POSTER PRESENTATIONS

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Simulating field conditions in a glasshouse environment using 'soil box' technology; Part 1. The structure of the experimental unit

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ABSTRACT

Developing glasshouse testing methods that generate results which translate accurately from the glasshouse to the field is extremely challenging. The glasshouse offers excellent control over environmental factors such as temperature, humidity, and light, but relies upon artificial systems for root growth and development (pots, trays, etc) that are not a realistic representation of the dynamic edaphic field environment. Zeneca's Western Research Center in California has developed 'soil box' technology to simulate field edaphic factors which, combined with glasshouse environmental controls, creates a realistic field-like evaluation of agricultural products. The soil boxes allow scientists to mimic field agronomic practices such as seed bed preparation, seeding depth, irrigation, planting arrangements, pesticide/fertilizer application patterns and techniques, and development of pest populations. In addition, the box provides a deep soil profile that simulates moisture regimes that arise under field conditions. Soil box technology has many applications including evaluating soil or foliar applied pesticides, growing crops to yield, and evaluating the phenotype of transgenic plants. The use of soil boxes has enabled Zeneca scientists to identify factors influencing field performance of agricultural chemicals and agronomic traits earlier in the progression of products toward commercialization. Additionally, soil box trials can be initiated year round, providing scientists with the opportunity to evaluate potential products under closely simulated field conditions prior to the actual field season, with added benefit of having precise control over the establishment of the desired level of pest pressure or growing conditions.

INTRODUCTION

Often, significant resource is invested in optimizing the performance of agricultural products in the glasshouse and laboratory only later to discover that the 'artificial' system did not accurately reflect the environment in which these products would be used. Therefore, initial glasshouse and laboratory evaluation of agricultural products requires results that translate or correlate well to the field results. Understanding this glasshouse to field correlation is particularly challenging when soils significantly influence the performance of the products being tested or when large plants are required and thus demand significant substrate support.

Much of the challenge in generating reliable data is a result of plant growing methods that typically rely upon artificial systems like small moveable pots and containers that require a great deal of irrigation for root growth and development. These containers are not a realistic representation of the dynamic edaphic field environment. To improve translation of products from the glasshouse to the field, Zeneca's Western Research Center in California has developed 'soil box' technology to simulate field edaphic factors on a large scale. Combined with the ability to manipulate the glasshouse environment, the soil box system enables scientists to conduct realistic field-like evaluation of agricultural products.

Soil boxes enable glasshouse work at a scale that is similar to the field and thus mimic field agronomic practices such as seed bed preparation. In addition, the boxes offer more latitude in varying seeding depth, irrigation, planting arrangements, and pesticide/fertilizer application patterns and techniques. Further, the size of the soil boxes allows the development of pest population numbers and distributions similar to levels of pressure encountered in the field. The deep soil profile simulates moisture regimes that arise under field conditions and reduces the need for artificially supplementing tests with large volumes of water on a daily basis.

SOIL BOX DESIGN AND METHODS

The initial soil box constructed was approximately 3 m by 12.2 m (an area of 36.6 m^2) and had a maximum depth of 61 cm. The sides were made of redwood and rest on the glasshouse floor. Redwood is ideal for this application because it is resilient and durable under moist conditions. The structure of the box is a rectangular frame with no bottom so all of the drainage from the soil goes directly to the glasshouse floor. To ensure proper drainage, an 8 to 15 cm layer of coarse gravel is placed in the bottom of the soil box. Above the gravel is a thin layer of fiberglass mesh to prevent loss of soil from the box into the glasshouse drainage system. The soil is placed directly on the mesh, and it fills the box to within two centimeters of the rim. Due to the volume of soil, additional structural support for the box is necessary in the form of brackets and steel supports that bolt the sides of the box to the floor. Threaded rods cross the width of the soil box at 1.5 m intervals to keep the sides from bulging or changing shape as the soil settles. A cross section of the soil box with structural support is diagrammed in Figure 1.

The box was designed so that one end could be removed to allow gravel and soil to be moved into the box using wheelbarrows and other construction equipment. Once the box is full, the end is replaced and is not removed again unless a large amount of soil is removed. Any type of soil can be used in the box but the choice must be carefully considered as it is fairly labor intensive to exchange the entire volume of soil (approximately 21.5 m^3). This soil box was built to grow corn and simulate Midwestern United States growing conditions therefore a clay loam soil (~30% clay, 2-4% OM) similar to Illinois soil was placed in the box.

Initial tests in the soil box were irrigated using a drip system regulated by a spring timer. The volume of soil was large enough that sufficient water was retained over several days for growing plants. After a two hour period of drip irrigation, corn seedlings need not be watered for as long as five days. The deep soil profile retains water similar to field soils. The box design allows enough drainage to prevent plants from growing in stagnant water or experiencing anaerobic conditions. In the box, soil moisture has been observed to move via capillary action (i.e. equilibrates from wet areas to dry areas) - typically this means that water moves from deeper layers to the surface in the same manner that soil moisture will move upward in the soil profile in the field under drying conditions. Naturally, the soil box does not have an infinite water table that can be drawn upon, but this system allows water to behave in a manner and time scale that is much closer to the field than using small containers of soil.

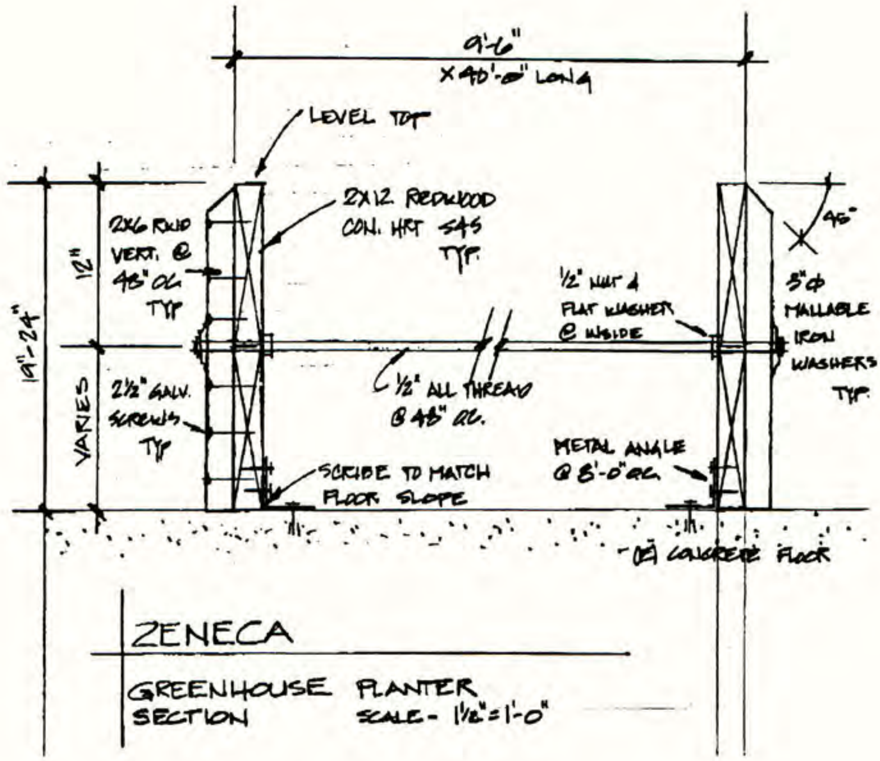

Figure 1. A cross section of the soil box. The thin horizontal bar across the middle of the picture is the threaded rod that holds the sides at a consistent width.

Care must be shown in selection of chemicals used for testing and maintenance in order to manage residues in the soil and prevent chemicals from draining with irrigation water from the soil box. To limit chemical residue of compounds with low mobility, contaminated soil can be removed, but this can be labor intensive. Chemicals that are highly mobile will either become distributed throughout the soil profile or will drain from the soil. Although this may be undesirable for some tests, it does highlight that soil boxes would be appropriate for studying chemical movement in the soil.

The large volume of soil is conducive to taking soil cores in the same manner that soil cores are taken in the field. The soil in the box closely simulates soil structure in the field, allowing the opportunity to conduct chemical and water mobility studies that provide more realistic parameters than laboratory soil columns. Initial testing in the soil box was conducted with tefluthrin applied in the planting furrows. Tefluthrin is highly immobile and thus does not distribute deeply into the soil profile (Bewick *et al* 1986, Bromilow 1987, Melkebeke *et al* 1990), therefore most residue could be removed during assessment when the corn roots were removed intact eight weeks after treatment. This process left very low concentrations of tefluthrin in the soil remaining in the box - less than 0.02 ppb.

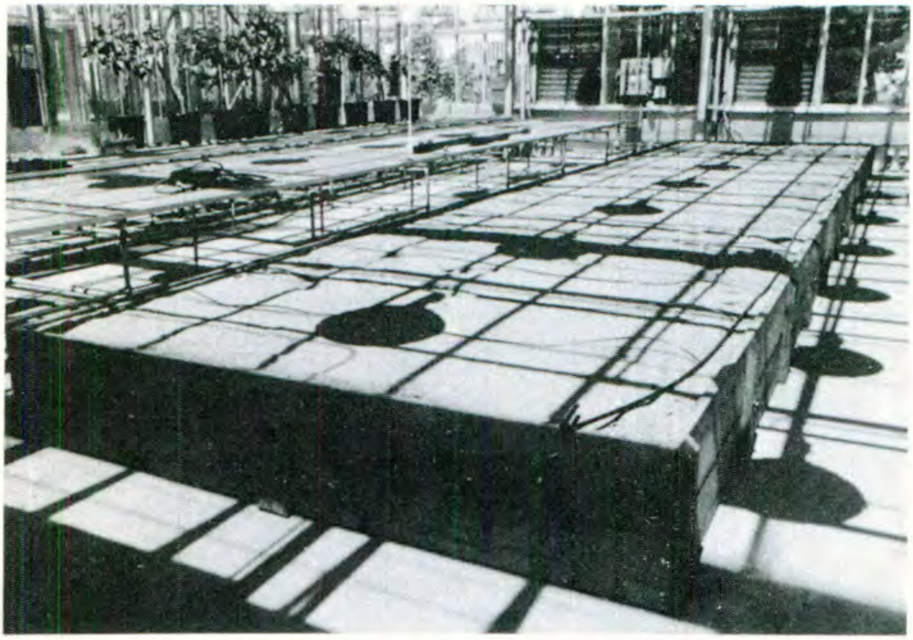

Figure 2. A finished soil box with the drip irrigation system on the soil surface.

For evaluation of potatoes, the soil box design included three separate partitions along the length of the box. This effectively divided the 12 x 3 m box into four separate 3 m x 3 m compartments, allowing for testing plant response to differing soil types. In addition, the large size of the planting area within the soil box allowed potato plants to be hilled through the growing season, which more accurately simulated field conditions. Finally, the drip irrigation system design included two drip lines for each row of potatoes, offset from the row by 15 cm; this configuration allowed for uniform water distribution to the developing tubers.

A third soil box was designed with the primary objective of conducting nematicide trials (Figure 3). The soil type selected for this box was optimized for nematode development. Additionally, the soil depth of the box was increased to nearly 1 m to provide a deep soil profile to mimic challenges posed by field conditions on nematicide efficacy which include migration of the nematodes downward in the soil to avoid the area of chemical distribution. Importantly, use of the soil box allows for the establishment of uniform nematode infestation levels, while minimizing the enhanced "efficacy" of nematicides commonly observed in potted plant tests.

At present, planting patterns and pesticide applications are completed using hand tools. Seed treatments, in-furrow, and T-band applications patterns have been applied using liquid and granular products in corn cropping systems. Insect pests are infested at the egg stage in dilute agar suspension (0.18%) using pipette equipment. This method allows for levels of infestation similar to the field and multiple waves of infestation. Between trials, the soil is cultivated with a hand guided tractor (rototiller).

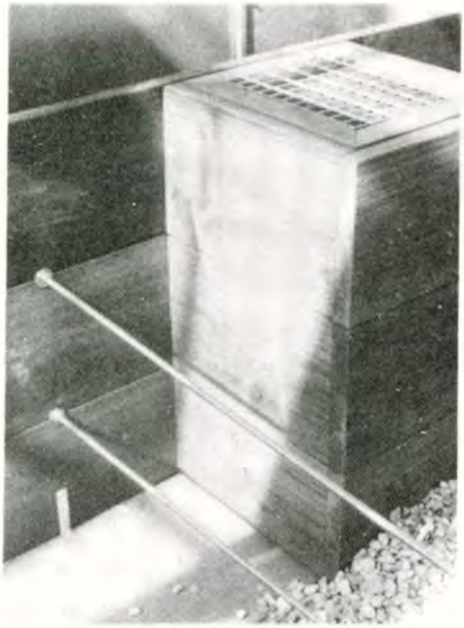

Figure 3. The structural support for the deeper nematode soil box.

Figure 4. The washing station.

Adjacent to the soil box, a washing station was built for cleaning and assessing plant roots and tubers (Figure 4). The drainage for the washing bins is facilitated by running a pipe from the catch basin below the washing station into the side of the soil box and down to the gravel layer.

DISCUSSION AND LESSONS LEARNED

Results from experiments conducted using the soil box were promising, but there were some observations on plant growth and development that warranted careful consideration. Corn plants germinated quickly, grew well, tasseled, and formed ears like plants in the field, but they tended to be elongated and smaller in diameter than corn in the field. Although this was initially thought to be caused by high stand counts, a reduction in stand from 10 plants/m to 8 plants/m did not reduce plant height overall. Even with supplemental light from metal halide lamps to extend day length, plants in the glasshouse do not receive enough sunlight to simulate strong summer light in the field. This was not a significant factor in soil insecticide studies, but it is a factor that should be considered in tests that depend on plant foliar development or yield for assessment. Elongation can be controlled or limited to some degree by the type of glasshouse heating system used and by varying the difference between day and night temperatures (Hanan 1998).

Having a large concentration of one crop in the glasshouse encouraged unwanted pests and disease to accumulate over the life of the test. It was necessary to develop comprehensive programs to control these problems with chemicals and mechanical means that would not interfere with the outcome of the tests. Strategies of pest control involved careful scouting followed by spot-applications of insecticide, or a more thorough regime of rotating weekly fungicide/insecticide applications. For example, silverleaf whitefly, *Bemisia argentifolii*, had the potential to be a major problem; susceptible crops in the soil box needed to be protected from this pest by an intensive spray regime.

Because environmental conditions such as light, temperature, and drainage can be variable even in a glasshouse, trial design had to be considered carefully. Soil boxes and subsequent trials should be arranged such that consideration is given to known temperature and light gradients in the glasshouse in order to maximize the value of a well conceived statistical design.

SUMMARY AND FUTURE WORK

The soil box technology has become an asset to scientists at Zeneca's North American research and development site. Conducting tests in soil boxes has characteristics that bring them very close to realistic field-like evaluations of agricultural products including deep soil profile, longer-term water retention, and good drainage. Soil boxes can be used to mimic field agronomic practices such as seed bed preparation, seeding depth, irrigation, planting arrangements, pesticide/fertilizer application patterns and techniques, and development of pest populations that are similar in proportion to the field.

Future interests include improving environmental factors like seasonal weather changes and mechanical means of maintaining tests. Thought has already gone into ways to simulate rainfall and wind abrasion as well as creating protocols for drought stress. There is also interested in utilizing equipment that simulates field equipment more closely to prepare the soil, plant, apply chemicals, and infest pests.

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Simulating field conditions in a glasshouse environment using 'soil box' technology; Part 2. Validation of methodology by evaluating soil applied corn rootworm insecticides

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ABSTRACT

These studies simulated a typical Midwestern US corn cropping system and evaluated the efficacy of tefluthrin and other soil applied insecticides for control of a moderate to high population of corn rootworms. Corn plants were removed from the ground with their root systems intact and damage from rootworm feeding was rated using standard field techniques for assessing root damage. Data from these tests indicated that damage to the untreated controls corresponded well with moderate to high pest pressure in the field. Levels of protection and numerical relationships between the relative activity of two applications patterns of tefluthrin were well correlated to field trials with similar levels of experimental error.

INTRODUCTION

Assessing the effects of corn rootworm injury in glasshouse experiments is extremely challenging using conventional methods of growing plants in relatively small containers. This is because corn roots grow and develop atypically in pots and it is challenging to coincide the growth stages of the rootworm with those of the corn plant which is crucial to simulating the field pest-crop complex.

Zeneca developed soil box technology in order to simulate field situations where soil pests occur in corn. With soil boxes, corn can be grown to yield, pest populations maintained near field levels, and plant growth stages co-ordinated with pest growth stages. Growing corn to tasseling stage in the presence of the pest also allows for the use of field damage grading assessment techniques that are standard for evaluation of mature field-grown corn roots.

MATERIALS AND METHODS

Tests were conducted in a soil box measuring 3 m by 12.2 m by 61 cm deep. The seed bed was prepared with a hand guided tractor (rototiller) to mix the soil and maintain consistency. Furrows were made with hand tools, and were spaced using 61 cm (24 inch) row spacing and 1.2 m length rows per application. Chemicals were applied by hand in either T-band, in-furrow or seed treatment patterns. After the compounds were applied corn seeds were sown in the furrows at a depth of approximately 3.8 cm. Corn varieties N4242, N7509, and Max

454 were planted at population of 8 to 10 plants/meter of row. The plants were watered using drip irrigation; after an initial two hour irrigation, plants were watered as needed. Tagline 12-12-12 fertilizer was added to new soil being added to the box between tests at a rate of 2.91 g/m^3 soil.

Western spotted cucumber beetle larvae (*Diabrotica undecimpunctata undecimpunctata*) were used as an indicator species for corn rootworm (genus *Diabrotica*) which is a major pest in Midwestern US corn (Krysan 1986). The eggs were suspended in a dilute agar solution (0.18% w/v) and pipetted into furrows alongside the corn rows 3.5 to 4 weeks (when the corn was 0.6 to 1 m tall) after planting. Egg populations ranged from 2000 to 4000 eggs/linear meter of row. Initial tests were infested once with 2000 - 3300 eggs/meter of row. Later tests were infested twice at two week intervals with 2000 eggs/meter of row for each interval. See Table 1 for infestation levels.

When the corn reached the tasseling stage, data were collected in the same manner as typically done in the field (Figures 1 and 2): corn plants were removed from the ground and intact root systems were soaked and washed to allow for rootworm feeding damage assessments using standard field techniques. Universities and field researchers generally use one of two assessment methods: the Iowa State University 1-6 Scale (Hill and Peters 1971) or a new Node Injury method, also developed at Iowa State University, in which the number of damaged root nodes are recorded directly rather than in the form of an index (J D Oleson personal communication). Values reported herein are results from using the Node Injury method because it is the most accurate reflection of the damage caused by the pest (Hanser *et al* 2000).

Figure 1. Removing corn stalks.

Figure 2. Removing roots for washing.

The data presented herein compare the results of five glasshouse tests utilizing the soil box and one field trial. The field trial design and treatment list was based on the results of box tests one and two and was conducted at Zeneca's Northern Regional Technical Center at Champaign. Illinois.

Tests were arranged in a randomized complete block design with 4 or 5 replicates. The blocks were defined by dividing the box across the 3 m width.

DISCUSSION

Data from these tests indicated that damage to the untreated controls (UTC) in the soil box corresponded well with moderate to high pest pressure in untreated field plots (Table 1). Results from several soil box tests are compared to a single field trial because we elected to use the Node Injury method of assessing root damage. (Node Injury data are incompatible with previous field assessments because those assessments employed only the Iowa State University 1-6 Scale.)

Table 1. Damage in untreated controls (column a) and standard errors of treatment means (column d) for tests performed in the soil box compared to a standard field trial. Comparison of the performance of standard tefluthrin granular treatments (columns b, c, e) in soil box and field tests using the Node Injury method. Values in lettered columns are the number of root nodes destroyed by rootworm feeding.

		# of root nodes destroyed				
		(a)	(b)	(c)	(d)	(e)
	Infestation level (eggs/m)	untreated	in-furrow	T-band	SEM	difference between patterns
Soil Box Test 1	3300	1.46	n/a	0.14	0.138	n/a
Soil Box Test 2	3300	1.33	0.36	0.10	0.093	.26
Soil Box Test 3	4000 (2 waves)	1.54	n/a	n/a	0.109	n/a
Soil Box Test 4	4000 (2 waves)	1.83	0.48	0.16	0.110	.32
Soil Box Test 5	4000 (2 waves)	1.41	0.86	0.35	0.085	.51
1999 Field Test	natural	1.67	0.33	0.21	0.144	.12

Standard error of the means from either soil box or field trials demonstrated no obvious differences in levels of variation between the tests (Table 1). Levels of feeding damage and numerical relationships between the relative activity of applications were well correlated to field trials including similar levels of variability (Table 1).

More data to quantify the degree of correlation of tests from the soil box to the field for corn rootworm control will be collected in July 2000 from several field tests and a soil box test comparing the same treatments.

Although the efficacy of tefluthrin varied slightly from test to test, the relationship between the two application patterns was consistent for all tests. It appears that data generated the soil box studies were even be slightly more discriminating of tefluthrin treatment patterns than were the data from the field study. These types of comparisons were difficult to make using plants grown in small greenhouse pots. Using soil boxes, tests that can make these comparisons and correlate well to the field can be applied year round rather than waiting for field opportunities to come once a year.

Figure 3. Assessing corn roots grown in the soil box.

Figure 4. Severe corn injury from rootworms.

A benefit of the soil box method is that it simulates a field-like situation with dependable testing conditions. For rootworm testing, this means that a population of pests that will emulate worst-case field scenarios is ensured for every test. This is also highlighted by a soil box has been constructed at Zeneca's Western Research Center to evaluate the efficacy of experimental nematicides. The use of this soil box has allowed for the development of relatively uniform densities of nematode populations, greatly reducing the large plot-to-plot variation often encountered in the field and the uncertainty of conducting trials in locations devoid of sufficient nematode populations to evaluate efficacy. The soil box dedicated to nematicide studies has a maximum depth of 80 cm, allowing for deep root growth profiles and nematode distributions mimicking actual field scenarios, thereby providing an accurate assessment of nematicide efficacy as a function of soil depth.

OTHER APPLICATIONS AND IMPROVEMENTS

Soil boxes have other applications for the evaluation of pesticide performance and agronomic traits to compliment full scale field trials. For example, soil boxes have also been used on several crops to evaluate the efficacy of compounds against foliar pest complexes. Typical glasshouse tests are often limited to one crop/pest complex, whereas the size of soil boxes allows for field-like pest populations and plant densities that encourage the pest to reproduce and distribute in a realistic manner. Studies are in progress to determine the correlation between soil box trials and actual field trials sharing identical treatment rates.

Besides entomological studies, Zeneca hopes to be able to use the soil boxes to evaluate fungicides and herbicides in a variety of use patterns. Crops can be grown to yield in soil boxes as Zeneca has done to evaluate the quality of potatoes and tomatoes.

Future interests for improvements to soil box tests include changing environmental factors that simulate environmental pressures in the field. For example, evaluating compounds under stressful conditions like excessively wet or dry conditions is a valuable way to distinguish between chemical analogues or formulations.

In the long term, the results from soil box tests can help environmental scientists to model the behavior of compounds and formulations - particularly distribution in the soil profile, runoff, volatility and degradation. Soil boxes may even be able to lend themselves some day the use of radiolabeled compounds to measure compound movement and breakdown.

SUMMARY

Soil box technology has improved Zeneca's ability to support and develop soil applied insecticides in corn. The methods of testing are similar to the field, including application patterns, pest infestation levels, and assessment of compound efficacy as protection from feeding by corn rootworm. For applications of tefluthrin to control corn rootworm, the correlation from soil box data to the field is close, and plot-to-plot variability of soil box tests is on the same order as a field test using the same application patterns.

Soil boxes are an excellent tool for growing crops to yield in the glasshouse. With careful considerations of chemical residues, soil box technology can be expanded to include experimentation in controlling nematodes, foliar pest complexes, and postemergence weed control. A future goal of Zeneca's is that soil box testing could lend itself well to techniques for creating and testing models of the behavior of pesticides in the soil environment.

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Comparison of herbicide performance in climate simulator, semi-field and field experiments

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ABSTRACT

The performance of tribenuron, ioxynil+bromoxynil and MCPA was compared in outdoor pot experiments, in climate simulators and in field experiments. Only minor differences were observed between the activity in outdoor pot experiments and in a climate simulator running at the same temperature and relative humidity. Generally, the activity of the herbicides was lower in the field compared to the pot experiments indicating the necessity of a 'transfer factor' when using results from semi-field experiments in field recommendations.

INTRODUCTION

In the development of the Danish decision support system for weed control, PC Plant Protection (PCPP), results from semi-field experiments have been used to support field data. The objective of PCPP is to minimise herbicide use without adversely affecting marginal returns. Based on input on the number and growth stages of the weed species in the field, PCPP selects the herbicides and doses appropriate to achieve the required effect. The choice of herbicide and dose is based on dose-response data of the various combinations of herbicides and weed species. The dose-response curves have been estimated by combining data from field experiments with a prior knowledge, from semi-field experiments, of the slope of the dose-response curves. Adjustment factors for growth stage and climatic conditions around the time of application have been estimated from semi-field experiments and experiments in climate simulators (Kudsk, 1989; Mathiassen *et al*, 1994). The structure and models in PCPP have been described in detail by Rydahl (1995) and Kudsk (1999).

Using the results from semi-field experiments in practice raises the question how well results from these experiments predicts the field activity of the herbicides. The objective of the present experiments was to compare the activity of different herbicides in outdoor pot experiments, pot experiments in climate simulators and field experiments.

METHODS AND MATERIALS

In four experiments, the efficacy of tribenuron, ioxynil+bromoxynil and MCPA was compared on pot-grown *Sinapis alba* plants placed outdoors and in climate simulators running at the same temperature and relative humidity regimes as outdoors. In two of the experiments, the efficacy of the herbicides was also examined on *S. alba* grown in the field.

Pot experiments

S. alba was grown in 2 litre pots in a soil/sand/peat mixture (2:1:1 W/W) including all necessary nutrients. The pots were placed on outdoor tables and after emergence the number of plants per pot was reduced to a pre-set number.

One day prior to spraying, half of the pots were transferred to a climate simulator where they were kept throughout the remaining trial period. In the climate simulator, temperature and relative humidity were adjusted every 5 minutes according to mean values collected by outdoor sensors in the previous 5 minutes. Consequently, the climatic conditions in the climate simulator was almost identical to outdoors except for light intensity as the maximum light intensity in the climate simulator was 500 $\mu E/s/m^2$.

The herbicides were applied at the 2- to 4-leaf stage of plants using a laboratory pot sprayer equipped with a boom fitted with two Hardi 4110-14 flat fan nozzles. Spray volume varied from 150 to 160 litres/ha between experiments. Plants from outdoors and plants from the climate simulator were sprayed simultaneously and were moved back to their growth environments immediately after spraying.

The three herbicides included in the experiments were: tribenuron (Express, 750 g a.i./kg), ioxynil+bromoxynil (Oxitril, 200+200 g a.i./litre) and MCPA (Herbatox M750, 750 g a.i./litre). Tribenuron was applied in mixture with 0.1% of a non-ionic surfactant. Each herbicide was applied at 6 doses and each treatment was replicated three times. Plants were harvested 2 weeks after application. Foliage fresh and dry weights were recorded.

Field experiments

Field experiments were conducted simultaneously with two of the pot experiments. *S. alba* was sown in the field on a sandy loam a few days prior to sowing in the pots. A randomised complete block design with a plot size of 6 m^2 was used with 4 replicates per treatment. The application of 6 doses of each herbicide was done with a self-propelled plot sprayer equipped with Hardi 4110-14 flat fan nozzles delivering a spray volume of 200 litres/ha. Application in the field and laboratory was carried out simultaneously. Two weeks after application a 0.25 m^2 quadrate was harvested in each plot and foliage fresh and dry weights were measured.

Statistical analyses

Within each experiment the dose-response curves of the herbicides applied to plants at each growing regime were estimated using a logistic four-parameter model (Kudsk, 1989):

$$U = \frac{D - C}{1 + \exp\left[2b(\log_{10}(ED_{50}) - \log_{10}(z))\right]}$$

where U is the plant fresh or dry weight, z is the dose and D and C are the upper and lower limit of the dose-response curve at zero and large doses. ED_{50} is the dose required to reduce plant shoot weight by half between the upper and lower limit and b is proportional to the slope of the dose-response curve around ED_{50}. By reparameterizing the model, ED_{70} doses were calculated. The suitability of the model in describing the data was assessed by a F-test for lack of fit comparing the residual sum of squares of the non-linear regression and the analysis of variance.

RESULTS

The ED_{50} and ED_{70} doses of the herbicides were estimated for each growth site. Of these two effect levels the 70% effect level is the most important and only the ED_{70} doses are shown in Figure 1. The ED_{50} doses will only be referred to in the text.

The activity of tribenuron tended to decrease in the order outdoor pots >climate simulators > field plots. However, significant differences in activity were only found between outdoor pots and the field and in experiment 4 only for the ED_{50} doses.

The activity of ioxynil+bromoxynil was similar on plants grown in outdoor pots and climate simulator apart from experiment 4 where the performance was significantly better in the climate simulator. The activity was lower in the field plots at both effect levels but in experiment 4 the field activity was only significantly lower than the activity in climate simulator and only at the 50% effect level.

The activity of MCPA tended to decrease in the order climate simulators > outdoor pots > field plots. At the 70% effect level, the activity was significantly higher in the climate simulator compared to outdoor pots in experiments 1 and 2 whilst no significant differences were found at the 50% effect level. The activity in the climate simulator was higher than the activity in the field irrespectively of effect level. In experiment 3, the activity on outdoor grown plants was also significantly higher compared to the field at the 70% effect level.

DISCUSSION

Generally, the activity of the herbicides was comparable on outdoor pots and pots in the climate simulator. However, a significant higher activity was found in the climate simulator than outdoors with ioxynil+bromoxynil in experiment 4 and MCPA in experiments 1 and 2.

The growing conditions in outdoor pots and in the climate simulator were very similar. The pots were sown on the same date and in the same growth medium. All pots were placed outdoors until one day prior to spraying when plants were transferred to the climate simulator. During herbicide application, one replicate from each growing regime was sprayed together and the plants were harvested on the same date. Consequently, the only parameter varying between the two treatments from application and until harvest was the growth site. As temperature and relative humidity were simulated very precisely, the most pronounced difference between the growth sites was the light intensity. Particularly in experiment 1 and 4 the maximum light intensity was lower in the climate simulator (450-500 $\mu E/s/m^2$) than outdoors (770-810 $\mu E/s/m^2$). The activity of ioxynil and bromoxynil has been shown to be inversely correlated with light intensity (Savory *et al.*, 1975) and the lower light intensity in the climate simulator could at least partly explain the higher activity of ioxynil+bromoxynil in the climate simulator. A similar relationship has not been shown for the phenoxyacetic acids but, as growth rate is closely correlated with light intensity, a higher growth rate could play a role in the lower activity on plants grown outdoors.

Previously, we have shown that the activity of ioxynil and tribenuron is influenced by climate (Mathiassen *et al.*, 1995). We have also found that the performance of the salt formulation of MCPA, which was used in the experiments, is affected by the relative humidity (unpublished). In the present results, the minor differences between the activity of the herbicides in the climate simulator and in the outdoor pots confirm that natural climate is simulated with sufficient accuracy in the climate simulators to ensure results with the same reliability as in outdoor pot experiments at least as long as light intensities are not extremely high.

Outdoor grown plants are exposed to wind and dust which can influence plant growth and, perhaps more importantly, damage the microcrystalline wax deposits on the leaf surface. This may lead to enhanced herbicidal activity by increasing the retention of the spray liquid and facilitating the penetration through the waxy layers (Garrod, 1989). However, in our experiments the plant surfaces can be assumed to be very similar at the time of application.

Comparison of the results from the pot and field experiments showed that, in general, field activity was lower than the activity on pot-grown plants. The ED_{70} doses of tribenuron were significantly higher in the field than on outdoor pots but they did not differ significantly from the ED_{70} doses on plants grown in the climate simulator. With ioxynil+bromoxynil and MCPA, the ED_{70} doses obtained in the field were significantly higher than those found in the climate simulator. In contrast significant differences between field-grown plants and outdoor grown plants were only found in experiment 3.

Several factors could be responsible for the higher dose requirements in the field. The growth stage, the soil humidity and the micro climate are factors which varied between pot and field conditions, and which are known to influence herbicide activity.

The growth stage of plants in the pots and in the field was similar in experiment 3, while in experiment 4 the average growth stage of plants in the field was smaller than in the pots (2 versus 3 leaves). However, in the pots, the number of plants was reduced to a low density of uniform plants where as in the field the growth stage varied much more and a proportion of the plants was, therefore, at a larger growth stage. As dose demand increases with growth stage (Kudsk, 1989), this could be responsible for some of the difference. Another factor of importance could be the higher plant density in the field. In contrast to the pots, plants in the field were not fully exposed to the spray solution as they in some cases covered each other.

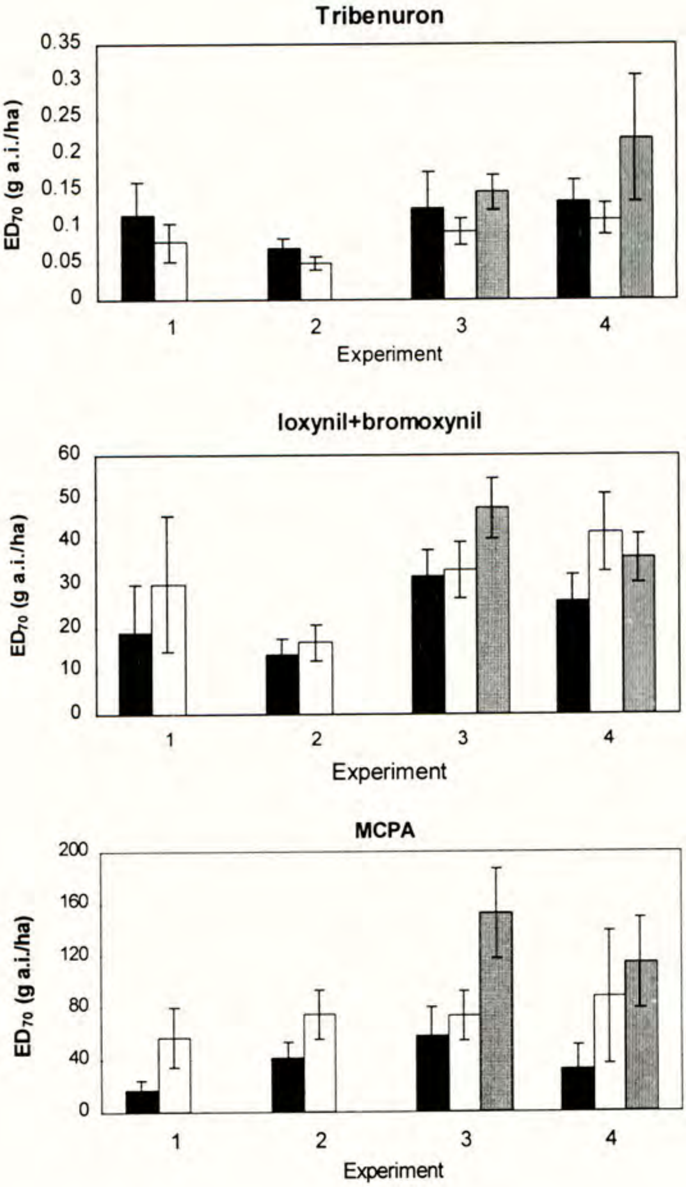

Figure 1. Estimated ED_{70} doses of tribenuron, ioxynil+bromoxynil and MCPA on *S. alba* in a climate simulator running outdoor climate ■, in outdoor pots □ and in the field ▥ .
The bars show 95% confidence intervals.

Herbicide performance is generally reduced at low soil moisture (Kudsk & Kristensen, 1992). The experiments including field plots were conducted in a period with low soil humidity. In experiment 3, the water potential of plants were measured to –5 bars in the pots but –10 bars in the field. Visually assessed soil humidity in the field was even lower in experiment 4. Finally, the micro climate at the soil surface may differ from that on an outdoor table or in a climate simulator. Several other factors could be mentioned but it is impossible to determine precisely the importance of each of these factors and their possible interaction.

In conclusion, the experiments have shown that it is necessary to apply some kind of a 'transfer factor' when converting results from pot experiments into farmers recommendations. In PCPP, this has been done by combining the results from semi-field experiments with field data and expert knowledge and, on basis of these data, adjustment factors for growth stage and climatic conditions have been generated.

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Glasshouse-to-field transfer; a case study in tralkoxydim adjuvants

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ABSTRACT

The solid adjuvant YF9779 gave a marked improvement in activity of tralkoxydim over the standard adjuvant TF8035 in the glasshouse. However, this improvement failed to translate to the field situation. A number of studies were carried out to understand the reasons for this glasshouse-to-field discrepancy. These demonstrated that the beneficial effect of YF9779 was mediated through the increase in spray solution pH brought about by the solid adjuvant carrier. In the field situation, the use of a higher tralkoxydim rate and tapwater with a greater buffering capacity than the deionised water used in the glasshouse, combined to offset the effect of YF9779 upon pH and hence no activity improvement was detected.

INTRODUCTION

Tralkoxydim is a cereal-selective graminicide sold in Canada and USA as a wettable granule (WG) formulation under the tradename 'Achieve' and used in combination with the liquid adjuvant 'Turbocharge' (coded TF8035). In recent years, work has been carried out at Jealott's Hill Research Station to investigate the development of a solid granular adjuvant formulation for use with tralkoxydim that would have the potential to be admixed within the herbicide WG pack.

This paper describes the identification of a highly active lead solid adjuvant in glasshouse testing which then failed to perform as expected in the field, and the studies that were carried out to understand this lack of glasshouse-to-field transfer.

MATERIALS AND METHODS

Glasshouse test plants were grown up either in 3" pots or as rows in trays, in an in-house compost mix and in a glasshouse set to 16°C day, 12°C night with a 14 h photoperiod. Supplemental lighting was provided by metal halide lamps. Test species were the grasses *Avena fatua* AVEFA and *Setaria viridis* SETVI. Pots were thinned to contain 3 or 4 evenly-sized plants per pot a few days prior to treatment. Trays contained rows with between 15-30 plants, depending upon species. Spray solutions comprised tralkoxydim as an 800 g/kg WG formulation dispersed in deionised water to which was added the respective adjuvant at a concentration of 0.5% wt/v (for solids) or v/v (for TF8035 liquid standard). Test plants were generally treated at a growth stage of 2-3 leaves and were sprayed in a laboratory tracksprayer using a 8001E nozzle at a spray pressure of 2 bars and application volume of 100 litres/ha. A dose response of 4 or 5 rates of tralkoxydim was employed with each adjuvant (depending upon test) and treatments were replicated 3 times for tray tests and 4 times for pot tests. Herbicidal efficacy was recorded by visual assessment, at 3 - 4 weeks after application, of % control compared to untreated control plants, where 0 = unaffected and 100 = complete kill. Where appropriate, these data were subjected to a modified logit transformation and then regression analysis to generate relative potencies for the various treatments.

Effect of ultra violet (u.v.) light upon performance was investigated by placing one batch of treated plants under a 'Honle' Solar Simulation lamp for 6.5 h immediately after spraying, whilst a corresponding set of plants was left under low fluorescent lighting in the spray laboratory. The plants were then transferred to a glasshouse set to the conditions described above for the duration of the test.

Comparisons of the effect of spray solution pH upon activity were made by diluting the adjuvants in water buffered using organic Trizma buffer. Comparison of activity on glasshouse- and outdoor-grown plants was made using plants grown outdoors in a mesh enclosed "birdcage" that permits environmental exposure but prevents bird damage.

RESULTS

Glasshouse screening of solid adjuvants

Glasshouse screening of novel solid adjuvant formulations with tralkoxydim identified a formulation reference YF9779 which was consistently around twice as effective as the commercial standard liquid adjuvant TF8035 at comparable rates of 0.5%. This superior activity of YF9779 was repeated in three separate glasshouse tests and it was also demonstrated that rates of YF9779 reduced to 0.25% were still significantly more active than 0.5% TF8035.

Figure 1 illustrates the comparative activity of YF9779 versus 0.5% TF8035 for both glasshouse and field data, where TF8035 activity = 1. For glasshouse data, relative potencies were estimated by regression analysis whilst for the field data, where dose responses were incomplete, comparative activity was estimated by visual comparison of the efficacy of the two adjuvants at identical tralkoxydim rates.

Field performance

Given its excellent glasshouse performance, YF9779 was tested in 4 Canadian field trials in Spring cereals. Two trials were conducted with 0.25% YF9779 and two with 0.5% YF9779, with one of each on AVEFA and the other on SETVI. It is clear from Figure 1 that whereas in the glasshouse YF9779 was 1.5 - 2 x more active than 0.5% TF8035, in the field YF9779 was 0.25 - 0.5 x as active as 0.5% TF8035. Therefore, the superior performance of YF9779 seen in the glasshouse failed to translate to a field situation.

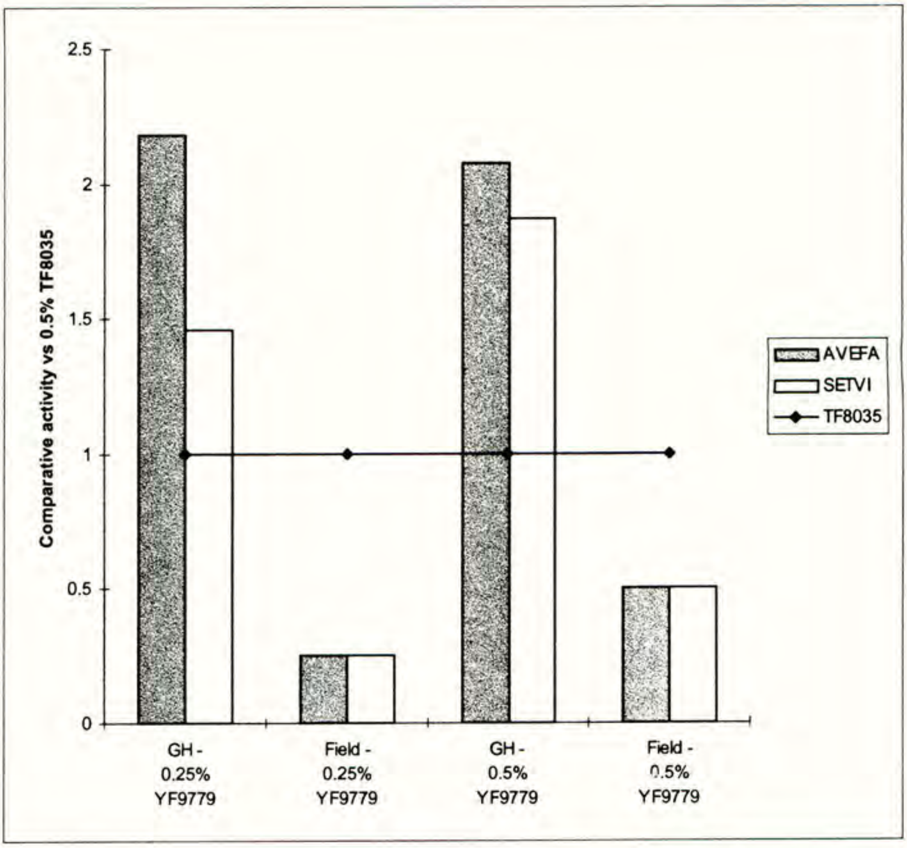

Figure 1. Comparative activity of YF9779 versus TF8035 in glasshouse and field.

Follow-up studies

A number of factors were suggested as possible explanations for the difference seen in adjuvant rankings in the field. These included;

(i) Differences between glasshouse and field batches of YF9779.

A glasshouse test compared the performance of the different batches of YF9779 used in previous glasshouse and field testing. There was no significant difference in activity between glasshouse and field batches (data not shown).

(ii) Differences in leaf-surface morphology between glasshouse- and field-grown plants.

It is well known that the cuticular morphology of glasshouse and outdoor plants differs quite significantly due to the effect of environmental factors such as wind and rain which can lead to abrasion of the epicuticular wax (Kudsk & Mathiassen, 1994). These differences in surface structure can result in differential adjuvant response.

A test was carried out to compare the performance of YF9779 with that of TF8035 on glasshouse plants and on plants grown outdoors in a birdcage. This showed that YF9779 was significantly more active than TF8035 regardless of whether it was tested on glasshouse or outdoor plants (data not shown). Although the outdoor test would have had some exposure to u.v. light, weather conditions during the test were mostly dull so a separate test was carried out to look at u.v. effects.

(iii) Differences in u.v. light levels between glasshouse and field.

Tralkoxydim, in common with other cyclohexanedione herbicides is susceptible to breakdown by sunlight. Radiolabel uptake studies (data not shown) demonstrated that the rate of uptake of YF9779 was slower than that for TF8035. Hence it is possible that in the field under the relatively high u.v. conditions of a Canadian Spring, the slower uptake of tralkoxydim a.i. with YF9779 might facilitate greater photodegradation and hence lower overall activity than for TF8035. In the glasshouse, where u.v. levels are minimal, photodegradation is unlikely to be a significant issue.

A glasshouse test was carried out to compare the performance of YF9779 with that of TF8035 under a Honle Solar Simulation lamp. YF9779 was superior to TF8035 under both high and low u.v. conditions (data not shown).

pH effects

Glasshouse testing had shown that an experimental liquid version, YF9939, of the lead solid adjuvant YF9779 was less active than the solid version, proving similarly active to TF8035. This focused attention on the role of the solid carrier (kraft lignosulphonate) in enhancing tralkoxydim performance. pH measurements revealed that 0.5% YF9779 was raising the pH of spray solutions made in deionised water to 7-9, compared to a pH of 5.5-7 for similar concentrations of TF8035 and YF9939. The spread in pH achieved for a particular adjuvant was in part due to variation in amount of tralkoxydim a.i. added at different rates (tralkoxydim being acidic will tend to lower the pH) and partly due to variation in initial pH of different batches of deionised water. Whatever the reasons, YF9779 spray solutions were consistently 1.5-2.5 pH units higher than corresponding YF9939 and TF8035 treatments.

In order to investigate the effect of pH on tralkoxydim/adjuvant performance, a glasshouse test was carried out comparing the activity of TF8035, YF9779 and YF9939, all added at 0.5% to spray solutions buffered at pH 5.5 and 7.5 respectively. Results are shown in figure 2.

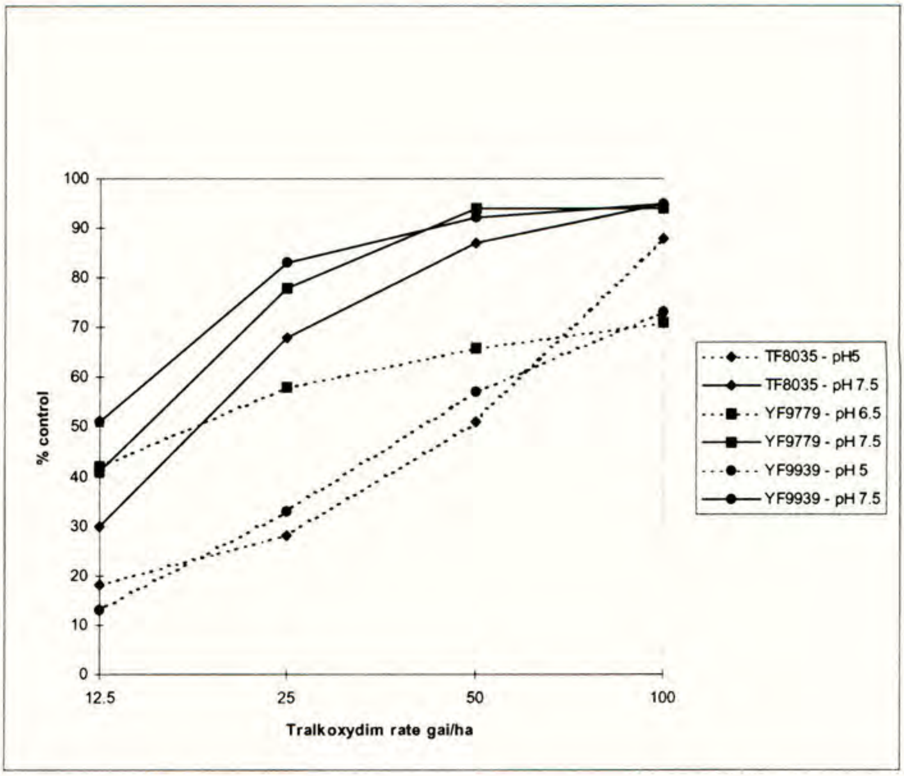

Figure 2. The effect of pH upon tralkoxydim performance with various adjuvants (mean % control of 4 grass weeds).

Reference to Figure 2 shows that there is a large effect of pH upon tralkoxydim performance which is much greater than differences due to adjuvant. Both TF8035 and YF9939 show similarly low levels of activity at pH 5 (lower 2 lines on graph) but when spray solution pH was increased to 7.5 both adjuvants showed a marked improvement in performance. Due to the nature of the solid carrier, YF9779 added to pH 5.5 buffered water raised pH to 6.5 and this treatment showed an intermediate performance to that seen at pH 5 and 7.5. YF9779 shows a similar level of activity to YF9939 at pH 7.5, both being marginally superior to TF8035.

These data therefore clearly demonstrate that the 2 x increase in tralkoxydim performance that was seen with YF9779 compared with the liquid version YF9939 and the standard TF8035 was caused by the effect of the supposedly inert solid adjuvant carrier upon spray solution pH rather than a conventional adjuvant-mediated benefit.

DISCUSSION

The failure of YF9779 to outperform TF8035 in the field as it had in the glasshouse is explained by

(a) higher application rates in the field (up to 200 g a.i./ha) than in the glasshouse, which mean that the additional tralkoxydim present in the spray solution will have tended to offset the pH effect of YF9779 by making the spray solution more acidic,

(b) the local tapwater used for preparation of field spray solutions had a higher initial pH (7.5-8) coupled with a greater buffering capacity than the deionised water used for glasshouse testing, and consequently showed a much smaller increase in pH upon addition of YF9779.

The increased tralkoxydim activity at more alkaline pH is somewhat surprising since one could expect a weak acid like tralkoxydim to be more active at acidic pH. It appears that under glasshouse conditions and with the formulation in question (800 g/kg WG) the benefit of increased a.i. solubilisation at alkaline pH outweighs the potential reduction in driving force for cuticular uptake due to increased polarity of tralkoxydim.

CONCLUSIONS

Many factors need to be considered when seeking to understand glasshouse-to-field transfer of pesticide performance. This paper demonstrates how it was possible to be misled by a glasshouse lead adjuvant that did not translate to the field owing to the difference in pH and buffering capacity of deionised and local tapwater, as well as, for a weak acid like tralkoxydim, the acidifying effect of the higher herbicide rates used in the field. As a result, subsequent glasshouse testing of adjuvants for tralkoxydim has been conducted in tapwater.

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Effective use of air for low drift of fine sprays

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ABSTRACT

As indicated at the previous conference, laboratory assessments of new pesticides are often done with a very fine spray from a twin fluid nozzle eg Potter Tower, or are sprayed to 'run-off', whereas in the field many different types of nozzles are used, some producing a coarse spray, especially to minimise spray drift. The aim of a new air-assisted nozzle is to employ stimulated pulsation to deliver more droplets in the 50 – 150µm diameter size range entrained in an airflow directed at foliage to reduce the risk of downwind drift. Wind tunnel studies showed that less drift was measured even with the application of small droplets. The nozzle lends itself to more accurate positioning relative to crop foliage while using less air than sprayers fitted with an air sleeve.

INTRODUCTION

The main emphasis in searching for new bio-active molecules has been the development of automated screening to process as large a number (c 100,000 – 250,000 per annum) of very small samples of chemicals, often less than 400µg per sample (Steinrucken and Hermann, 2000). However the translation of applying a molecule or a biological agent that is active under laboratory conditions to successful field use requires treatment of plants and pests in a situation which simulates more accurately the way in which the pesticide will be applied by a farmer.

At present, most laboratory sprayers used in the screening tests operate with a twin-fluid nozzle that produces a fine spray (Matthews, 1994). However, in the field many farmers have used air induction nozzles that provide a coarse spray to minimise downwind spray drift. However, the dosage of certain pesticides may need to be increased as large droplets may not be retained on small leaf surfaces (Jensen, 1999). Some leaf surfaces are especially difficult to wet with large droplets. Many studies have pointed out the advantages of small droplets to minimise droplet bounce even when the pesticide is formulated with a suitable surfactant (Brunskill, 1956, Webb et al., 2000). Thus, refinement of spray application technology in the screening process is an important area for development. This paper describes the use of air to adjust the spray spectrum produced from conventional flat fan nozzles.

The SPRAY nozzle

A flat fan hydraulic nozzle is used in conjunction with an air-jet from a Roots-type blower. The fan-shaped air-jet is directed to impinge on the liquid jet close to the orifice of a conventional flat-fan nozzle. This air-jet with a comparable momentum of the liquid sheet breaks the edge of the liquid sheet and causes it to stretch and bend. The thinning of the sheet and associated oscillatory motion causes the formation of smaller droplets than in the absence of the air-jet. Furthermore, the effect of the air-jet on the liquid results in cyclical separations of the airflow, or a 'galloping motion', so that packets of droplets are produced typically at audible frequencies. Droplet size is influenced by the flow of air through the air-jet as well as the choice of hydraulic nozzle and operating pressure. One example of the effect of air-flow on droplet size and the proportion of spray droplets that are between 50 and 150μm diameter is shown in Table 1.

Studies with various earlier prototype nozzle configurations (Miller *et al.*, 1994) led to the present design. (Fig 1.). Wind tunnel tests demonstrated the reduction in drift potential (Table 2).

Fig 1 Air-jet attached to hydraulic nozzle

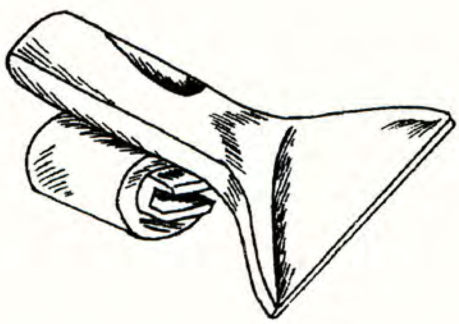

Table 1. Example of Volume Median Diameter (VMD) of spray with F110/0./3 nozzle. Droplet spectra measured with Malvern Particle Size Analyser. Nozzle - 15 cm from beam. 300 mm lens. [Proportion of the spray as percentage by volume between 53 and 150μm is shown in italics.]

Liquid pressure Bar	Air pressure (bar)			
	0	1.0	1.8	2.0
2	174 [*35.4*]	118 [*50.25*]	91.5 [*58.4*]	85 [*58.1*]
3	146 [*42.2*]	124 [*49.9*]	107 [*54.9*]	93.5 [*61*]

Table 2. Reduction in potential drift. (from Miller, Tuck and Rubbis, 1994)

Nozzle	Operating pressure (bar) Liquid	air	Liquid flow rate (l/min)	Total drift as % of nozzle Output
Fan 110/0.6/3 nozzle.	3.0		0.635	10.21
Twin Fluid.	3.1	1.3	0.69	4.96
SPRAY air-jet 80° 03.	3.0	3.0	0.625	1.73

DISCUSSION

The air-jet nozzle should provide a useful tool in spray chamber studies as it can be used to manipulate the spray droplet spectrum and simulate conditions more appropriate to field conditions. The distribution of the spray across the swath is similar to flat fan nozzles in commercial use. In particular the nozzle can be used in the field trials as wind tunnel tests have confirmed that there is less potential downwind spray drift as the small droplets are entrained in the airstream. Air between the packets of droplets is considered to reduce the impact of any other air-flow, either induced by the forward speed of the sprayer or the wind, so that the droplets remain within the air-jet. This reduction in drift potential allows smaller droplets to be projected to the intended foliar target. This is considered to be very important in view of the policy in many countries to minimise pesticide usage.

Improved coverage, achieved by applying smaller droplets, can reduce wastage of the active ingredient on non-target surfaces, especially the soil when foliage is the intended target. Detailed biological assessments of the performance of the nozzle are now needed to confirm whether the dosage required can be significantly reduced in contrast to the observed increase needed when applying certain pesticides with the air induction nozzles. In contrast to the provision of air assistance through a sleeve, the volume of air required per nozzle is reduced, but is greater than that used in twin-fluid nozzles (Matthews, 2000). However, unlike twin fluid nozzles, with an internal air-liquid mix, the air-flow is sufficient to assist droplet impaction within a crop canopy.

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Nozzle and chemical type effect on the dose response of barley powdery mildew

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ABSTRACT

A dose response for barley powdery mildew *Erysiphe graminis* f. sp. *hordei* was established in the field for sulfur, epoxiconazole and prochloraz. Control in the field began to fall at only a quarter of the manufacturers recommended doses. The effect of nozzle type was that the nozzles, which produced a fine uniform spray (flat-fan BCPC fine and medium quality), achieved the best control. Contrasting laboratory dose responses showed a loss of control with each chemical at $\times 10^{-5}$, $\times 10^{-3}$, and $\times 10^{-3}$ of the full dose respectively.

INTRODUCTION

Differences between effective doses in the laboratory and field in pesticide application are due to many biotic and abiotic factors (Enfalt. *et al.* 1997). However, the most important factor effecting loss in control in the field is ineffective application technology (Hislop 1987; Matthews 1997). Where the spray target is the crop, much of the chemical applied in the field is lost as drift and deposition to the ground. Chemical that does reach the target plant also has to deposit in the correct area for the pest in question. The deposit distribution varies in importance depending on the chemical used and the pest type in question. It might be expected that an even coverage of the spray solution would be the most effective for control of a phytopathogen such as powdery mildew. As the systemicity of the chemical increases the dependence on application efficacy, is assumed to decrease. Taking into account the effect of different spray characteristics and chemical activity control in the field was established. Control achieved in the field was compared to that achieved in the laboratory.

METHODS AND MATERIALS

Field dose response

Model system

For the field trials the model system was winter barley (Prisma) and powdery mildew (*Erysiphe graminis* f. sp. *hordei*). Each plot was 3 by 2m separated by a 3m-guard area consisting of bare soil. The guard area was introduced to reduce negative infection pressure from unsprayed controls and poor treatments (Bainbridge and Jenkyn 1976; Plank 1960). Once the crop reached an appropriate growth stage and an infection (natural inoculum) had developed, the plots were treated.

Chemicals

Sulfur, prochloraz and epoxiconazole were applied at 160, 80, and 40 g/ha, 202.5, 101.25, and 50.625 g/ha, 62.5, 31.25, and 15.625 g/ha respectively. All chemicals were applied at 200 litres/ha. These chemicals were chosen for their different levels of activity and systemicity. Sulfur was applied as a low activity (defined here as a chemical with only protective action), contact 'mildewicide' (not foliar feed). Prochloraz was applied as a non-systemic, high activity (defined here as a chemical with protective and curative action) 'mildewicide'. Epoxiconazole was applied as a high activity, systemic fungicide (Russell 1999; Tomlin 1997).

Nozzles

Four nozzle types were investigated; three flat-fan nozzles, fine, medium and coarse spray qualities (BCPC classification scheme) and a representative air inclusion nozzle. The air inclusion nozzle was chosen because of the increasing interest in this nozzle type and its unusual deposition characteristics. The nozzles were obtained from Sprayer Systems Co.®, the flat-fan nozzles were from the extended range XR 110 015, fine; XR 110 04, medium; and XR 110 06, coarse: The air inclusion nozzle came from the air induction venturi range AI 110 025.

Thirty-six treatments were applied in total, four nozzles applying three chemicals at three doses. Each treatment was replicated three times in a randomised block design along a soil inequality gradient.

Sprayer

A four-wheel drive All Terrain Vehicle mounted with a battery-powered pump and a 25 litre tank was used. Three single nozzle assemblies were mounted at 50cm intervals on a dry boom extending to one side of the vehicle 50cm above the crop. Patternator measurements showed that this nozzle spacing and height would give the most uniform spray pattern for all nozzle types.

Assessment of response

After the plots were treated and the deposits characterised, percentage infection counts were taken through the canopy over time. The development of infection was then compared to that found on the unsprayed plots and levels of control extrapolated. Unsuitable weather delayed spraying until growth stage 47 - 49 (Tottman and Broad 1987), where the flag sheaths were opening and the awns becoming visible. As a result no measurement of yield was taken.

Spray deposit characteristics

A fundamental part of this work was to characterise the spray deposited by each nozzle throughout the canopy and to the ground. A direct relationship between the spray deposit characteristic and control in the field was achieved by adding a tracer to the chemical tank mix. When the deposits had dried sample plants were removed from each plot and the deposit distribution measured. Qualitative and quantitative measurements were taken of percentage cover and uniformity using an OPTOMAX image analyser. Quantitative volumetric measurements were taken using a fluorescence spectrometer. The fluorescent tracer Tinopal CBS-X (Ciba Speciality Chemicals) can be visualised in the dry state and in solution. Thus, both of the assessment methods could be used in succession on the same sample thereby reducing variation and allowing direct relationships between spray characteristic and volume to be taken from the results. Image analysis data showed the mean percentage cover readings from the OPTOMAX image analyser. Percentage cover readings are a measurement of the total area in the field of view covered by the fluorescing spray droplets. A coefficient of variation is then applied to the % cover readings. Finally the spread of the data is measured, by counting the number of % cover readings residing in three different percentage cover categories. Category 1 was the number of readings taken with no deposit, category 2 was % cover readings of less than $1mm^2$, and category 3 was % cover readings of more than $1mm^2$.

Laboratory dose response

To develop a laboratory dose response for barley powdery mildew (*Erysiphe graminis* f .sp. *hordei*) a technique developed at Portsmouth University that measures spore viability on fungicide impregnated agar was applied. Powdery mildew spores were inoculated on fungicide impregnated agar via a Potter Tower modified for uniform and controlled distribution of spores for laboratory experiments (Chowdhury 2000 unpublished). Germination counts were taken at 24, 48 and 72hrs.

RESULTS AND DISCUSSION

Spray deposit characteristics

In terms of volume, the medium and coarse flat-fan and air inclusion nozzles all deposited similar spray quantities on the target surface. The fine nozzle deposited significantly less ($P<0.05$) than the coarse and medium nozzles but similar amounts to the air inclusion nozzle (Table 1). A summary of the results from the image analysis show that whilst the fine and medium nozzles produce a relatively uniform distribution, the coarse and air inclusion nozzles produce a less uniform distribution (Table 2 & 3). It appears from examination of the deposit images that a few very large droplets were responsible for the increased cover readings for the coarse and air inclusion nozzles compared to the fine and medium nozzles.

Table 1. Average spray volume (μl/cm^2) deposited on the target surface by each nozzle type. LSD = 0.064.

	Air Inc.	Fine	Medium	Coarse
Volume μl/cm	0.42	0.38	0.45	0.45

Table 2. The average % cover readings and co-efficient of variation from image analysis for the four different nozzle types.

Nozzle	% cover	% CV
Air Inc.	4.53	200
Fine	2.52	125
Medium	2.77	138
Coarse	4.03	167

Table 3. Spread of the % cover data from image analysis readings for the four different nozzle types

Spread of data	Fine	Medium	Coarse	Air inclusion
0	38	43	43	54
<1, >0	60	56	51	36
>1	2	1	6	9

Field trial one

There was no interaction between treatments however, each separate treatment produced significantly different mildew infection levels. Of the chemicals (Table 5), epoxiconazole produced significantly ($P<0.001$) better levels of control than prochloraz and sulfur. Half doses gave significantly ($P<0.001$) higher levels of control than quarter and eighth doses

(Table 6). The fine and medium quality flat-fan nozzles produced significantly ($P<0.001$) better levels of control compared to the air inclusion and coarse quality nozzles for each of the chemicals and doses (Table 7).

Table 4. Mean arcsine corrected % infection data for each chemical.

Chemical	Epoxiconazole	Prochloraz	Sulfur
	7.38 b	10.74 a	10.84 a

Table 5. Mean arcsine corrected % infection data for each dose.

Dose	Eighth	Quarter	Half
	10.72 a	10.05 a	8.19 b

Table 6 Mean arcsine corrected % infection data for each nozzle.

Nozzle	Air Inc.	Coarse	Medium	Fine
	11.12 a	10.22 a	8.54 b	8.74 b

The high activity systemic chemical (epoxiconazole) did improve control in comparison to the contact lower activity chemicals (prochloraz and sulfur). All chemical types however, were affected by the different spray characteristics. Control efficiency was reduced at just a quarter of the recommend dose. Complete control was not achieved in any treatment.

Laboratory bioassay

Ten fold dilutions for each chemical revealed that mildew control was retained down to 10^{-3} of the full dose for epoxiconazole and prochloraz, and 10^{-5} for sulfur. Average spore germination was 34% lower than the usual values obtained with this method which are around 50% (Chowdhury 2000).

Table 7. Percentage control for each chemical at eight different doses, not corrected for untreated mortality.

Dose	1	x 10^{-1}	x 10^{-2}	x 10^{-3}	x 10^{-4}	x 10^{-5}	x 10^{-6}	x 10^{-7}
Sulphur	100	100	100	100	100	99	96	87
Prochloraz	100	100	100	98	90	89	89	66
Epoxiconazole	100	100	100	99	97	97	69	92
Control	66							

Differences between the laboratory and field are large. However, total uniform coverage of all surfaces is not possible in the field. This has a major influence on field performance. Other factors, such as erosion of deposits by wind and rain, also reduce field performance. Considering the spray characteristic results, it seems that uniformly distributed tightly "packed" small droplets produce the best control levels for powdery mildew. Distribution is more important than slight differences in volume with all the chemical types. This can be seen by the improved effect of the fine spray quality nozzle, which showed improved biological performance even though it deposited the lowest overall quantity of spray on the target. By careful choice of nozzle and chemical type, improved control in the field can be achieved thereby allowing dose reduction.

This work is continuing. A full laboratory dose response is underway in order to produce a precise dose-response curve. Moreover, a second field trial is also in progress, investigating a larger dose range in an attempt to produce a field dose response curve. This experiment will help to define the effect of nozzle type on the nature and shape of the dose-response curve. In turn, dose reduction with effective application technology should be predictable.

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A new technologically unique adjuvant for use with fungicides and insecticides

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ABSTRACT

Fungicides and insecticides have been used for many years for the control of diseases and insects. A technologically unique adjuvant, HM8802-A, was formulated with improved wetting and spreading characteristics than conventional surfactants and crop oil concentrate adjuvants. In several field tests, HM8802-A increased pesticide efficacy compared to the pesticide applied alone. HM8802-A also was more effective in enhancing pesticide efficacy than conventional adjuvants in most trials. This was attributed to the improved deposition and coverage afforded by HM8802-A compared to no adjuvant or the other adjuvants, which was predicted by the physical characteristics of the adjuvant.

INTRODUCTION

Fungicides and insecticides have been in use for the control of diseases of plants and control of insects for many years. For the materials to be effective, they must be applied such that they reach the target either by thorough coverage of the plant surface or by entering the plant through the leaf surface. Several factors influence the efficacy of fungicides and insecticides and these are not limited to coverage, deposition or distribution through the plant canopy, or absorption into the plant. Formulating a pesticide to be appropriate for all the application variables is not practical, due to factors such as variation in the quality of the spray carrier and spray volume.

Research has demonstrated that oil-based adjuvants can enhance deposition of pesticides (Farris, 1989; Farris & Hirrel, 1992). For example, Farris & Hirrel (1992) reported a 25 to 60% increase in deposition at lower canopy heights in cotton when a crop oil concentrate was added to the spray mixture. Organosilicone-based surfactants can reduce dynamic surface tension substantially, resulting in thorough coverage of the target surfaces (Policello & Murphy, 1993; Stevens, 1993). The thorough coverage of sprays when organosilicone surfactants are included in the spray mixture can improve pest control (Stevens, 1993). Conventional surfactants can also reduce surface tension of the spray droplet, improving coverage and retention compared to water alone (de Ruiter *et al*, 1990). An adjuvant which combines all of these properties into one product would then have substantial advantages over other adjuvants. Research was undertaken to develop an adjuvant, designated HM8802-A, which would have physical/chemical characteristics similar to all of these adjuvant types but would have substantial pesticide enhancement compared to these adjuvants.

MATERIALS AND METHODS

The physical and chemical properties of several adjuvants were determined according to approved methodology or standardized testing procedures of the product development laboratory. Various parameters were measured to attempt to characterize the adjuvants in terms of spreading and coverage using standards developed by American Society for Testing and Materials (Methods E 2-0044-99 and D1331-89).

Table 1. Physical properties of adjuvants utilized in research trials.

Adjuvant	Adjuvant type[1]	Rate % v/v	Static surface tension, mN/m	Contact angle	Spread factor
None		0.0	72.0	94	1.0
HM7912	COC	1.0	35.3	59	2.0
HM8802-A	MSO-Osi Blend	0.5	27.6	37	3.0
HM9110	NIS	0.25	30.0	47	2.0
HM8902	Osi Blend	0.125	22.7	0	5.5
Silwet L-77	Osi	0.125	22.6	0	8.0

[1]Abbreviations: COC=crop oil concentrate, MSO=methylated seed oil, NIS=nonionic surfactant, Osi=organosilicone surfactant, TAE=tallow amine ethoxylate

Based upon surface tension, contact angle, and spreading data (Table 1), HM8802-A has physical properties similar to nonionic surfactant (HM9110) or crop oil concentrate (HM9712) adjuvants more so than to organosilicone-based nonionic surfactants (HM8902 and Silwet L-77). Based upon these data, it would be expected that HM8802-A would enhance fungicide and insecticide efficacy in the same way as nonionic surfactant or crop oil concentrate adjuvants.

RESULTS AND DISCUSSION

The enhancement of fenbutatin oxide efficacy by adjuvants was evaluated in apples. Both HM9110 and HM8802-A enhanced fenbutatin oxide compared to the miticide applied alone, as measured by mite counts (Table 2). Based upon the physical parameters determined, it would be expected that HM8802-A and HM9110 would have similar enhancement of fenbutatin oxide efficacy. However, HM8802-A enhanced fenbutatin oxide efficacy more effectively than HM9110, a nonionic surfactant.

At the label rate, the product prochloraz plus cyproconazole provided good to excellent control of septoria in winter wheat on leaves 1 and 2 (Table 3) but at the reduce rate of product, control of septoria was unacceptable. However, HM8802-A increased control of septoria at the lower rate being equal to that of the full rate of the fungicide applied alone. In contrast, the film-forming adjuvant, NuFilm actually reduced control of septoria compared to the fungicide applied alone.

Table 2. The influence of adjuvant on *Tetranychus mcdanieli* control by fenbutatin oxide at 1.12 kg ai/ha in apples.

Adjuvant	Rate % v/v	Mites per leaf at days after treatment 5		11		18		25		32	
None	0	12.88	a	12.88	a	38.88	b	30.80	b	44.16	a
HM9110	0.25	16.88	ab	9.76	ab	24.68	ab	8.56	a	15.08	a
HM8802-A	0.75	9.28	a	7.60	a	14.72	b	8.96	a	16.28	a
Untreated		30.96	b	47.36	c	26.72	ab	16.56	b	40.00	a

Means within a column followed by the same letter do not differ significantly.

Adjuvant effects on the control of *Botrytis cinerea* by iprodione in grapes were also evaluated. Both HM8802-A and HM7912 extended iprodione control of bunch rot and reduced the severity of the disease compared to iprodione applied alone (Table 4). HM8802-A gave greater enhancment of fungicidal activity than did HM7912. HM8802-A has better spreading characteristics than HM7912, which may account for its greater enhancement of fungicidal activity.

Table 3. The influence of adjuvant on *Septoria* spp. control by prochloraz and cyproconazole in wheat.

Prochloraz and cyproconazole rate[1]	Adjuvant	Rate % v/v	% *Septoria* control Leaf 1	% *Septoria* control Leaf 2
1X	None	0	100	70
0.5X	None	0	90	30
0.5X	HM8802-A	0.5	95	70
0.5X	NuFilm	0.12	70	20
0	None	0	20	0

[1]For prochloraz and cyproconazole rate, 1X=label rate, 0.5X=one-half label rate

Pyrausta nubilalis is an important insect pest of corn in the US. Both HM9110 and HM8802-A added to the spray mixture with cypermetluin decreased damage caused by *P. nubilalis* to corn compared to cypermethrin applied alone (Table 5). HM8802-A gave greater enhancement of insecticidal activity than did HM9110. HM9110 and HM8802-A have similar physical characteristics on the spray solution (Table 1) but HM8802-A was more effective in enhancing insecticidal activity than HM9110.

Table 4. The influence of adjuvant on *Botrytis cinerea* control by iprodione at 840 g ai/ha in grapes.

Adjuvant	Rate % v/v	Clusters, % infected		% Severity	
		9-16-93	10-12-93	9-16-93	10-12-93
None	0	1.8	4.3	2.5	3.5
HM7912	1	1.3	4.3	1.3	3.0
HM8802-A	0.5	0.5	1.8	1.3	2.5
Untreated		5.0	13.8	5.0	8.8
LSD (0.05)		2.7	5.3	3.4	6.1

Adequate coverage and deposition are required for maximum insecticide performance in cotton, especially for *Heliothis* spp. control. HM7912 added to the spray solution with spinosad increased spray deposition compared to spinosad applied alone when using hollowcone nozzles at 420 kPa spray pressure (Figure 1). HM8802-A further increased spray deposition compared to HM7912.

Table 5. The influence of adjuvant on *Pyrausta nubilalis* control in corn with cypermethrin applied at 0.112 kg ai/ha.

Adjuvant	Rate % v/v	Cavities per stalk	Cavity length mm	Percent control
None	0	0.98	36.6	42
HM9110	0.25	0.73	24.1	59
HM8802-A	0.5	0.38	13.0	69
Untreated		1.23	37.1	50
LSD (0.10)		0.58	16.8	38

Further work was undertaken to evaluate the enhancement of spinosad control of *Heliothis* spp. by HM8802-A. Results indicated that HM8802-A increased *Heliothis* control at the reduced rate of spinosad and was equal to the high rate of spinosad applied alone (Figure 2). This was probably due to the increased and more uniform deposition of spinosad when HM8802-A was included in the spray mixture (Figure l, Redding *et al*, 1998).

This work together with other unpublished research has demonstrated that HM8802-A can enhance the efficacy of several fungicides and insecticides. Although HM8802-A has physical properties similar to that of other conventional adjuvants such as nonionic surfactants and crop oil concentrates, HM8802-A frequently improved pesticide efficacy to a greater extent than these other adjuvant types. HM8802-A has a slightly lower contact angle than nonionic sntfactants (e.g. HM9110) or crop oil concentrate adjuvants (e.g. HM7912). This lower contact angle and the subsequent greater spread factor can result in greater coverage when HM8802-A is added to the spray solution and this would partially account for the improved efficacy. Research work has also demonstrated that HM8802-A improved

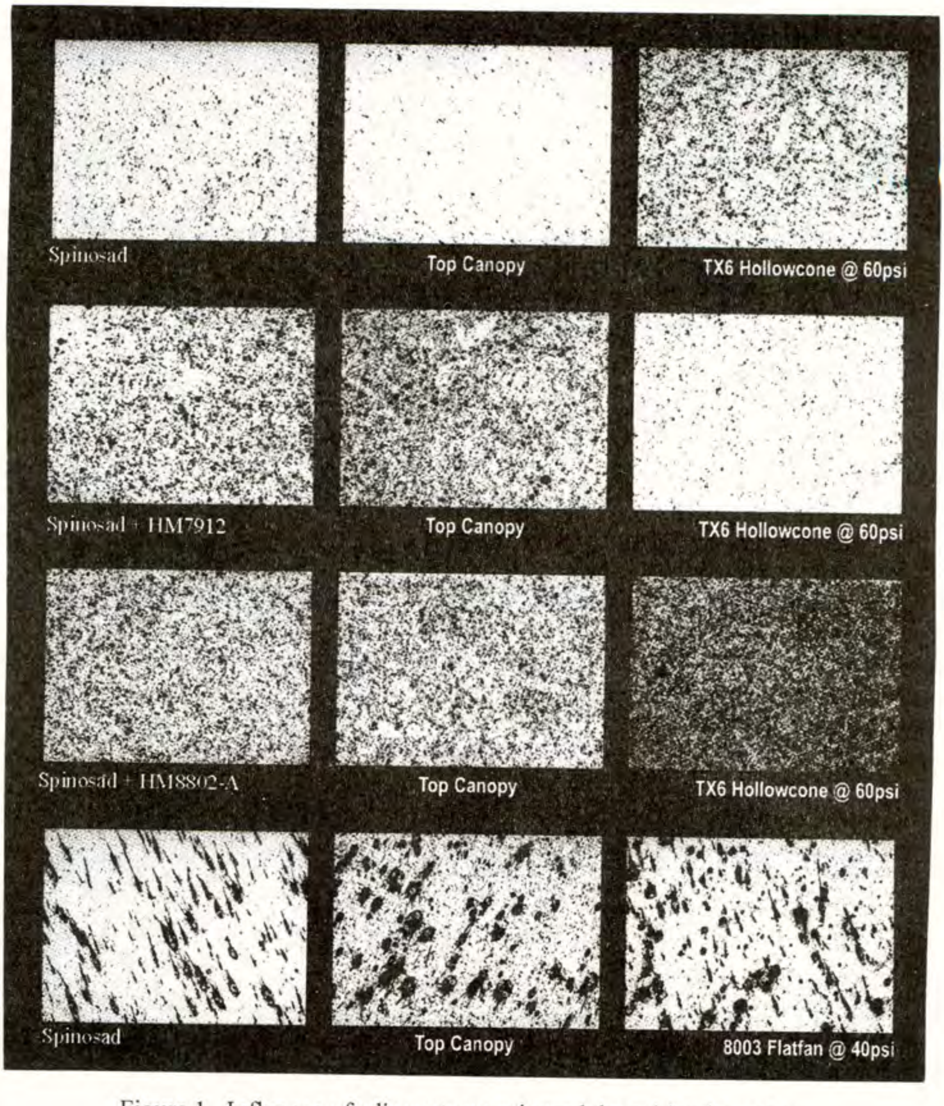

Figure 1. Influence of adjuvants on spinosad deposition in cotton.

pesticide deposition in cotton. The improved deposition of spinosad in cotton probably accounted for the enhancement *Heliothis* spp. control by spinosad when HM8802-A was added to the spray solution. HM8802-A is a technologically unique adjuvant that improves the control achieved by both insecticides and fungicides by increasing coverage and deposition of the pesticide.

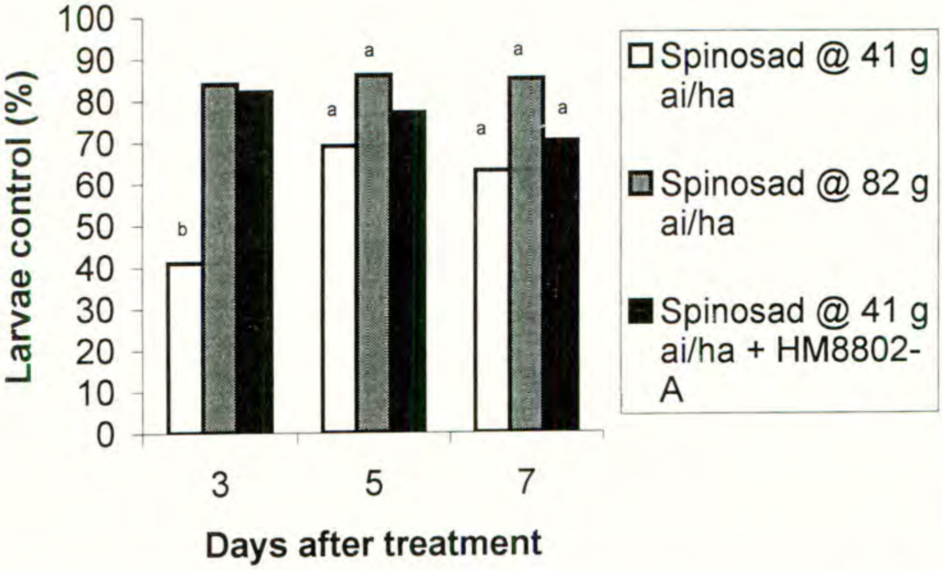

Figure 2. Influence of HM8802-A on *Heliothis sp.* larvae control with spinosad in cotton.

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