NS	10-15
2,4D LVE	NS	Avoid nozzles that produce small droplets that may drift	>3
Clarity (dicamba)	NS	Coarse	3-50

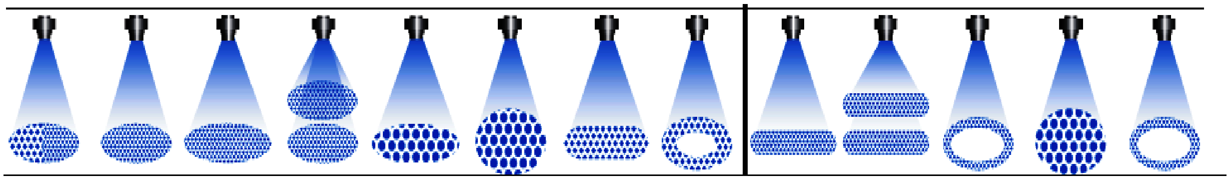
NS: indicates nozzle type or droplet size was not specified on label. (Source: Hartzle and Hanna, 2016)

A stepwise procedure is proposed by the different researchers to select the appropriate nozzle based on the detailed study of factors responsible for the effective herbicide application (Klein and Kruger, 2011; McCloskey *et al.*, 2012; Grisso *et al.*, 2013; Slocombe and Sharda, 2015). The procedure is as follows:

Step 1: Consult the label: The pesticide label specify the important information like, application rates, condition needed for herbicide application, controllable weeds, recommended spray volume for the chemical, droplet classification, nozzle type, nozzle spacing and height adjustments and other useful information. If the label has not specified the information about the nozzle, then the suitable nozzle can be selected based on the guidelines given in table 6.

Step 2: Select operating conditions: select suitable speed of operation, desired nozzle spacing, spray volume and operating pressure. The spacing of the nozzles are decided based on the spray angle, nozzle height and spray overlap requirement. However, 30 inch space preferred for most broadcast applications and it can be changed if desired. If the label does not recommend nozzle spacing or spray volume, then the standard recommendations should be followed.

Table 6. Nozzle guide for spraying



	Broadcast spraying								Band and Direct spraying				
	Extended range flat fan	**Standard flat fan**	**Drift guard flat fan**	**Twin flat fan**	**Turbo flood wide angle**	**Full cone**	**Flood nozzle wide angle**	**Rain drop hollow cone**	**Even flat fan**	**Twin even flat fan**	**Hollow cone**	**Full cone**	**Disc and core cone**
							Herbicides						
Soil in-corporated	Good	-	Very good	-	Very good	Very good	Good	Good	-	-	-	-	-
Pre-emergence	Very good (on low pressure)	Good	Very good	-	Very good	Very good	-	Good	Very good	Good	-	Good	-
Post-emergence (Contact)	Good	Good	-	Very good	-	-	-	-	Good	Very good	Very good	-	-
Post-emergence (Systemic)	Very good (on low pressure)	Good	Very good	-	Very good	-	-	Good	Very good	Good	-	-	-

(Source: Slocombe and Sharda, 2015)

Step 3: Calculate required nozzle discharge: To select specific orifice size, spray volume, nozzle spacing, and travel speed the discharge rate needs to be calculated: The required nozzle discharge rate for a spraying system is used to calculate as:

$$\text{Nozzle output (L/min/nozzle)} = \frac{\text{Spray application rate (L/ha) x travel speed (km/h) x nozzle spacing (m)}}{600}$$

Step 4: Consult a nozzle catalog: Nozzle catalog should be consulted to find a specific nozzle number or size. Using the nozzle type selected from the application guide (Table 5), review the specification of these nozzles in the discharge-capacity column to select a nozzle that gives a desired droplet classification at low pressure, which allows a range for fine-tuning. Generally, the greater the operating pressure, then droplets will be smaller and they increase drift potential. Conversely, larger orifices produce larger droplets. If the discharge rate is not found in the catalogs, then operating pressure should be calculated using known catalog conditions:

$$\text{Pressure 1} = \frac{(\text{LPM 1})}{(\text{LPM 2})} \times \text{Pressure 2}$$

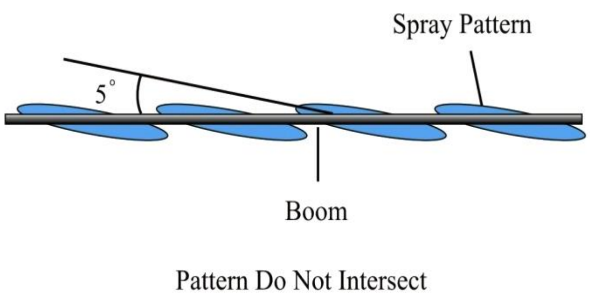
Where: 1 = the desired condition; 2 = the known catalog specifications.

Avoid using the higher pressure, as it may cause the spray drift and put strain on sprayer components. Simultaneously, avoid pressures less than the recommended minimum pressure, because spray patterns begin to distort and cause poor spray uniformity.

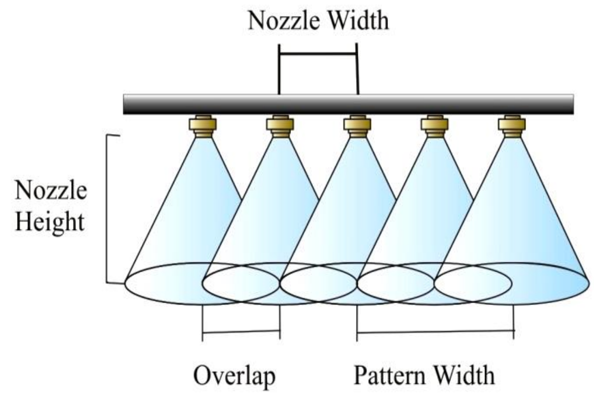
Step 5: Calibrate the sprayer: Sprayer needs to be calibrated once the nozzle has been selected. Use the nozzle catalog to initially set up the sprayer and then use the "ounce" calibration method to evaluate and adjust the sprayer for accurate application (Slocombe, 2014; Slocombe and Sharda, 2015).

Nozzle set-up on spray boom

A special care should be taken while setting the nozzles on the boom. Nozzles of different materials, types, spray angles or spray volumes should not get mixed on the same spray boom. The mixture of nozzles will produce uneven distribution of spray. Fan nozzles produce a flat, oval spray pattern with tapered edges. Because of tapered or reduced volumes in the outer edges of the flat fan spray pattern, nozzles must be carefully aligned to prevent interference and adjust the proper height, so that adjacent patterns along the boom get overlapped for uniform coverage. Uniform pattern is achieved when the overlap is 50 percent to 100 percent of the nozzle spacing (Figure 2). Care should be taken, to select the different nozzles for different types of herbicide application.



a. Flat-fan nozzles angled 5 degrees from the boom



b. Nozzle overlap of 100 percent

(Source: Grisso *et al.,* 2013; Slocombe and Sharda, 2015)

Figure 2. Orientation of the nozzle on a boom to obtain a spray overlap

In most of the cases 20 inch nozzle spacing is in the boom, but, the 30 inch nozzle spacing having more advantageous. If a boom built with 20 inch nozzle spacing, then it should be configure with 30 20 inch nozzle spacing during rebuild. If an 80-degree nozzle spaced at 20 inches is replaced with a 110-degree nozzle spaced at 30 inches, these advantages may be seen (Grisso *et al.,* 2013; Slocombe and Sharda, 2015): boom height remains the same; orifice size is increased by one-third; drift potential is reduced; fewer nozzles to purchase and maintain; potential to increase screen size (less clogging); nozzle spacing matches 30-inch rows during field spraying.

CONCLUSION

Understanding the function of spray nozzle and spray pattern produced in agricultural herbicide spraying equipment is most important to control the weeds effectively. In general, for post-emergence application of herbicides flat fan nozzle, and for pre-emergence soil application floodjet nozzles are recommended. Nozzles made by ceramic/stainless steel/polymer material are preferred over brass nozzles. The selected nozzle is not only efficient in controlling the weeds but it also helps to save the chemicals, water and operational time, reduces the drift risk hazards, increases nozzle life and ensures economical spraying operation

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