Responsible Pesticide Application

Delivery, Deposition, Uptake, Regulation and Testing

A report for

By David Gooden

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Foreword

Pesticides are an integral part of most agricultural sectors and their use into the future is necessary to underpin ongoing increases in productivity to enable farmers to feed the world. The process of applying pesticide involves distribution of an active ingredient onto a target. The aim is to achieve maximum uptake of the active ingredient by the target with minimum movement off target.

Pesticide application is a complex process starting with product selection and an understanding of the target, and then using the best practice available to accurately distribute the product. There are numerous variables which when well managed, can greatly reduce the risk of drift and off-target contamination. This complex process requires a high level of knowledge and understanding, practical skills, well maintained and up to date equipment, and probably most importantly a desire or will to protect the environment and enable sustainable use of pesticides into the future.

There is an abundance of research findings and information on advanced spray application technology from all over the world. However much of this knowledge fails to become integrated into practical solutions as a result of the gap between research and practical application. Many scientific papers and reports are confined to libraries and scientific journals and there are a limited number of application specialists who can adequately link research and practice to provide simple and profitable on-ground solutions for the benefit of operators, farmers and manufacturers alike. Contradictions between field representatives and misinformation also add to the confusion and act as a barrier to the adoption of better spray application practices.

The challenge is to reward spray operators who adopt best practice application and promote the benefits which include lower costs, associated with reduced product usage due to better uptake and reduced losses through off-target movement.

This report aims to identify research gaps in Australia, seek out new technologies being developed in Europe and north America, and highlight some of the methods being used to improve adoption of best practice spray application, both regulation and education.

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Finally, and most importantly to my wife Heidi and son Isaac, it is through missing the people close to me that makes me appreciate the special people in my life and the love we have for each other.

Abbreviations

µm	Micron = 1/1000 of a millimetre
AEA	Agricultural Engineers Association
AIE	Agricultural Industry Executive
APVMA	Australian Pesticide and Veterinary Medicines Authority
ASAE	American Society of Agricultural Engineers
BCPC	British Crop Protection Association
CPA	Crop Protection Association
CTF	Control Traffic Farming
DIX	Drift Index Potential
ECHA	European Chemicals Agency
EU	European Union
JKI	Julius Kühn-Institut, Federal Research Centre for Cultivated Plants
LERAP	Local Environmental Risk Assessment Procedure
NAAC	National Association of Agricultural Contractors
NFU	National Farmers Union
NRoSO	National Registration of Spray Operators
PMRA	Pest Management and Regulatory Agency
PPP	Plant Protection Products
PWM	Pulse Width Modulation
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
UK	United Kingdom
VMD	Volume Median Diameter

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Executive Summary

Background to study

Pesticides are an integral part of most agricultural sectors and their use into the future is necessary to underpin ongoing increases in productivity to enable farmers to feed the world. The process of applying pesticide aims to achieve maximum uptake of the active ingredient by the target, with minimal movement off target. Application of pesticides using best practice, with a focus on reducing losses to the environment, will ultimately result in increased pesticide efficacy, and therefore reduced pesticide use and less impact on the environment.

The study looked at pesticide application, pesticide regulation and sprayer inspection schemes, as well as operator training in The UK, Europe and North America.

My aim was to:

- Identify new technology that could be adopted in Australia;
- Evaluate how different methods of regulation affected practices in the field and adoption of best practice; and
- Evaluate the pros and cons of a sprayer inspection scheme and a range of methods being used overseas to ‘license’ spray operators.

I travelled through England, Ireland, Europe, the United States of America, and Canada. I met with farmers, spray operators, specialist researchers in spray technology, agronomists, and chemical, boomspray and nozzle manufacturers. A large part of my research focused on application technology, including point source contamination and equipment cleaning.

Key Findings

- Much of the research in the European Union is focused on reducing pesticide use and measuring nozzles for spray drift
- There is no international standard for measuring and assessing nozzles
- Buffer zones in Europe can be reduced by adopting drift reduction technologies, an excellent method of encouraging adoption of best practice.
- Voluntary sprayer inspection scheme linked with farm quality assurance program (price premiums and market access) is successful in the UK, but has not reduced the level of faults in booms over time.

- Spray operator licensing based on initial training and assessment, with ongoing training based on a points system (UK) appeared to result in well trained, up-to-date operators.
- Bio-beds are a practical option for disposing of point source contamination (filling and boom cleaning).
- There are few practical technical specialists in the field of pesticide application. Personnel who link all parts of the industry to increase adoption of new and improved technology.
- There is a reduction in Pesticide choice throughout the European Union (EU) and this is leading to more expensive new chemistry and increased tillage to control weeds.

Key Recommendations

- Continue development of nozzles to improve droplet size spectrum when spraying at high speed. Educate operators on the best nozzle to use for each application job, matching the nozzle correctly with product, target and atmospheric conditions.
- Research into the effect of target surface structure on pesticide retention and efficacy.
- R&D is required in CTF (Controlled Traffic Farming) and inter-row seeding systems, as it is becoming more and more widely adopted. How does full stubble retention change the micro-environment within the paddock and what are the effects on spray efficacy and spray drift. What are the benefits to the environment and community?
- Research into bio-beds in Australia to determine their suitability and the best ways to manage them in the warm climate.
- Boomspray manufacturers work with spray operators and other stakeholders to develop more effective, time-efficient and user-friendly solutions to rinsing and decontaminating equipment.
- Downwind buffer zones being added to pesticide labels should be able to be reduced when operators use drift reduction technology.
- Operator training needs to be improved. Australia should look at a *National Register of Spray Operators* (NRoSO) similar to that in the UK using a points system rather than refresher courses which often only benefit the training organisation. There should be spray operator accreditation which trains operators to use their individual equipment. There is a need for more practical training and stewardship programs by the sprayer manufacturers.
- A boomspray testing scheme would help operators ensure equipment maintenance is up to date and provide another point of contact for operators to learn about their equipment.

Introduction

My family farming business is based primarily on annual winter cropping in southern New South Wales. I am the principle spray operator and, like the vast majority of broad acre farmers, I regularly apply pesticides including herbicides, insecticides and fungicides to control weeds, insects and crop disease. Pesticide use on our farm has increased over the past two decades due to economic pressures on the production system and the subsequent need to optimise crop yield.

It is my belief that by applying pesticides correctly (using best practice with a focus on reducing losses to the environment – evaporation and drift) pesticide efficacy will be increased, pesticide use will therefore be reduced, and the environment and my family will be less impacted. It is important to be able to apply products where and when they are required, but an understanding of all the issues involved in the process – from when the pesticide drum arrives on my farm, during application and then dealing with the empty container – is fundamental to a successful result.

Pesticide application has improved in our business over the past decade through a willingness to learn, change and improve our equipment. What is the next step? How can Australia engage all spray operators across the numerous industries where pesticide application is an integral operation (grains, cotton, horticulture, turf, forestry, nursery, home garden, local government) and improve what they do to become best practice? The individual spray operator is the one responsible for pesticide drift and associated problems; however the operator relies on the broader industry, which is ultimately responsible for education, advice and regulation of product choice, application technique and equipment type and operation. My research is targeted at how pesticide application can be improved across industries and for all spray operators.

Pesticides are widely used in agriculture to control weeds, insects and crop disease, reducing labour, energy and water requirements, and optimising potential crop yield and ultimately farm income. Pesticides also reduce the reliance on cultivation and the associated potential for soil erosion.

Pesticide application has a long history. The first known pesticide was elemental sulphur dusting used in ancient summer about 4,500 years ago. Pesticide use increased from the 1940s onward with the development of synthetic pesticides based on triazine and carbolic acids such as 2,4-D and glyphosate (Ritter, 2009).

Spray drift, the physical movement of pesticides away from the intended target area, is a serious concern due to:

- A loss of efficacy
- Environmental contamination
- Health risks to people and animals
- Damage to susceptible crops.

Some amount of spray drift is largely unavoidable however techniques to reduce the level of spray drift and, as a result, minimise the impact are well researched and demonstrated.

Despite the risk of adverse impacts on both human health and the environment pesticide use does offer many benefits including maximising both yield and quality of agricultural products, helping to ensure a more reliable supply of a wide variety of affordable agricultural produce to the world's rapidly growing population.

Spray drift and the risks associated with the application of pesticides in agriculture are attracting increasing attention from the media and general public, as well as the scientific community. Governments strive toward balancing the argument and delivering guidelines for sustainable agricultural production whilst maintaining the health and wellbeing of both the community and the environment.

It is critical that farm advisors, producers, spray operators, spray equipment manufacturers and pesticide manufacturers understand the full complexity of these issues and actively promote positive solutions which are practical, economical and sustainable. I believe there needs to be a renewed emphasis on training and education, and the development of a new level of professionalism for operators, in order to meet the demands of community, consumers and the increases farm productivity necessary to feed the world.

Pesticides alone are not the key to successful, sustainable farming practices. Farmers and researchers around the world have shown that an integrated approach to managing pests in any farming system is more profitable in the long term than any system that relies solely on the use of chemicals. For example, by using a crop rotation along with high barley seeding rates and tall cultivars, in combination with early cut silage Harker *et al*. (2009) demonstrated that by using only 25% herbicide rate to control wild oats over five years they were able to significantly reduce wild oat population and often increase crop yield. Other cultural methods to control weeds, such as rotational tillage and mechanical removal of weeds, can also help reduce dependence on pesticides and make farm businesses more profitable and sustainable.

Objectives

The overall objective of the project was to promote the adoption of the best practice spray application process by engaging key stakeholders (including government, chemical and spray applicator manufacturers, researchers, farmers and spray operators) and by applying principles from around the world on ways to simplify pesticide application whilst maximising pesticide efficacy and field efficiency, and sustaining the environment.

The three key objectives were:

1. *Investigate* ***pesticide application***: determine the most effective machinery and methods for pesticide application and develop a better understanding of the effect of droplets, adjuvants and plant structures on efficacy and drift.

2. *Evaluate* ***pesticide regulation***: determine if regulation is effective in reducing both the pesticide use and their direct impact on the environment. How does this relate to Australia's decision to impose larger buffer zones than Europe?

3. *Evaluate* ***sprayer inspection schemes and operator training***: determine if systems in place deliver real benefits to operators and the community.

I visited England, Ireland, Belgium, Netherlands, Denmark, Germany, Canada and the USA seeking answers from farmers, researchers, regulators, industry representatives, chemical manufacturers and boom spray manufacturers.

The Benefits and Risks of Pesticides

Benefits

The use of pesticides in plant-based production systems has many benefits including, but not limited to:

- Reduction in energy use
- Reduction in water use (requirement)
- Increase in potential yield
- Reduction in labour
- Reduction in the reliance on cultivation resulting in reduced risk of soil erosion.

It is estimated production costs in agriculture would be 75% higher without the use of pesticides (Fernandez-Cornejo, Jans, & Smith, 1998). In another study, fruit and vegetable losses during transportation could be up to 50% higher if pesticides were not used (Commission on Life Sciences, 2000). Another benefit of pesticide use is the reduced mortality rate from malaria as a result of better mosquito control.

Risks

There are a number of risks to the operator (truck, forklift, handler, boomspray operator), community and environment associated with the use of pesticides. Risks can be associated with key stages in the life of a pesticide including:

- Storage (manufacturer, reseller, on-farm)
- Transport
- Application
- Disposal of excess and containers

The focus of this project is application and one of the key risks during application is the physical movement of a pesticide away from the intended target area. Movement can occur when spray droplets move as a vapour or gaseous substance and/or through secondary transport via wind (commonly known as drift), or in surface water, ground water or movement of soil after application.

Consequences of spray drift include:

- Damage to sensitive adjoining crops and other susceptible off target areas
- Contamination of soil and water
- Illegal pesticide residues
- Health risks to animals and people
- A lower-than-intended dose on the target resulting in reduced efficacy and increased cost (Nuyttens, De Schampheleire, Baetens, & Sonck, 2007)

Understanding the risks is an important function for all stakeholders, but particularly governments, who regulate pesticide use. There is significant investment into scientific research into fully understanding the nature of the risk and the hazards involved. This understanding can then be used to develop risk management actions to greatly reduce these risks.

Pesticide Application

The pesticide application process involves an active ingredient (natural or synthetic) contained within a product being put into solution with water and sometimes adjuvants, then atomised and distributed to the target. A number of factors play a key role in determining how successful each spray application is. As boomsprays increase in width, tanks get bigger and desired operating speed gets faster, is becomes essential that operators develop a better understanding of the application process and how each of these factors affects the results, in particular spray drift.

Spray Drift

Not all pesticides applied reach the target. In some post emergent spraying cases only 5-20% of the product applied effectively reaches the target. The rest either misses the target but remains within the zone being treated, runs off the target reaching the soil, or moves off target in vapour or mist as drift (Combellack, 2010).

The factors which impact on drift include:

- Weather conditions (Air temperature, humidity, wind velocity)
- Droplet size and quality
- Droplet velocity
- Chemical properties of the spray solution
- Boom height
- Boom stability
- Crop height and type which changes wind velocity compared to bare earth
- Air assistance on boom
- Spray shields
- Field barriers

Each of these factors can be controlled or the impact minimised as discussed in the following sections.

Impact of barriers on spray drift

Barriers can be an effective buffer for mitigating spray drift. Barriers such as hedges, trees (Wolf, Caldwell, & Pederson, 2004) and even grass have been cited as reducing the concentration of airborne particles (Miller, Lane, Walklate, & Richardson, 2000). An understanding of how effective they can be and knowledge of the characteristics of an effective barrier, will give land managers greater scope to prevent off target movement and the ability to reduce the width of buffer zones.

Weather conditions

Weather conditions are a key factor impacting the spray application process. Air temperature and relative humidity play a huge role in droplet survival and performance and in spray drift. Weather conditions can not be modified but timing of spray application to occur when weather conditions are optimal for reducing the risk of spray drift and increasing efficacy is critical. Use of wind speed data and the relationship between temperature and humidity (delta T) greatly assists operators to assess weather conditions prior to application. Spraying when conditions are optimal can greatly improve the outcome of each spray operation.

The challenge in Australia is the need by broad acre crop producers to cover increasingly large areas in the very limited periods of time when weather conditions are suitable. Therefore an understanding of weather and its impact on spray droplets is essential so operators can maximise droplet delivery, retention and uptake of pesticides.

Properties of the Spray Solution

The chemical, biological and physical properties of the spray solution and the target pest will affect how a pesticide behaves once it leaves the boom and subsequently how effective it is. In order for a pesticide to be effective, spray liquid droplets deposited on the target pest must adhere and be taken in. This process is influenced by: droplet size and velocity; droplet surface tension; droplet contact angle; size and concentration of chemical in the droplet; inclusion of air in droplets; ability of the droplets to adhere to the target surface which is affected by the surface structure of the target (e.g. presence or absence of hairs); structure of the plant and crop canopy; presence of water on the target surface; and weather conditions, particularly temperature and relative humidity.

Water (left) and water plus crop oil (right) demonstrates the importance of understanding droplet characteristics, such as surface tension, to ensure applied pesticide stays on the target and is taken up.

When liquid is ejected from a hydraulic nozzle it forms a spray sheet which is then broken down into droplets. Upon impacting a target the droplet will go through an expansion and retraction phase. The droplet will be retained if the adhesion force is greater than the excess of its kinetic energy following contact.

At droplet impact there are competitive forces working against each other and include inertial, viscous and surface tension. During impact, droplets undergo extreme elongational deformations and those with high viscosity undergo increased energy dissipation during expansion and retraction which enhances droplet retention.

Dynamic surface tension is the rate at which the force is operating on the surface of a droplet to minimise its area and it affects droplet size and adhesion. Surface tension varies depending on the plant surface structure. Inertial forces are increased by droplet size, higher emission velocity and gravity and are lowered by drag, evaporation and distance.

Larger droplets (>250µm) lessen retention unless a surfactant is added to reduce the surface tension, otherwise the inertial forces are greater and the droplets are likely to bounce off. High application volume (>100 L/ha) tends to decrease retention and in general dynamic surface tension <40mN/m will increase retention (Combellack, 2010).

Carriers in the product and adjuvants (or additives) are used to alter the droplet behaviour and improve adhesion and efficacy of the pesticide. However plant or target surface structure is just as critical to droplet retention. Critical knowledge about the impact of target surface structure on retention, and therefore pesticide efficacy is lacking and requires investment in research.

Droplet Velocity

There is some research focused on how droplet velocity impacts on droplet performance, canopy penetration and adhesion. Droplet velocity is a key part of the delivery process and effects drift or off target movement. Slow moving small droplets are more prone to evaporation and therefore movement to off target zones. Droplet velocity also impacts on the retention of droplets by the target. Fast moving droplets can bounce off the target.

Important differences in velocities have been observed depending on the nozzle type and size. For the same droplet size, droplet velocity is highest for standard nozzles, followed by low-drift nozzles and air-inclusion (ai) nozzles (because of the lower ejection velocities caused by pre-orifice and venturi effects) (Nuyttens, De Schampheleire, Verboven, Brusselman, & Dekeyser, 2009). However in reality, droplet from air induction nozzles will generally be larger for the same nozzle size and therefore velocity will be very different.

Large droplets will have higher velocity. However, with an ai nozzle, if a chemical additive is used to create bubbles within the droplets, large droplets will move slower as they are less dense. On impact, the air bubbles within the droplets absorb energy and these large but aerated droplets are more easily retained on the target. For example, large droplets can be applied and retained if a non ionic surfactant is used, but retention is lessened if oils are used with ai nozzles as there will be no bubbles, droplet density, thus velocity will rise and droplet bounce will be enhanced as the droplets move faster and there are no bubbles to absorb the energy.

(WOLF, 2005) also describes the ability of coarser droplets to create a vacuum and pull fine droplets down and reduce losses due to air entrainment and the fluid dynamics occurring around the liquid sheet.

Droplets decelerate as a result of air resistance and smaller droplet sizes slow down more rapidly compared to larger droplets due to the effect of air drag (Nuyttens, De Schampheleire, Verboven, Brusselman, & Dekeyser, 2009).

A better understanding of droplet velocity will allow operators to choose the correct nozzle based on the target and its position in the canopy and also to reduce losses and improve deposition.

Droplet size and Uptake

Droplet size is not just about retention and reducing drift. Droplet size is an important factor in the uptake of the active ingredient. It is particularly important in glyphosate, where the concentration gradient within the droplet is driving absorption. The table below, adapted from Feng *et al* (2003), shows a lower proportion of coarse droplets (491 µm) were retained compared to fine droplets (175 µm,) but more of the coarse droplets were absorbed. The net effect is a higher uptake of glyphosate from the coarser droplets. The larger droplets are producing a larger driving force for absorption. Following on, if higher retention can be achieved, with the understanding of absorption, dose rates may be able to be reduced – a win /win situation for the environment and the farmer.

Glyphosate retention and absorption in corn in the USA with two different droplet sizes, produced by different nozzles.
(Feng, Chiu, Sammons, & Ryerse, 2003)

	Fine droplets	**Course droplets**
Droplet size	175 µm	491 µm
Nozzle	TeeJet XR 110-015	TeeJet AI 110-015
Retained	47%	38%
Absorbed	30%	49%
Net Effect	**14% uptake**	**19% uptake**

Adjuvants

Adjuvants are tools which influence the physical and chemical properties of spray solutions to enhance pesticide performance. Some improve application characteristics such as changing the surface tension of droplets (for example non ionic surfactants), and others enhance biological activity to help with absorption. Types of adjuvants include surfactants (non ionic and ionic), oils, ammonium fertilisers, stickers, drift control and depositing agents, anti foaming agents, pH adjusters and buffers as well as water conditioners and compatibility agents.

Applying the right herbicide with the right concentration and type of adjuvant is a major task for the user. The right adjuvant depends on weed characteristics (e.g., species, growth stage, and cuticle), environmental conditions (e.g., temperature, light, humidity, and rainfall), application method (e.g., water quality, spray tank environment and agitation, spray volume, and droplet size), and physicochemical properties of the herbicide. (Foy & Green, 2004)

Droplet classification

Currently there is no international standard for droplet size measurement or a standard nozzle testing procedure. Spray droplets are measured by Volume Median Diameter (VMD). The VMD is defined as the droplet diameter where 50% of the volume is produced in droplets with a smaller diameter. Droplet size can also be given as a number e.g. 250 microns (µm)

There are variations in some of the testing procedures used around the world to determine spray quality and this can produce different results. There is no international standard making it hard to know how to compare results and which results should be used. There is a BCPC (British Crop Protection Council) Standard used in Europe and UK. Australia and the USA rely on the ASAE – S -572.1 standard (American Society of Agricultural Engineers); for example 250µm is equal to a medium droplet.

The difference in VMD from different nozzle testing systems.
(Betts, 2010)

Droplet Size Categories (approximate)					
Category	**Symbol**	**Colour code**	**Approximate VMD range (PDPA)**	**Approximate VMD range (Oxford)**	**Approximate VMD range (ASAE S-572.1)***
Extra fine	XF	Lilac			<60
Very fine	VF	Red	<157	<136	61 – 135 0.097 mm
Fine	F	Orange	157 – 256 206	136 – 256 154	136 – 255 0.190 mm

Medium	M	Yellow	257 – 360 308	174 – 214 194	256 – 340 0.288 mm
Coarse	C	Blue	361 – 437 476	215 – 334 274	341 – 440 0.372 mm
Very coarse	VC	Green	438 – 526 482	335 – 412 373	441 – 525 0.453 mm
Extremely coarse	XC	White	>526	>412	526 – 655 0.590 mm
Ultra coarse	UC	Black			>656 0.656 mm
* Data extracted from American Society of Agricultural Engineers (ASAE) standard S 572. Data is an average of three laser measuring instruments (Malvern, PMS and PDPA)					

The Boomspray

The boomspray is the key piece of machinery used to apply pesticides in the grains industry. The boomspray is used to distribute or apply the pesticide at a uniform rate over the target area. Its proper use should offer safety to the operator and minimise off target losses and point source contamination. The most important part of the boomspray is the nozzle which atomises the spray solution to deliver the chemical at the correct dose rate.

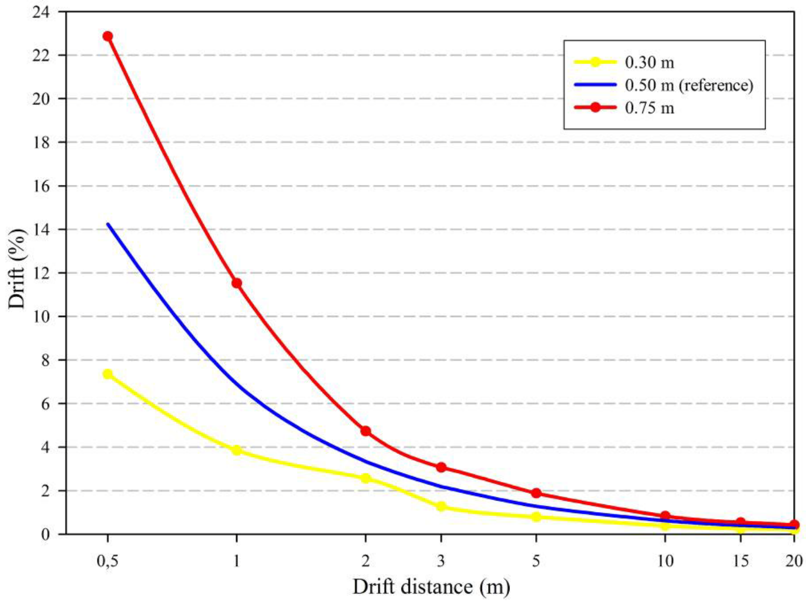
Development of boomsprays has been rapid and is on-going, aiming to meet the demands of regulations, reduce economic losses, boost efficiencies and improve pesticide efficacy. Today's farmers and spray operators demand high work rates and simple solutions with positive economic outcomes.

It is natural for boomspray manufacturers to be focused on market forces and sales looking at aspects such as size, comfort, colour and promoting their brand. It would be preferable for them to develop overall solutions that provide farmer friendly, practical options which benefit the environment and the operator. For example, in Canada and Australia some manufacturers do not fit taps on boom ends, a simple addition which when fitted makes flushing boom lines simpler. The EU however is developing standards to ensure manufactures produce equipment that is suitable, efficient and operator and environment friendly.

The Boom

Boom height has a significant effect on drift. As boom height increases both the quantity of drift and the distance it travels increases.

(Nuyttens, De Schampheleire, Baetens, & Sonck, 2007)



Boom stability also impacts on spray distribution. In Germany at Julius Kühn-Institut, Federal Research Centre for Cultivated Plants (JKI) a spray boom platform was developed to replicate field condition movements in three dimensions looking at tilt (movement of the end of the boom up and down) and yaw (movement of the end of the boom fore and aft). Because uniformity of distribution is such an important part of spray applications they wanted to test the relationship between boom movement and spray distribution in simulated 'real crop' situations. They found the coefficient of variation for spray distrubition at the boom tip for tractor mounted boomsprays ranged from 10 to 22%, while trailing booms gave considerably less variation (Herbst and Wolf, 2001). Figure 2 below shows the variation in spray distribution for various machines (type, width and speed).

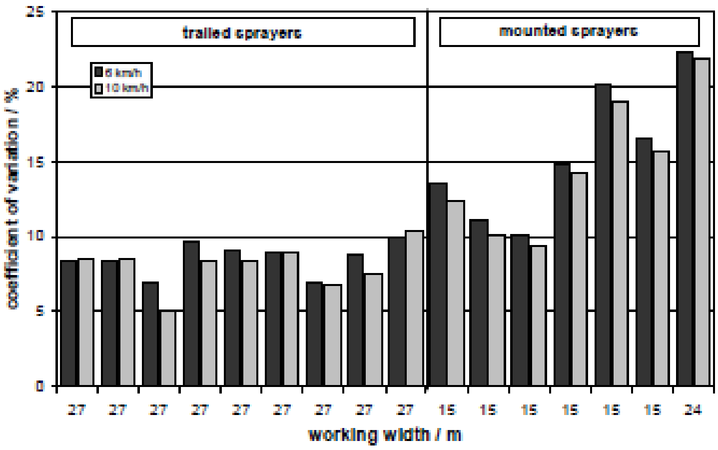


Figure 2: Spray Distribution at boom tip for different sprayers showing mounted sprayers have higher yaw movements than trailed sprayers (Herbst & Wolf, 2001).

The Nozzles

Nozzles are one of the most important and easily changed components on a boom spray. They determine flow and droplet size at any given pressure and distribution pattern of the liquid. The main types of tapered flat fan nozzles used in broad acre cropping are:

- Standard e.g. TeeJet XR, Hardi FF
- Pre-orifice e.g. TeeJet DG, Hardi MD
- Venturi air induction (low pressure) e.g. Lechler IDK, TeeJet AIXR
- Venturi air induction (high pressure) e.g. Teejet AI, Hardi Injet, Agrotop TurboDrop
- Twin fluid nozzles e.g. Optispray

Development in nozzles has provided some of the solutions developed for applying pesticide at high and more variable speeds. The challenge with spraying at higher speed is that pressure increases along with flow and with standard nozzles and the use of automatic rate controllers this in turn decreases droplet size. Solutions include developments such as twin line booms and variable rate nozzle tips, such as the Varitarget® and Pulse Width Modulation (PWM) nozzle. These systems allow for a more precise rate-droplet size control than a conventional rate-control system. In the case of PWM nozzles the use of spray pressure to control nozzle output is replaced by the duty cycle of a pulsating solenoid. Pressure and droplet size remain fairly constant throughout the duty cycle range with the pressure changed to manage droplet size if necessary. The pulse width modulation technique is unique, in that one nozzle is equivalent to four standard nozzles in terms of flow rate. Rate is adjusted by an electronic valve which pulsates according to the rate required. At 100% duty cycle the nozzle is operating at full capacity, while at 50% it acts like a nozzle half the size.

Twin Fluid nozzles are another alternative which provide the flexibility to control spray quality by adjusting the air pressure in relation to flow at the nozzle. The benefits are improved control of spray quality over a larger speed range and more flexibility in changing water rates.

Spray Angle (forward and rear facing)

There has been recent interest in nozzles that deliver on an angle after it was found improved coverage was achievable by changing the forward and rear facing angle of a nozzle. As a result some manufacturers are now focused on further refining nozzle angles but caution must be used as nozzle angle is just one of a number of factors influencing deposition.

Research in Belgium in 2010 found spray angling improved crop penetration but not the deposition at the bottom side of the leaves in an ornamental crop (Foque & Nuyttens, 2010). The experiments showed a significant and important variation in spray deposition and coverage in dense crops.

Spray application technique affects deposits on the bottom side of leaves, crop penetration and the uniformity of liquid distribution on the crop. The use of air assistance (see "Air Assist Booms" below) generally improves crop penetration and deposition on the bottom side of the leaves and reduces spray deposition in the top crop layer, in particular on the top side of leaves. This results in more uniform distribution over the entire crop canopy. The effect of air support on crop penetration was most pronounced with the standard 0° nozzle angle. Without air support, spray angling can improve crop penetration, but not the deposition at the bottom side of leaves (Foque & Nuyttens, 2010).

Research in Canada demonstrated a combination of double nozzles, air-induced sprays and faster travel speed increased spray retention on vertical targets by more than 100% (WOLF, 2005). When nozzles were angled, the front nozzle appeared to increase deposition more. When single nozzles were used, orientating them forward resulted in greater deposits than orientating them backward, and maintaining low boom height increased deposits, as did fast travel speeds and coarser sprays.

Air Assist Booms

Other systems which enhance droplet performance include air booms eg Hardi Twin Air® or sleeve booms which use air to create a positive movement of air into the crop to achieve good spray penetration and coverage, and the added benefit of reduced off target movement.

An example of air assist boom taken by David Gooden, Ireland, 2010

Spray Shields

The uptake of boom shields is not high in Australia however they have been shown to reduce drift when compared to the same nozzle without a shields (Wolf, Grover, Wallace, Shewchuk, & Maybank, 1993). In Ireland and UK booms fitted with shields provide excellent drift reduction and deposition into highly dense cereal crops.

Pesticide Application and the Cropping System

No Till Inter-Row Farming System

As Australian farmers move toward no-till, controlled traffic and inter-row sowing cropping systems changes to the way we manage weeds and other pests should be investigated. Opportunities may exist to improve pest control while at the same time reducing the risk of spray drift.

A study in Canada by Wolf T. M., Caldwell, Harrison, & Hall, (1996) demonstrated that some of the changes that occur when a farming system changes can be advantageous. The study compared wind speed at 0.5m high in a conventional farm system using stubble burning and to that in a no-till stubble system where crop residues are retained. The results showed a 15% decrease in wind velocity at 0.5 m high where stubble was retained, with larger percent reductions at lower wind speeds and measurement heights. This would reduce the likelihood of spray drift and improve the efficacy of spray applications. Figure 3 below shows the results from the wind tunnel experiment conducted by Wolf and shows that standing stubble significantly reduces airborne drift compared to bare earth. The study also showed that weeds grown in a stubble environment developed an architecture which increased their spray retention, contributing to their greater sensitivity to herbicide applications.

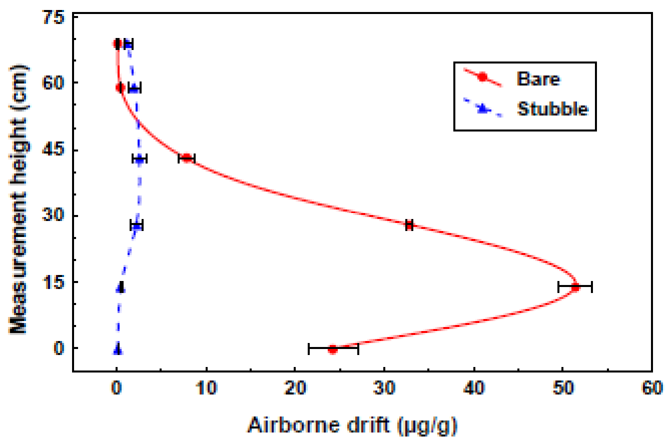


Figure 3: Downwind spray drift deposited on cotton strings 2m downwind from an 8002 nozzle for bare soil and a 28cm tall wheat stubble canopy (Wolf T. M., Caldwell, Harrison, & Hall, 1996)

Sprayer cleaning and waste disposal

The focus of the sustainable pesticide use directive in the EU was to minimise damage caused by pesticides to soil, water and the environment. One identified risk is point source pollution which occurs where spray equipment is washed or where pesticides are loaded into the boomspray. In an overview of the risk of water contamination by plant protection products in

Europe during pre- and post-treatment operations Jaeken & Debaer (2005) found that 40–90% of surface water contamination is attributed to direct losses – point sources.

A number of solutions have been put into practice including:

- Purpose built filling stations that include a concrete bunded area to contain and direct any spillage or waste water into a separate tank for appropriate disposal using a biobed system (see section following), or a water cleaner like Sentinnel® used in Belgium which uses a chemical process to remove organic material by flocculating particles.

Photo by David Gooden, 2010

Purpose built filling station in England 2010

- Triple rinsing of the spray boom reduces the level of spray concentration left in tank however not all operators triple rinse as it takes longer to do and you have to stop and change over taps. A study conducted in Denmark showed that only one spray unit out of seven regularly used sprayers met the maximum concentration level of 1%, stipulated by the French and Denmark governments (Andersen, Jorgensen, Nilsson, & Wehmann, 2010).

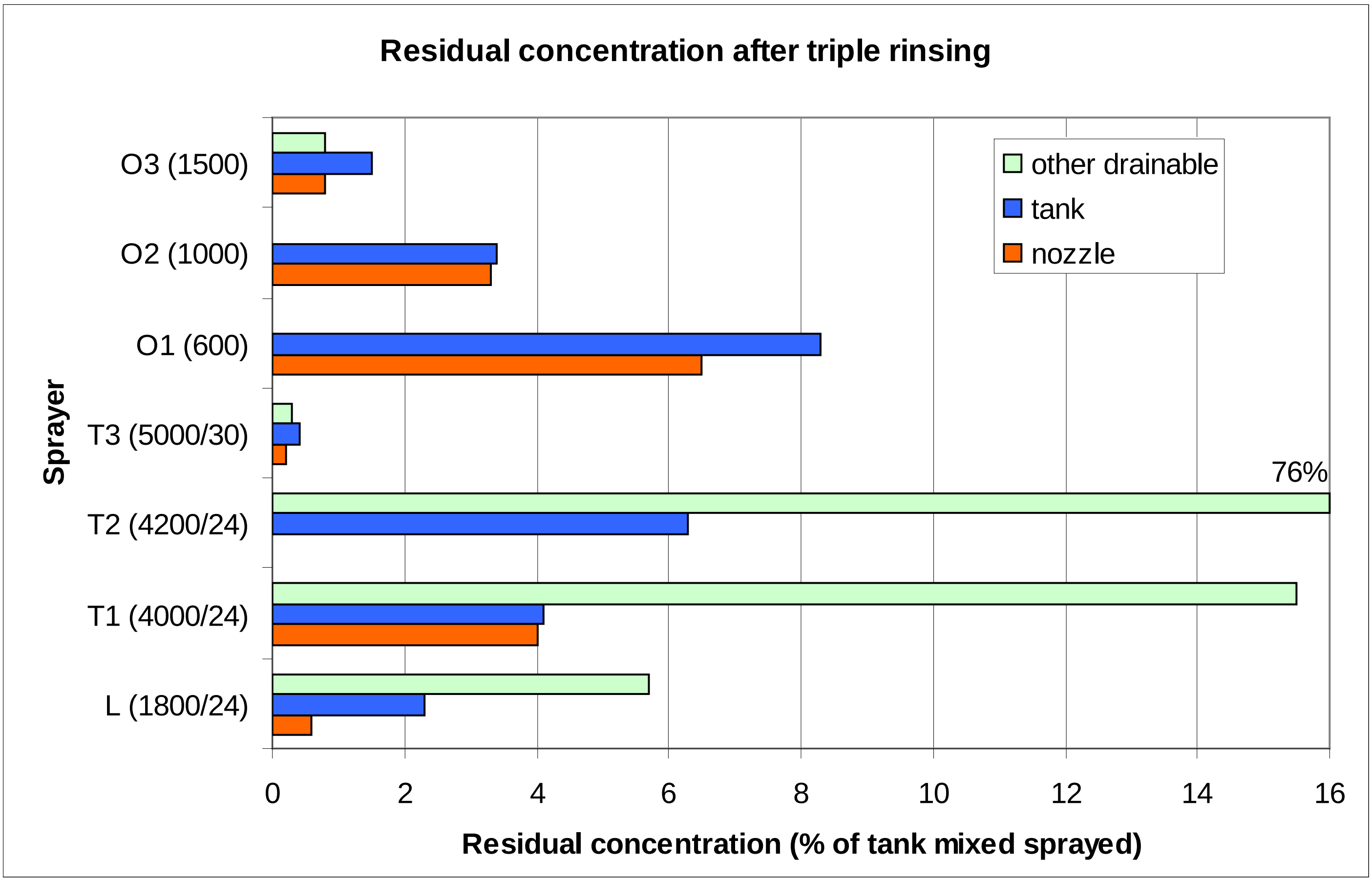


Figure 4: Residual concentration at various places on sprayers after triple rinsing – relative to an original tank mix set to 100%. *Other drainable* refers to concentration in filter housing or filling valve showing the highest value found for the sprayer. ***L*** is lift mounted, ***T*** is trailer sprayer and **O** is orchard sprayer. Tank volume (L) and boom size (m) in brackets. For O1 and O2 there were no *Other drainable* measurement. One nozzle residual was 0 (T2). The highest residual was 76% (T2 other drainable). (Andersen, Jorgensen, Nilsson, & Wehmann, 2010)

Manufacturers in Denmark and Belgium (AAMS and Kyndestoft) have developed a solution involving the use of a separate pump (12V) for continuous flow of water from the clean water tank into the main tank and hoses via low-flow tank rinse nozzles. The remnant residue is continuously diluted and replaced. To flush all hoses and valves with more and more clean water, all valves have to be activated for 3-5 seconds. This is done three times through the process. Operating the pump and valves can be done from the tractor when driving in the treated area.

Equipment and infrastructure improvements are the key to risk mitigation. Solutions that balance cost and benefit should be developed through intensive multi-stakeholder consultations. A common understanding of each others problems will deliver the knowledge to find the best solutions.

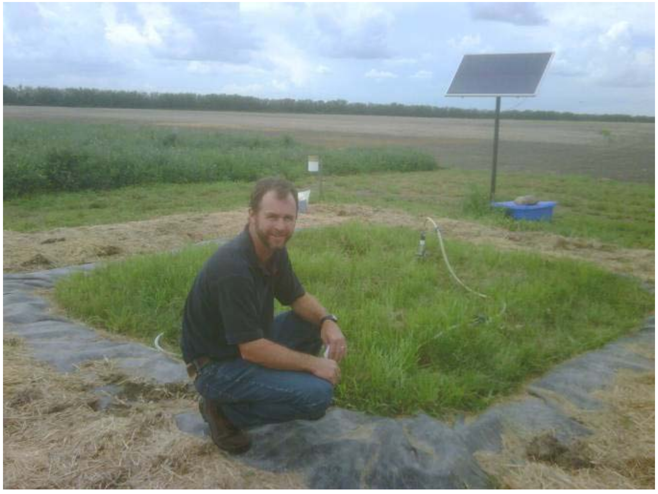
Bio-beds

The purpose of a bio-bed is to remediate contaminated spray liquid. The aim of the system is to contain all liquid spills and wash-down waste from the spray application process. This means the area should be bunded (contained with a small levee) and used for all pesticide handling and clean down, including transferring chemical from container to boomspray.

Bio-beds began in 1992 in Sweden when Gören Olson had the idea that micro-organisms could break down small amounts of pesticides. He developed a site to park the sprayer over a pit filled with a mixture of topsoil, straw and compost and sown to turf on top to help with water management through evapotranspiration.

There are two ways of building a bio-bed.

1. *Offset system* where the liquid is intercepted on a concrete bunded area and transferred to the biobed area via a pump or drip irrigation. (see photos below)
2. *Drive over system* where the biobed is below the bunded pesticide handling area. Filling, measuring, and cleaning would all take place in this area.



Bio-bed trial at Bayer Research Farm, Indian Head, 2010.
By M. Belyk, 2010.

Source: David Gooden, Belgium, 2010

A containment station with biobed below system

Bio-beds require a mix of straw (50% by volume, lignin/cellulose material), a humified carbon source (25% by volume, compost material) and soil (25% by volume, mix of clay, sand and silt). Turf on the top will also help manage moisture and keep active bugs in the rooting area to help break down pesticides.

There are approximately 2800 bioremediation systems in the world most of which most are in France, Sweden, UK and Belgium.

Issues associated with bio-beds include:

- Excess water during certain periods. Turf on top helps.
- The bio-bed mix degrades steadily and a top up is required each year, with the whole bio-bed mix needing replacement every five to seven years.
- Disposal of waste compost. Highly regulated in the EU which is impacting on the uptake.

Emerging Technology

Technology	Description	Application in Australia
Garfords Robocrop	Mechanical weeding device	Some in use in organic industry
Weed sensing (e.g. Weedseeker, Weedit)	Uses infra red technology to sense ‘green’ to apply herbicide only to weed. Technology being improved to determine crop/weed density and apply a rate accordingly (variable). Will also be used to identifying weeds (intelligent sprayer).	Price may prohibit adoption. Technology well suited to Australia, particularly in fallow weed control situations.
Variable rate nozzles	Vary the output at each nozzle across the boom as it turns to get uniform coverage along the length of the boom. Also auto shut-off nozzles and direct injection of chemical at the nozzle tip.	Particularly important as booms get wider. Very applicable in Australian broadacre cropping. Direct injection at nozzle tip will address many cleaning and contamination issues.
Sensors in orchard sprayers	Will identify trees, apply pesticide only to tree. Also ability to vary flowrate according to density of canopy, applying pesticides on target at optimum rate.	Suited to Australian orchards – reduced off-target, reduced pesticide usage particularly in large orchards.
Single drop applicator or Droplet on Demand (DOD), Denmark	In early development stage. For high value intensive crops. Aim to identify weeds and apply a droplet to the target weed like an inkjet printer. Will significantly reduce the amount of pesticide applied; non selective herbicides could be used in sensitive crops.	Suited to high value crops such as vegetables, where customers would embrace less pesticide use.
Laser weed control, Denmark	Has limited scope except to demonstrate that it is possible to control weeds with a laser beam. Weed size and type as well as laser time and size impact on the result.	Unlikely to be suited to broadacre situation.
New nozzles	Continued development. Focus on drift reduction and pesticide deposition. Also ease of operator use over a wide range of variable speeds. Capability to produce required droplet size, easily changed on the go. Example: twin fluid nozzles (Optispray, Airtec, Airjet)	Suited to Australian broadacre use. Often a very economic option.
Electrostatic charge of spray fluid	Laboratory testing has shown potential but field results variable.	Too early to tell.
Tattler® blocked nozzle sensers	Senses nozzle vibration to monitoring flow. As flow is reduced by a blockage, vibration is reduced (Giles, 2006).	Will be released commercially soon.

Pesticide Regulation

All over the world pesticides are regulated to some degree. The aim is generally the same, however the method varies widely. Pesticides are regulated to ensure they don't present unacceptable risks to the public, to people who apply them, to the environment or to animals. (direct.gov.uk, 2010).

Regulators seek answers to the health and safety concerns of the community and impose regulations because spray operators are not expected to understand the detail about each specific product being applied. The regulators, for example the Australian Pesticides and Veterinary Medicines Authority (APVMA), are therefore responsible for overseeing and/or commissioning evaluation of pesticides. Specific characteristics to be determined may include:

- The quantity of active ingredient likely to be deposited at specific distances downwind for a defined droplet spectrum and at a range of wind speeds
- Absorption level and rate through the skin of a child playing in a back yard at a specified distance downwind from an orchard spraying operation
- Breakdown rates of an active ingredient in sunlight, in the soil or by plant metabolic activity, and the impact of this on the products suitability as a food or for trade
- Risk to livestock grazing a pasture adjacent to a target zone – level of intake; which tissue(s) would it be distributed into; and how long would it remain in those tissues before being metabolised or excreted? (APVMA Guidleines, 2008)

In most countries, pesticides must be approved for both sale and use by a government agency using the label as the mechanism for directing the user how to apply the product.

The challenge for researchers and regulators is how to determine best practice application techniques for each of the many products available in order to minimise drift whilst improving deposition onto the targets to increase pesticide efficacy.

Who Regulates Pesticide Use

Statutory authorities in most developed countries oversee the sale and use of agricultural pesticides.

Statutory Authorities Regulating Pesticide Use		
Country	**Authority/legislation**	**Role, comments**
Australia	Australian Pesticides and Veterinary	Oversees registration

	Medicines Authority (APVMA)	
USA	Environmental Protection Agency (EPA)	Approves the use and sale of products
Canada	Pest Management Regulatory Agency (PMRA)	A branch of Health Canada who administer the *Pest Control Act* on behalf of the Minister of Health.
EU	Regulation for Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) June 2007	Regulation underpinning the use of plant protection products (PPP) permitted for use (Frequently Asked Questions about REACH, 2010)
	European Chemicals Agency (ECHA)	Central co-ordination and implementation role. Manages the registration, evaluation, authorisation and restriction processes for chemical substances to ensure consistency across the EU.
EU member states	Own agency	Implement and comply with EU directive (REACH)
UK	Chemicals Regulation Directorate (CRD) under the Health and Safety Executive (HSE)	Implements REACH
Netherlands	Board for the Authorisation of Plant Protection Products and Biocidesesticides (Ctgb)	Implements REACH
Denmark	Environmental Protection Agency (EPA)	Manages pesticide use under the *Chemical Substances and Products Act* which allows for the REACH provisions on classification, labelling, storage and use of approved substances.
Germany	BVL (Federal office of Consumer Protection and Food Safety	Implements REACH
Belgium	Federal Agency of Health, Food Safety and Environment.	Implements REACH

Pesticide Regulation in the European Union

Each country or member state in the European Union (EU) is subject to the legislation Regulation for Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH, June 2007). It is a uniform body of legislation which underpins the use of plant protection products (PPPs) and is used to maintain consistency between countries and to reduce regulatory costs. It is then up to each member state to implement the directive to the minimum standards/limits set by REACH.

The significance of REACH

Along with the introduction of REACH all PPPs came under review. Chemical manufacturing companies had to submit data to demonstrate the toxicity, safety and use of each active ingredient and the cut-off criteria. Active substances are banned based on hazardous characteristics – any substance with a harmful effect on humans was banned. No carcinogen, mutagens, reproductive toxins or endocrine disrupters are allowed. In addition any product considered hazardous to the environment, a persistent organic pollutant or persistent bioaccumulative, and toxic substances are also banned.

Unlike the previous regulation REACH has no risk evaluation. Normally when considering risk, both exposure and hazard is taken into account. For example a venomous snake is hazardous to humans. However when it is in a cage there is no exposure and the risk removed. In another example, when considering a PPP which is hazardous to fish, a buffer zone will avoid exposure and reduce the risk of a hazardous event occurring.

REACH has dramatically reduced the number of products available to farmers in the EU. For example the following products will be phased out over time

- Fungicides: mancozeb, fenbuconazole, iprodione, tebuconazole
- Herbicides: amitrole, glufosinate, molinate, pendimethalin and tralkoxydim

Depending on the classification and lack of available alternatives some substances, such as the herbicides 2,4D, carbetamide, metribuzin and triflusulfuron and the insecticide dimethoate, will be permitted until alternatives are available.

Many active ingredients were not submitted for approval because of the cost of collecting data and lack of data protection. In January 2009, the list of active ingredients to be phased out because no application for approval was submitted totalled 64. The list includes clethodim, diclofop-methyl, fluozifop-P, metosulam, oxyfluarfen, thiobencarb, tecbuthylazinecarbixin, fenbuconazole (Informa UK Ltd, 2009).

All this is leading to limited choice of product and restrictions in management practices making it difficult for farmers to be sustainable. It has also added extra cost to pesticides as the process for compliance is more difficult and lengthy due to the data required to register a new product.

The Sustainable Use of Pesticides

The European Commission set up a directive for the sustainable use of pesticides to provide guidelines to ensure that as few pesticides are used as possible, through applications at the right time and in the right dosage. It is up to the member states to justify that pesticides are used in a sustainable and limiting way, that they promote and support low pesticide /input use and user have to switch to lowest risk products.   It ensures member states establish a National Action Plan for pesticide use which:

1. Highlights ways to reduce risks and impacts of pesticide use;

2. Encourages integrated pest management; and
3. Have measurable results which can be evaluated.

It is in this way that each country then has its own flexibility to determine how it implements the directive and thus creates variations between countires on how pesticides are applied and the direction of research and priorities.

Approach to Regulation across the EU

Following on from the EU Sustainable Use of Pesticide (2006) directive, each member state has developed an individual National Action Plan to fulfil the requirements of the framework. These plans vary significantly in their approach and method, with the minimum outcome being the constant.

In the majority of member states (Germany, Netherlands and UK) drift reduction is the focus. However in Belgium, the focus is on drift reduction and reduced overall pesticide use, while in Denmark, they are leading the world with research directed towards reducing both pesticide and nitrogen use. With the aim of regulating pesticide use in an effort to protect European consumers and the environment, member states are looking to use as few pesticides as possible, through applications at the right time and in the right dosage. Risk mitigation is a feature of the directive which ensures a system which provides adequate training and information for professional and private users.

Denmark

Prior to the implementation of the Sustainable Use of Pesticide directive there was discussion in the EU about implementing a pesticide tax. As a result Denmark legislated for a reduction in pesticide use by implementing a pesticide tax of 35% on all pesticides sold and by providing funding to research options to reduce pesticide usage.

In Denmark legislation and restrictions have dominated the approach to pesticide (and nitrogen) management. The primary goal is to avoid the use of pesticides. Nitrogen quotas are now in place and farmers must grow ‘capture crops’ – high nitrogen using crops to ‘mop up’ leftover nitrogen in the soil.

United Kingdom

The United Kingdom accepted a proposal put forward by the farming and crop protection industry to minimise the environmental impacts of pesticides. Interestingly five industry bodies drove the initiative including the National Farmers Union (NFU) representing farmers unions from England, Wales, Scotland and Northern Ireland, Crop Protection Association

(CPA), Agricultural Industry Executive (AIE), Agricultural Engineers Association (AEA) and the National Association of Agricultural Contractors (NAAC).

This Voluntary Initiative set targets in 3 main areas:

1. Developing a *National Register of Spray Operators* (NRoSO)
2. *National Sprayer Testing Scheme* (NSTS)
3. Implementing *Crop Protection Management Plans* registered with the National Farmers Union (NFU).

The purpose of the voluntary initiative was to demonstrate that pesticide losses to the environment and the protection of the environment and communities can be maintained through research, training and testing. The aim was to achieve this through: good planning; effective sprayer training accreditation; applying pesticides with equipment tested to meet certain standards; and the use of drift reduction technology.

The initiatives are linked back to some commercial benefits. For example, to be part of the Farm Assurance scheme (a national quality assurance program) farmers must be using crop protection management plans and be (or be using) registered spray operators with NSTS approved equipment. The Farm Assurance scheme gives farmers not only market access but price premiums as well. The development of the scheme by industry and this tangible link to overall farm profitability via Farm Assurance has led to the success of the scheme, although is has become a form of farm subsidy or in direct payment.

Sprayer licensing is based on initial training in combination with a points based system for ongoing updates and refreshers. When licensed sprayers attend a training event they will earn points, the number depending on how technical the ‘training’ is.

Other EU Countries – Germany, Belgium and the Netherlands

Most of the EU member states have taken a top down approach based on regulations and restriction. They focus on setting standards; drift reduction and buffer zone requirements whilst ensuring reduced pesticide use.

The Pesticide Label – the Most Important Document

On a global scale, Chemical manufacturers and government registrants invest significant time and effort into the development of the pesticide label. It is the most important piece of information linking the user to the correct use, mixing and application of the product. Product labels vary between countries in order to comply with specific regulations and requirements for pesticide.

Most farmers find labels confusing and contradictory and often rely on past experience and generalisations to apply a product.

In Australia, labels are legally binding and have both advisory and mandatory statements to direct users on the correct application procedure. Advisory statements include mixing method and rate and mandatory statements include spray buffer zones, droplet size and weather conditions.

Buffer Zone Legislation

Buffer zones (or mandatory no spray zones) are areas which separate the area being treated with a pesticide and a sensitive area (e.g. waterway, sensitive crop, inhabited area). Their purpose is to provide a sufficient buffer when pesticides are being applied to reduce the risk of off target contamination by spray drift protect these areas from pesticides. It is important therefore to be able to assess spray drift under certain conditions using a set of known parameters such as product, nozzle type and weather conditions. There are drift assessments conducted all over the world however there is no standard method. The purpose of this section is to comment on how countries assess drift and determine and implement the use of buffer zones.

Buffer zones in the **UK** and **Europe** range from 1 to 200m and vary according to the risk associated with both the pesticide and spray application equipment being used. The driving force behind buffer zones in Europe is surface water quality. Buffer zones are determined for each pesticide and are stated on the label. They are based on the level of toxicity of the product and can be reduced in practice by using one or more drift reducing application techniques. Determination of the buffer zone in the UK for a specific situation is achieved by undertaking a Local Environmental Risk Assessment Procedure (LERAP) and using nozzles which have an appropriate star rating to indicate drift reduction. Use of best agricultural practice ensures a 1m non spray zone on all field edges.

In the **United Kingdom** pesticides are classified into two categories and equipment is given a star rating. Category B includes herbicides and fungicides and for these pesticides buffer zones can be reduced by conducting a LERAP. The equipment star rating is based on drift where: a reference sprayer has no drift reduction: a one star rating sprayer has 25% drift reduction; two star rating equals 50% drift reduction; and three star rating equals 75% drift reduction.

As part of the LERAP the variable to buffer zone width also depends on water course width and application or dose rate. The applicator consults tables that are matched to the drift potential of the sprayer in question. The pesticide dose and water course width are selected, and the corresponding buffer zone distance is recorded. Smaller buffer zones are awarded for wider watercourses and lower application rates.

In **Australia** the APVMA is incorporating mandatory 1 to 500m downwind buffer zones on all new products labels. The APVMA also requires the label to indicate the largest droplet size (under the ASAE S-572 standard) consistent with delivering high efficacy. Those products which require an aquatic or terrestrial buffer zone will be nominated on the label. No reduction in downwind buffer zone can be made under current legislation even with the use of drift reducing technology.

Germany has a system classification called DIX (Drift Index Potential). Buffer zones are set by the regulatory authority BVL (Federal Office of Consumer Protection and Food Safety) according to toxicity data for each pesticide. Buffer zones can be adjusted by the applicator according to the drift potential of the sprayer as determined by research at the Julius Kühn-Institut, Germany the size of the water course (if present) and the presence of vegetation.

Buffer zone legislation was introduced in Belgium in 2005. Buffer zone widths are mentioned on the product label with 7 possibilities based on the toxicity of the product. This buffer can be reduced by using equipment classified into the four drift reduction classes (standard, 50%, 75% and 90%). The table below shows how buffer zones can be reduced for the various categories.

Effective buffer zones for field crop sprayers in Belgium

Drift reduction class	**Buffer zone on the pesticide label**						
	2 m	**5 m**	**10 m**	**20 m**			
	Standard technique				**50%**	**75%**	**90%**
Standard	2 m	5 m	10 m	20 m	30 m	40 m	200 m
50%	1 m	2 m	5 m	10 m	20 m	30 m	40 m
75%	1 m	2 m	2 m	5 m	10 m	20 m	30 m
90%	1 m	1 m	1 m	1 m	5 m	10 m	20 m
Under all conditions: 1 m non spray zone on field edges (Good Agricultural Practice)							

Sprayer Inspection Schemes and Training

Several countries in the EU including UK, Belgium, Netherlands, Germany, France and Sweden currently have spray inspections schemes and by 2013 all member states will be required to implement their own scheme which meets the European standard. Voluntary testing schemes have become mandatory in most states. They involve an inspection of field crop and orchard sprayers every three to five years in most countries and as often as each year under the voluntary scheme in the UK.

The test is essentially a detailed 'roadworthy' inspection and can include tests on nozzle flow or distribution, pump flow, agitation, gauge accuracy, leaks, safety guards, plumbing, boom stability and boom controls. The purpose is to ensure safety of operators, accuracy of application and reduction of contamination.

In the UK, where boom spray testing has been conducted for several years, the number of machines being tested and found with faults has only be reduced marginally.

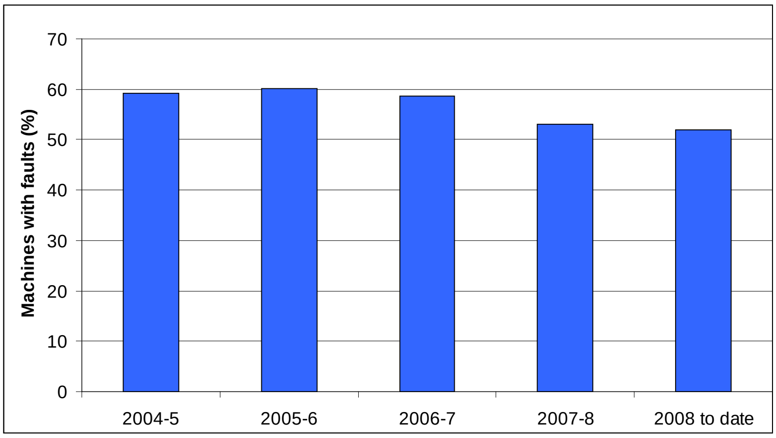


Figure 5: Proportion of boomsprays tested under the UK National Sprayer Testing Scheme each year since 2004 being found to have faults.

Under the Voluntary Initiative in the UK spray operators and farm managers, advisors and resellers are required to participate in ongoing training. Farmers attending accredited events such as field days, technical workshops, seminars and information days are awarded points which count towards meeting a yearly total for accreditation. The scheme rewards farmers for increasing their knowledge and helps ensure they are up to date with the latest information. Sprayer inspection schemes have helped to increase the value of second hand machinery and in the UK it satisfies crop assurance schemes and food retailer protocols.

In Belgium the testing scheme is operated by the government whereas in most other member states a separate organisation manages the program using trained inspectors to carry out testing. Consistency between assessors and training of the assessors are key requirements to a successful system.

A survey in countries both with and without compulsory boomspray testing showed that the testing is the most reasonable and profitable component of the whole pesticide application regulatory process. Average pesticide use reduction resulting from regular boomspray testing and improved, regular and ongoing maintenance was between 5 and 10%. The savings regularly exceed the cost of repair and inspection (Gill, 2007).

The testing scheme does add costs to the producer and spray owner. It is difficult to evaluate the real benefit of such a scheme given the size and uniqueness of each participating country. To be successful any scheme must incorporate spray operator accreditation to maximise the benefits to industry, the environment and the community. This will equip the user with the right knowledge of their own spray equipment ensuring it will perform at best practice level.

Recommendations

Pesticide application in Australia covers many agricultural sectors including grains, cotton, fodder, horticulture (fruit, vegetable and nursery), forestry and natural resource managers, local government and home gardeners. It also covers operators, advisors, regulators, retailers, sprayer manufacturers and pesticide manufacturers. However currently there is no means to bring all these participants together and have a whole of industry approach to research, development and extension for the pesticide application industry.

Spray operators must be empowered with knowledge to better understand what they are doing and the impact on the environment, the community and the customers. With knowledge and understanding there will come a willingness to improve the outcomes for all parties concerned.

Spray operators need to be given good reason to adopt better application techniques. A better understanding of the principles of spray application and the impacts of environmental contamination though point source and off target movement will help, but there will need to be some financial benefit for widespread adoption. Australian society has to start rewarding operators who deliver benefits to the environment and the consumer, rather than demanding or legislating for change.

The spray application industry must come together as a whole and be proactive in its approach, learning form what has happened in other countries with the aim of working under less regulation but producing a cleaner greener product with less impact on the environment. Having looked at the methods being used in the USA, Canada and through Europe to improve the sustainable use of pesticides the following recommendations are pertinent for Australia.

Regulation

Boom spray assessment

Boom sprays should be assessed and made to meet a set of standards including: nozzle flow/ distribution; rate control performance; pump output; gauge accuracy; soundness of plumbing (no leaks); contamination points; and ability to be cleaned. In the first instance, a survey of spray application equipment could be used to identify key issues with Australian equipment and prioritise education and training. Boomspray assessment could be linked to quality assurance programs.

Benefits for users of drift reduction technology

Allowance needs to be given with regard to downwind buffer zones to operators who use drift reduction technology *and* have training *and* the demonstrated knowledge to apply pesticides using best practice, similar to the Voluntary Initiative Scheme used in the UK.

Spray operator accreditation

Linked to the sprayer inspection scheme, operators need to be better trained in the practical use of the equipment they are using. Accreditation should be an ongoing process and could be based on the UK points system where operators get points from attending events such as field days, seminars and training workshops. Some of the ownership of training should come under a stewardship program operated by the spray equipment manufacturers.

Manufacturers

Sprayer plumbing design

Improvements are needed to boom spray plumbing to reduce: contamination points; equipment cleaning time; time taken to charge-up boom lines; and water volume required to clean out. Adequate tank agitation is also required. Sprayers need a circulation system so that the boom line can be charged prior to paddock entry and cleaned without disposing concentrated solution in the field.

Training

Sprayer and spray component manufacturers need to be involved in the ongoing training of spray operators in some type of stewardship program.

Industry

Australia needs an across-industry (product) spray application organisation to link stakeholders and coordinate the research, development and extension effort and deliver practical solutions.

The industry would also benefit from more application specialists who can link all the sciences involved in the spraying process and provide technical training and advice to operators. Industry specialists could also play a significant role in promoting the improvements occurring in spray application and educating the general public to allay unfounded fears over environmental and personal contamination.

Research

Key areas of research include:

- Field studies to ground truth spray drift models used by the APVMA to determine downwind buffer zones. The models used are based on Ag Drift models developed in the

United States and are generally untested in practice. Field testing in Europe is conducted at speeds up to 14km/hr and is therefore irrelevant to broadacre crop spraying in Australia.

- Off target movement of spray and weed control under controlled traffic farming systems with retained standing crop residue. Does standing stubble reduce off target movement and are weeds easier to control in this system?
- Improvement in pesticide efficacy using coarse droplets in order to reduce spray drift while achieving pest control objectives. There may also be an added benefit with reduced dose rates.
- Bio-beds and other methods to reduce point source contamination, especially with techniques to clean drums and lids, and reduce waste residue water during cleaning.

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Plain English Compendium Summary

Project Title:	Responsible Pesticide Application: Droplet Delivery, Deposition, Uptake, Regulation and Testing
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Objectives	To investigate ways to improve spray application through the adoption of new technology and a better understand of the droplet delivery, deposition and uptake process. To evaluate the impact of regulation and the pros and cons of spray inspection schemes.
Background	There is increasing awareness from the public about pesticide use. Technology and scientific reports on pesticide application are abundant, however some fail to generate maximum benefit because there is often conflicting opinions and often a lack of understanding of the basic principles of the spray application process. There are large differences in Buffer zones between Australia and the European Union and drift reduction schemes in the EU also reward those operators who use equipment which reduces the impact on the environment.
Research	Spray application researchers were visited along with spray operators, farmers, industry representatives, boom spray, nozzle and chemical manufacturers throughout England, Ireland, Belgium, Netherlands, Denmark, Germany, Canada and the USA. A review of literature also took place.
Outcomes	Pesticide application in Europe and the UK is different to broad acre crop spraying in Australia. However, we can learn about ways to manage point source contamination, boom spray design, clean out and waste water disposal. Furthermore drift reduction schemes are an excellent method of encouraging the adoption of best practice. A better understanding of adjuvants and plant structures will help improve pesticide efficacy.
Implications	The pesticide application industry must come together as a whole and have a proactive approach with the aim of working under less regulation but producing cleaner greener products with less impact on the environment.
Publications	GRDC Advisors Update Young, 2011