Session 4B

Formulation and Application Technology for the Future

Chairman:	Dr Graham Matthews *IPARC Imperial College Silwood Park, Ascot, UK*
Session Organiser:	*Duncan Webb* *Health & Safety Laboratory, Buxton, UK*
Platform Papers:	4B-1 to 4B-4
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Application technology – future trends and directions

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The main pressures currently influencing pesticide application technology in arable crops and that are likely to dominate future developments are the need to achieve:

i. high work rates so as to make timely applications, cover capital and operating costs and make good use of the available labour;
ii. uniform deposits at the target level that are important for efficacy for a wide range of products and are mainly related to nozzle characteristics and boom suspension performance;
iii. high levels of drift control so that the contamination of non-target organisms, including bystanders and residents in the countryside is minimised;
iv. good weed, disease and insect pest control with a decreasing product range and increasing constraints on the ways that products are used aimed at minimising the environmental implications and the effects of resistance on pesticide use.

For boom sprayers operating in arable crops, work rate is increased by using wider booms, higher forward speeds and lower application volumes. With existing sprayer designs, increasing spraying speeds and boom widths makes it more difficult to keep the boom at the intended height above the crop and increasing boom height has been shown to be a major factor influencing spray drift. Data from wind tunnel tests measuring airborne spray profiles at 2.0 and 5.0 m downwind of a single nozzle (Table 1) showed that increasing boom height by 200 mm could increase the drift risk by a factor of four and that boom height must be maintained if the full benefit of using drift reducing nozzle designs is to be realised. The use of a wind tunnel test with single nozzles may exaggerate the effects of boom height on drift but the effects shown in Table 1 have also been reported from field tests by a number of authors. There is also evidence from a number of studies to show that higher forward speeds increase the risk of drift particularly in low wind speeds.

Table 1. Relative airborne spray volumes measured 2.0 and 5.0 m downwind in a wind tunnel with single 110° nozzles of different designs, at different heights and in a mean wind speed of 2.0 m/s using a conventional nozzle at 500 mm as reference for both distances. (Data from project work funded by The Pesticides Safety Directorate).

Boom height, mm	Conventional flat fan nozzle		Extended range/variable pressure nozzle		Air induction nozzle	
	At 2.0 m	At 5.0 m	At 2.0 m	At 5.0 m	At 2.0 m	At 5.0 m
500	1.0	1.0	1.5	1.2	0.9	0.4
600	1.9	1.1	5.6	2.1	1.4	0.8
700	4.1	1.7	6.3	2.8	2.5	1.5
800	5.6	2.0	8.5	4.1	2.6	1.6
900	8.5	3.6	10.9	6.7	3.5	2.4
1000	10.6	5.6	14.7	9.0	4.0	2.9

Sensing and control systems are now being developed to aid and monitor the height of a boom. However, if booms are going to become substantially wider than 24 m, then maintaining a height of 500 mm will be challenging. Boom stability in both roll and yaw will also be important particularly if low boom heights are to be used since heights below the design value have important implications for the volume distribution pattern and uniformity of deposits at the target level. The use of increasing forward speeds is likely to have implications for boom stability and the way air flows around the spray, boom and vehicle, and further work is needed to investigate the effects of using such higher speeds.

Results from a recent review have indicated that the uniformity of deposit at the target scale rather than coverage may be an important parameter with regard to efficacy in many circumstances and that large droplet size distributions from some nozzle designs can give high levels of efficacy with all but small targets while also reducing the risk of drift. Therefore the need to maintain high levels of deposit uniformity, reduce drift and achieve high work rates with wide boom and higher speeds leads to the need to review nozzle arrangements on the boom to accommodate increased boom heights, use lower spray angles and a different nozzle spacing along the boom.

The use of nozzle designs that reduce drift and operate by generating large air included droplets (i.e. air-induction and twin-fluid nozzles) can only be fully exploited if nozzle selection approaches recognise the droplet size distributions and variability of deposit associated with different nozzle types and individual designs. The implications for both efficacy and drift control in a wide range of conditions needs to be recognised. While a relevant body of data is now becoming available, there is a need to extend existing spray/nozzle classification procedures to accommodate a wider range of nozzle types. Such a classification will initially facilitate the improved manual selection of appropriate nozzles but will also provide a database that can be used in automated control systems that are now being developed. The use of new control systems that will include an interface with an in-field location system will enable different application strategies to be implemented and recorded in different parts of the field to match target requirements and environmental constraints. A reduced drift strategy may then be used and recorded near field boundaries compared with other parts of the field with implications for improved chemical use and demonstrating compliance with the requirements for human and environmental safety.

Application technology is also likely to have an increasing role in minimising pesticide use and operating with a decreasing range of active ingredients. This will be based on identifying targets and matching applications to those targets. As an example, research is now looking to extend the use of vision guidance that is commercially used to steer mechanical weeding systems down crop rows, to identify the positions of volunteer potato plants in carrot and onion crops and apply a targeted spray treatment only to the weed. The trigger for this research was the loss of registration for metoxuron and the failure to identify other fully selective herbicides that could be used in its place. The development of such a system has implications for defining optimum values for parameters such as the applied dose, volume and distribution over the targeted weed as well as addressing issues concerned with minimising the contamination of the main crop.

It is concluded that application and formulation technology will play an increasingly important role in achieving the optimum and safe performance from a reducing range of active ingredients in the future.

An overview of recent investigations into potential bystander exposure to pesticides

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The current assessment for bystander exposure to spray drift is based on data obtained by Lloyd & Bell (1983). The application conditions used in these experiments were a 12 m boom set 0.5 m above the ground with a forward speed of 8 km/h, with a limited range of nozzles. The survey of application practice (Garthwaite, 2004) suggests that typical spraying parameters have changed, with wider booms (24 m) and faster forward speeds (12 km/h) being commonplace. The combination of wider booms and faster speeds are likely to result in booms being raised, and boom heights of 0.7 m above the ground and greater are thought to be typical. Increased boom height is likely to be one of the most important factors in increasing drift levels.

It seems likely, therefore, that the experimental conditions used by Lloyd & Bell could lead to lower levels of spray drift than those that may be occurring typically in current practice. The objective of the first part of the work was to establish whether the existing exposure assessment, based on Lloyd & Bell, is sufficiently representative of the exposure to spray drift occurring in modern application practice.

The exposure of the public to vapours following a pesticide application has also come under recent scrutiny. There are few data available that are relevant to UK conditions, and so the objective of the second part of the work was to obtain measurements of vapour concentration in air, relevant to UK conditions, following a pesticide application.

Two sets of experiments were conducted during 2005, the first of which measured airborne and deposited spray downwind of an application of epoxiconazole using two application settings giving different levels of drift, and the second of which made similar measurements downwind of an application of trifluralin, together with measurements of airborne vapour concentrations for up to 72 hours. Results showed a large difference in spray drift between two experimental runs with identical 'high-drift' application settings (Table 1), much greater than the difference in windspeed would suggest. The bystander contamination from spray drift was also different for the two runs, the highest equal to the maximum measured by Lloyd & Bell (Table 2).

Table 1. Epoxiconazole in airborne spray at three distances downwind, % applied dose

Downwind distance	Run 1 High drift	Run 2 High drift	Run 3 Low drift
2.0 m	51.0	3.9	0.3
5.0 m	27.3	2.62	0.16
8.0 m	15.9	4.16	0.23
Windspeed, m/s at 3.0 m	3.3	2.2	5.5

It is not possible from these data alone to deduce that changes in application conditions lead to higher bystander exposure from spray drift, although other published data strongly suggests that spray drift has increased in recent years. Table 2 also shows that as distance from the sprayer reduces from 8.0 m to 2.0 m, bystander exposure increases significantly.

Table 2. Total spray deposits, ml spray liquid, on mannequins. (An exposure of 0.1 ml spray liquid is used in the current risk assessment)

	Run ,1 high drift		Run 2, high drift		Run 3, Low drift		Lloyd and Bell, 8.0 m	
	2.0 m	8.0 m	2.0 m	8.0 m	2.0 m	8.0 m	Mean	Max
Adult	1.06	0.50	0.08	0.01	0.24	0.02	0.07	0.50
Child	0.45	0.05	0.04	0.00	0.27	0.03		

In the second set of experiments, measurements of trifluralin vapour showed that trifluralin was still being detected in the air after 72 hours when the experiment stopped. Differences between experiments (Table 3) could not be explained solely by temperature and windspeed. Concentrations were higher at 0.7 m above the ground (representing a child) than at 1.5 m (representing an adult). The trifluralin was not incorporated after application, contrary to label recommendations, in order to maximise volatilization.

Table 3. Mean concentrations of trifluralin (ng/l), measured approximately 2 m from the edges of the treated area.

Measurement position	Height, m	Run 1		Run 2		Run 3	
		24-hour mean	peak	24-hour mean	peak	24-hour mean	peak
East	0.7	5.4	9.2	6.5	8.9	19.7	78.1
East	1.5	2.2	3.3	2.4	3.0	n/a	n/a
North	0.7	5.8	20.7	3.5	4.6	16.4	87.7
North	1.5	2.9	5.2	1.8	3.5	13.2	31.9

The current exposure assessment for pesticide vapours assumes a maximum 24-hour mean concentration of 15 ng/l. Peaks in the concentration (measured over 1 or 2 hours) exceeded this level in runs 1 and 3, but when averaged over 24 hours, only during run 3 was this concentration exceeded. In all cases, the 24-hour mean was highest for the 24 hours immediately following application and subsequently declined to lower levels. Measurements were made immediately downwind of the treated area: consideration of probable worst-case behaviour is unlikely to conclude that a bystander or resident would remain at this distance for 24 hours. Estimations of potential exposure also need to take into account time-dependent patterns of both concentration and inhalation rates.

There is evidence to suggest that the exposure levels used in the current risk assessment can, on occasions, be exceeded, in some circumstances. However, the circumstances and likelihood of occurrence are unknown. Work continues in the BREAM project to identify ways in which the risk assessment can be improved and in which exposure can be reduced through the development of a predictive model of spray and vapour drift.

This work was funded by the Pesticides Safety Directorate, Defra, UK.

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Aerial granule application of flutriafol for soybean rust control

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Introduction

Asian soybean rust is one of the most important diseases of soybean mainly because early defoliation and reduction on yield. Due to difficulties on detection and aggressive infection rates, preventative applications on stages R1 and R2 are most used by farmers in Brazil if the disease is not detected in earlier stages. Godoy & Canteri (2004) reported that rust control was found to be more efficient with preventative applications, showing the importance of the application timing for the success of the treatment. For that reason, there is a large demand for application systems with high operational performance and efficiency in order to provide the good timing for the control.

The best results for preventative applications were found with fine and very fine droplets but this technology is prone to drift and evaporation reducing the time available for spraying (Antuniassi, 2007). Based on that scenario the aerial application of granule fungicides on the vegetative stages of soybean may be desirable since this kind of application has high operational performance, does not show risk of evaporation and is almost drift-free, resulting in larger and flexible time intervals for application. Also, longer fungicide residual effect may reduce the number of applications needed on the season. The aim this study was to evaluate flutriafol as a granule formulation using aerial application for Asian Soybean Rust control.

Methods

The experimental work was set up at the Filadélfia Farm, Campo Verde/MT, Brazil, on a commercial soybean field. The aerial application of granules was done after adjusting swath width and calibration according to ASABE S241.3 and S386.2 standards. The Ipanema EMB 202 aircraft was equipped with an Aeromot granule spreader. Flights were performed at 177 km/h, 10 m high and 20 m swath width. The rust control was done with one aerial granule application of flutriafol (Impact 1,5 GR, with 15 g a.i./kg) at the rates of 10, 15 and 20 kg/ha (respectively 150, 225 and 300 g a.i./ha) followed by none, one or two complementary ground applications of flutriafol + methil tiofanate (Impact Duo) at the rate of 0.6 l/ha (60 + 300 g a.i/ha), with mineral oil adjuvant at 1% v/v. Granule flutriafol had temporary registration for soybean in Brazil by the time this work was set up in the field.

The experiment was a split plot design with 3 treatments (10, 15 and 20 kg/ha of the granules) divided in three sequences of fungicide treatment (only granules, granules + 1 complementary application and granules + 2 complementary applications), with four replications. Granules were applied at V6 stage and liquid application was done from R3 to R5.5. Soybean rust was evaluated by incidence and severity analysis with averages compared by the Confidence Interval at 90% (CI 90%). The first complementary application was done the day the rust was detected on the field, 41 days after the granule application (41 DAG). The second complementary application was 15 days after detection. These applications were done by knapsack sprayer, with fine droplets and 100 l/ha.

Results and discussion

Flights were done at 28.8 to 29.1°C, 65 to 66% RH and 7.7 km/h crosswind speed. The coefficients of variation of granule distribution were 23.5% for 10 kg/ha, 18.9% for 15 kg/ha and 25.5% for 20 kg/ha. These values may be considered compatible to similar broadcast ground granule applications. The system was accurate with less than 0.5% error since granule consumption on the plots was 112 kg against a predicted 112.5 kg. The fungicide treatment showed better performance for higher granule dose rates at 41 DAG (soybean at R3), with incidences of 40, 30 and 34% respectively for 10, 15 and 20 kg/ha. The same happen to severity, with 0.2, 0.1 and 0.1%. At 49 DAG (R5.1) the same tendency could be observed with 4.2, 2.2 and 2.0% severity, with significant difference between 10 and 20 kg/ha by the CI 90%. This tendency was shown even on the plots with the first complementary application by the time rust was detected (41 DAG). On those plots, it was possible to observe that the complementary application reduced the level of severity in the same way for all granule rates (2.6, 1.3 and 1.1% respectively for 10, 15 and 20 kg/ha).

These results showed that residual effect of the granule fungicide could be observed around 50 DAG. Looking at the sequence of fungicide applications (granule + complementary) at 49 DAG, 10 kg/ha followed by one complementary gave 2.6% severity while 20 kg/ha with no complementary treatment showed a lower value (2.0%). This tendency reveals a potential for reduction on the number of application and/or larger time intervals between them, giving support to the initial hypothesis of this work. That means the granule application may became a high value tool for rust control after granule fungicides are fully developed and registered for soybean, since this would be a high performance application technology with lower risk of drift and reduced influence of weather restrictions. That would enable rust control programs with good performance for the best in terms of control timing, as described by Antuniassi (2007). There was no influence of granule dose rates at 56 DAG (R5.1), with a range of rust severity between 8 and 15% for the plots without complementary applications and 2 to 6% for the plots with one complementary. The last evaluation (71 DAG, R5.4) showed how important were the complementary applications along the season. Rust severity was 55, 75 and 89% respectively for two, one and none complementary treatments with significant differences by Confidence Interval at 90%.

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New spraying technologies for locust control in Central Asia: MiGs vs Micronairs

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Locust control in Kazakhstan, Uzbekistan, and other Central Asian countries of the former Soviet Union targets several locusts and many non-swarming grasshopper species. The most important economic species are the Asian Migratory locust *Locusta migratoria migratoria* L., the Moroccan locust *Dociostaurus maroccanus* (Thunberg), the Italian locust *Calliptamus italicus* (L.), and such non-swarming grasshoppers as *Aeropus sibiricus* (L.), *Arcyptera microptera* (F.d.W.), *Dociostaurus kraussi* (Ingen.) and others (Latchininsky *et al.*, 2002). The areas treated annually against these pests increased after the collapse of the USSR in 1991 and culminated with 10.4 million ha in the year 2000. The bulk of the control (> 80 %) was applied to the populations of the Italian locust.

Most anti-acridid treatments were done aerially using crop duster planes. The Soviet specialists were the first in the world to introduce aerial insecticide treatments into locust control in 1922-1925. In 1947, an ANTONOV-2 aircraft, which was specially designed for agricultural uses, was launched into mass production. Over half a century since its inception, this extremely durable, single-engine biplane still remains the leading agricultural aircraft in Central Asia, although the number of operational planes is dwindling. Its low take-off and landing speed and robust construction allows it to be used in a variety of field situations without building special airstrips. Just a 200 m long stretch of dirt road is enough to ensure safe operation. The plane carries a huge 1,200 l insecticide tank and can be equipped with different types of dusting and spraying equipment. Typically, it's a boom with 80 nozzles which produces a 40 m treated swath. This allowed for a high work rate of up to 1,200 ha/day. Besides the aerial applications, treatments are also applied from the ground using boom or (more often) rotary ventilator-type tractor sprayers. Inexpensive and very numerous, these sprayers remain the work-horse of anti-locust treatments even despite their very low work rate of only 40 ha/day.

The collapse of the USSR in 1991 brought significant changes in the economies of the newly-independent post-Soviet republics. Agricultural production was in a deep recession. In Kazakhstan, the former "bread basket" of the Soviet Union, the area of grain production decreased more than 50% in ten years, from 24 million ha in 1987 to 11 million ha in 1998. The abandoned fields became weedy fallows which created the most favorable habitats for the Italian locust and pest grasshoppers. In Kazakhstan, the situation was especially serious. In 1999, about 220,000 ha of cereal crops were destroyed by the Italian locust with an estimated damage of US $15 million. The anti-locust campaign of the year 2000 in Central Asia broke the world record in the annual areas treated against locusts: in Kazakhstan alone, 947,000 l of chemical insecticides were applied to 8.1 million ha. The cost of campaign exceeded US $23 million, with $20.1 million coming from governmental sources. In addition, over two million ha were treated in Russia and about 300,000 ha in Uzbekistan (Latchininsky *et al.*, 2002).

The Kazakhstan 2000 campaign became a showcase of diverse spraying equipment. Almost half of all treatments (43%) were done from ground machines. Among them, still the most numerous were the conventional, tractor-driven ventilator sprayers (3,500 units), which treated over three million ha. Thirty ANTONOV-2 aircraft treated over 1 million ha, or 15% of all areas. In addition to the conventional aircraft and tractors-driven sprayers, there were several other spraying platforms used in the campaign. Giant aerosol foggers were developed in one of the formerly secret Soviet defense-oriented scientific enterprises in Novosibirsk (Siberia). The spraying device is mounted on a 5-ton truck. The core of the sprayer is the enormous air compressor based on an engine from the MiG-15 fighter jet refurbished after its primary use. Some recent modifications utilize TUPOLEV-154 engine. The insecticide tank has a 1,500 l capacity. The fogger produces extremely fine aerosol droplets, with a median diameter between 10 and 20 μm. The treated width reaches 2,000 m and the insecticide dose rate is 0.15 l/ha and higher, which allows for a work rate of up to an incredible 5,000 ha per night. The treatments with this fogger are possible only during the night and under very low wind, otherwise the aerosol cloud may be driven kilometers away from the target. This technology proved very efficient in the control of forest insect pests, when it is necessary to quickly cover vast areas in sparsely populated zones. In locust control, the concerns over environmental safety limited the foggers use to large continuous treatment blocks situated far from villages, water bodies and other sensitive areas. Nevertheless, high productivity and fast coverage resulted in a sizeable proportion of anti-locust treatments (31 %, or 2.5 million ha) done by 60 of these machines in 2000.

There are more than 50 formulations of over 20 active ingredients registered for acridid control in Central Asia. The list is dominated by pyrethroids and also includes organophosphates, benzoyl-ureas, chloro-nicotinyls and phenyl-pyrazoles. Most products are water-based emulsifiable concentrates (EC) and only a few are oil-based Ultra-Low Volume (ULV) formulations. The ULV spraying was not very common until recently. The primary reason is the lack of locally manufactured, reliable and efficient atomizer sprayers. In the recent years, the situation started to change, and more and more atomizer sprayers (mostly, manufactured by Micron Sprayers, although some are assembled locally) are making their way into Central Asian countries.

The ULV technology has several uncontested advantages over the conventional, full volume spraying of EC formulations. This technology produces droplet sizes (50-100 μm) which are consistent and most appropriate for acridid targets. It does not require dilution of formulation, saves water, minimizes the evaporation of the insecticide, and eliminates additional application costs related to mixing. The biggest advantage of the full-volume, water-based formulations, is pragmatic: there is still a large quantity of conventional sprayers available in Central Asian countries. However, the recent practices showed the tendency of the ULV technology being increasingly accepted by both, end-users and regulatory authorities. At this point of time, the locust control market in Central Asia is still dominated by the water-based formulations and conventional spraying equipment, but the pendulum has started to shift towards the ULV. So far, supported by an "army" of tractor-driven sprayers, the MiGs are still holding the battle, but the Micronairs are coming, slowly but surely.

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Performance of ground spraying for soybean rust control

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Introduction

Asian soybean rust is one of the most important diseases of soybean mainly because early defoliation and reduction on yield (Camargo, 2005). According to Antuniassi (2006), application techniques for rust control must offer high performance on spray penetration and leaf coverage because of soybean dense canopy, even for systemic fungicides. Godoy & Canteri (2004) reported that rust control was found to be more efficient with preventative applications. For that reason, there is a large demand for application systems with high operational performance and efficiency in order to provide the good timing for the control. Antuniassi (2006) reported that after the 2004/2005 season in Brazil there was an increase demand for low volume systems (below 30 l/ha) and vegetable oil became a popular adjuvant. The aim of this study was to evaluate different ground application systems for Asian Soybean Rust control with tebuconazole + carbendazin.

Methods

The experimental work was set up at the Ponte de Pedra Farm, Rondonópolis/MT, Brazil, on a commercial soybean field. By the time the experiment was set up on the field rust severity was 1% on the upper and 18% on the lower parts of the soybean plants. The curative rust control was done with two applications of tebuconazole + carbendazin (Orius 250 EC + Bendazol 500 SC) at the rates of 0.3 + 0.3 L c.p./ha (75 + 150 g a.i./ha). The first application was at R1 (aerial at 12 l/ha, fine droplets, soybean oil adjuvant + emulsifier) and the second was 20 days after with a self propelled sprayer, only on the experimental plots, according to the treatments: rotary atomizer with oil adjuvant, 25 l/ha, fine droplets; rotary atomizer without oil, 25 l/ha, fine droplets; Electrostatic ESP system, 16 km/h, 18 l/ha, Teejet TX VK4, very fine droplets; Electrostatic ESP system, 22 km/h, 18 l/ha, Teejet TX VK4, very fine droplets; Hypro Twin Cap system, fine/medium droplets, 120 l/ha, Hypro TR 02 F 110 and LD 02 F 110; Hypro Twin Cap system fine/fine droplets,120 l/ha, Hypro TR 02 F 110 and TR 02 F 110; and hollow cone nozzles, 120 l/ha, Hypro HCX 04, very fine droplets. Soybean oil was used on the treatments with adjuvant, at the rate of 1 l/ha, plus 0.03 l/ha of emulsifier. The experiment was designed as a randomized block with seven treatments and four replications. Rust severity, grain yield and fungicide deposits were analyzed by the Confidence Interval at 90% (CI 90%). Carbendazin deposits were measured by HPLC. For this measurement samples with 15 leaves each were taken on three parts of the soybean canopy (upper, medium and lower) in each plot. Those leaves were washed on water in order to extract the fungicide up to 60 minutes after spraying.

Results and discussion

Applications were done at 26.6 to 31.8°C, 63.5 to 76.5% RH and up to 8.8 km/h crosswind speed. The analysis of fungicide deposits on the lower part of the canopy showed tendency of lower deposits for the ESP system with significant differences by the CI 90% to the rotary atomizers. Rotary atomizer plus oil adjuvant had significantly higher deposits than all the treatments. However, this difference was not significant to the rotary atomizer without oil. Deposits on the medium part of the canopy were lower for the ESP system, but this difference was not significant to the Twin Cap with medium and fine droplets. All other systems gave similar deposits on the medium part of the canopy.

Deposits on the upper part of the canopy were similar to all the treatments, with higher values to both rotary atomizer with oil adjuvant and the ESP 22 km/h. Rust severity was similar to all treatments on the upper part of the canopy, with no significant differences up to 29 days after the application. This control on the upper part of the canopy was important to keep some of the yield potential of the crop since medium and lower leaves were severely infected by the rust, with high level of defoliation. The ESP system gave higher level of rust severity on the medium and lower part of the canopy without significant difference by the CI 90% only to the Twin Cap with medium/fine droplets.

There were no differences between rotary atomizers with and without oil adjuvant in terms of rust severity. Soybean yield was similar to most of the treatments with the best average for the ESP 16 km/h, however without significant difference to the others. Twin Cap Medium/Fine and ESP 22 km/h had no difference from the non-treated areas (control plots). Soybean yield was also similar to the rotary atomizers with and without oil adjuvant.

General results showed that low volume systems like rotary atomizers gave appropriate performance compared to conventional systems (hollow cone at 120 l/ha), giving support to the trends described by Antuniassi (2006). However, most of the time systems with higher volumes and fine droplets also gave adequate performance. There was a general tendency for soybean yield results to be more similar to the rust control on the upper rather than the lower part of the canopy. That can be explained by the high level of rust severity and defoliation on the lower parts of plants, making the rust control on those leaves less important. For that reason systems like the ESP had average yield despite the poor rust control on the lower parts of the canopy.

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Effect of nozzle type and spray angle on the control of Fusarium head blight of wheat

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Introduction

Fusarium head blight (FHB) is a serious disease of wheat. The disease can result in significant yield reductions and can reduce grain quality through mycotoxin contamination and seed infection.

Control of FHB is problematic. Fungicides can be used but their effects are often variable under field conditions. This variability has been attributed to a number of factors, but most notably to timing of fungicide application. Less, however, has been published on the effects of application technology on disease control. The work reported here tested the hypothesis that nozzle type and increased spray angle could reduce the severity of visual FHB symptoms in glasshouse-grown wheat plants.

Materials and methods

A glasshouse pot experiment was sown on the 2 April 2002. Five spring wheat seeds of the cultivar Cadenza, treated with the fungicides bitertanol and fuberidazole, were planted 2.5 cm deep into John Innes No 2 compost in 10 cm diameter plastic pots. Plants were subjected to natural light and day length and were grown without artificial heating. Plants were treated with fenpropimorph as required to control powdery mildew (*Blumeria graminis* (DC.) Speer) and pirimicarb to control aphids. A compound (NPK) fertilizer (20:10:10) was applied at second node detectable GS32 at the rate of 3 g pot^{-1}.

Isolates of *Fusarium culmorum* were obtained from the Harper Adams University College culture collection and were subcultured on potato dextrose agar in 9 cm diameter Petri dishes. The plates were placed in an incubator in the dark at 20°C for seven days. Plates were then transferred to an incubator with UV lighting at 15°C for 10 days. A spore suspension was produced by ‘washing’ each plate with 5 ml of sterile distilled water twice and passing the washings through two layers of muslin. The resultant spore suspension was adjusted to concentration of 150,000 spores ml^{-1} with the aid of a heamocytometer.

Wheat plants were inoculated with conidia at the beginning of anthesis GS61 by spraying ears to run off (approximately 3 ml ear^{-1}) with a hand-held atomizer. Clear polythene bags were then placed over each ear for 48 hours.

Plants were treated with two fungicides, tebuconazole and metconazole, at maximum dose rate in 200 l ha^{-1} three days after inoculation. The fungicides were applied through Hardi-iso LD-015-110 flat fan nozzles and Lechler 90-015 bubble jet nozzles at a pressure of 3 bar. Spray angles of 0, 30 and 60° to the vertical were used.

Control treatments of no spray and water applied through the flat fan nozzles at a 0° angle were used giving a total of 14 individual treatments. Each treatment was replicated eight times and was assigned to a position according to a randomized block design.

A visual assessment of the extent of FHB symptoms was performed 28 days after inoculation.

Results

Fusarium head blight symptoms were observed 28 days after inoculation. The two control treatments, no spray applied and water only, had mean disease severity scores of 52.7% and 46.9% respectively. A paired two tailed 't' test gave no evidence to suggest ($P = 0.59$) that these values were significantly different from each other. The remaining treatments were angular transformed and analysed using factorial analysis of variance with fungicide, nozzle and spray angle as factors. There was no evidence of any significant interactions ($P>0.05$) between factors. Significant differences in disease severity were seen between the two fungicides and the three spray angles used but not the two nozzles (Table 1).

Table 1 The effect of fungicide, nozzle and spray angle on the severity of Fusarium head blight of wheat

Factor	Treatment	Visual percentage disease severity angular transformed
Fungicide	tebuconazole	21.7
	metconazole	18.7
Nozzle	flat fan	20.7
	bubble jet	19.6
Spray angle	0°	25.7
	30°	18.5
	60°	16.3

SED for Fungicide (1.13), nozzle (1.13) and spray angle (1.38)
P for Fungicide (0.008), nozzle (0.328) and spray angle (<0.001)
CV = 27, D of F = 77

Discussion

In this present study metconazole appeared to be more effective at reducing FHB symptoms than tebuconazole. The numerical difference between the two fungicides was small but statistically significant. There is evidence from previous work that both fungicides give similar levels of control with the most effective being dependant on the specific conditions of the given experiment.

The similarity in control between the two nozzles is not necessarily surprising given the test conditions. However the real issue with nozzle type and indeed spray angle, which did have a marked effect on disease severity, is coverage of the target. The conclusion from this work is that a change in spray angle increased coverage of the target thereby effectively increasing fungicide dose rate. In addition increased distribution of the spray on the wheat head may have contributed to the observed increased disease control. Results from this single glasshouse experiment do suggest that spray angle could play an important role in increasing the efficacy of fungicides for the control of FHB.

Reduced Agent and Area Treatments (RAATs) of rangeland grasshopper infestations using ultra-low insecticide dose rates and kairomonal attractants

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Grasshoppers annually consume about 25% of rangeland forages in the 17 western states of the U.S. at an estimated loss of $950 million. During outbreaks, grasshoppers inflict severe damage to rangeland and crops and require large-scale applications of broad-spectrum insecticides to control them. For example, during the 1986-88 outbreaks, over 8 million ha of rangeland were treated with 5 million l of insecticides at a cost of over $75 million. Because of dwindling federal funding, the responsibility for grasshopper control in the western U.S. is borne almost entirely by the producer. Therefore, there is a compelling need to develop economically and environmentally viable strategies of grasshopper management, which sustain profits, reduce the insecticide expense, and preserve non-target fauna. A dramatic upsurge of grasshopper populations accelerated by drought in the first years of the 21st century has enhanced the urgency to develop new, efficient grasshopper management approaches.

Reduced Agent and Area Treatments (RAATs) is a strategy of integrated pest management (IPM) for rangeland grasshoppers in which the rate of insecticide is reduced from traditional levels and untreated swaths (refuges) are alternated with treated swaths (Lockwood & Schell, 1997). RAATs work through chemical control, meaning grasshoppers are killed in treated swaths and as they move out of untreated swaths, and conservation biological control, which allows predators and parasites preserved in untreated swaths to suppress grasshoppers. RAATs can reduce the cost of control and the amount of insecticide used by more than 50% (Lockwood *et al.*, 2000). If a standard insecticide application costs $6.25 per sprayed ha, the equivalent RAATs program costs approximately $2.90 per ha protected. In 2003, about 160,000 ha of rangeland were protected from grasshoppers in the state of Wyoming using RAATs, which saved the local agriculturists over half a million dollars. Successful operational RAATs programs have been conducted in twelve western states.

Besides the economic advantages, RAATs strategy has tangible environmental benefits. Using RAATs, 60 to 75% less insecticide is applied to rangelands for grasshopper control. This translates into a significantly lower impact on non-target organisms when compared to full rate, blanket application of insecticides for conventional grasshopper control treatments (Smith *et al.*, 2006).

Effective RAATs strategies include aerial and/or ground applications of insecticides with long residuals, such as Insect Growth Regulators. Ground application of RAATs with a sprayer mounted on a heavy-duty all-terrain vehicle (ATV) was implemented on replicated 8-ha plots of short-grass prairie in SE Wyoming. The insecticide used was an insect growth regulator diflubenzuron (Dimilin 2L) at a dose rate of 18 g of a.i. per ha, which is half of the maximum labeled dose rate. Pre-treatment grasshopper densities ranged from 18 to 34 individuals per square m. Grasshopper communities were dominated by second and third instar nymphs of *Aulocara elliotti, Ageneotettix deorum* and *Melanoplus spp.*

Insecticide was applied in 6-m swaths as 50, 33 and 20% coverage. Fifty percent coverage yielded 83% of corrected mortality 21 d after application. Thirty-three percent coverage resulted in 78% of corrected mortality, while twenty percent coverage yielded 62% of corrected mortality 21 d post-treatment. Taking into account the costs of the insecticide and labor, the 33% coverage appeared to generate the best compromise for sufficient control and acceptable cost of the operation.

Vegetable oils have kairomonal properties to acridids primarily due to the presence of linoleic and linolenic fatty acids. These fatty acids are dietary essentials for grasshoppers and, once volatilized, can be detected by the grasshoppers' olfactory receptors (Bomar & Lockwood, 1994). The fatty acids may also be token stimuli for necrophagic grasshoppers seeking other nutrients, such as proteins, which are abundant in insect cadavers. Due to the presence of these fatty acids, certain vegetable oils used as insecticide carriers can function as "liquid baits" and markedly enhance the efficacy of aerial grasshopper control programs (Lockwood *et al.*, 2001).

To determine if kairomonal attractants also enhance efficacy of ATV applied RAATs-diflubenzuron treatments, a vegetable oil adjuvant, canola, treatment was compared to a mineral oil spray adjuvant treatment, Crop Oil Concentrate (C.O.C.), and a water carrier only treatment. The insecticide was applied at a dose rate of 18 g of a.i. per ha in a 33% coverage, for all replicated treatments. The adjuvant combinations included 1) 584 ml/ha of C.O.C, and 2) 146 ml/ha of C.O.C. (necessary for emulsion of the vegetable oil) and 438 ml/ha of canola oil. Without any adjuvants (with only water added), the diflubenzuron application yielded 69% control 21 d post-treatment. Adding C.O.C. increased the control to 83%, and the combination of canola oil and C.O.C. resulted in 89% control 21 d after application. Surfactant and kairomonal properties of adjuvants can enhance the effectiveness of diflubenzuron and thus ensure adequate protection from pest grasshoppers.

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The implications for efficacy of adopting air induction nozzles in cereal production

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Optimising fixed costs for broad acre crop production has necessitated a reduction in labour and machinery costs on UK farms. This has resulted in the need for high sprayer work rates to apply pesticides at the correct time. In addition to ensuring that the tank filling operation is time efficient, high work rates have been achieved by adopting wider spray booms, higher forward speeds and lower water volumes. All these can increase the risk of spray drift. However, in many situations, air induction nozzles can reduce significantly the risk of spray drift, particularly at low volumes, whilst maintaining the field performance of pesticides. This paper reviews experimental evidence to identify those situations where these nozzles can be adopted without a loss in pesticide efficacy.

Air induction nozzles

This nozzle design employs an orifice that controls flow rate and an air intake between the inlet and outlet orifices so that air is drawn into the nozzle body by a Venturi action. Many designs use a long mixing section as part of the nozzle to facilitate good mixing of air and spray liquid before the spray is delivered *via* a relatively large fan-shaped orifice. A coarser spray of air-included droplets is produced in comparison with the equivalent conventional flat nozzle. However, retention on foliage is aided by their relatively low speed and the 'shock absorption' properties facilitated by air inclusion. Research has shown that the levels of sedimenting drift produced by commercial and prototype air-induction nozzles are strongly correlated to droplet size distribution.

Research has also shown that there is a wide range of performance (in terms of volume median diameter) for versions of this nozzle design as produced by different manufacturers. This makes generic conclusions on the efficacy of pesticides applied through air induction nozzles unsound unless nozzles that reflect the full range of possible/available drop sizes are tested.

There is no correlation between the size of air induction nozzles and droplet size: droplet sizes produced by nozzles from different manufacturers do not rank in the same order across the range of nozzle sizes. With conventional hydraulic nozzles, drift increases with reduced nozzle output (and lower water volumes) and therefore the need to control drift is greater as volumes reduce. This is typically not true for air induction nozzles and the design is able to achieve reductions in drift of more than 75%, particularly with the smaller nozzle sizes. This makes them especially suited for reducing the drift associated with low volume spraying at high forward speeds.

Implications for efficacy

A review of published and unpublished experiments has indicated that at pressures of around three bar and total volumes of around 100 l/ha, air induction nozzles provide equivalent control with fungicides and herbicides to the corresponding conventional flat fan nozzle, provided that the targets are sufficiently large and easily accessible. Under marginal conditions for their adoption, air induction nozzles that produce the smaller droplets are more likely to produce equivalent control to conventional flat fan nozzles.

Research into the fungicide control of *Mycosphaerella graminicola* in wheat (*Triticum aestivum*) when the flag leaf is fully emerged, a growth stage when the crop canopy is relatively open and where the target is the top three leaves of the crop, has shown equivalent control with both air induction nozzles and conventional flat fan nozzles when applied at 100 l/ha. There is some evidence to suggest that where total volumes are reduced to 50 l/ha, the air induction nozzles providing the larger droplets result in poorer *M. graminicola* control than those providing the smaller droplets or from conventional flat fan nozzles.

Research has not been carried out for applications made when the crop canopy is likely to be dense, i.e. at the ear at one cm stage until the first/second node stage of cereals. Control of rusts may be required on the lower leaves at this time in order to reduce the level of disease at later growth stages. Field observations based on the 2007 brown rust epidemic in wheat (*Puccinia recondita*) in the UK suggest that air induction nozzles and total volumes of 100 l/ha may have resulted in reduced levels of control on the lower leaves when compared to conventional flat fan nozzles and/or higher volumes. This may also apply to fungicides for the control of stem base diseases, plant growth regulators and herbicides applied at those growth stages when the crop canopy is dense.

Perhaps surprisingly, with fungicides applied to the ears of wheat at a total volume of 100 l/ha, air induction nozzles have provided equivalent control to conventional flat fan nozzles of *Fusarium* species and the resulting mycotoxin production.

The size of the weed appears to determine whether air induction nozzles provide the same level of control with foliage acting herbicides as conventional flat fan nozzles at a total volume of 100 l/ha, provided that the crop canopy is not dense. Experiments have indicated that conventional flat fan nozzles provide superior control when grass weeds, such as *Alopecurus mysosuroides* have three leaves or less, or broad-leaved weeds, such as *Veronica persica*, have two leaves or less. Again, when the size of the weed is marginal for air induction nozzles, those providing the smaller droplets will offer better control.

A recent experiment on the application of a product mix of the herbicides flufenacet and pendimethalin, applied pre-emergence of the crop and weeds for the control of *A. myosuroides*, indicated that air induction nozzles gave inferior control to conventional flat fan nozzles when numbers were assessed when the weeds were tillering prior to the application of a post-emergence herbicide. Pendimethalin is a shoot uptake herbicide and flufenacet is taken up by the shoots and roots. Both are relatively insoluble and so it can be hypothesised that the reduced inter-deposit distances associated with the conventional flat fan nozzles may be expected to result in the herbicides being more likely to be located close to emerging shoots. However, it should be noted that the spray pressure in this single experiment was only two bar and hence marginal for air induction nozzles.

Typically, applications through conventional flat fan nozzles provide equivalent or improved efficacy at total volumes of 100 l/ha when compared to 200 l/ha. Findings from elsewhere in Europe suggest that total volumes higher than 100 l/ha can result in equivalent control from conventional flat fan nozzles and air induction nozzles in circumstances where air induction nozzles provide inferior control at a total volume of 100 l/ha.

Prototype to improve the quality of phytosanitary products application in a trellised vineyard

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Abstract
A prototype sprayer was constructed with its nozzle holder booms forming a kind of tunnel that travels over the plants. Spraying is thus performed in an enclosed space, preventing the shower of droplets from being blown away by the wind, reducing the evaporation rate and giving a very short distance between the nozzles and the plant surface. The efficiency of the applications was determined using water-sensitive paper and an in-house artificial vision system. The results show that the mean coverage percentage exceeded 54 % - sometimes reaching up to 79 %.

Introduction
Spraying should deposit droplets in such a way that they strategically cover all the plant surface. Reducing the droplet diameter leads to greater plant coverage rates and efficiency. A prototype sprayer for treating trellised grapevines was designed, constructed and tested. The aim was to use tiny droplets to achieve greater application efficiency, to reduce the actual amounts required and to achieve the maximum effect of those delivered.

Characteristics of the tunnel sprayer prototype
The sprayer nozzles used were cone type. A 45^{o} angle was used during the assays. Five nozzles were placed at the front and back of each tunnel. The machine can apply the product on two rows of plants per pass.

Fungicide application
The fungicide used in all assays was copper oxychloride. This was applied at a dose of 200 lha^{-1} (10 gl^{-1} water), calculated by taking into account a leaf area index (LAI) of 2.75, a mean droplet diameter of 250 µm, 80 droplet impacts per cm^2 of leaf and a 10 % loss of product.

Fungicide was applied at three different pressures: 0.1, 0.3 and 0.6 MPa. In order to apply the same amount of pesticide per hectare, the equation for the flow-pressure curve of the spraying boom nozzles and the displacement velocity equation, expressed in m/s, in function of the engine rotation speed (expressed in r.p.m.), was calculated.

The prototype was tested in a 12 ha trellised vineyard planted 1.5 m apart in rows, with 3 m between these rows. Before the product was applied, 36 water and oil sensitive paper strips were fixed to either side of the outer leaves of plants in every row, placed on the lower, middle and upper parts of every plant in each row. This was performed for the three different pressures.

To determine the percentage of paper surface covered by the sprayed droplets, a PC, a scanner and an in-house program were used, providing an artificial vision method that inspects the digitised images and determines the percentage of the leaf surface covered by the droplets.

Results

Table 1 shows the mean of percentage of surface covered at the different assay pressures by the prototype.

Table 1. Mean values percentages of the scripts surface covered by the droplets.

Pressure (MPa)	Under side of leaf	Upper side of leaf
0.1	5.79 a	21.60 a
0.3	9.87 ab	36.07 b
0.6	15.12 b	54.30c

The maximum mean coverage obtained was 54%, and on occasions more than 79% coverage was achieved.

Conclusions

A great variation in the percentage of the water-sensitive paper covered, and the influence of spraying pressure on this coverage was observed. This may be due, in part, to the high density of leaves on these plants, as well as the great variability in vine leaf orientation.

Significant differences ($p=0.05$) were seen in the coverage achieved at the three different pressures.

The coverage obtained on both sides of the leaves increased with nozzle pressure.

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Using uniform design and partial least-squares regression to prepare hypertonic emulsifiable concentrate

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Development of triazophos 20% hypertonic EC has been used as a case study in this paper.

Experimental design

Three factors (independent variables) were set as follows: (1) New Azone (NA), denoted by χ_1 (%); (2) Penetrating Agent T (PaT), denoted by χ_2 (%); and (3) BREAK-THRU S240 (S240), denoted by χ_3 (%). Each factor has four levels, *i.e.*, 1 to 4, and the value for each level is 0, 1%, 2% and 3%, respectively. Two dependent variables were selected as follows: (1) Y_1, difference of wetting time between pesticide preparations without and with penetrating agent; (2) Y_2, difference of penetration time between pesticide preparations without and with penetrating agent.

In this paper, by using DPS (Data Processing System) software of v6.50, UD table was set up as follows:

Table 1 $UD_4(4^3)$

Preparation	NO.	1	2	3
N_1	1	3	3	1
N_2	2	4	1	3
N_3	3	1	2	2
N_4	4	2	4	4

Results and analysis

Four types of triazophos 20% EC that contained penetrating agents were prepared based on table 1. One type of triazophos 20% EC that contained no penetrating agent was prepared as control (CK). The type and dosage of emulsifiers in all EC preparations were same. The wetting time and the penetrating time of the five preparations were tested by canvas sedimentation method. The wetting time and the penetrating time of CK were all 202.37s. The testing results of the two dependent variables, Y_1 and Y_2, were listed in table 2.

Table 2. Testing results of dependent variables

EC	Y_1 (second)				Y_2 (second)			
	Repetition			mean	Repetition			mean
	1	2	3		1	2	3	
N1	102.97	109.47	103.99	105.48	-87.32	-87.07	-86.79	-87.06
N2	119.83	106.33	102.59	109.58	13.9	14.62	14.9	14.47
N3	63.89	67.71	64.81	65.47	63.89	67.71	64.81	65.47
N4	171.14	173.61	170.63	171.81	122.12	114.96	106.24	114.44

The partial least-squares (PLS) regression was adopted to analyze the data. During the process of modeling, the two dependent variables were considered to optimize together.

Based on the data in Table 2 and by PLS regression, the resulting models, two quadratic equation models, were obtained as follows.

$$Y_1=73.9696+43.6935\chi_1-22.3466\chi_2-6.7913\chi_3-6.2855\chi_1^2+9.3735\chi_2^2+6.2855\chi_3^2-5.8333\chi_1\chi_2-8.3807\chi_1\chi_3+5.4142\chi_2\chi_3 \quad \text{......(1)}$$

$$Y_2=111.8502-76.22631\chi_1-73.5157\chi_2-1.6368X_3+10.3337\chi_1^2+13.5614\chi_2^2-10.3337\chi_3^2+1.1631\chi_1\chi_2+13.7783\chi_1\chi_3+24.6379\chi_2\chi_3 \quad \text{......(2)}$$

R^2 of model (1) and model (2) were 0.9883 and 0.9978, respectively. These suggested that regression level of each of the two models were good. When adopting maximum value for Y_1 and Y_2, we gained the best combination of independent variables, in which χ_1, χ_2 and χ_3 were 0, 3.0%, 3.0%, respectively. And the predicting value of Y_1 and Y_2 was 176.21s and 137.18s, respectively. In other words, when the dosage of NA, PaT, and S240 was 0, 3.0%, and 3.0%, respectively, the wetting and penetrating abilities of triazophos 20% EC obtained optimization, and the wetting time and penetrating time were 26.16s and 65.19s, respectively.

A new type of triazophos 20% EC that contained 0% NA, 3% PaT, and 3% S240, denoted by N5, was prepared. By testing, wetting time and penetrating time of N5 were 26.27s and 65.26s, respectively. So, the testing value of Y_1 and Y_2 was 176.10s and 137.11s, respectively. It was very close to the predicting value of Y_1 and Y_2, which was 176.21s and 137.18s, respectively. Compared with the other four preparations, N1, N2, N3, and N4, the difference between the testing values and the predicting values of Y_1 and Y_2 was very small (table 3). It indicated that the models have a good forecast capability. It also showed UD and PLS regression could successfully be used for developing of hypertonic EC.

Table 3. Comparing the values of predicting and testing

Preparation	Y_1		Y_2	
	Mean of testing value	Predicting value	Mean of testing value	Predicting value
N1	105.48	105.68	-87.06	-87.47
N2	109.58	109.76	14.47	14.13
N3	65.47	65.90	65.47	64.56
N4	171.79	170.98	114.44	116.08
N5	176.10	176.21	137.11	137.18

Discussion

In a completed experiment, we need to prepare a total number of $4^3=64$ EC, to test wetting and penetrating time of about $64\times3=192$, and to record 384 data; In orthogonal designation, considering interaction between two factors, we need to prepare a total number of $(4-1)\times3+(4-1)\times(4-1)\times3+1=37$ EC, to test wetting and penetrating time of about $37\times3=111$, and to record 222 data. If we apply UD, only 4 EC should be prepared, 12 degrees be tested, and 24 data be recorded.

In the present study, there existed two dependents and three independents. Any variation in each of the independents could lead to corresponding changes of the dependents. PLS regression had capacity to optimize the two dependents simultaneously, while stepwise regression, a commonly used regressive analytical method of UD, could not.