SESSION 7A

OPTIMISING THE USE OF SEED TREATMENT PESTICIDES

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Seed treatment: uses and benefits

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ABSTRACT

This paper outlines the uses and benefits of seed treatment. The objectives of seed treatment are to promote establishment, maintain yield, maintain or improve quality and reduce disease multiplication and spread. These objectives are met mainly through the control of a variety of pests and diseases, both seed and soil-borne. They are also met through enhanced seedling/plant growth. In addition to meeting these objectives, seed treatment affords benefits in the areas of environmental, user and consumer safety.

INTRODUCTION

Seed treatment has been defined as "the application of bioactive chemicals, or antagonistic or symbiotic micro-organisms to the seed prior to sowing" (Schwinn, 1994). However, in a wider sense it can encompass the processing of seed by, for example, technologies utilising moist heat (Forsberg, 2001) or electronic cleaning (Schröder *et al.*, 1998), although in practice seed treatments usually comprise synthetic fungicides and insecticides (Grimes, 1999). Seed, in the context of seed treatments, can include tubers (Hewett & Griffiths, 1986) and bulbs (BCPC, 2001) although it usually refers to true seeds, fruits or dried inflorescences (Anon., 1985).

WHY ARE SEED TREATMENTS USED?

Seed treatments are used for a number of specific reasons but the main objectives for treatments are to:

- Promote establishment
- Maintain yield
- Maintain or improve quality
- Reduce disease multiplication and spread

These objectives are most commonly achieved through the control of diseases and pests, which can be seed-borne, soil-borne, or air-borne. Seed-borne inoculum can be either superficial, as is the case with Bunt where spores are located on the seed's surface, or deep seated within the embryo e.g. loose smut. Some pathogens can be both superficial and deep seated e.g. Fusarium (Bateman, 1983). Surface contamination can be controlled by contact-acting fungicides that effectively disinfect the seeds' surface (Bateman, 1983), whereas to control deep-seated infections or soil-borne inoculum a degree of systemicity is required (Bateman, 1980).

Soil-borne diseases or pests may attack the germinating seed or emerging seedling or affect the crop latter in the growing season. Again, the nature of the attack may require contact or systemic activity from a seed treatment, as well as a degree of persistence if targeted against an attack on emerged seedlings. Persistence may be as a result of the systemic nature of the pesticide within the plant e.g. fluquinconazole in wheat, or as a consequence of formulation technology e.g. the micro-encapsulation of tefluthrin. Pathogens can be solely seed-borne e.g. loose smut (*Ustilago nuda*), solely soil-borne e.g. take-all (*Gaeumannomyces graminis*), or be both seed and soil-borne e.g. *Mycosphaerella pinodes*.

To effectively control air-borne pathogens and pests seed treatments must be active against their target and systemic within the plant. Examples being triadiminol used to control of powdery mildew (*Erysiphe graminis*) in wheat and barley and imidacloprid used to the control aphids in sugar beet and cereals.

Seed treatments have also been used for weed control although the use of herbicides on seed is rare. The most notable example is thiocarbazil, used to control *Echinocloa* spp. in rice paddies. More common however is the use of safeners to protect seed from herbicide damage. Safeners are available to protect seed from non-selective herbicides e.g. glyphosate or selective herbicides e.g. alachlor and metalachlor. Herbicide safeners such as oxabetrinil, fluxofenim and flurazole are most commonly used on sorghum (Grimes, 1999).

Seed treatments can also be used to enhance crop nutrition and stimulate seedling growth. Nutrients such as nitrogen, phosphate and the micro-nutrients copper, magnesium, molybdenum and zinc can be applied to seed to compensate for mineral deficiencies in soil. Similarly, nitrogen-fixing *Rhizobium* can be applied to seeds of legumes prior to planting to encourage nodule formation. Compounds such as L-cystine derivative and folic acid, although not nutrients, have been used on seed as biostimulants.

Where precision drilling of small irregular shaped seeds is required e.g. sugar beet, seeds are often encased in a pellet (Kelly, 1988). The pellets allow seeds to be sown mechanically and in addition provide a carrier for pesticides. Colourants are usually used to identify the seed and any pesticide treatments. Colour can also be used to deter birds feeding and, where required, repellents may also be added to deter wildlife from eating seed (Greig-Smith, 1988)

THE BENEFITS OF SEED TREATMENT

The seed industry and the farmer can both gain benefits from seed treatments. Brandl (2001) has listed the commercial benefits to the seed industry, and these will not be expanded upon here. Instead, the benefits to the end-user, the farmer, will be explored.

As previously stated, the main objectives of seed treatment are to promote establishment, maintain yield, maintain or improve quality and reduce disease multiplication and spread. If these objectives are met then it is clear that seed treatment has afforded a benefit. However, the distinct benefit from seed treatment lies in its ability to produce these results where other methods cannot or where the use of other methods is less advantageous. Distinct benefits from seed treatment can be seen in the following areas:

- Effective pest and disease control
- Seed health
- Reduced environmental impact
- Increased operator and user safety
- Consumer safety i.e. low residues

Effective pest and disease control

The control of pests and diseases can be achieved by the application of pesticides to the soil or to foliage e.g. spraying. However, these methods of delivery are sometimes not feasible owing to practical constraints or to expense e.g. soil drenching. Also the nature of pest attack may render such treatments ineffective. The strength of seed treatment lies in its timely delivery of pesticide to the seed or close soil environment following sowing, during germination and prior to seedling emergence. The control of seed-borne infection by pathogens such as *Microdochium nivale* or soil-borne take-all can only be achieved commercially through effective seed treatment, and the true benefit from early disease control of foliar diseases e.g. *Mycosphaerella gaminicola* by fluquinconazole is now becoming apparent (Parker & Lovell, 2001).

Seed health

It is the effectiveness of seed treatments against seed-borne diseases that makes them an integral part of the seed multiplication process (Rennie, 1993). Without effective control, diseases such as bunt can rapidly increase in subsequent generations (Dillon Weston & Engeldow cited in Yarham & Jones, 1992). Indeed, it has been stated that cereal seed should never be sown for more than two generations without treatment (Rennie & Cockerell, 1994). Interestingly, conventional seed treatments have been used in the production of organic seed stocks (Atkinson & Watson, 2000) although this practice will cease in the EU from 1 January 2004.

However, recently, it has been suggested that the use of seed treatments in winter wheat should focus on need rather than on routine application (Cockerell *et al.*, 2001) – at present the vast majority of cereal seed is treated in the UK. This suggestion fits well with the concept of sustainability, as it would clearly form part of an integrated approach to seed and ware crop production. The key question with respect to seed treatment according to need is, when is treatment needed? It is not within the scope of this paper to debate this point, but it is pertinent to raise the issue as it does highlight the versatility of seed treatments. They are versatile because they are able to control effectively many seed-borne and soil-borne pathogens (Yarham & Jones, 1992) over a wide range of soil conditions. This makes them a valuable tool for the farmer to use when managing the risks from not only known but also unknown hazards that may affect their emerging crops.

Reduced environmental impact

Environmental benefits can be gained from the use of seed treatments. These gains come mainly from the precise placement of low or reduced rates of active substance. The issue of precise placement is clear as seed treatment, by definition, places the pesticide where it is required. This leads to few problems with off target contamination through drift and therefore seed treatments are not affected by statutory buffer zones e.g. LERAP. The issue of low rates of use can be demonstrated with reference to the control of pests in sugar beet. In the UK, seed treatment and the application of granules can control soil-borne sugar beet pests. Aphids can be controlled by seed treatment, the application of granules and by foliar sprays. Examples of the amount of active substance applied per hectare are given in table 1. In this example it can be seen that seed treatments are comparable to foliar sprays and less than the granular application. Reduction in pesticide use through seed treatment is best illustrated by the work of Kosters *et al.* (1993). They demonstrated that seed treatment with chlorpyrifos could reduce the amount of pesticide needed to control cabbage root fly (*Delia radicum*) in Brussels sprouts by 99%.

Table 1. Amount of active substance applied per hectare to control soil-borne pests and aphids in sugar beet from seed treatment, granule application and application of foliar sprays applied at maximum individual dose rates.

Pesticide	Target	Method of delivery	kg of a.s. ha^{-1}
Seed treatment	Soil pests	tefluthrin	0.010
Seed treatment	Soil pests & aphids	imidacloprid	0.120
Granules	Soil pests & aphids	aldicarb	0.760
Spray	Aphids	pirimicarb	0.140
Spray	Aphids	lambda - cyhalothrin	0.015

Seed treatments have had undesirable effects on wildlife, for example the deaths of a large number of geese caused by the organophosphorus compound carbophenothion (Bailey *et al.*, 1972). However, this issue has been addressed by the regulatory system (Hart & Clook, 1994) and by encouraging best practice by farmers (MAFF, 1998)

Operator, farmer and consumer safety

The seed trade or specialist contractors on farm treat most of the treated seed. Operator exposure in these situations can be managed effectively by engineering controls backed up by the use of personal protective equipment (Chambers, 1994). This reduces farmers' exposure to seed treatments to handling treated seed. Under The Seed Regulations 1993, treated seed must be labeled with the chemical or trade names of any treatments used. In addition non-statutory guidelines giving safety information on labels (BCPC, 2001) should help farmers use treated seed safely. Seed treatment residues in the harvested crop are usually below the limit of detection owing to their long harvest interval. Consumers are therefore at little risk from seed treatment pesticide residues.

CONCLUSIONS

Seed treatments play an important role in promoting crop establishment, maintaining yield and maintaining or improving quality. They also play a key role within the seed multiplication process by controlling seed-borne diseases. Most seed treatments are fungicides or insecticides and as such can provide the base for an integrated crop protection programme. The benefits of seed treatment, in addition to efficacy, are reduced environmental impact, and user and consumer safety.

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Meeting the requirements for modern seed treatment application

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ABSTRACT

There have been significant advances in seed treatment active ingredients over the last decade and with them, increased demands placed on the accuracy of application. Particular advances have been made with insecticidal seed treatments such as imidacloprid in cereals, but the performance of these products in the field can depend upon both the overall loading to seed and the evenness of seed to seed distribution. Seed treatment machinery has evolved over the years to cope with the increased demand for rapid throughput, ease of maintenance and shifts in formulation types. However, the increased requirement for repeatable, accurate application and traceability has placed additional pressures on machinery design. Whilst simplicity of operation is a requirement for machinery design, it is inevitable that the responsibilities placed on personnel who apply seed treatments will necessitate specialist training.

INTRODUCTION

The general principles for seed treatment application have changed little since the comprehensive review by Jeffs & Tuppen in 1986. At that time, two of the most notable changes taking place in the UK cereal seed treatment industry were the transition from powder to liquid formulations and the recent introduction of systemic fungicides such as triadimenol (Wainwright *et al.*, 1979). However, changing requirements in specific areas have further pushed the demands on machinery design and the main influencing factors may be categorised into:

1. The biological need that defines seed to seed loading and overall loading. This also should take into account the balance between performance and crop compatibility.
2. The physical characteristics of the treated seed which affect flow rate through the drill and handling.
3. Cost/efficiency considerations. The machine performance in terms of tonnes of seed per hour treated not only gives the seed merchant increased throughput over the season, it allows greater flexibility to cope with short periods of high demand e.g. associated with the trend to earlier drilling. Ease of cleaning and maintenance should be taken into account.
4. Safety requirements as recommended by operator exposure studies and COSHH requirements.
5. Traceability. The ability to trace back through the accurately recorded stages of seed treatment allows management to audit the procedure, provides background data for field performance investigations and can give confidence to crop assurance schemes.

These same factors are influential whatever the seed type, though this paper will concentrate on small seed/high throughput situations particularly relevant to cereals in the UK. Sugar beet and vegetable seed treatment has been reviewed by Halmer (1994) and application to potato tubers by Rollett *et al.*, (2001). The parameters for any of the above may be redefined at any time as new demands are made and consideration will be given here to the biological needs for accurate application by some of the more recently introduced seed treatments.

The introduction of the systemic cereal seed treatment Baytan (triadimenol & fuberidazole) in 1980 led to an increased requirement for accuracy of treatment loading to ensure that the appropriate quantity of a.i. was present to provide persistent control of foliar diseases. However, there was always the possibility to manage later infections using foliar sprays. A further requirement for accuracy arose in the mid 90's when the systemic insecticide imidacloprid was introduced for sugar beet and subsequently cereals, for controlling aphid vectors of virus. Should the aphicide fail, the symptoms of virus infection appear later in the life of the crop when it is too late to redeem the situation by use of a sprayed treatment. Imidacloprid treatments must be applied to a high quality standard and subsequent advances in machinery design and monitoring systems together with operator training have led to beneficial 'knock-on' effects in other areas such as facilitating traceability. With the recent introduction of two new actives, namely fluquinconazole and silthiofam, for take-all control there is yet again a renewed emphasis on quality of application.

THE REQUIREMENT FOR ACCURACY

BYDV control with imidacloprid

Imidacloprid in Sibutol Secur, Raxil Secur and Baytan Secur offers control of aphids which transmit BYDV in cereals (Schmeer *et al.*, 1990). Performance of imidacloprid against BYDV is related to a number of factors including drilling date and seed rate (Miles *et al.*, 2001). However, it is assumed that the seed treatment is applied accurately. Five rate profile trials using imidacloprid, with an untreated level of 80.4% BYDV, drilled from 20 – 23 September 1995 at seed rates greater than 150 kg/ha, showed a reducing level of performance as the dose rate fell back (Figure 1). This curve would be even steeper for early September drilled crops with lower seed rates because of the greater rate of dilution in the rapidly growing plants and the tendency for the incoming aphids to be concentrated on fewer plants.

The consequences of poor loading may result in a lower level of BYDV control than anticipated. Once symptoms are seen in the crop it is too late to apply a spray treatment.

In addition to absolute loading it is also important to ensure even loading. In order to simulate uneven application, a trial was set up with the barley cultivar Pearl to compare 5% admix of untreated seed mixed with 95% of an evenly applied seed sample compared with an evenly applied sample. The trial was drilled on 19 September 2000 at a seed rate of 160 kg/ha. An assessment of virus on 31 March showed 52.5% BYDV on the untreated, 5% virus on the imidacloprid treated, and 12% BYDV on the 5% admix seed. The untreated plants acted as a reservoir for wingless aphids which were also able to infect imidacloprid treated plants later in the autumn once the active had been sufficiently diluted. This observation confirmed the importance of not only absolute level of loading but also the importance of an even seed to seed distribution.

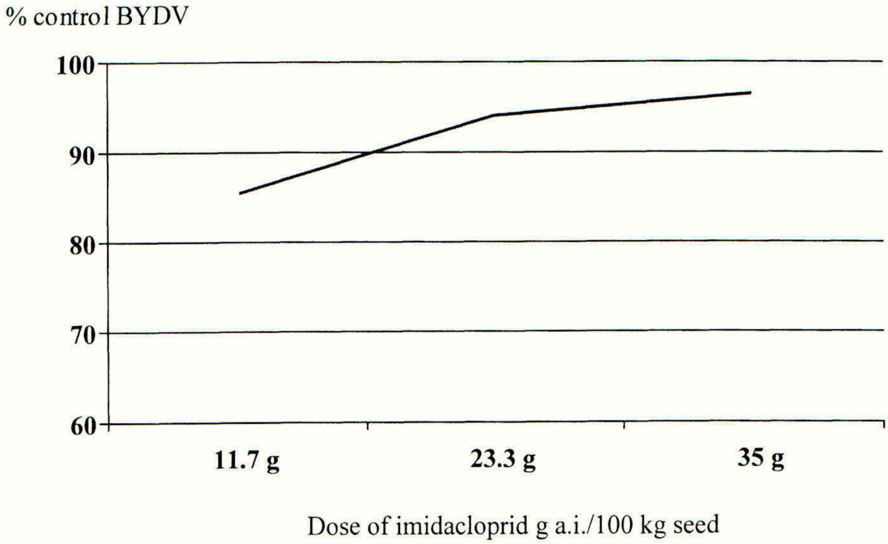

Figure 1. Control of BYDV at a range of imidacloprid dose rates.

Take-all control with silthiofam

Take-all (*Gaeumannomyces graminis var. tritici*) is a damaging soil-borne fungus. It is a major factor limiting the yield of second and subsequent wheats in the rotation. In recent years the introduction of two seed treatment active ingredients fluquinconazole (Lochel *et al.*, 1998) and silthiofam (Beale *et al.*, 1998) has resulted in significantly increased activity

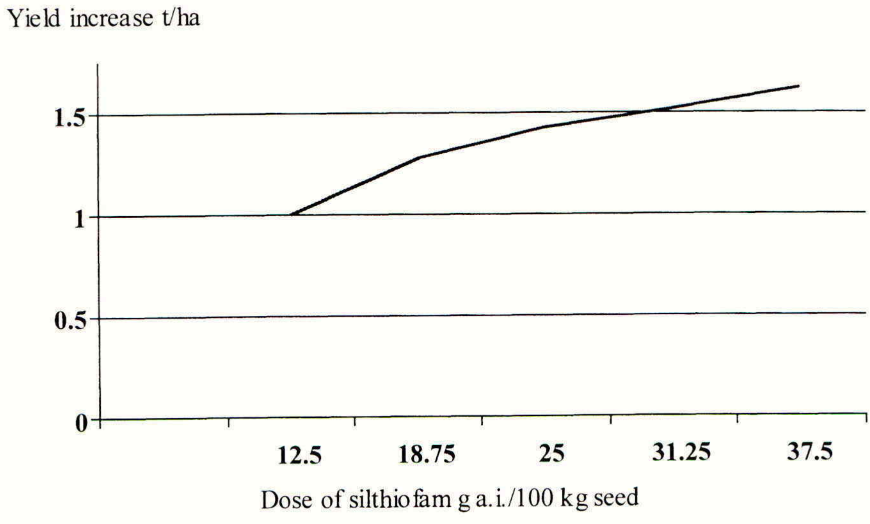

Figure 2. Yield increase from silthiofam at a range of dose rates
7 trials Take-all index > 50

Take-all control and the subsequent level of yield were compared at a range of dose rates in Monsanto trials from 1994 – 1999 (Figure 2). Yield response was related to dose of silthiofam, especially at Take-all index greater than 50. This has obvious implications for accuracy of application and supports measures to improve the quality of treatment.

ACHIEVING THE DESIRED LOADING

Many factors influence the final loading on the target seed. These include the seed treatment formulation(s), the treatment metering and application equipment, seed quality, seed handling, the use of additives and the skill of the operator.

Seed treatment formulation affects seed bulk density, seed flow ability, seed to seed distribution and cover of each individual seed as well as the adhesion to the seed surface both during and after treatment. Co-application of treatments will modify the characteristics of each, an extreme example being the addition of manganese treatments, where the very high levels of solids involved lead to dust formation and subsequent losses during seed handling. The application of dry formulations in the UK has now been superseded as has the application of true liquids, the former because of poor adhesion to the seed and the latter because the flowable suspensions now used do not contain solvents and are inherently safer to personnel.

Metering of seed treatment product is effected by various means and an operator needs to understand factors that affect performance if an accurate output is to be maintained. Volumetric metering is performed by diaphragm pumps with ball valves, volumetric jars with adjustable probes to alter the volume dispensed, and peristaltic pumps. All will work very well with true liquids but can become inaccurate with flowable suspensions which may have particles in them capable of affecting ball valve performance, or air due to agitation or intake leakage, which reduces the real output of all. Intake to and output from these pumps can have a major effect on their metering performance, particularly that of peristaltic pumps. Peristaltic pumps give very good accuracy provided they are plumbed correctly (flow restrictions must be minimised).

Ultimate accuracy of application can be achieved by applying a weighed dose to a known weight of seed. This method is applicable to batch treaters and overcomes inaccuracies due to the limitations of volumetric metering.

Seed treaters can be classified into two main types using either a continuous or a batch process. The former type consists of three components: (i) seed metering, (ii) primary application chamber (iii) secondary mixing – usually (in the UK) by an auger or paddles in a chamber. Batch treaters consist of seed metering or weighing followed by a treatment chamber where primary application and secondary mixing both take place.

Seed metering in continuous treaters is achieved by rotary metering wheels or adjustable collar on cone (Jeffs & Tuppen, 1986). The former is largely influenced by grain density (hectolitre weight) whilst the latter is also influenced by the ease of flow of the grain as well as its density. Throughput is likely to be changed by every change of grain lot so adjustments and/or calibrations are necessary to achieve maximum accuracy. Collar adjustments have been automated on some machines using mechanical or electronic sensing of throughput to feedback and maintain a pre set tonnes per hour.

In batch treaters the batch size is given by a weigher (mechanical or electrical) or by a rotary valve (adjustable for speed and time of run). Accuracy of weighing needs to be regularly checked and the rotary metering needs to be adjusted for each grain lot.

Primary application occurs in a chamber before secondary mixing in continuous treaters. With the true liquids originally used in this process, the primary distribution was very important as secondary movement of treatment from seed to seed was limited by rapid absorption of solvents into seeds. With the flowable suspensions now used, good primary distribution is more difficult and secondary transfer between seeds consequently more important.

In batch treaters the primary application is in the same chamber as the secondary mixing. This ensures that the rapidly moving and mixing seeds sweep up any liquid, which may miss seeds during the primary application. The secondary mixing is rapid in batch treaters using the Rotostat principal but it is aided by the addition of water which keeps the treatment mobile on the seed surface and prevents adhesion of dust and treatment to the machinery parts. Secondary mixing in continuous treaters is slower, less vigorous and generally takes place over a longer period. An extended mixing time requires higher water application rates to achieve optimum seed to seed treatment distribution and to prevent over drying which leads to loss of treatment to machinery parts and dust formation.

Seed quality can affect the final loading. Obvious losses occur when a batch of barley is very susceptible to skinning but dusty seed (e.g. soil, fungal spores) causes difficulties in distribution during treatment and subsequent losses during handling. Further loss of treatment may occur during drilling. Losses of Baytan from seed during pneumatic drilling were recorded as 32% for dry powder (DS) and 6% for flowable (FS) formulations (Bayer internal report TM 37). DS formulations are no longer used but where manganese has been co applied, losses approaching the level of a DS are to be anticipated where a pneumatic drill is used.

Seed additives which contain polymers and colours can reduce dust during and immediately after treatment. However, when subjected to vigorous mechanical handling after drying (as encountered during pneumatic transfer) their efficacy is limited. Not all additives are safe to the seed and it is possible for them to affect the performance of the active ingredients. Guidance should always be sought from manufacturers prior to use.

TRAINING REQUIREMENTS

A skilled, conscientious operator is fundamental to the achievement of the best performance from a seed treatment machine. A candidate attaining, by examination, the National Proficiency Tests Council's certificate for Pesticide Application module 11 in seed treating equipment, verifies basic competence (Table 1). A certificate is also a legal requirement (Food and Environment Protection Act – 1985) for any user of pesticides born after 31 December 1964 unless working under the direct and personal supervision of a certificate holder. Until September 2000 there were different test requirements for static (PA11B) and mobile (PA11A) plant operators.

Table 1. Seed treatment certificates awarded since1988 (NPTC 1/7/2002)

PA11A	PA11B	PA11 (Since 9/2000)	Total
776	941	130	**1847**

To consistently achieve the standards of the best companies requires suitable equipment, experience and further training. In 2000 Bayer plc introduced the Precision Treated Seed (PTS) concept to support best practice by seed suppliers. PTS only applies to static plants where full traceability of the seed crop is possible. Bayer engineers inspected the plant of participants, examining equipment and systems. Operators were given advanced training to improve application accuracy and quality (evenness on the seed) also their NPTC knowledge was refreshed and a certificate of participation issued to NPTC PA11 holders. Advice and technical support is provided and samples of production tested for accuracy and quality at Bayer plc's Elm Farm Support Centre. Traceability is enhanced by keeping application records and retaining samples of treated seed from every seed batch and change of treatment.

The need for PTS came from the exacting requirements for accuracy and quality of application of treatments containing imidacloprid and, consequently, similar training was as important for operators of mobile seed treatment equipment. Traceability of treatment is again achieved and the aims of the Verified Seed scheme to which mobile companies may subscribe through the NAAC are enhanced. In the period 2000-2002, a total of 295 operators received this additional advanced training.

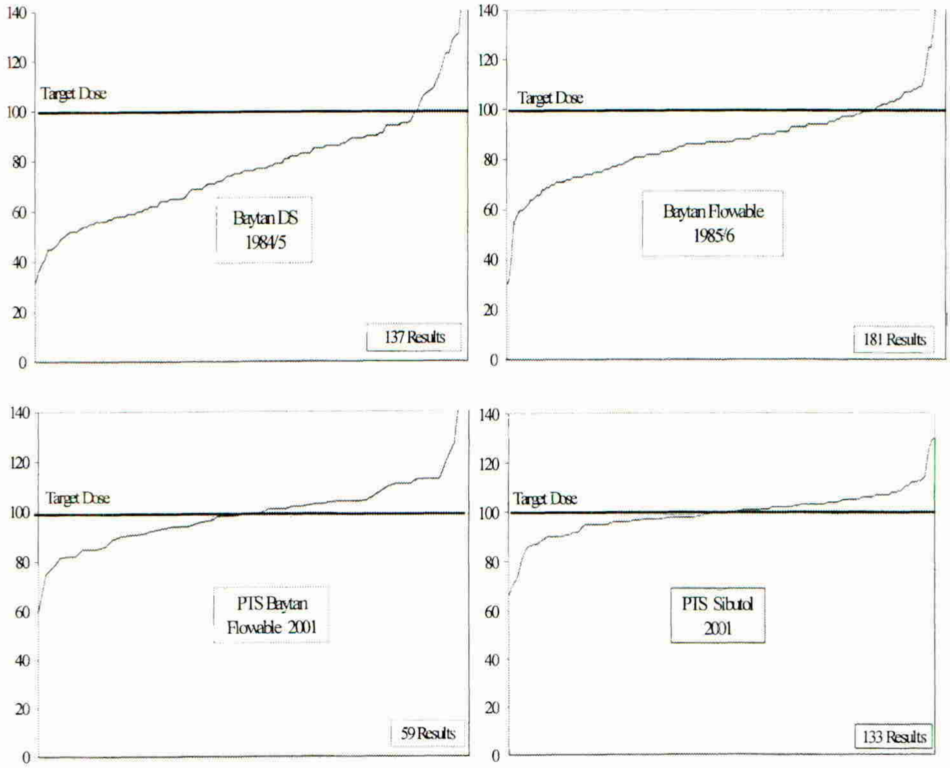

Figure 3. Percent achievement of target dose of treatment on seed samples taken at random from commercial production.

Monitoring since the early 1980's has shown improvements in the targeting of treatments on cereal seeds as can be seen from the series of graphs in Figure 3. Analyses of loading levels were carried on seed samples taken at random from commercial production.

The ideal is a graph with a solid fill to the Target Dose line. As can be seen from the Baytan DS results from 1984/5 this was a long way off with a mean dose of 76%. The introduction of Baytan flowable improved the situation so that the mean dose was 88%. The introduction of PTS saw the mean dose of Baytan flowable rise to 100% but still a number of samples had too high or too low doses. The PTS Sibutol results with a mean dose of 99% came nearest to the ideal for cereals.

Seed loadings are affected by formulation, active ingredient and the nature of the seed surface. PTS results for treatment on barley gave a mean loading of 91%, lower than other PTS results. This was most probably caused by the ease with which some barley samples lose skin, and with it, the treatment.

CONCLUSION

Change and rationalisation within the cereal seed industry, which continues today, was earlier alluded to by Elsworth (1987). He observed the decline in numbers of seed plants and the improvement in the performance of machinery, and anticipated the future need for 'key personnel of high calibre'. Clearly there is a conflict between the seasonal nature of the work and the need to train and invest in staff able to cope with the necessary high standards. However, in our 'compensation culture' a failure of a seed treatment in the field through poor application could easily lead to expensive compensation claims or litigation. The responsibility for accurate spray application given to a trained farm spray operator, who can typically treat 60 hectares in a 4 hour period, is well recognised. No less recognition should be given to a seed plant operator who in a similar period could treat 100 tonnes of seed – sufficient to drill at least 600 hectares.

Developments in machinery design continue, particularly in the area of measurement of treatment by weight, so ensuring consistency in quantity of treatment applied. The inherent difficulties in calibrating both seed, and seed treatment flow through a continuous treater, means that such machinery needs more frequent monitoring, particularly when short production runs are required. The ability to apply an exactly measured weight of treatment to a measured quantity of seed in a batch treater signifies this approach as most appropriate for the future. Efficient methods of measuring seed coverage are being sought (Maude, 2002) which will allow the monitoring of treatment quality. With the closeness of harvesting and drilling, an especially rapid turn-around time is needed in crops such as cereals and oilseed rape. In an ideal situation the monitoring of treatment quality would be such that the information would be available before the seed was sown.

High application standards for seed treatments are necessary and can be met currently. The challenge for the future will be to develop and maintain those standards consistently against a background of falling agricultural returns when pressures conspire to cause regression.

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The effects of surfactant and water volume on the coverage of the seed surface by a seed treatment formulation

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ABSTRACT

An image analysis system has been developed (Maude, 2001) and used to determine the extent of treatment coverage on seed. The effects of varying application parameters on coverage have been investigated and a clear relationship between coverage and efficacy of a fungicidal seed treatment established. Equimolar concentrations of different types of surfactant (nonionic, anionic and silicone based) have significantly different effects on coverage and biological control. Varying the concentration of surfactant also affects coverage and efficacy. Low surface tension and low contact angles give rise to improved wetting and spreading of the treatment on the seed surface. Where a seed treatment alone gives poor coverage of seed, this can be significantly improved by dilution / co-application with water. This correlates with significant improvements in biological control.

INTRODUCTION

The worldwide production of economically viable crops depends upon reliable production systems where seed quality and seed protection are essential. The primary objective of a seed treatment is to provide protection for the germinating seed, and the emerging seedling, against fungal pathogens and / or insect attack.

Seed treatment technologies were reviewed (Brandl, 2001) where the continuing challenge of applying an even distribution of treatment (at low doses either undiluted or diluted) to the seed was related to formulation research. Reference was also made to the use of formulation inerts to improve bioavailability and activity at reduced rates.

Treatment quality is often measured using seed loading analysis. However this technique determines the amount of chemical on the bulk seed and / or single seed and does not take into account the quality of treatment coverage and distribution on the seed. The extent to which seeds are covered by the treatment is an important aspect of functional seed treatments which is less well defined in terms of biological efficacy.

Image analysis has been established as a technique used to determine the extent of treatment coverage on seed. This paper describes further use of this technique for the optimisation of formulation and application parameters for seed treatment products.

MATERIALS AND METHODS

Image analysis system

The image analysis system described previously (Maude 2001) can be used to measure the coverage of treatment on treated seed. The system, illustrated in Figure 1, is used with Media Cybernetics Image-Pro® Plus version 3.1 for windows software.

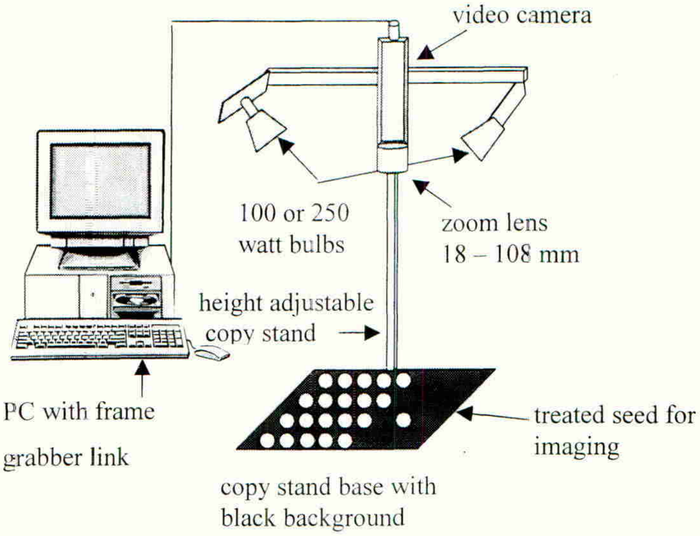

Figure 1. Image Analysis System

Measuring

To minimise shadowing, 21 seeds (20 treated and one untreated) were placed on a black background. The complete seeds, were then thresholded, outlined and measured. The coloured treated areas on the seed were then separated via thresholding and measured. To obtain the percentage area of coloured treatment on the seed surface the colour measurement was then expressed as a percentage of the complete seed area. The untreated seed was included to aid the thresholding process.

Formulations

Formulations containing 5 % w/w thiabendazole and 15 % w/w blue pigment (20 % w/w dispersed solids) with different silicone, nonionic and anionic surfactants were used. The formulation colour was optimised with a selection of different seed types to identify a system with good contrast for image analysis. The formulation components are identified in Table 1. The formulations were prepared by combining the surfactant and water with low shear stirring followed by addition of the thiabendazole and Irgalite Blue GLG.

Table 1. Formulation Components

Component	Trade name	Chemical name
Active Ingredient	Thiabendazole	2-(thiazol-4-yl)benzimidazole (TBZ)
Pigment	Irgalite Blue GLG	Copper phthalocyanine CAS :147-14-8
Nonionic / silicone surfactant	Silwet L77	Polyalkylene oxide-modified polydimethylsiloxanes, Trisiloxane (PDMS)
Nonionic surfactant	Volpo T10	Polyethoxylated alcohol based on tridecanol (PEAT)
Anionic surfactant	Morwet EFW	Na naphthalene formaldehyde condensate (NaNFC)
Anionic surfactant	Aerosol OT100	Na dioctylsulphosuccinate (NaDSS)

Seeds

A flat maize seed of a uniform pale yellow / white colour was selected as a suitable seed substrate for use with this image analysis system. The seed (cv Silverio) was supplied by Maisadour, France.

Seed treatment – "Glass Jar" method

The treatment at the required application rate, was injected onto the inside of an 800 ml squat form beaker containing 100 g of seed, close to but not touching the seed surface. The beaker was then swirled vigorously for 30 seconds to coat the seed and to encourage distribution of the treatment between seeds. The treated seeds were then transferred to a plastic weighing boat for drying at room temperature.

Pathogen selection for *in-vitro* efficacy method

Fusarium moniliforme Sheldon was selected as a pathogen known to infect maize.

Efficacy method

To determine seed treatment formulation efficacy the method developed (refer to Maude 2001 for detail) for the *in-vitro* inoculation, treatment and assessment of maize seed was used.

Surface tension

Formulation surface tension was measured using a White torsion balance.

Contact angle

Formulation contact angle was measured directly on the maize seed substrate. A method was developed using a 10x measuring magnifier, fitted with a 180 ° graduated graticule. The magnifier was clamped directly in front of a lab jack so that the height of the seed could be varied. The jack was levelled prior to use. Ten droplets of each formulation were transferred to ten seeds, the graticule aligned and the contact angle of each droplet measured. The contact angle for each formulation on maize seed was taken as the average of the ten measurements.

RESULTS

Determination of the effect of co-application of water on colour coverage and efficacy

The technique of co-applying water with seed treatments, where low application volumes of the seed treatment are used, to improve distribution on the seed substrate is often practised (Bacon *et al.* 1986). To investigate this technique and the effect on colour coverage, the product was applied undiluted to the seed and also co-applied with water. Two formulations containing PDMS and NaNFC respectively were selected for this study. The formulations were applied at 2 g product / kg seed i.e. constant dose. Water was co-applied at 0, 1, 2, 4 and 6 g / kg seed using the Glass Jar treating technique. Image analysis was carried out, with accuracy estimated to be ± 5%. Results are shown in Figure 2.

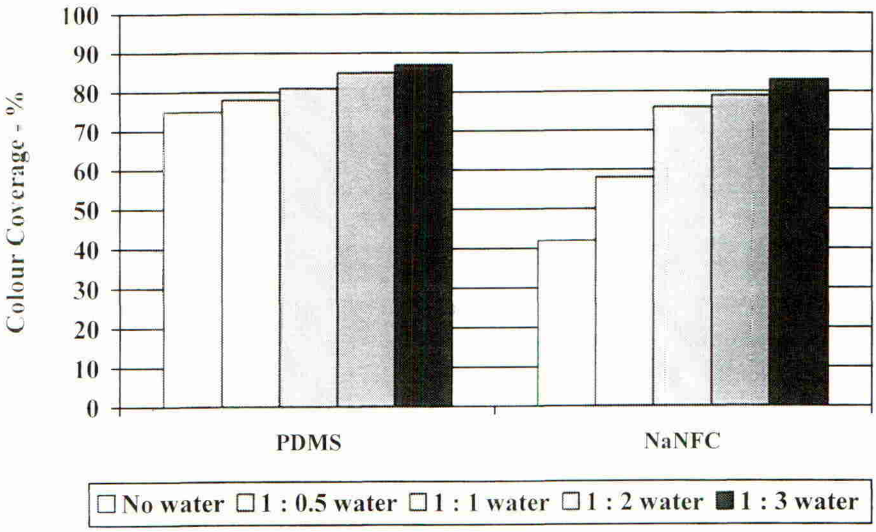

Figure 2. Variation in Colour Coverage with Increase in Applied Water Volume

The data in Figure 2 demonstrate that coverage is affected by the co-application of water. For both formulations, as the total volume of treatment applied is increased through use of water, colour coverage is improved.

Comparing the surfactant effect with colour coverage, the formulation containing PDMS gave greater than 70 % colour coverage on the seed without the use of water. Since the coverage achieved with the formulation alone is very good, the improvement in coverage achieved through co-application of water is less significant.

In contrast, for the formulation containing NaNFC colour coverage of the formulation alone on seed is poor. However, when the formulation is co-applied with at least an equal amount of water, colour coverage is almost doubled.

An investigation was then carried out using the above formulations and conditions, with co-application of water to establish the effect on efficacy. Results are shown in Figure 3.

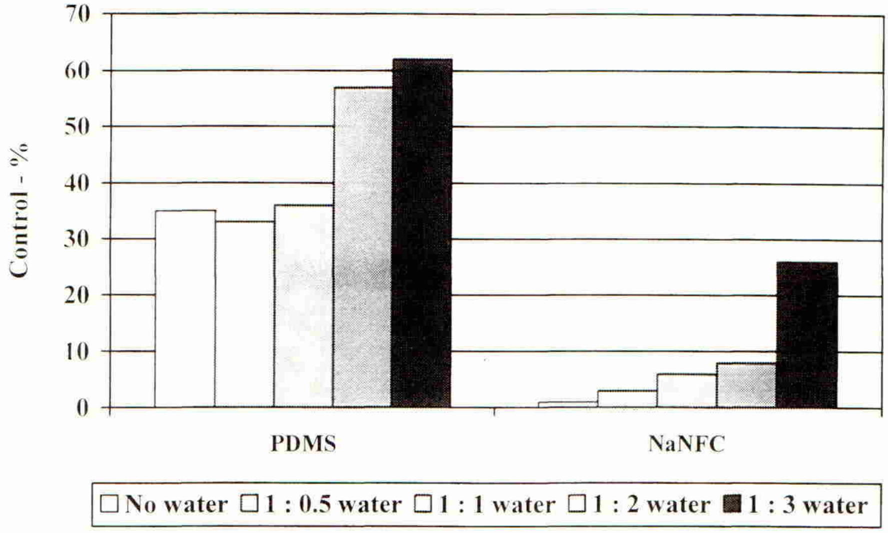

Figure 3. Variation in Formulation Efficacy with Increase in Applied Water Volume

Comparing the surfactant type with efficacy, for a constant active ingredient dose applied neat, the formulation with PDMS is over 30 times more efficacious than the formulation with NaNFC. If the two formulations applied with the highest dilution of water are compared, the PDMS formulation is over twice as efficacious as the NaNFC formulation. These data show that for a constant active ingredient dose, co-application of water and use of different surfactants improve efficacy.

Determination of the effect of surfactant type and concentration on colour coverage and efficacy

The previous results demonstrated an effect on both colour coverage and efficacy when different surfactants were used. To investigate these effects further, four surfactants (Table 1) were tested. The surfactants were used at equivalent molar concentrations. A formulation containing a blend of PDMS and NaNFC was also prepared to investigate the combined surfactant effect. Each formulation was applied at 0.05, 0.1, 0.2, 0.4 and 0.6 g / 100 g seed. Colour coverage and efficacy was measured as described previously. Results are shown in Figures 4 and 5.

The data in Figure 4. show that at all application rates the formulations with nonionic surfactants give better colour coverage than the anionic surfactants. These differences are more significant in the critical region at low application volumes, where both low active ingredient and low volumes are applied. The colour coverage achieved when NaNFC is combined with PDMS compares favourably with that achieved using the nonionic surfactants.

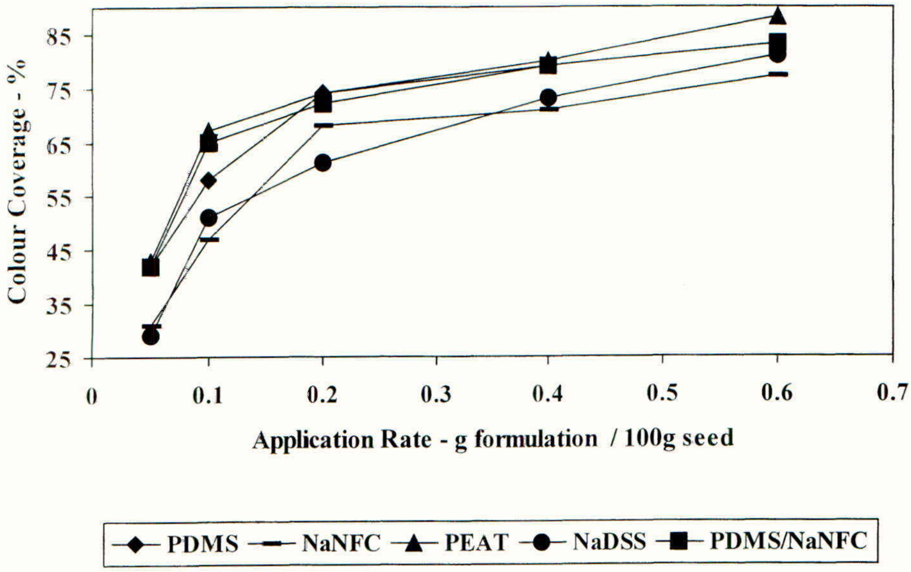

Figure 4. Variation in Colour Coverage with Surfactant Type and Concentration

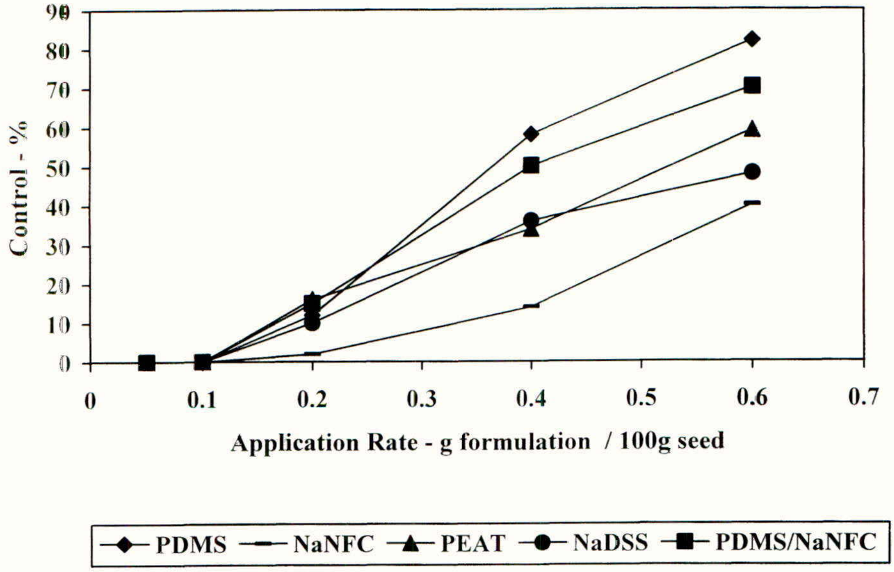

Figure 5. Formulation Efficacy with Surfactant Type and Concentration

The data presented in Figure 5 show that, in general, the nonionic surfactants and the nonionic / anionic blend give better biological control compared to the anionic surfactants. Where an application rate of 0.2 g / 100 g seed is used the efficacy of the formulation containing PDMS is increased six-fold relative to the equivalent formulation with NaNFC. By combining equal amounts of PDMS with NaNFC (giving the same total molar concentration as the single surfactants) the efficacy of the NaNFC formulation is significantly improved to give equivalent performance to the PEAT formulation.

Comparing the colour coverage and efficacy data show that relatively small changes in coverage correspond to larger increases in control i.e. the relationship is not a linear one.

Determination of the relationship between surface tension and contact angle

The surface tension (accuracy ± 0.1 mN/m) of each formulation and their contact angles (accuracy ± 5 °) on maize seed were determined, at about 20 °C, with the results given in Table 2.

Table 2. Formulation surface tension, contact angle and % control

Formulation surfactant	Surface tension mN/m	Contact angle on maize - °	% Control at 0.4 g / 100g
NaNFC	39.3	50	14
PEAT	33.8	30	34
NaDSS	28.5	10	36
PDMS / NaNFC	25.5	5	50
PDMS	25.2	5	58

These data show that the largest differences in surface tension and contact angle are between PDMS and NaNFC, with PDMS having the lower values for both properties. Low surface tension and low contact angles indicate high surface activity, giving better wetting and spreading of the formulation on the seed surface, better coverage and, ultimately, better efficacy. Although surface tension measurements give better resolution, in terms of characterizing the physical properties of formulations and surfactant on seed, the contact angle direct measurement method is probably the more relevant as it directly involves the surface properties of the seed.

Relationship between biological control and surface tension

The data presented in Figure 5 show the relationship between surfactant type and concentration and efficacy. To investigate the relationship between biological control and surface tension the efficacy data for formulations applied at 0.4 g / 100 g seed are shown in Table 2 and are plotted against surface tension in Figure 6. The results indicate a relationship between the formulation surface tension and biological efficacy - as surface tension decreases, indicating better wetting and spreading properties, the efficacy increases. A similar trend between formulation contact angle and biological efficacy is also apparent from the data in (Table 2).

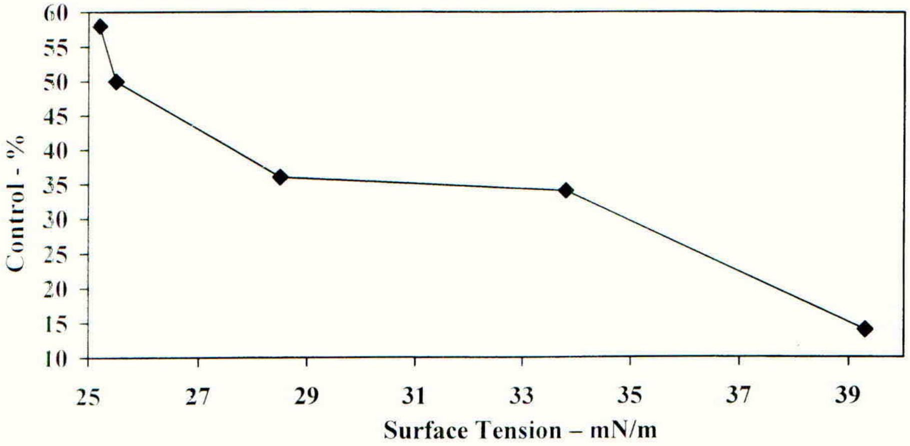

Figure 6. Variation in Formulation Efficacy with Surface Tension

CONCLUSION

With the help of image analysis, it has been demonstrated that it is possible to relate coverage of a seed treatment directly to biological efficacy. By comparing the effects of different surfactant types, it is possible to relate coverage and efficacy to physical properties of the seed treatment, such as surface tension and contact angle. This, in turn, indicates that there is considerable potential for optimising efficacy through selection of formulation ingredients and thereby reducing the quantities of pesticide needed to give the required levels of efficacy.

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Variety as a factor in the response of winter wheat to silthiofam seed treatment

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ABSTRACT

Trials were carried out in second and third wheat situations during the growing seasons 1999/2000 and 2000/2001 to examine the response of 18 winter wheat varieties to silthiofam seed treatment. Comparable first wheat yield data were derived from Recommended List variety trials. The mean yield in second / third wheat situations was 2.25 t/ha lower than in first wheats. Silthiofam produced a mean yield response of 0.84 t/ha. Varieties differed significantly in the amount of yield lost when grown as second or third wheats, but not in their response to silthiofam.

INTRODUCTION

Take-all, caused by the soil-borne fungus *Gaeumannomyces graminis* var. *tritici,* is a highly damaging disease of the roots of wheat and barley. It is a major factor limiting the yield of these crops when they are grown as second or subsequent wheat or barley crops in an arable rotation. Until recently, chemical control was not an option, but seed treatments providing significant activity against take-all have now become available (Beale *et al.*, 1998; Löchel *et al.*, 1998).

There are indications from UK Recommended List (RL) variety trials that some wheat varieties suffer a greater reduction in yield than others when grown as second, rather than first, wheats (Anon., 2001; Bayles *et al.*, 2001). This suggests that varieties might differ either in their resistance to take-all infection, or their ability to tolerate similar levels of infection. Differences in either of these characteristics could result in differences in response to take-all control.

This paper presents results of field trials comparing the responses of a wide range of UK wheat varieties to the control of take-all using silthiofam (previously MON 65500) seed treatment.

METHODS

Nine trials (Table 1) were carried out in second or third wheat situations during harvest years 2000 and 2001 to compare the performance of winter wheat varieties with and without silthiofam seed treatment. Trials included 25 varieties in 2000 and 32 varieties in 2001, with 18 varieties being common to the two years.

The trials sites provided a wide geographic spread. Five trials were grown in second wheat positions in the rotation and four trials were in third cereal positions, following two previous wheat crops or a sequence of wheat and barley crops.

Table 1. Silthiofam seed treatment x variety interaction trials, 2000 and 2001; location, previous cropping and take-all severity

Year	Location	Previous cropping *	Take-all index**	
			GS39	GS71-80
2000	Cheshire	WW/WW	high	very high
2000	Devon	WW/WOR	high	high
2001	Devon	WW/WW	high	high
2001	Norfolk	WW/WB	high	high
2001	Cambridge	SB/WW	low	high
2001	Northumberland	WW/WOR	low	high
2000	Northumberland	WW/WOR	low	moderate
2001	Shropshire	WW/POT	moderate	low
2000	Lincolnshire	WW/POT	very low	very low

* WW – winter wheat; WOR – winter oilseed rape; WB – winter barley; SB – spring barley; POT – potatoes

** assessed on roots of cv. Equinox in discard plots adjacent to trial.
very low = index <1; low = index 1- 9; moderate = index 10-24; high = index 25-49
very high = index ≥ 50

Seed was treated with 'Sibutol Secur' (bitertanol + fuberidazole + imidacloprid), at a rate of 400 ml/100kg seed (56+3.4+35g a.i./100kg seed), either alone, or co-applied with silthiofam at a rate of 200ml/100kg seed (25g a.i./100kg seed). Trial design was a randomised split plot with 3 replicates. In the first year, seed treatment (with or without silthiofam) was allocated to main plots and varieties to sub-plots. In the second year main plots consisted of varieties and sub-plots of seed treatment.

All trials received a comprehensive foliar fungicide programme, to control foliar diseases and eyespot. Barrier plots of the variety Equinox, adjacent to the trial, were sampled at flag leaf emergence and again during grain filling for assessment of take-all symptoms on the roots. This provided an indication take-all severity in the trial area, which has been used to group the trials in Table 1. In four trials, take-all root symptoms were already severe by flag leaf emergence. In a further four trials, symptoms were only slight or moderate at the flag leaf stage, but, in two of the four, developed to severe levels during grain filling. In the final trial, take-all symptoms were negligible throughout.

Plots were harvested for determination of grain yield.

RESULTS

Results are presented for the 18 varieties common to both years of trials. Grain yields were analysed in an over-trials analysis of variance. Table 2 shows mean untreated yields and response to silthiofam for the nine trials. Untreated yields ranged from 5.53 t/ha in the Devon (2000) trial to 10.29 t/ha in the Northumberland (2000) trial. Yield responses to silthiofam ranged from as little as 0.14 t/ha in the Shropshire (2001) trial to 2.23 t/ha in the Devon (2000) trial. There was a tendency for yields to be lowest, and response to silthiofam highest, at sites where severe take-all developed relatively early in the season. However, there was a wide range of responses across severely infected sites, indicating that at some sites response to take-all control was limited by other factors.

Table 2. Grain yield without silthiofam and yield response to silthiofam in variety interaction trials (mean of 18 varieties)

Year	Location	Yield without silthiofam t/ha	Response to silthiofam t/ha
2000	Cheshire	5.89	0.56
2000	Devon	5.53	2.23
2001	Devon	5.98	2.12
2001	Norfolk	7.24	0.76
2001	Cambridge	9.68	0.34
2001	Northumberland	8.28	0.31
2000	Northumberland	10.29	0.93
2001	Shropshire	7.69	0.14
2000	Lincolnshire	9.97	0.18
Mean		7.84	0.84
significance of trial effect		P<0.001	P<0.001
S.E trial means		0.143	0.120
LSD trial means(P=0.05)		0.400	0.338

Table 3 examines the effect of variety on response to silthiofam and compares this with the yield lost by each variety when grown as a second (or subsequent) wheat in these trials compared with its average first wheat performance in UK RL trials over the same two year period.

The mean yield deficit compared with the first wheat situation was 2.25 t/ha, with a highly significant difference between varieties. Notably, Equinox incurred a significantly larger deficit (3.21 t/ha) than all other varieties and Charger a lower deficit (1.48 t/ha) than all except Napier and Rialto. The mean yield response to silthiofam was 0.84 t/ha. Although there was no overall significant effect of variety in the analysis of variance, the response shown by Equinox stood out as being particularly high.

Table 3. Effect of variety on yield loss in second, compared with first, wheat crops and on response of second wheats to silthiofam seed treatment

Variety	1st wheat* Yield t/ha	2nd wheat** Yield loss compared with 1st wheat* t/ha	2nd wheat** Yield response to silthiofam t/ha
Deben	10.61	2.22	0.75
Tanker	10.52	2.17	0.90
Napier	10.49	1.73	0.61
Equinox	10.45	3.21	1.30
Savannah	10.42	2.21	1.08
Claire	10.36	2.47	0.68
Biscay	10.35	2.40	1.07
Madrigal	10.28	2.51	1.05
Riband	10.23	2.45	0.76
Consort	10.23	2.30	0.76
Option	10.22	2.27	0.86
Buchan	10.14	2.36	0.75
Malacca	9.83	2.37	0.71
Charger	9.79	1.48	0.67
Rialto	9.73	1.84	0.70
Shamrock	9.48	2.25	0.71
Soissons	9.22	2.06	0.88
Hereward	9.21	2.17	0.94
Mean	10.09	2.25	0.84
significance of variety effect	P<0.001	P<0.001	NS
SE variety means	0.103	0.202	0.170
LSD variety means (P=0.05)	0.287	0.566	0.475

* mean of 43 UK Recommended List variety trials in 2000 and 2001 in first wheat situations
** mean of 9 seed treatment x variety interaction trials, 2000 and 2001 (Table 1)

DISCUSSION

It is well established that rotational position has a major influence on the yield of a wheat crop, with the yields of second or subsequent wheats being lower than those of comparable first wheats. Nix (1995) concluded that second wheat crops yield on average 12.5% less than first wheat crops and that third wheat crops are a further 10-15% lower yielding, giving a yield depression of 21-26% compared with first wheats. The average yield depression in RL variety trials in second wheat situations is around 9% (Anon. 2001), slightly less than the estimate for farm crops. This is probably because yield data from variety trials grown on sites with high levels of take-all may be rejected because of excessive error variation. A comparison of the yields of varieties in the nine second and third wheat trials described here with their yields in first wheat RL trials indicates an average yield reduction of 2.25 t/ha or 22.3%.

Although take-all is undoubtedly a major factor limiting yield in second and subsequent wheat crops, other factors, such as increased severity of eyespot, and reduced fertility may also contribute. In the second / third wheat trials discussed here, the effects of diseases other than take-all can be largely discounted due to the use of comprehensive fungicide programmes designed to control foliar diseases and eyespot. Silthiofam seed treatment produced an average yield response of 0.84 t/ha. With no direct means of measuring the potential yields of first wheats in the trials, the yields of the same set of varieties in first wheat RL trials in the same two years were taken as an estimate. Based on these figures, it can be concluded that the average yield response to take-all control by silthiofam was equivalent to 37% of the yield differential between first and subsequent wheats. Given that silthiofam achieves about 40% control of take-all (Beale *et al.* 1998), this result indicates that take-all was probably responsible for the majority of the yield depression.

These trials confirmed that wheat varieties differ in the amount of yield they lose when grown as second or subsequent wheats in the rotation. Since take-all is the major factor responsible for these losses, it was perhaps surprising that varieties did not also differ in their response to silthiofam. This may be partly due to the limited precision with which seed treatment x variety interactions can be measured in field trials where there is a typical patchy distribution of take-all (Spink *et al.* 1998). Despite this inherent problem, Spink *et al.* (2002) showed that the varietal effect on size of response approached significance for six varieties over three seasons. In this example, Equinox gave the largest response and Rialto a relatively small response, which is compatible with the results for the larger set of varieties analysed here.

Silthiofam seed treatment clearly lessens the yield penalty associated with growing a second or subsequent wheat crop and all the UK wheat varieties tested here showed a positive response. Although there are hints of differences in the response of varieties, results to date are inconsistent and the best advice is to base the decision to treat on an assessment of take-all risk, irrespective of variety.

ACKNOWLEDGMENTS

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