Best Management Practices for Herbicide Application Technology

Tom Wolf
Agriculture and Agri- Food Canada, Saskatoon Research Centre, 107 Science Place, Saskatoon, SK S7N 0X2.
E-Mail: tom.wolf@agr.gc.ca

Summary

Effective, Economical, and Environmentally Friendly – the three Es of spray application. In practical terms, the three Es mean the pesticide has to do a good job controlling the pest while allowing the operation to be fast, inexpensive, and low-drift. Viewed individually, or in groups of two, each of these goals is achievable. But meeting all three together requires compromise. Success relies less on a herbicide's knockout punch, and more on integrating application with agronomic considerations that help herbicides do their job. For example, perhaps timely application is more important than perfect control; this may mean that coarser sprays, though possibly less effective, provide an overall advantage if they allow sprays to be applied at the right time. Any application approach has to be reconciled with continuing trends in the equipment, such as the use of heavier, faster machines and the need to cover more area in less time. All of these have implications for nozzle selection, because changes in boom height or travel speed affect nozzle performance. A better understanding of these three factors is necessary so that appropriate nozzle, sprayer, or water volume selections can be made. Inevitably, compliance with spray quality or wind speed restrictions on product labels will require applicators to apply coarser sprays no matter what type of sprayer they use. Selecting the correct nozzles and using them properly will be the key ingredients to success.

Introduction

Spray application has changed more in the past ten years than in the previous fifty. Not only are we spraying a greater diversity of crops with more types of crop protection agents and larger, more efficient machines, we're also under the scrutiny of a public that is increasingly interested in what they think are sound agricultural practices. As a result, regulations that protect public spaces, especially air and water, have been emerging and will continue to force change in the industry[7].

Herbicides should technically only be used when cultural management practices can't provide effective weed control. And when we do use them, the need for herbicide effectiveness has to be balanced with getting the job done quickly and making sure we don't harm non-target areas[4]. Given these constraints, what are the best management practices for producers in these times? This article will examine this question in two parts. First, I review the implications of faster travel speeds that seem to come with most new sprayer purchases. Second, I discuss approaches to nozzle selection and operation that ensure that weed control, operation efficiency, and environmental objectives (the three Es) can be met.

Travel Speed Trade-offs

One of the most challenging aspects of new sprayer technology is the higher travel speeds that these machines are capable of. Marketing of these sprayers often uses productivity as a key justification for the often enormous cost of these units. For example: "More acres or hectares per hour results in more profits!" But in practice, fast travel speeds result in changes, some of which are difficult to manage. They are:

- *Larger nozzles.* Keeping volumes the same require that larger flow rates be used. This pushes spray quality coarser and complicates nozzle selection.
- *More horizontal trajectory for larger droplets.* All droplets will initially be moving forward with the boom. Soon, only the larger ones keep that trajectory. The smaller ones lose their inertia and become prone to displacement by wind[11].

- *More turbulence, creating drift.* Boom, spray pattern, and tractor units impart significant aerodynamic effects that can reduce spray deposition. Air moving past the edges of spray patterns creates turbulent vortices that pull fine droplets from their flight path. These swirling vortices of fine droplets hang behind the sprayer, vulnerable to drift[15].
- *More variation in spray pressure.* For sprayers with automatic rate controllers, pressure is linked to travel speed with a square root relationship. That means for every doubling of travel speed, pressure must increase four times to maintain a constant application volume. At higher average travel speeds, necessary variations in speed can result in dramatic changes in spray pressure that either exceed the nozzle's capabilities (at low speeds) or the pump's capacity (at high speeds).

  Assume that a given nozzle has a 60 psi (415 kPa) operating range, i.e., it develops an acceptable pattern at 30 psi (205 kPa) and can be operated to 90 psi (620 kPa). This pressure range allows a travel speed variation of about 25% from the average (Table 1). At a speed of 8 mph (13 km/h), the sprayer can slow down to 6 mph (10 km/h) and speed up to 10 mph (16 km/h) without exceeding the nozzle pressure range.

  However, the picture changes at an average speed of 16 mph (26 km/h). Now, the minimum speed becomes 12 mph 19 km/h), hardly slow enough for some rough terrain or tight turns. Slowing down further means sub-optimal pressures for these nozzles resulting in some possible reductions in herbicide performance because of poor spray patterns. The opposite problem occurs with units capable of more than 20 mph (32 km/h). Accelerating to those speeds from 16 mph will require pump pressures that may not be possible, or can result in fine, drift-prone sprays for some nozzles.

  Table 1: Changes in travel speed range for two nozzles

Nozzle	***Spray Volume***		***Travel Speed***		***Spray Pressure***	
Size[§]	*US gal/acre*	*L/ha*	*mph*	*km/h*	*psi*	*kPa*
0.15	7	65	6.0	9.7	34	235
			8.0	12.9	61	420
			10.0	16.1	96	660
0.3	7	65	12.0	19.3	34	235
			16.0	25.8	61	420
			20.0	32.2	96	660

§ Nominal flow rates stamped on nozzles are given in US gallons per minute of water at 40 psi (275 kPa) spray pressure

- *Greater damage in wheel tracks, more dust.* Faster speeds mean faster wheel revolution. For a sprayer wheel, this can mean not only greater soil disturbance in the track, but also significant displacement of air behind it. Both factors, added to by the weight of larger sprayers, result in a greater likelihood of wheel tracks in which weed control is reduced. Addition of higher flow nozzles, preferably well back of the wheel, can overcome part of that problem. Dust can be a contributing factor to reduced herbicide performance, especially for water-soluble herbicides that can bind strongly to soil particles (glyphosate and diquat are the best-known examples).
- *Higher booms.* Faster speeds result in less time to respond to boom movements resulting from uneven terrain. Many operators find it necessary to raise the boom to prevent contact with the ground. Too high a boom will increase drift potential, decrease canopy penetration, and lower the effectiveness of any angled nozzles (an automatic boom height controller would help in this situation).

Travel speed is used to justify higher productivity, which in turn justifies higher capital costs. However, boom width may be a more sensible means to increase productivity with fewer disadvantages. Changing from a 90 foot

(27 m) to a 120 foot (37 m) boom increases capacity by 33% at reasonable costs. Wider booms weigh more, require higher pump capacity, and may need to be operated at a higher height but these problems can be managed with existing technologies such as automatic boom height controls.

Buffer Zones

In Canada, the Pest Management Regulatory Agency (PMRA), an agency operating within the federal Department of Health, is responsible for administering the Pest Control Products Act (PCPA) and developing regulations that govern pesticide use. Part of their mandate is to ensure that off-target impacts of pesticides are minimal and that sensitive organisms are exposed only to acceptable risks. Efforts to protect water from pesticide contamination have resulted in the prescription of buffer zones on labels. Buffer zones are defined as setback distances from the downwind edge of the spray swath to the upwind edge of the sensitive habitat[7]. The size of the buffer zone depends on the sensitivity of non-target organisms to the pesticide, as well as the weather conditions and sprayer setup that were assumed during the risk assessment.

Buffer Zones operate on the premise that the further the source of the pollutant is from the sensitive area, the less pollution there will be. Similarly, the smaller the source is, the lower the pollution[14]. The latter can be used as a tool to reduce buffer zone requirements. For example, if applicators use coarser, less drift-prone sprays, lower boom, or spray under lower wind conditions, buffer zones can be reduced (Figure 1). Details on how such a system will work have been developed by the PMRA, but have yet to be finalized.

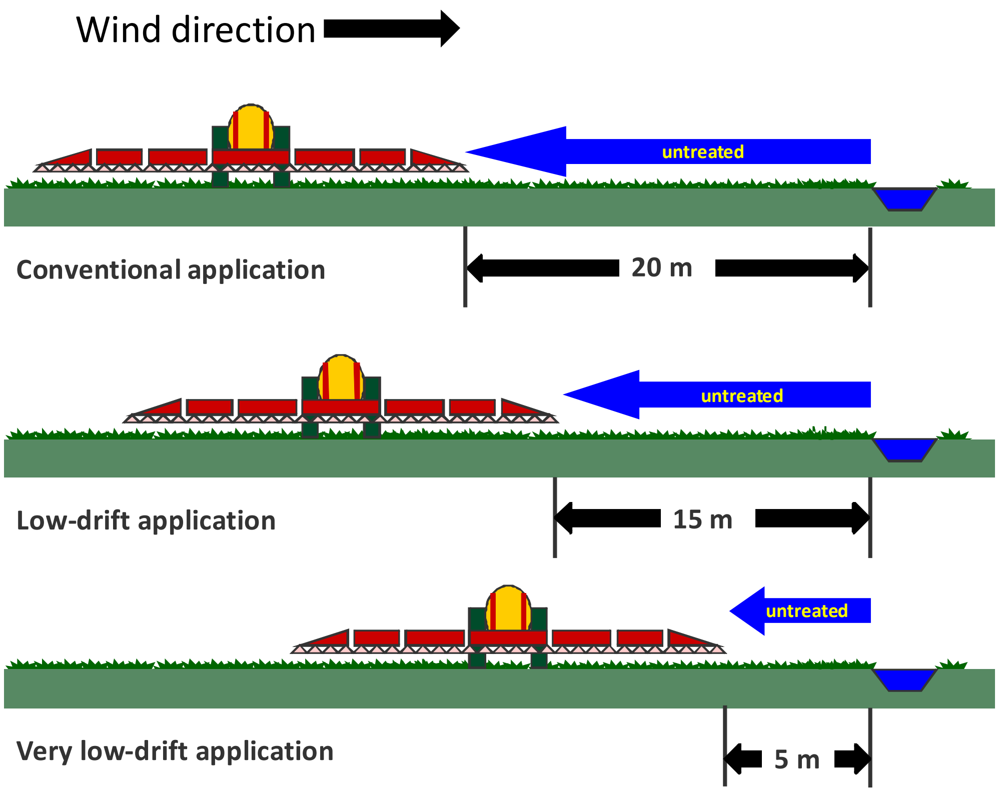

Figure 1: Buffer zones, and how they may change with different application methods

Best Practices

Earlier, we spoke about the three Es of spraying: Efficacy, Economy, and Environment. Let's now focus on the role of nozzles in the three Es, and add some practical advice. Best spraying practices can be summarized in four main rules: (a) choosing the best nozzle for one's needs, (b) matching water volume to spray quality and crop canopy, (c) knowing and using the right pressure for your nozzle, and (d) ensuring good patterns.

A. Choosing the best nozzle type for your needs

Despite the large selection of individual nozzle manufacturers and models in the marketplace, the vast majority of these can be reduced down to only four unique nozzle types: conventional flat fan, pre-orifice flat fan, low-pressure air-induction, and high pressure air-induction. The selection of the most suitable nozzle for an individual producer, or cropping scenario, is the first step in best management practice.

Conventional Flat Fan

This most enduring of nozzles has been the mainstay of the spraying business for generations, and forms the basis of almost all improved technologies since then. An elliptical orifice converts a pressurized liquid into a tapered flat fan. Droplets ranging in diameter from 5 to over 1000 µm (1 µm = 0.001 mm) are produced[3]. The relative proportion of the total spray volume in each size category depends on the orifice dimension (narrower shape results in wider fan angles and finer sprays), size (larger orifices produce coarser sprays), pressure (higher pressures produce finer sprays), and characteristics of the liquid being atomized (most surfactants produce slightly finer sprays and most oils produce somewhat coarser sprays through these nozzles, but exceptions to this rule are many and varied[9]. Key advantages of this nozzle are its reliability and proven performance under many conditions, and the fact that it allows the lowest pressures and water volumes due to its generally finer spray quality compared to other nozzles [as low as 20 psi (140 kPa) and 3 US gpa (28 L/ha)]. Its key disadvantages are its propensity for producing large amounts of damaging spray drift, a characteristic that also limits its upper recommended pressure to about 60 psi (415 kPa).

Pre-Orifice

A variation of the conventional flat fan, the pre-orifice nozzle uses an internal pressure drop to achieve a coarser spray. A circular pre-orifice meters the spray and provides the pressure reading to the operator. An elliptical exit-orifice has a slightly higher flow-rate, resulting in a pressure drop. Internal nozzle design permits a good spray pattern to be maintained despite the actual lower operating pressure of the nozzle. Key advantages of the nozzle are drift reduction of approximately 50%, depending on the nozzle (can be as high as 90% for some designs), and, due to the mostly modest changes in spray quality, reliable efficacy at lower volumes (as low as 5 US gpa or 47 L/ha). Other benefits are reasonably wide pressure ranges and a good fit for grassy weeds when pressures are optimized to prevent very coarse sprays (as defined by the American Society of Agricultural and Biological Engineers, ASABE). Among its disadvantages is the need for higher minimum pressures to prevent a collapse of the spray pattern to unacceptably narrow angles. Examples are the TeeJet DG, Turbo TeeJet, Hypro LD, Hypro Guardian, and Wilger SR, MR, and DR nozzles. Within the Wilger product line, the SR nozzles are the finest, comparable to most other pre-orifice products, and the DR nozzles are the coarsest, with spray quality comparable to high pressure air-induced nozzles.

Air Induced

Air-induced nozzles are a variation of the pre-orifice nozzle with a novel addition, an internal venturi. The venturi, a trumpet-shaped channel, draws air into the nozzle body, where it mixes with the spray liquid. The result is a spray that contains some of this air, much of it incorporated into the droplets themselves. Two unique features make these nozzles attractive: first, they have a unique ability to reduce the volumetric proportion of fine, drift-prone droplets, resulting in very low-drift sprays. Second, the incorporation of air into the remaining droplets alters their behaviour, improving retention on spray targets relative to their non-air-amended counterparts[10]. In essence, the result is a low drift spray that behaves like a conventional spray. However, users must be aware of the limitations of the technology: fewer fine droplets and more large droplets results in fewer overall droplet numbers. This can affect coverage in some situations, especially with low water volumes. There are two types of air-induced nozzles to choose from: the low pressure and high pressure air-induced nozzles.

Low-Pressure These popular nozzles include the Air Bubble Jet, the Greenleaf AirMix, the TeeJet AIXR, the Lechler IDK and Hardi MiniDrift (same nozzle), and the Hypro ULD. Their key advantages are their ability to reduce drift about 70%, and the ability to use them at near "normal" pressures of about 40 to 60 psi (275 – 415 kPa). As a result, they have wider effective pressure ranges than their higher pressure counterparts (see below). These nozzles, when used at correct pressures and application volumes, are good general purpose nozzles[12, 13]. Disadvantages are the somewhat higher pressure and water volume requirements compared to conventional nozzles, with minimum limits for good efficacy of about 40 psi (275 kPa) and 5 gpa (47 L/ha), respectively, for the pre-seed herbicide glyphosate. Sprays into a canopy, or with other products, often require more water (see below)[1].

High Pressure These nozzles provide superior drift protection, and include many of the earliest features that were introduced about 10 years ago. Their main advantage is improved drift reduction, as high as 70 to 90% compared to conventional flat-fan nozzles. They've shown very good performance with many herbicides on broadleaf weeds[12], and also with fungicides[8]. The key operational guidelines are high pressure, with a requirement of least 60 psi (415 kPa) to work well, and higher water volume, with at least 7 US gpa (65 L/ha), especially for grassy weeds. Examples are the TeeJet Air Induction, Lechler ID, Albuz AVI. The Greenleaf TurboDrop XL falls in between the high and low pressure categories, with a wide pressure- and spray-quality range. Some nozzles are not recommended for use in western Canada. For example the TeeJet TTI produces sprays that are categorized as ASABE Extremely Coarse, being limited to industrial or turf uses where better driftcontrol is required and much higher water volumes compensate.

Making the right choice

Operators need to identify their priorities before choosing a nozzle: Better drift control? Best pressure range? Very low water volumes? The nozzle choice is fundamental to meeting these objectives. Operators will likely need to change nozzles on their sprayer as their objectives change.

B. Matching water volume to spray quality and crop canopy

The coarser the spray quality, the higher the water volume must be[5]. There are two main reasons for this. Firstly, there must be enough droplets per square centimetre to hit the target. This is most critical for pre-seed burnoff, where weeds are small, and where low-volume, coarse sprays may miss weeds entirely. Secondly, there must be sufficient coverage on the target for the pesticide to do its job. This is most important for contact herbicides such as bromoxynil, glufosinate, and diquat, and for insecticides and protective fungicides[13]. It is also important for grassy weeds, most of which have difficulty retaining the larger droplets. For in-crop herbicides, minimum recommended volumes are 5 to 7 US gpa (47 to 65 L/ha), for fungicides minimum volumes are 10 to 12 gpa (95 to 110 L/ha). Regardless of nozzle, the taller and leafier the crop canopy, the more water is required to penetrate it in the absence of air assist[2]. Slower travel speeds also benefit canopy penetration[11].

C. Knowing and using the right pressure for the nozzle

Even a good nozzle won't work well at the wrong pressure. Air-induced nozzles and some pre-orifice nozzles require higher pressures to operate properly. The most common reason for performance complaints is from the use of pressures that are too low for the proper functioning of low drift nozzles, resulting in poor spray distribution between nozzles (refer to section D. Ensuring Good Patterns). If a sprayer cannot produce sufficiently high pressures, nozzles requiring higher pressures should not be used. In general, optimum pressures for the various nozzle types are: Conventional, 20 to 50 psi (140 to 345 kPa), pre-orifice, 30 to 60 psi (205 to 415 kPa), low-pressure air-induced, 40 to 70 psi (275 to 480 kPa) or more, high pressure air-induced, 60 to 90 psi (415 to 620 kPa) or more. Higher pressures increase drift potential, but less so for pre-orifice and air-induced nozzles. Air-induced nozzles can be used at higher pressures than stated, with very little penalty in terms of drift. If wide pressure ranges are needed to accommodate variations in travel speed, it is best to select nozzles that operate well at lower pressures (Table 2).

Table 2: Percent change in travel speed resulting from a 50 psi (345 kPa) change in operating pressure, at low, medium, and high average pressures. Application volume is 7 US gpa (65 L/ha)

Nozzle Type	***Nozzle Size***[§]	***Pressure psi***	***Pressure kPa***	***Speed mph***	***Speed km/h***	***Percent Speed Range***
Low Pressure	0.4	20	140	12.2	19.6	61
		70	480	22.8	36.7	
Medium Pressure	0.3	30	205	11.2	18.0	48
		80	550	18.3	29.5	
High Pressure	0.3	50	345	14.4	23.2	34
		100	690	20.4	32.8	

§ Nominal flow rates stamped on nozzles are given in US gallons per minute of water at 40 psi (275 kPa) spray pressure

D. Ensuring good patterns

Whereas finer sprays from conventional nozzles can re-distribute themselves with wind or turbulence, thus covering up poor patterns, the coarser droplets produced by low-drift sprays will go where they're pointed. Therefore, there is only one chance to get uniform coverage across the boom. For coarse sprays, a good guideline is to achieve a nozzle pattern width at the target height that is twice the nozzle spacing, resulting in 100% overlap for every nozzle. This is accomplished by selecting wider angle nozzles, increasing pressure, or adjusting boom height. By increasing overlap, the coarsest droplets at the pattern edge are mixed in with the more abundant, finer droplets found in the middle of a pattern.

Application Technology in Context

Spray application is often seen as an independent process, with little relationship to other practices. This is an oversimplification which can be best illustrated with the following example: Let's assume that an applicator wants to improve weed control, or reduce herbicide rates. Often, the spray operation is considered critical, either through finer droplets, lower carrier volumes, adjuvants, etc. But in practice, the ability to improve herbicide performance depends more on agronomic factors that favour vigorous crop development, such as the relative rate of emergence of the weed compared to the crop or the competitive ability of the crop or cultivar, perhaps as dictated by seeding methods. Even when reliance is placed on the herbicide, its performance likely depends more on the inherent susceptibility of the weed to the herbicide, the weed staging at the time of spraying, and the weather conditions that surround the application window than on the nozzle being used. This not to suggest that spray method is not important, but perhaps that its role is not to over-ride, rather to supplement, other factors. Greater utility and efficacy may be gained from a herbicide by utilizing low drift technology, simply from the opportunity it provides the applicator to take advantage of better crop or pest staging.

Drift Control an Agronomic Tool?

The western Canadian experience has been that coarse sprays offer significant value to producers, either due to the wider weather window of opportunity for conducting a spray application, or the improved drift control near sensitive areas. We have learned to use them in ways that maintain good efficacy over a broad range of conditions. Low-drift sprays can therefore be viewed as means to achieve timely removal of pests, a basic agronomic management goal. Reducing the incidence of spray drift additionally supports greater diversification into rotational crops that have agronomic benefit, as well as precision application of non-selective sprays between rows where selective herbicide technology is unavailable.

Future of Application Technology

Agricultural production is on a long-term path that will continue to demand greater efficiencies and attention to detail by growers and advisors. Ongoing research activities help identify areas where management efforts give the greatest return, and then to focus on these. In the area of spray technology, high returns are achieved when technology facilitates timely and efficient application that reliably protects both yield potential and environmental health. There are several fronts in which we will continue to see improvements over the next decade. The most important of these is improved control over droplet size and application rate. Variable rate and variable spray quality technologies already exist in the form of twin fluid atomizers, pulse-width modulated flow controls, and variable orifice technologies, but none of these are commonplace. Perhaps a reason is the lack of research data that provides compelling spray quality or rate prescriptions for specific cropping scenarios[6]. Where economic drivers are insufficient to cause change, regulatory pressures may require it. For example, some European areas are utilizing Geographic Information Systems (GIS) to identify environmentally sensitive areas where limits on application rates or spray qualities can be placed. Adoption of control systems that make compliance with these restrictions possible for the applicator will depend on the state's willingness to enforce these ideas.

Progress in another area of research involving site specific application remains slow. The ability for equipment to sense the presence of weeds, either by shape, colour, or hyperspectral characteristics, is possible but limited. Such technologies will remain uneconomical in the short term as long as our most common herbicides are inexpensive, selective, and effective. However, the days when we make uniform broadcast applications for pests that are spatially aggregated are almost certainly numbered.

References

1. Armstrong-Cho, C., G. Chongo, T. Wolf, Y. Gan, T. Hogg, E. Johnson, and S. Banniza. 2008. The effect of carrier volume on ascochyta blight (Ascochyta rabiei) control in chickpea. Crop Protection 27 1020-1030.
2. Bache D. H. 1985. Prediction and analysis of spray penetration into plant canopies. In: Southcombe, E.S.E. (Ed.), Application and Biology, BCPC Monograph No. 28. BCPC Publications, Croydon, pp. 183-190.
3. Chapple, A. C. and F. R. Hall. 1993. A description of the droplet spectra produced by a flat-fan nozzle. Atomization and Sprays 3:477-488.
4. Hislop, E. C. 1987. Can we define and achieve optimum pesticide deposits? Aspects Appl. Biol. 14:153-172.
5. Howarth, G.M., F. A. Holm, and T. M. Wolf. 2004. Interaction of droplet size and carrier volume for coverage and efficacy. Aspects of Applied Biology 71:231-238.
6. Knoche, M. 1994. Effect of droplet size and carrier volume on performance of foliage-applied herbicides. Crop Protection 13:163-178.
7. Kuchnicki, T.C., A. E. Clarke, D. L. François, J. D. Glaser, V. A. Hodge, and T. M. Wolf. 2004. Use of buffer zones for the protection of environmental habitats in Canada. Aspects of Applied Biology 71:133-140.
8. Kutcher, H. R. and T. M. Wolf. 2006. Low-drift fungicide application technology for sclerotinia stem rot control in canola. Crop Protection 25:640-646.
9. Lefebvre, A. H. 1989. Atomization and Sprays. Hemisphere Publishing Corporation, New York, 421 pp.
10. Miller, P.C.H., C. J. Mawer, and C. R. Merritt. 1989. Wind tunnel studies of the spray drift from two types of agricultural spray nozzle. Aspects of Applied Biology 21:237-238.
11. Nordbo, E., K. Kristensen, and E. Kirknel. 1993. Effects of wind direction, wind speed and travel speed on spray deposition. Pesticide Science 38:33-41.
12. Wolf, T. M. 2000. Low-drift nozzle efficacy with respect to herbicide mode of action. Aspects of Applied Biology 57:29-34.
13. Wolf, T. M. 2002. Optimising herbicide performance – biological consequences of using low-drift nozzles. Aspects of Applied Biology 66:79-86.
14. Wolf, T. M., B. C. Caldwell, J. L. Pederson, and A. J. Cessna. 2004. Interaction of riparian vegetation and nozzle type for drift deposit reduction. Aspects of Applied Biology 71:183-190.
15. Young, B. W. 1990. Droplet dynamics in hydraulic nozzle spray clouds. p. 142-155 in L. E. Bode, J. L. Hazen, and D. G. Chasin, eds. Pesticide Formulations and Application Systems, 10th Volume, ASTM STP 1078. American Society for Testing and Materials, Philadelphia.