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INTEGRATED PEST CONTROL STRATEGY FOR STORED GRAIN - SURFACE PESTICIDE TREATMENTS OF AERATED COMMERCIAL AND FARM STORES TO CONTROL INSECTS AND MITES

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INTEGRATED PEST CONTROL STRATEGY FOR STORED GRAIN - SURFACE PESTICIDE TREATMENTS OF AERATED COMMERCIAL AND FARM STORES TO CONTROL INSECTS AND MITES

by

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Contents.

ABSTRACT

A storage strategy to control insects without using pesticides was devised for the HGCA in 1990. This was based on reducing grain temperature by ambient aeration and monitoring pests, using novel traps. This has now been extended by admixing pesticide to the grain surface, to control upward migrating insects and by monitoring mite numbers which were not examined earlier.

In a farm-scale test, six, 20 tonne bulks of wheat at an initial moisture content (m.c.) of 15% and a temperature of 17 - 18 °C were infested with 1 adult/kg. of Oryzaephilus surinamensis and Sitophilus granarius and 1/2kg. of Cryptolestes ferrugineus. Subsequently, all bins were cooled at a rate of 6 cfm/t (10 cu m/h/t) using 0.2 kw fans attached to differential thermostats set at 4 °C. Three of the bins had 2% (active ingredient) Pirimiphos methyl insecticidal dust raked into the surface at the recommended rate of 45 g/sq. m.

In the first year, the grain was cooled to below 5 °C after 240 hours aeration at a cost of 2 p/t. Afterwards temperatures increased steadily by about 0.7 °C/week. The moisture content was reduced marginally, by up to 0.5%. Numbers of insects decreased as the temperature fell, but O.surinamensis was detected in the untreated, but not the treated bins in the spring. Mites exceeded 1000/kg. at the surface of the untreated, but not the treated bins. Thus the surface treatment of ambient aerated bins supressed the mid-winter mite population increase and the the spring resurgence of insects.

The farm-scale test was carried through into a second year, to see if changing the differential thermostat setting to 2°C after December would maintain low temperatures for a longer time and to discover the fate of the insect survivors. Temperatures were once more reduced to below 5 °C after 232 h aeration at 2 p/t and maintained until the spring using 581 h at 5 p/t. The O. surinamensis survivors were not able to recover their initial numbers but S. granarius was discovered at the surface of the untreated bins in mid-winter, duplicating a problem that has been previously noted in commercial stores. The surface treatment prevented this. Populations of graniverous mites were of no consequence in the second year, due to the reduced m.c. and the presence of low numbers of predatory mites.

The survival of insects in bins that were cooled alone, is contrary to previously reported results. Examination of meteorological records showed that the warm first year of the farm-scale experiment had higher mid-winter ambient temperatures than previously and thus permitted less aeration, higher grain temperatures and enhanced insect survival. The insect strains used in this experiment were also more cold tolerant than those used earlier.

The strategy, including surface treatment using Etrimfos, was also applied in a 2500 t commercial store where two, 45 kw fans were switched on and off by a differential thermostat and a time clock, to use off-peak electricity. Pest-free storage at low temperatures was maintained until June but cooling was unexpectedly slow and expensive, with temperatures below 5 °C being attained in February at an estimated cost of 50 p/t. This was probably due to the high airflow of 32 cfm/t, 6 times the recommended norm, which was intended to dry the grain when necessary, as well as to cool it.

In conclusion, surface admixture has proved to be a valuable adjunct to the storage strategy, achieving near pest-free storage and reducing pesticide use and costs to the absolute minimum.

1. BACKGROUND INFORMATION

The storage of grain continues to be a critical and often misunderstood link in the chain from field to consumer. The length of storage is largely determined by the success of the conditioning applied in store. If grain is not dried and then cooled or treated with chemicals, infestations of insects, fungi and mites are inevitable and quickly make the product unsaleable or unusable. Although there are local commodity surpluses, this is not true worldwide; problems are largely those of storage and distribution. Successful export of surpluses must depend on achieving superior quality, including freedom from pests.

Scientific developments in the 1960s allowed grain to be stored in large quantities for the first time, without the certainty of infestation. The foremost of these techniques were cooling and insecticide admixture. The predictability of safe storage had important economic benefits; it meant that processors could buy grain when the market price was at its lowest and be sure that it would still be in good condition when it came to be used. Previously grain had been purchased when needed, not necesarily at advantageous prices.

It is widely supposed that grain is protected mainly by chemical means but recent surveys of farm grain stores (Prickett, 1989) and of commercial sites (Prickett and Muggleton, 1990) have corrected this misapprehension, as the table below shows.

The percentage of farm stores and commercial sites <u>using</u> insecticides and aeration systems

	Insecticide		Cooling
	Fabric	Grain	
Farms	52.1	9.7	60.2
Commercial	85.8	67.5	90.6

Unfortunately, research priorities have not always reflected the users' needs, so there is relatively little information worldwide on the technique of aeration (although it is often forgotten that much research on insect biology is aimed at the application of effective physical control methods). Grain must be dried to prevent fungal growth and following this must be cooled to prevent moisture movement caused by convection currents within the grain mass. Neither of these jobs can be dealt with by chemical means. Consumer demand for pesticide free food, the increasing problem that insects may develop resistance to pesticide treatments and the cost of insecticide use all point toward an increased reliance on physical control methods. On the other hand, physical methods are slow to deal with pest outbreaks and in such cases it may be most appropriate to apply relatively expensive control procedures such as admixture, fumigation or controlled atmospheres.

It is clear that the most effective method of grain storage will be an integrated approach, using the most economic combination of control methods available, to achieve predictably pest-free grain storage. Some theoretical approaches to this problem have already been made in Australia (Longstaff, 1986) and in America (Hagstrum and Flinn, 1990). In those countries, the weather after harvest is too warm to allow cooling for several months, so fumigation could be applied intermittently until the arrival of cool weather. Fortunately, this complex and expensive approach is not appropriate for the cooler, damper climate of Great Britain.

The first practical trials of integrated grain storage were funded by the HGCA. Wilkin et al. (1990) showed the advantages and limitations of a storage strategy aimed at maintaining pest-free grain. This strategy was based on cooling to prevent moisture movement and pest increase and the use of insect 'traps' to monitor populations of introduced pests. It demonstrated that infested grain could be cheaply cooled to 5°C in the British climate so that the insects used in the test all died. However, the grain surface was identified as a vulnerable area, where the temperatures could not be controlled, where upward migrating insects could survive and where mite populations develop as the grain absorbed moisture in the winter. Potential economies in fan running hours were identified that depended on the greater uptake of automatic control. That there is much scope for such an improvement in the industry was confirmed by Prickett and Muggleton's (1990) survey of commercial sites (some sites used more than one method).

Methods of fan control employed on 153 commercial sites (%)

Manual	Timer	Thermostat Normal	Thermostat Differential	Thermostat and Humidistat
84.3	3.3	7.8	2.0	17.0

The experiments detailed in this report were designed to develop the integrated storage strategy to deal with surface insect infestations, to examine the problem of mites for the first time and to test the strategy in a large commercial store. Sources of variation that might affect its application, namely climate and insect strain, were also examined.

2. FARM-SCALE EXPERIMENTS

i. Objectives

1. To monitor mite populations in aerated grain.
2. To test the survival and behaviour of field strains of insects in aerated grain.
3. To compare conventional with novel sampling methods for monitoring insect numbers.
4. To find the effect on pests of complementing the aeration regime with a surface admixture treatment.
5. To verify the estimate of fan power required.

ii. Introduction

In the first HGCA-funded integrated control project (Wilkin et al., 1990) careful monitoring of insect numbers, using novel trapping techniques, showed how cooling with ambient aeration could be used to eliminate three insect species from stored wheat in the course of a 9 month storage period. This was complemented by field work in which surface infestations of Sitophilus granarius in aerated stores were eliminated by raking insecticidal dust into the grain surface.

However, the idea of using peripheral treatments of insecticide, to complement the aeration regime, was initially conceived to deal with a different insect species:- Oryzaephilus surinamensis, which had previously been shown to migrate upwards in aerated bins (Armitage and Stables, 1984; Armitage et al., 1983). This species had also shown the ability to survive at the surface of aerated bins when it was confined there (Armitage and Llewellin, 1987) but, despite this, when it was free to move it was not found to remain at the surface (Wilkin et al., 1990).

To prevent infestations moving out of aerated bins and causing a nuisance elsewhere it would seem a logical step to kill the insects by using a surface insecticidal treatment as they move to easily accessible surface layers of a grain bulk. This would avoid the need to turn the entire bulk at great energy and manpower cost. It would also reduce the amount of pesticide used.

The previous integrated control experiment did not examine the effectiveness of the aeration regime in controlling mite numbers. As mites occur more frequently than insects in bulk grain (Prickett, 1989; Prickett and Muggleton, 1990), they are often regarded as being more troublesome. Therefore, it is essential that any control strategy should prevent mites from reaching unacceptable numbers. Fortunately, they are normally controlled adequately by drying grain to a moisture content in equilibrium with a relative humidity below which they can complete their development. This is 65 - 70% r.h (Cunnington, 1965) and equates to a grain m.c. in the region of 15%, depending on temperature (Henderson, 1987). Reduction in temperature of grain at a given moisture content also reduces its equilibrium relative humidity (e.r.h.). However, surface grain absorbs moisture during the damp winter months, so the mites often develop as surface infestations in otherwise dry grain (Armitage, 1984). These surface mite infestations are ideally situated for treating with a surface insecticidal admixture. Wilkin and Stables (1985) found that surface insecticides controlled existing infestions of Glycyphagus destructor in field trials but only etrimfos controlled Acarus siro . However, in laboratory trials it became clear that low temperatures had retarded the insecticidal action. Use of surface treatments to supress the development of infestations have been reported.

It was therefore decided that the next large-scale experiment should examine the advantage of surface admixture, when complementing a normal aeration regime. Therefore mite and insect populations were compared in 6 aerated bins of wheat, three of which were surface admixed with Pirimiphos-methyl dust.

iii. Materials and methods

a. Oct. 1989- June 1990

i) Loading the grain bins

Six bins, each measuring about 3mx3mx3.5m and housed within a barn, were sequentially filled with about 20 tonnes of wheat. The grain was initially received in August 1989, at 13-14% moisture content (m.c.). As this was too dry to allow the development of mites, the grain was turned and wetted to achieve 15% m.c., in equilibrium at 25°C with 70% r.h. (Henderson, 1987). The grain was then turned a second time to ensure the moisture was evenly distributed. The dampening process was commenced in September, but due to a mechanical breakdown, was not completed until October.

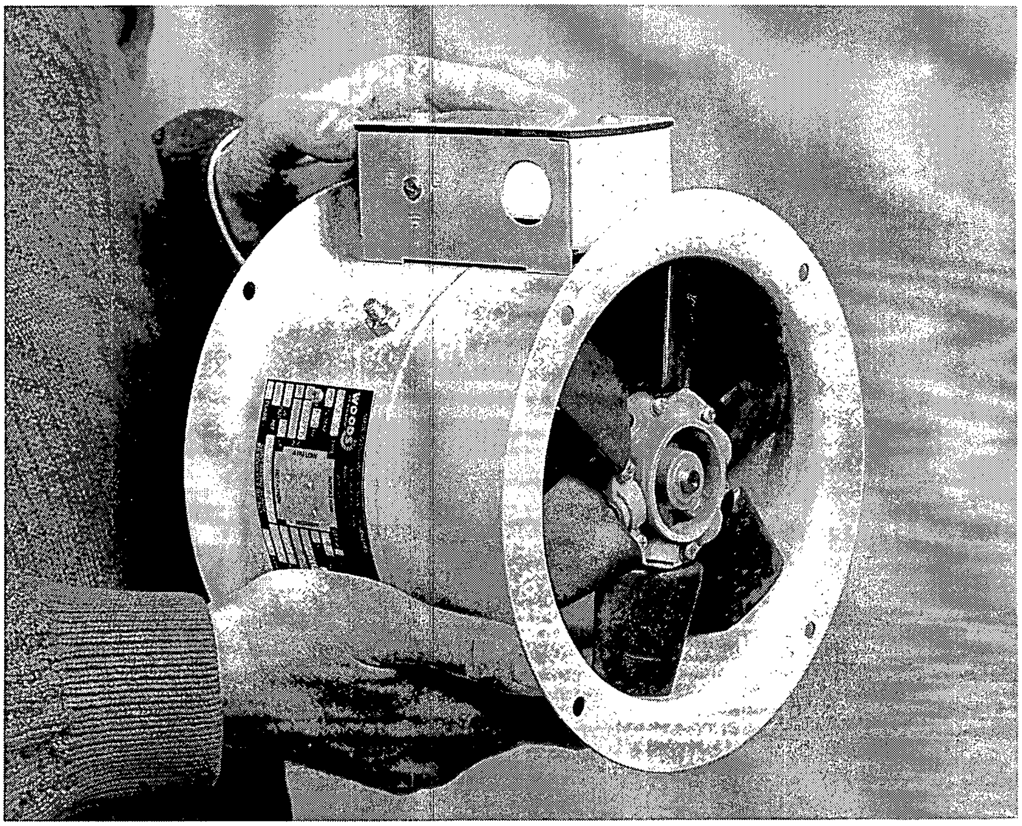
ii) Aeration regime

Each bin was fitted with an aeration system using axial fans (Fig. 1) of approximately 0.02 kW output (20 W). These blew air upward through a central duct of 25 cm diameter beneath the grain. Air was ducted to the fans inlet from outside the barn to avoid recirculation of warm air.

The time of fan operation was controlled by a differential thermostat which switched the fans on when the temperature, measured by a single probe at the centre of one of the bins and 0.5m below the surface, exceeded ambient air temperature by 4°C.

The airflow was adjusted to 10 cu m/h/t by partial blanking of the fan inlet. Airflow measurements were made using a hot wire anemometer. A duct of the same diameter as the fan inlet (15

Fig. 1
Small, 20 w output fan, used to aerate 2.5m deep, 25 tonne farm bins.



cm) and 75 cm long was attached to the fan inlet and measurements were made half way along the duct. At the end of the test the airflows were checked using a pitot tube and inclined micro manometer (BS 848 and 1042) and by measuring the airflow at the surface by timing the movement of a bubble along a glass tube (Burrell and Armitage, 1979).

iii) Temperature recording

Temperatures were monitored continuously using Squirrel data loggers and thermocouples at 2 positions and four depths in each bin. These were at the centre and 0.5 m from the outer corner and at depths of 0.5, 1.0, 1.5, and 2.0 m. Manual readings of temperature were also taken daily at the start of the test and weekly or twice a week later, when temperature changes were slow.

iv) Artificial infestation

Each bin was infested with 1 adult/kg. of both O.surinamensis and S. granarius, and with 1 adult/2kg of Cryptolestes ferrugineus. The insects were strains collected in the year prior to the experiment in a countrywide survey of commercial grain stores.

A total of 10 strains of O. surinamensis and 8 of S. granarius were bulked and mixed and the results used to set up 50 new cultures from which the initial experimental infestation was made up. The C. ferrugineus were harvested directly from cultures set up after initial reception of the insects from the commercial stores.

The insects were introduced into 13 positions in each bin and at 3 depths; 0.5 m, 1.0 m and 2.0 m. Thus 39 jars of insects were prepared for each bin. To achieve the required infestation density, about 513 of O. surinamensis and S.granarius and 256 C. ferrugineus were introduced into each position in each bin.

The insects were introduced by pushing a plastic pipe to a depth of 2m in each position; this was then emptied of grain using a vacuum cleaner. A jar of insects containing a little grain was then poured down the pipe and the pipe was raised to 1m depth. Another jar of insects was introduced, and so on.

Twelve kg of grain at 16-17% m.c. was divided into twenty-four, 0.5 kg batches. Into 12 were introduced approximately 12,000 mixed stages of the mite Acarus siro and into the other 12, the same number of Glycyphagus destructor. These were allowed to breed to provide an acarid innoculum for each bin and were combined with the insect innoculum and inserted in the same manner.

The insects were inserted on 18th October and left for 1 week before the insect monitoring devices were put into place for the first time on 25th October.

v) Conventional sampling

Fifteen 250 g spear samples were taken from each bin from 5 columns and 3 depths (surface, 1 m and 2 m). The columns were at the centre of the bins and half way to the centre from each of the 4 sides. These samples were taken the day before aeration commenced and thereafter, monthly. These were sieved through 2 mm and 0.7 mm mesh for insects and mites respectively and then the moisture content was determined by drying finely ground 5 g duplicate samples in a ventilated oven at 130 °C for 2 h (BS 412).

vi) Insect traps

Sixteen pitfall traps were inserted into the surface of each bin in an equidistant 4x4 grid. Nine probe traps were inserted at the surface of each bin in an equidistant 3x3 grid and the process was repeated at 1m and 2m, so there were 27 probe traps per bin. The probe traps were inserted to 1 m and 2 m depth by pushing them down with metal rods and were withdrawn using cords of rope or fishing line of appropriate breaking strain.

The pitfall and probe traps were withdrawn and the insects within counted after 1 week. They were used to sample the contents of the bins on 2 consecutive weeks before aeration commenced, for 4 consecutive weeks afterwards and thereafter, monthly.

Fifty bait bags, distributed equidistantly around the interior base of the barn wall were used to monitor insects leaving the bins and emigrating from outside.

vii) Insecticide treatment

Three of the 6 bins had 2% active ingredient 'Actellic' (Pirimithos-methyl) insecticidal dust raked into the surface grain to a depth of 0.3 m at a rate of 45 g/sq.m. Four equidistant samples were taken at the surface of each bin for chemical analysis. The treatment was carried out and aeration commenced on the 7th November, after the sampling for insects and mites.

viii) Resistance monitoring

The S. granarius population was known to be susceptible to Malathion, but no test was available for Pirimiphos-methyl and the C. ferrugineus population was not tested as there were too few individuals available. However, it was likely to be succeptible to Pirimphos-methyl.

Before the O. surinamensis were inserted into the bins, a sample of 103 adults was tested for resistance to a discriminating dose of 0.6% Pirimithos methyl in 'Risella' oil applied to filter paper. Adult beetles were exposed to the insecticide following the standard FAO method (Anon., 1974).

Before the surface of the grain was treated and during the course of the experiment, further tests were made on adult beetles collected from the probe and pitfall traps. Before the treatment, samples of insects caught at each trapping level were combined for testing, but afterwards the insects from the pitfall and probe traps at the surface were combined, as were the contents of the probe traps at 1m and 2m. Beetles from each bin were tested separately and those collected after the surface treatment were held for at least 14 days on clean food before being exposed on the treated filter papers.

ix) Outloading sampling

At the end of the test, the grain was sampled for insects at outloading, by taking 1 kg samples every 15 minutes.

b. Oct. 1990-May 91.

In the experiment commencing in October 1990, the general details remained as above, with three small changes. Bait trapping was discontinued, due to the low numbers of insects caught the previous year. The peripheral temperature measurements were taken at the surface and at depths of 0.5 m, 1.0 m and 1.5 m instead of 0.5 m and depths of 1.0 m, 1.5 m and 2.0 m as occurred the previous year and at the centre of the bin. Finally, the differential thermostat was set at 4°C only until the end of December, when it was turned down to 2°C, to try to maintain low temperatures for a prolonged period.

iv. Results

i) Temperatures and hours of aeration

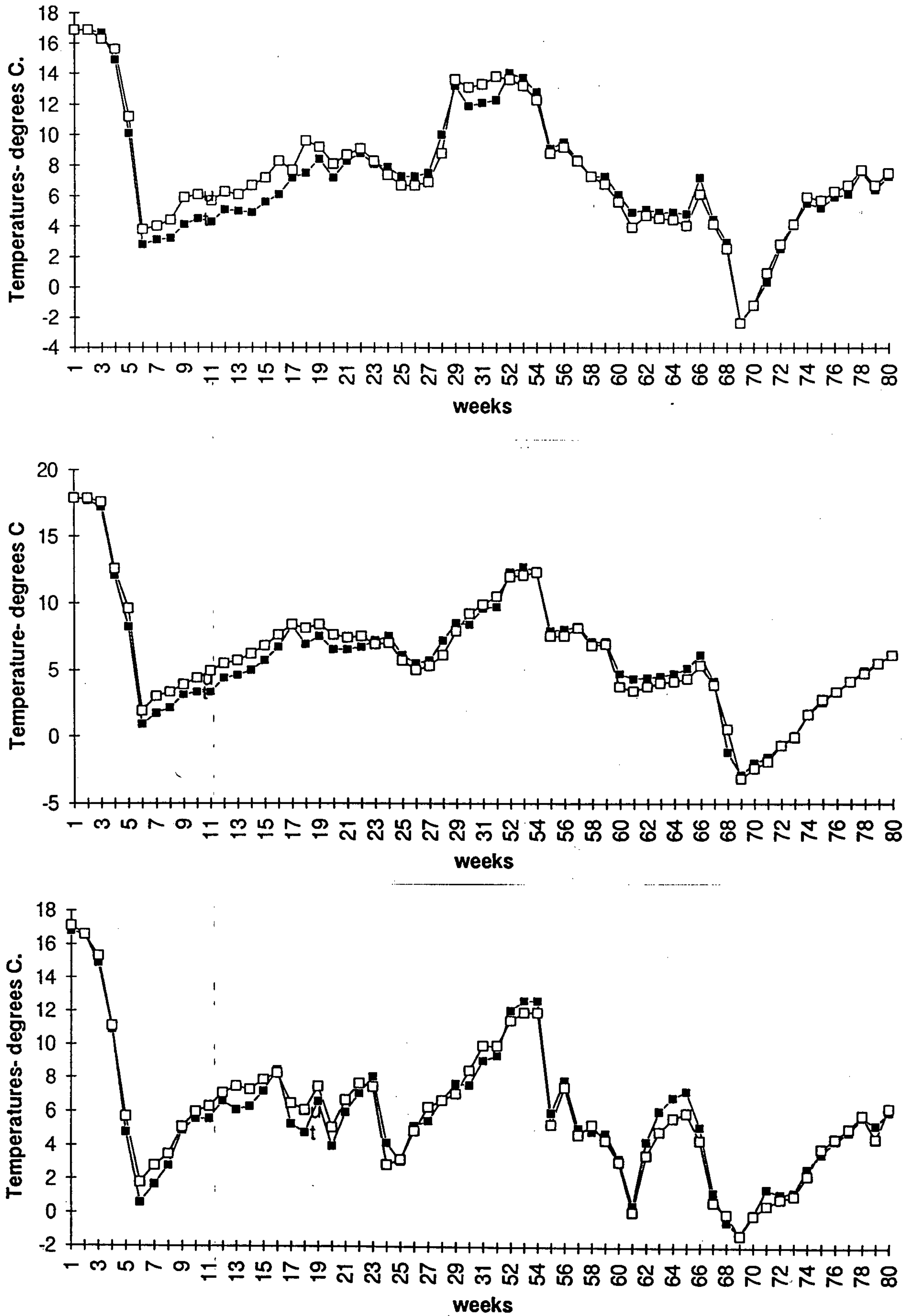
a. Oct. 1989-June 1990

Temperatures, initially at 17-18 °C at the centre of the bins (Table 1, Fig. 2) and 15-17 °C at the periphery, (Table 2) fell a few degrees to 15-17.5 °C and 13-14 °C respectively, in the 3 weeks allowed for the insects' "settling in" period.

Temperatures at all levels and in all bins had mainly fallen below 10 °C after 136 h of aeration (Table 3) by the 5th week (2 weeks after aeration commenced). They were mainly below 5 C after a further week, at the end of November, after 224 h aeration. Thereafter, mean temperatures edged up as there was little subsequent aeration, so they increased to 6-8 °C by February, both at the centre and the periphery. The temperature of grain in the untreated bins was consistently higher than in the treated, but not usually by more than 1.5°C.

Fig 2.

Temperatures in surface treated (open symbols)) and untreated (closed symbols) aerated bins of wheat (n=3). Top, 0.5m ; middle, 1m ; bottom, 2m.



Temperatures rose steadily from almost 7 °C to about 15 °C at the periphery and 10 °C at the centre between February and June with usually less than 1 °C difference between treated and untreated bins.

b. Oct 1990-May 91

Temperatures fell swiftly from around 15 °C in October, to below 5 °C in mid December (Tables 4,5) after 250 h aeration (Table 6). They reached a minimum below zero in mid February after 581 h aeration, then rose by May to 6-8 C at the centre and nearly 10 C at the side.

ii) Aeration

The airflow entering the treated bins was a mean of 201 cu m/h (197- 217) or 10 cu m/h/t. Only 2 of the 3 aerated bins could be measured as the duct in bin 6 became blocked at the end of the test. The airflow entering these was also 201 cu m/h/t (204, 197).

The bubble meter is intended mainly as a measure of eveness of air distribution. Swifter air movement occured at the centre of the bins than the edge. The airflow at the centre was 1.2x (1-1.3) that at the side of the treated bins and 1.3x (1.1 & 1.6) for the untreated bins. The airflow estimates at the surface by this method were 88 cu m/h (86-92) for the treated and 85 cu m/h (88 & 82) for the untreated.

iii) Moisture content

a. Oct 1989-June 1990

Initially, the moisture content of grain at 1m and 2m was about 15 %, with no difference between treated and untreated bins (Table 7). The surface was slightly higher at 15.5 % m.c. The m.c. of the surface rose to nearly 17 % in all bins by December and remained there, while the moisture content at 1m and 2m dropped by 0.2-0.5 %. There was a difference, probably unimportant, of 0.1-0.2 % m.c. between treated and untreated bins.

Between February and June, moisture contents fell at the surface from about 17 % to 13 % but moistures at 1 m and 2m remained about the same, at 14.5 %.

b. Oct 1990 - May 1991

Moisture contents at the surface rose from 14.7-15.5 % between October and January and fell to 14 % in May (Table 7). At 1m they remained about 14.3 % and at 2m rose from 14.6-14.8 % to just over 15 %.

iv) Mites

a. Oct 1989-June 1990

At the start of the experiment, numbers of Glycyphagus spp in treated and untreated bins were of the same order at all depths and bins; between 21/kg and 79/kg (Fig. 3, Table 8). At the surface of the untreated bins, numbers rose to exceed 500/kg for most of the time between December and March while they were usually below 5/kg in the treated bins. They fell to below 20/kg in the untreated bins by May when there were still less than 5/kg in the treated bins.

At 1m numbers of this genus rose steadily from 48/kg to nearly 100/kg in the untreated bins by May, while treated bin numbers were below 5/kg until May when they rose to about 70/kg At 2m, Glycyphagus increased to exceed 200/kg in the untreated bins in April and May, when there were also over 100/kg in the treated bins.

Numbers of Acarus spp. were initially of the order 1-5/kg (Fig. 4, Table 9). At the surface of the untreated bins, numbers of Acarus rose to exceed 1000/kg in February, then fell to below 20/kg by May. In the treated bins they were always below 10/kg and usually below 3/kg at the surface.

At 1 m, numbers in the untreated bins rose sharply to over 800/kg between March and May, while in the treated bins, they remained below 20/kg. At 2 m, Acarus in the untreated bins remained below 10/kg until February and below 50/kg until May, when they reached nearly 1000/kg. Numbers in the treated bins were of a similar order.

Cheyletus eruditus were initially present at 0-3/kg (Fig.5, Table 10). At the surface of the untreated bins they rose to about 20/kg by May and in the treated bins they fluctuated between 1/kg and 6/kg. At 1 m and 2 m, they were below 6/kg throughout the year in both sets of bins.

b. Oct. 1990-May 1991

Glycyphagus fell from about 60/kg at the surface of the untreated bins in November to less than 1/kg in May, while numbers in the treated bins were at or below 3/kg (Table 8). At 1m, numbers of this mite in both sets of bins were below 5/kg. At 2 m, they fell from about 40/kg in the untreated bins, to less than 10/kg while in the treated bins, they were usually less than 10/kg.

Few Acarus (Table 9) were found at the surface or 1 m, where they were below 1/kg in both sets of bins. At 2 m, numbers were slightly higher but they were still less than 10/kg with two exceptions. They reached 75/kg in December in the untreated bins, and 13/kg in the treated bins in February.

Fig. 3.
Comparison of nos./kg. of *Glycyphagus* (n=5) in surface treated (t) and untreated (u) aerated bins of wheat (n=3). Top, surface; middle, 1m; bottom, 2m.

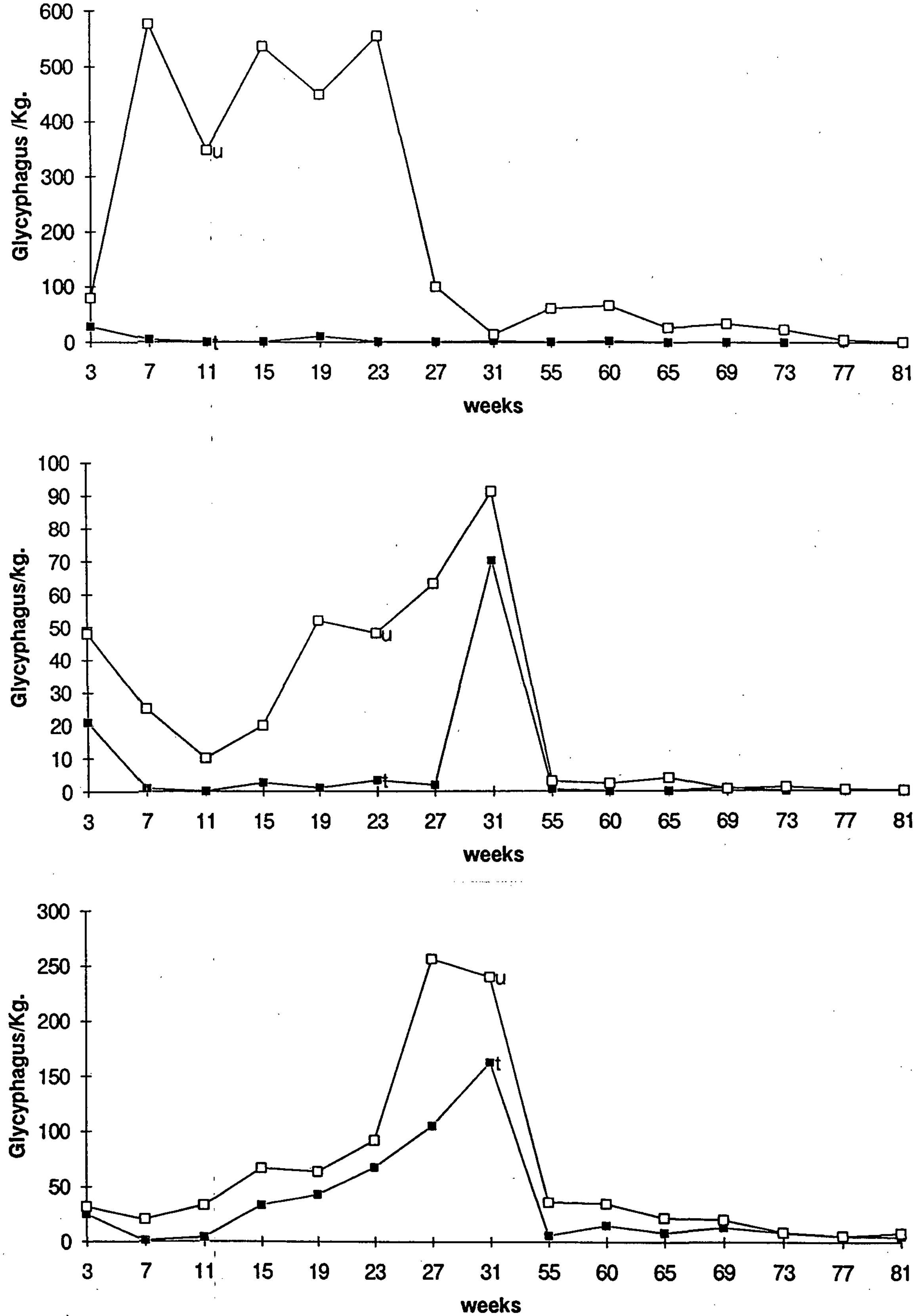


Fig. 4.
Comparison of nos./kg. of *Acarus* (n=5) in surface treated (t) and untreated (u) aerated bins of wheat (n=3). Top, surface; middle, 1m; bottom, 2m.

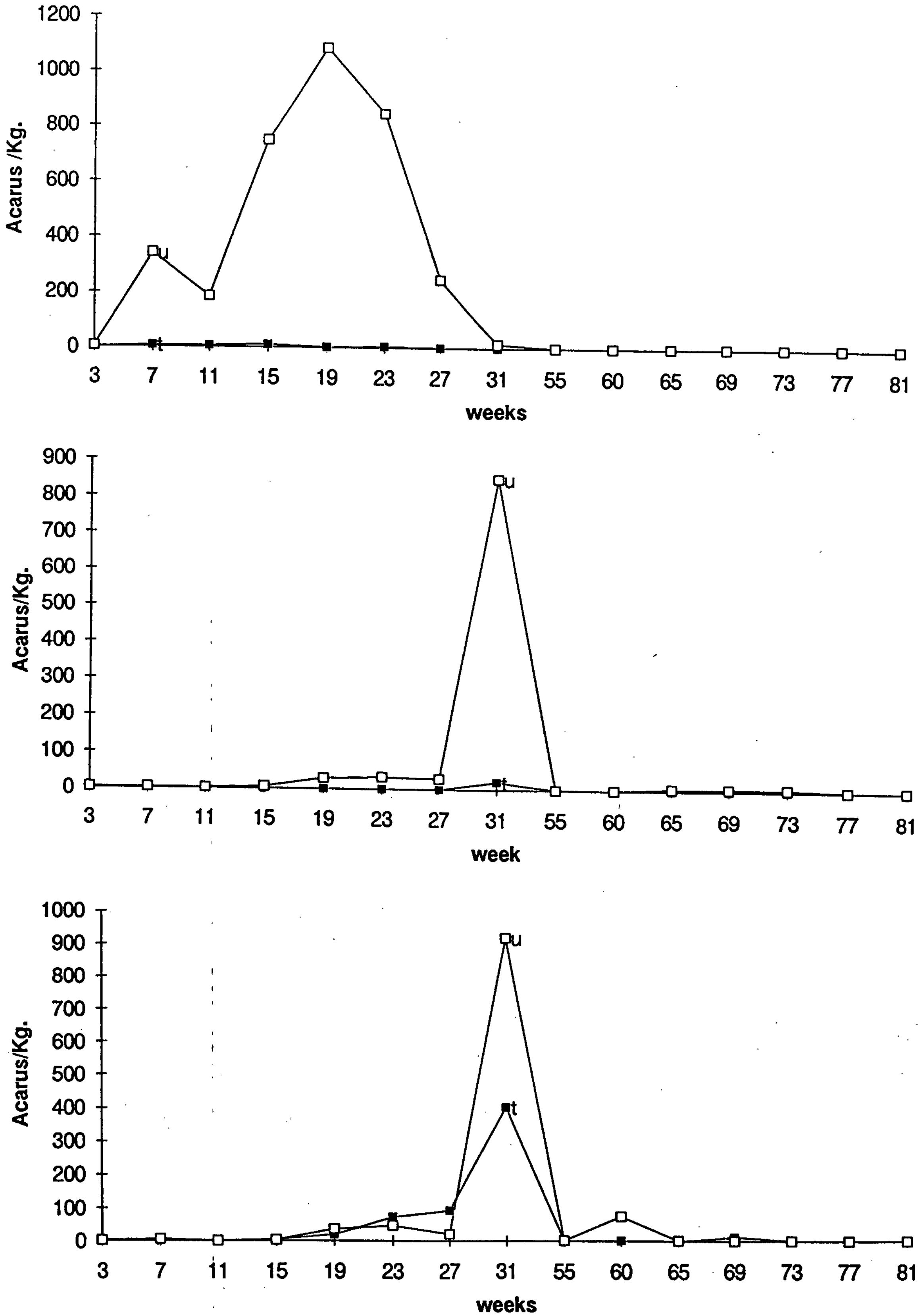
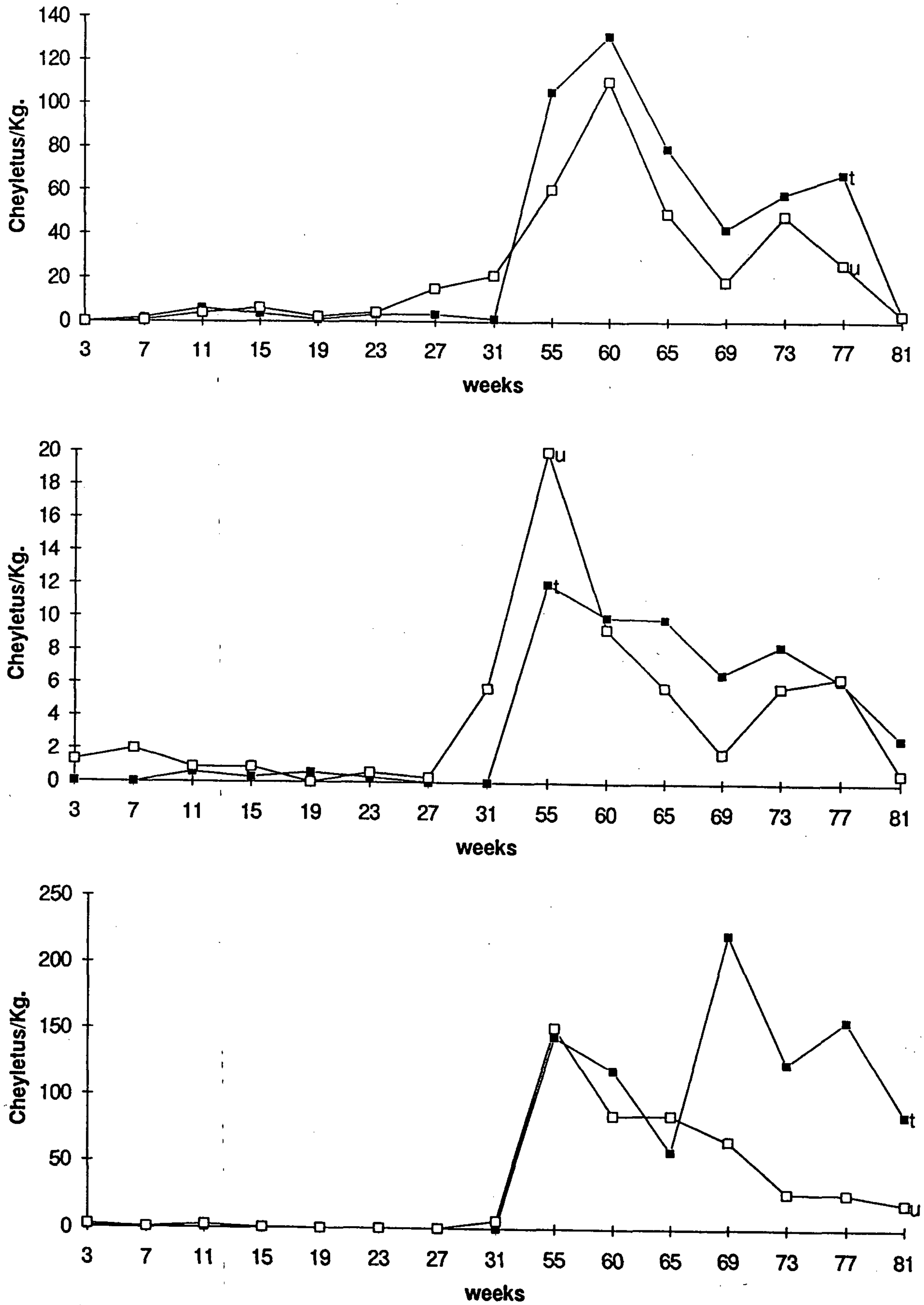


Fig. 5.
Comparison of nos./kg. of *Cheyletus* (n=5) in surface treated (t) and untreated (u) aerated bins of wheat (n=3). Top, surface; middle, 1m; bottom, 2m.



The predatory mite, Cheyletus sp. was the commonest mite in the second year. At the surface it exceeded 100/kg in December and then declined to less than 5/kg in both sets of bins (Table 10). At 1m, numbers were usually below 10/kg. At 2 m, numbers in the untreated bins fell from over 100/kg to below 20/kg between November and May while treated numbers fluctuated between 58 and about 150/Kg., without any apparent trend.

v) Insects (Spear samples)

a. Oct 1989-June 1990

Numbers of insects in spear samples were generally too low and variable to enable statistical analysis, so standard errors (s.e.) have not been given in the tables. No striking differences between numbers of insects found in treated and untreated bins were noted during the experiment.

On the first sampling occasion, the conventional sampling appeared to overestimate the numbers of S. granarius (Table 11) and O. surinamensis (Table 12). Overall, it suggested nearly 2/kg of these 2 species were present. While S.granarius were found mainly at 1 m and 2 m, O. surinamensis occured mainly at 1 m. Numbers of C. ferrugineus estimated using the spear samples were close to those introduced (Table 13), although none were found at the surface.

Numbers of S. granarius found in spear samples remained of the same order as initially and they continued to be found at the same depths. However, the numbers of live insects decreased and only 1 live S. granarius was found after January. Numbers of live or dead O. surinamensis fell after the initial sampling and thereafter remained below 1/kg at 1 m and 2 m but they exceeded 1/kg at the surface of both sets of bins in April and May. Numbers of C. ferrugineus recovered remained of the same order as initially and 7 of the 8 captured during sampling at the end of January, were alive. Only two live were found on the last 3 sampling occasions.

b. Oct. 1990-May 1991.

Only 5 live S. granarius were found in 7 samplings (630 samples) in all the bins (Table 11). The last live weevil was found in January in one of the untreated bins, at the surface. Dead S. granarius or fragments of this species continued to be found at all levels and their numbers were about 2/kg. A single live O. surinamensis was found at the surface of an untreated bin in May and only 10 were found during the second year of the experiment (Table 12). Only 1 live C. ferrugineus was found in the spear samples (Table 13).

vi) Insects (in traps)

a. Oct 1989-June 1990

For the first two samplings, O. surinamensis was most common in probe traps at 1 m in all bins (Fig. 6, Table 14). After the surface treatment had been carried out and aeration had commenced, the numbers of this species at the surface increased, but the first week after aeration they were still commonest at 1 m. Latterly, however, they were usually commonest at the surface. Peak numbers at the surface occurred the first week after aeration in the treated bins and one week later in the untreated bins.

Until December, there was no consistent difference between the numbers of O. surinamensis found at the surface of treated and untreated bins but between February and June, their numbers were always highest in the untreated bins. Here they increased between February and May to exceed 200/bin in the untreated bins while there were less than 10/bin in the treated.

At 1 m and 2 m, few O. surinamensis were found in all bins, from December on, and numbers had dropped from over 100 to less than 5 (in 27 traps at each depth).

In the pitfall traps (Fig. 7, Table 15), numbers of O.surinamensis dropped over the first two weeks before aeration, then rose to a peak 2 weeks afterward. On the first 2 sampling occasions there were more of this species at the surface of the bins that were subsequently treated, than the others. Thereafter, numbers were lower in these bins for 9/10 samplings. Until May, few occured in the treated bin but in the untreated bin numbers of live still exceeded 10/bin. Between February and May, numbers of this species increased to over 50/bin in the untreated, compared with 10/bin in the treated.

For the first 4 weeks of the experiment, S. granarius was markedly commoner in probe traps at 1 m than at 2 m and commoner at 1 m than at the surface (Fig. 8, Table 16). For the first 3 weeks, higher numbers were trapped in the treated bins at 1m than in the untreated and in the untreated bins at 2 m than in the treated. There were no consistent differences between the sets of bins and by the end of January, very few S.granarius were found anywhere.

In pitfall traps (Fig. 7, Table 15), numbers of S. granarius were higher in the untreated than the treated bins after week 5. Between late January, until May, less than 1 S. granarius was found per treated bin but their numbers still exceeded 20 in the untreated bins in January and 8 per untreated bin were found in May, 10 times the numbers in the treated bins.

C. ferrugineus was commoner in probe traps at 1 m than 2 m and commoner at 2 m than the surface for the first 2 samplings

Fig. 6.
Comparison of nos. of *O.surinamensis* caught in probe traps (n=9) in surface treated (t) and untreated (u) aerated bins of wheat (n=3). Top, surface; middle, 1m; bottom, 2m.

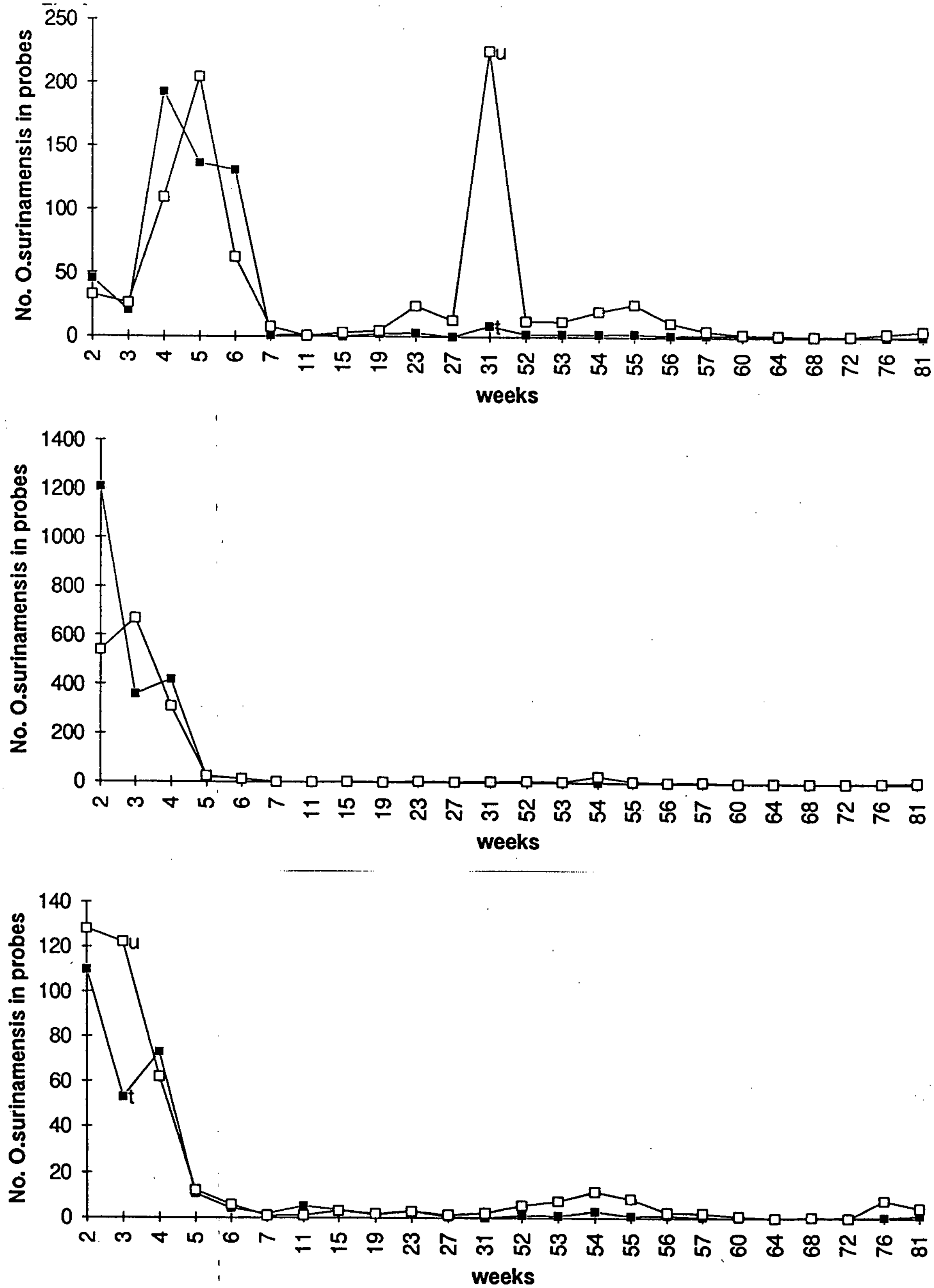


Fig. 7.
Comparison of nos. of insects caught in pitfall traps (n=16) in surface treated (t) and untreated (u) aerated bins of wheat (n=3), Top, *S.granarius*; middle *C.ferrugineus*; bottom *O.surinamensis*.

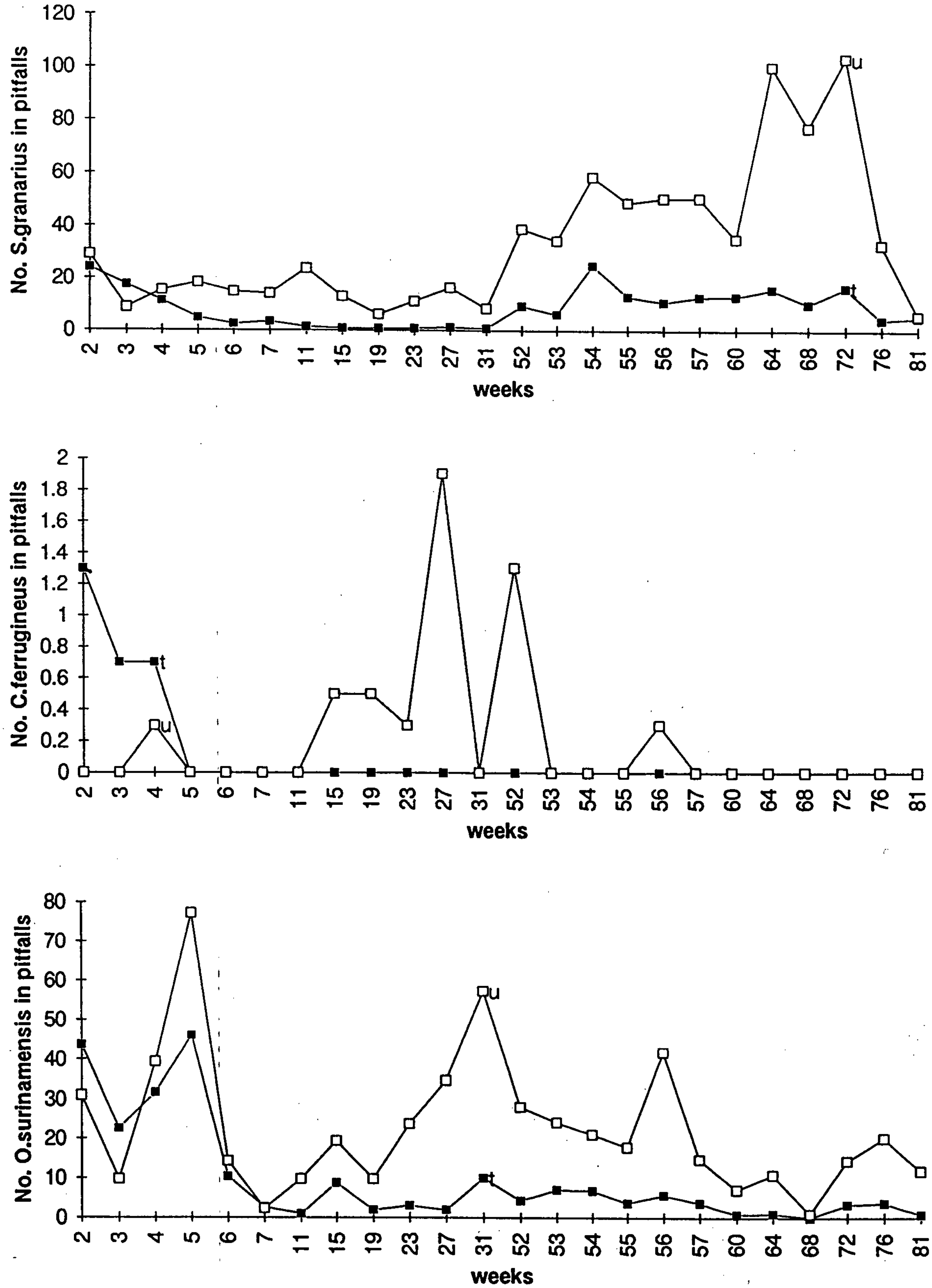


Fig. 8.
Comparison of nos of *S.granarius* caught in probe traps (n=9) in surface treated (t) and untreated (u) aerated bins of wheat (n=3). Top, surface; middle, 1m; bottom, 2m.

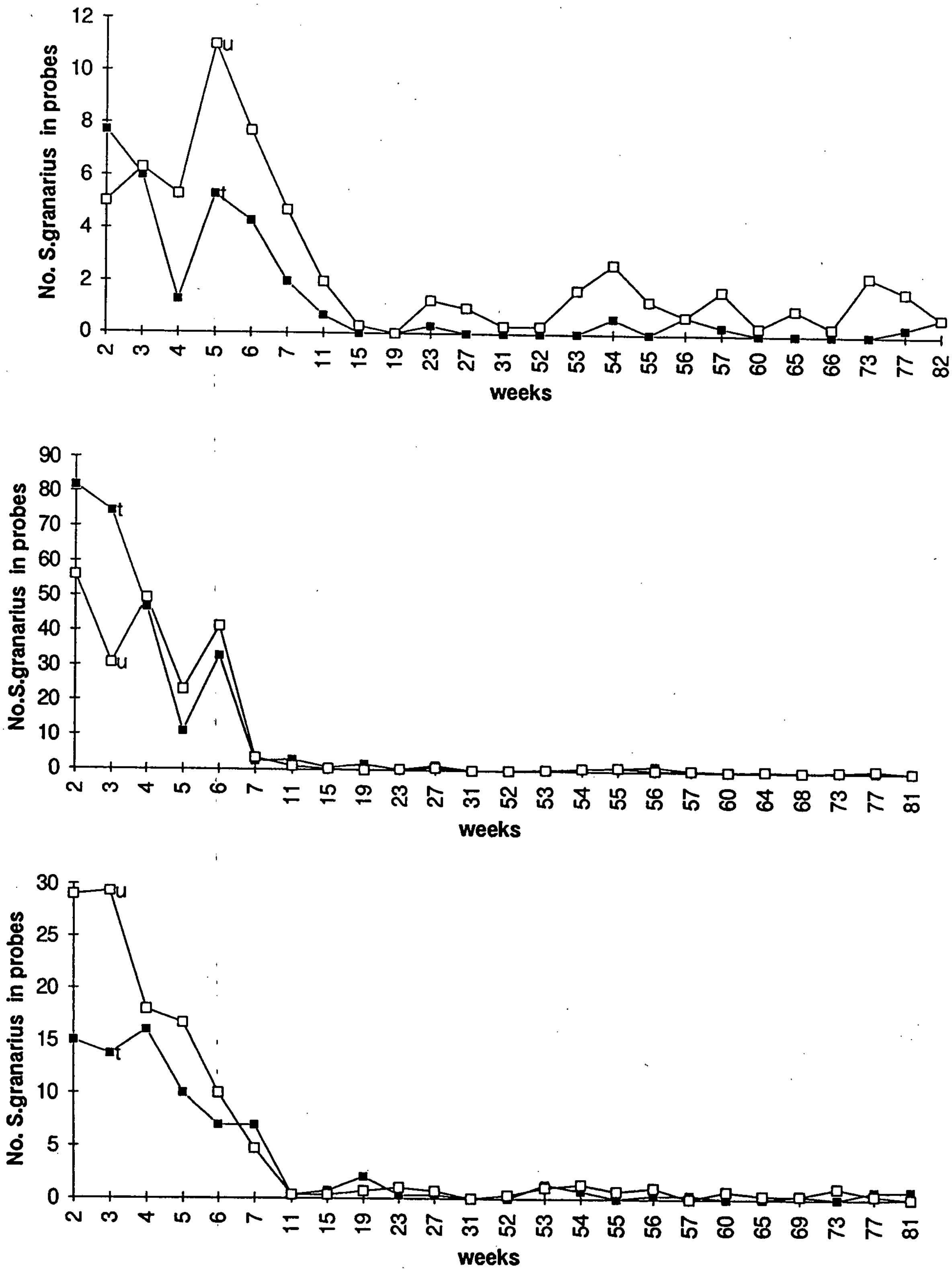
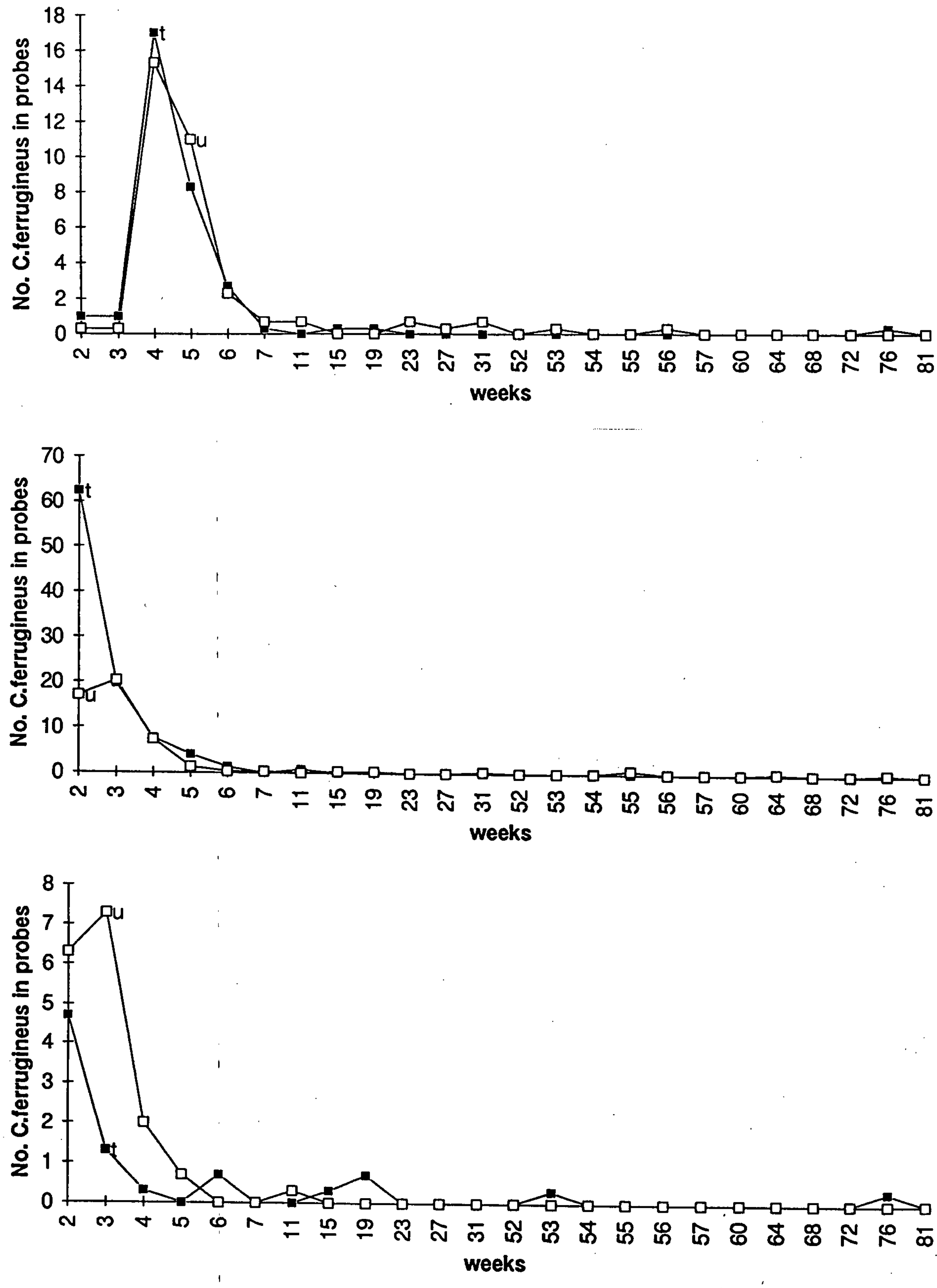


Fig. 9.
Comparison of nos. of *C.ferrugineus* caught in probe traps (n=9) in surface treated (t) and untreated (u) aerated bins of wheat (n=3). Top, surface; middle, 1m; bottom, 2m.



(Fig.9, Table 17). After aeration, it was commonest at the surface for 3 weeks but numbers everywhere fell in the following weeks to less than 1/bin in 27 traps.

Too few C. ferrugineus were found in the pitfalls to discern any trends (Fig.7, Table 15) but a few adults were still being found in April.

Few of the introduced insects of any species and no C. ferrugineus were found in the bait bags inside the barn housing the bins. The most consistently trapped species were Cryptophagus spp. (Table 18).

b. Oct. 1990-May 1991

Probe traps caught few S. granarius (Table 19) and fewer still C. ferrugineus (Table 20). Rather more O. surinamensis were found than the two former species and more were usually caught in untreated than treated bins at all levels (Table 21). Peak numbers trapped of this species occurred at the surface and were about 25 per untreated bin, the 1st week after aeration was recommenced, compared with 2 per treated bin. Numbers at the surface fell rapidly thereafter to less than per untreated bin by January but rose to over 4 in May. Only one or two individuals were found sporadically in the 3 treated bins during this time. There was some evidence of an increase in O. surinamensis trapped at 1m and 2m during April and May in the untreated bins. At the end of the test, numbers at all levels were similar and there were over 4/27 traps at all levels in the untreated bins, compared with 1 or less in the treated bins.

The pattern was very similar for the pitfall traps (Table 22). Peak numbers of O. surinamensis occured 1 week after the probes and were over 40/bin in the untreated bins compared with about 6/bin in the treated. They declined to 1/bin or less everywhere in February but rose again in the Spring. At the end of the test in May, when there were less than 1/bin in treated bins compared to over 10 in the untreated bins.

Numbers of S. granarius in pitfall traps from untreated bins rose to a peak of about 100/bin in January and March, compared with approximately 15 per treated bin. By May numbers had declined to about 5 in both sets of bins.

vii) Resistance monitoring

a. Oct 1989-June 1990

The result of testing the O.surinamensis before they were put into the bins showed 90.3% were knocked down by the discriminating dose. Therefore, about 10% can be considered as resistant to Pirimiphos-methyl.

Tests on the first two post-treatment samples (Table 23) showed no significant difference in knockdown between insects from different depths in either the treated or untreated bins and therefore depth has not been taken into account when comparing samples from these dates.

Sampling of the untreated bins showed a consistent frequency of knockdown to Pirimiphos-methyl throughout the period and no significant change from that of the founding population. The knockdown by Pirimiphos-methyl in the first two pre-treatment samplings from the treated bins did not differ significantly from the founding population or from that in the untreated bins. Subsequent samplings from the treated bins were too small for any comparisons to be made.

b. Oct. 1990-May 1991

During 1990, the numbers of beetles caught at each depth was small and therefore samples have been combined so that comparisons can be made. In fact, nearly all the insects tested came from the surface traps. In addition, the numbers of adults caught in the traps in the treated bins was too small for comparisons to be made between the frequencies of knockdown on different sampling occasions. Combining the results for all the samples taken from the treated bins during 1990 gives 19 knocked down out of 28 tested, a frequency of 68% knockdown which is significantly different (chi 2 (Yate's correction) = 8.42, 1df) from the result for the treated bins, where a total of 584 beetles were knocked down out of 649 tested, giving 90% knockdown.

viii) <u>Insecticide treatment</u>

Before treatment, no organophosphorus compounds were detected on the grain. After treatment, the treated bins had a mean of 7.2 mg/kg at the surface while the others had less than 0.1 mg/kg. The intial level in the treated bins fell to 3.6 mg/kg after a year and to 2.2 mg/kg at the end of the test in May 1991.

ix) <u>Outloading sampling</u>

The grain was despatched in 5 loads in 4 days between 1.7.91 and 5.7.91. Thirty two samples (8 kg.) were taken and these yielded 35 <u>S. granarius</u>, or fragments thereof, (4.4/kg.) of which only one was alive, therefore over 97% were dead. In addition 3 dead <u>O. surinamensis</u> (0.4/kg) and 2 dead <u>O.surinamensis</u> (0.3/kg.) were found. As each load comprised elements of more than one bin, it was not possible to distinguish between treated and untreated bins.

v. Discussion

In the first year, the six bins were cooled from 15-20 °C to 10 °C at a cost of 1.2 p/t in 36 days and to 5 °C in 43 days at 2 p/t (assuming the 20 W output fans consumed 30 W and an electricity tarriff of 6 p/kWh). The rapid cooling to below 10°C precluded any of the insects completing their development. At 20 °C, O. surinamensis takes 80 days (Howe, 1956), S. granarius 57 (Eastham and Segrove, 1947) and C.ferrugineus 109 (Smith, 1965). Only S. granarius completes its development at 15 °C and this takes 144 days. There was no evidence from the sampling or trapping that any increase in insect numbers took place during this initial cooling stage.

In the second year, temperatures were once again reduced to 5°C after 232 h aeration at an estimated cost of 2.1 p/t. These temperatures were well maintained into the spring using a total of 581 h aeration at a total cost of 5.2 p/t. Not all of the extra 349 h aeration that occurred once the grain had reached 5 °C was entirely necessary. It was a result of a spell of untypically severe weather in late February, of a malfunction of one of the thermostat probes which allowed an unknown period of inapropriate aeration and of the choice to turn the differential thermostat setting to 2 °C, to maintain the low temperatures.

The catch of insects in probe and pitfall traps fell progresively after the start of the test. This was probably a result of a combination of increasing mortality and decreasing catch efficiency with falling temperatures and consequent lowered insect mobility. However, a few live insects (<1/trap) were still being trapped in March, although it is doubtful that they would have been detected by a less rigorous sampling regime.

There was evidence that the most active insects; O.surinamensis and C. ferrugineus moved to the surface when aeration was started, although the effect was not as marked as when the grain was initially warmer (Wilkin et al., 1990). However, it is interesting to note that the surface treatment did not immediately kill the insects as they were still able to move into the traps. Hence there was no great difference between catch in treated and untreated bins. Barson (1991) has discussed the slow action of pesticides at low temperature. A further interesting feature is the large number of dead insects found in the untreated bins which were not noticed in the earlier experiment by Wilkin et al., (1990). This suggests some of the insects from the treated bins were escaping into their untreated neighbours and presumably, vice versa. It seems likely that some insects picked up a lethal dose of pesticide as they wandered through the treated grain. However, the slow action of Pirimiphos-methyl at low temperatures allowed the insects to wander into the traps before dying.

The main points of interest from the farm-scale test after October 1990 are the increase in O. surinamensis caught in spring in the untreated bins and the peak mid- Winter catches of S. granarius. It is very likely, although not possible to confirm, that the low catches of insects in the treated bins in 1990 were again were mainly due to cross-over from the untreated bins. This integrated approach therefore continued to be highly succesful.

The spring increase in O. surinamensis catch indicates that aeration alone was unable to eliminate the introduced infestation. In previous tests (Armitage and Llewellin, 1987; Wilkin et al., 1990) aeration completely eliminated the insects by spring. Possible explanations for this disparity include the different survival ability of the field strains of insects and milder conditions occuring in this second experiment (it was the warmest winter for 20 years). These possibilities are fully explored and demonstrated in Parts 3 & 4 of this report.

The continued high catch of S. granarius during the winter seems highly illogical since the reduced temperatures should have reduced the insects' mobility. However, it compares well with several observations in aerated Intervention stores (Wilkin et al., 1990), where mid Winter infestations of this species were detected and subsequently eliminated using surface insecticide applications. One possible explanation is that the diurnal warming of the surface layers permitted developing S. granarius to emerge but that the diurnal cooling did not kill developing stages of the field strain of insects. Another possibility is that the insects were invading from an undetected residue source nearby.

There was no initial evidence of a selective effect by the surface treatment on the proportion of resistant beetles in the population. This suggests, either that the dose applied was sufficient to kill both resistant and susceptible insects, or that any selective effect on beetles at the surface was masked by immigration of unselected beetles from the lower layers. Later on, although the number of beetles collected from the treated bins was small, there was an indication that the surface treatment was selecting for an increased frequency of resistant beetles. Given the small size of the population in the treated bins and bearing in mind the possibility that they were migrants from the untreated bins, this increased frequency of resistance may not be a problem in the short term. In the longer term, or given a founding population with a high frequency of resistance, there is a possibility that resistance may not be controlled in these circumstances.

The initial moisture content of the grain beneath the surface was 15% m.c. which, at 15-20 °C, the grain's initial temperature, is in equilibrium with an r.h. of 60-65% r.h. (Henderson, pers. comm.) and just unsuitable for mite development. Aeration reduced the r.h. further, so some grain was as dry as 14.5% m.c., which at 5 °C, the temperature to which the grain ultimately fell, is only at 50-55% r.h. The low numbers of mites that were able to develop shows the effectiveness in controlling mites, of drying the grain adequately before storage and then cooling it.

At the surface, however, the grain was able to absorb moisture and it achieved nearly 17% m.c., in equilibrium with an r.h. over 70%. Consequently, <u>Glycyphagus</u> and <u>Acarus</u> were able to develop infestations of several hundred/kg. The surface treatment was able to prevent significant numbers occurring at a cost of about 120 p/bin for the chemical. However, populations of mites which approached the mid-winter surface peaks, occurred at 2m in the spring in both sets of bins.

Table 1
1989-90 A comparison of weekly mean (and s.e.) spot readings of temperature (°C) at the centre of treated (t) and untreated (u) bins of wheat (n=3).

date	week	0.5		1.0		1.5		2.0	
		t	u	t	u	t	u	t	u
27.10	1	16.9	16.9	18.0	17.9	18.1	17.9	16.8	17.1
		(0.2)	(0.3)	(0.3)	(0.6)	(0.2)	(0.6)	(0)	(0.5)
1.11	2	16.9	16.9	17.7	17.9	17.5	17.6	16.6	16.6
		(0.2)	(0.3)	(0.3)	(0.6)	(0.1)	(0.5)	(0.2)	(0.4)
8.11	3	16.7	16.3	17.2	17.6	16.9	17.1	14.9	15.3
		(0.2)	(0.6)	(0.2)	(0.4)	(0.1)	(0.2)	(0.2)	(0.3)
15.11	4	14.9	15.6	12.1	12.6	11.4	11.9	10.9	11.1
		(1.2)	(1.1)	(0.9)	(0.5)	(0.8)	(0.2)	(0.5)	(0.3)
23.11	5	10.1	11.2	8.2	9.6	8.0	9.5	4.8	5.7
		(0.2)	(0.6)	(0.4)	(0.3)	(0.7)	(0.3)	(0.4)	(0.5)
30.11	6	2.8	3.8	0.9	1.9	0.4	1.7	0.6	1.8
		(0.9)	(0.6)	(0.7)	(0.6)	(0.4)	(0.4)	(0.7)	(0.4)
8.12	7	3.1	4.0	1.7	3.0	1.0	2.6	1.7	2.8
		(0.2)	(0.3)	(0.6)	(0.3)	(0.5)	(0.2)	(0.7)	(0.4)
13.12	8	3.2	4.4	2.1	3.3	1.3	2.8	2.8	3.5
		(0.3)	(0.3)	(0.6)	(0.3)	0.6)	(0.3)	(0.3)	(0.5)
22.12	9	4.1	5.9	3.1	3.9	2.9	3.5	4.9	5.1
		(0.5)	(0.6)	(0.2)	(0.3)	(0.2)	(0.3)	(1.6)	(0.7)
28.12	10	4.5	6.1	3.3	4.4	3.5	4.1	5.6	6.0
		(0.6)	(0.5)	(0.2)	(0.3)	(0.5)	(0.3)	(1.5)	(1.1)
2.1	11	4.3	5.7	3.3	4.9	3.7	4.6	5.6	6.3
		(0.5)	(0.5)	(0.1)	(0.3)	(0.6)	(0.3)	(1.2)	(0.5)
12.1	12	5.1	6.3	4.4	5.5	4.8	5.6	6.6	7.1
		(0.3)	(0.5)	(0.2)	(0.3)	(0.5)	(0.2)	(0.9)	(0.6)
15.1	13	5.0	6.1	4.6	5.7	5.4	6.3	6.1	7.5
		(0.4)	(0.3)	(0.2)	(0.2)	(0.5)	(0.4)	(0.4)	(0.6)
23.1	14	4.9	6.7	5.0	6.2	5.6	6.9	6.3	7.3
		(0.6)	(0.4)	(0.5)	(0.2)	(0.5)	(0.5)	(0.3)	(0.6)
30.1	15	5.6	7.2	5.7	6.8	6.6	7.3	7.2	7.9
		(0.4)	(0.7)	(0.4)	(0)	(0.7)	(0.8)	(0.4)	(0.8)
7.2	16	6.1	8.3	6.7	7.6	7.5	8.0	8.5	8.3
		(0.3)	(1.3)	(0.7)	(0.3)	(0.9)	(0.8)	(0.9)	(1.0)

Table 1 cont'd

date	week	0.5m t	0.5m u	1.0m t	1.0m u	1.5m t	1.5m u	2.0m t	2.0m u
14.2	17	7.2 (0.9)	7.7 (0.6)	8.3 (0.9)	8.4 (1.1)	6.9 (0.5)	8.5 (0.8)	5.3 (0.4)	6.5 (0.3)
21.2	18	7.5 (0.5)	9.6 (1.1)	6.9 (0.2)	8.1 (0.6)	6.2 (0.2)	7.3 (0.4)	4.8 (0.4)	6.1 (0.4)
28.2	19	8.4 (0.2)	9.2 (0.7)	7.5 (0.2)	8.4 (0.3)	6.7 (0.5)	7.7 (0.1)	6.6 (0.5)	7.5 (0.4)
7.3	20	7.2 (0.3)	8.1 (0.4)	6.5 (0.2)	7.6 (0.4)	5.1 (0.3)	6.0 (0.4)	4.0 (0.3)	5.1 (0.3)
14.3	21	8.3 (0.2)	8.7 (0.3)	6.5 (0.2)	7.4 (0.2)	5.6 (0.2)	6.2 (0.4)	6.0 (0.4)	6.7 (0.2)
21.3	22	8.8 (0.3)	9.1 (0.4)	6.7 (0.3)	7.5 (0.5)	6.2 (0.2)	6.6 (0.2)	7.1 (0.7)	7.7 (0.4)
28.3	23	8.1 (0.5)	8.3 (0.6)	7.2 (0.3)	6.9 (0.6)	6.7 (0.1)	6.5 (0.7)	8.1 (0.6)	7.5 (0.9)
4.4	24	7.9 (0.6)	7.4 (0.9)	7.5 (0.4)	7.0 (1.1)	7.1 (0.4)	6.8 (1.3)	4.2 (1.2)	2.9 (1.7)
11.4	25	7.3 (0.3)	6.7 (1.0)	6.1 (0.4)	5.7 (1.2)	3.6 (0.4)	3.7 (0.7)	3.1 (0.3)	3.2 (0)
18.4	26	7.3 (0.3)	6.7 (1.3)	5.5 (0.3)	5.0 (1.2)	4.4 (0.2)	4.1 (0.8)	5.2 (0.3)	4.9 (0.8)
25.4	27	7.5 (0.5)	6.9 (0.9)	5.7 (0.3)	5.3 (0.9)	4.9 (0.3)	4.7 (0.5)	5.5 (0.3)	6.3 (0.7)
2.5	28	10.0 (0.7)	8.8 (0.7)	7.2 (0.8)	6.1 (0.4)	6.3 0.8)	5.7 (0.1)	6.7 (0.5)	6.7 (0.5)
9.5	29	13.2 (0.9)	13.6 (0.8)	8.5 (0.9)	7.9 (0.3)	7.3 (0.9)	6.5 (0.1)	7.7 (0.6)	7.1 (0.5)
16.5	30	11.9 (0.2)	13.1 (0.7)	8.4 (0.7)	9.2 (0)	6.7 (0.3)	7.7 (0.3)	7.6 (0.5)	8.5 (0.5)
23.5	31	12.1 (0.3)	13.3 (0.6)	9.6 (0.3)	9.9 (0.1)	8.0 (0.2)	8.7 (0.2)	9.1 (0.2)	10.0 (0.5)
31.5	32	12.3 (0.4)	13.8 (0.8)	9.7 (0.4)	10.5 (0.3)	8.7 (0.6)	9.7 (0.4)	9.4 (0)	10.0 (0.5)

Table 2
1989-90 A comparison of weekly mean (and s.e) spot readings of temperature (°C) at the edge of treated (t) and untreated (u) bins of wheat (n=3).

date	week	0.5 t	0.5 u	1.0 t	1.0 u	1.5 t	1.5 u	2.0 t	2.0 u
27.10	1	16.0 (0.5)	15.9 (0.6)	16.3 (0.6)	17.1 (1.4)	16.1 (0.5)	16.0 (0.7)	15.9 (0.8)	15.3 (0.6)
1.11	2	15.3 (0.5)	15.3 (0.6)	15.8 (0.6)	15.6 (0.7)	15.6 (0.7)	15.7 (0.6)	15.3 (1.0)	14.7 (0.7)
8.11	3	13.1 (0.4)	12.8 (1.1)	13.6 (0.5)	13.7 (1.5)	13.3 (0.3)	13.7 (1.5)	13.3 (0.8)	13.1 (1.4)
15.11	4	12.2 (0.5)	12.4 (0.5)	10.6 (0.6)	12.2 (0.5)	10.4 (0.7)	11.8 (0.4)	10.3 (0.8)	11.4 (0.4)
23.11	5	9.8 (0.4)	10.1 (0.4)	9.5 (0.5)	10.1 (0.4)	8.8 (1.0)	9.8 (0.4)	8.6 (1.2)	9.9 (0.5)
30.11	6	5.0 (0.3)	5.7 (0.6)	3.5 (0.2)	4.5 (0.7)	2.8 (0)	3.7 (0.8)	2.7 (0.3)	3.7 (0.9)
8.12	7	3.7 (0.3)	5.1 (0.5)	3.5 (0.2)	4.5 (0.6)	3.5 (0.3)	4.4 (0.7)	3.6 (0.3)	4.4 (0.8)
13.12	8	3.7 (0.2)	5.1 (0.3)	3.5 (0.3)	4.7 (0.5)	3.5 (0.3)	4.5 (0.6)	4.4 (0.7)	4.8 (0.7)
22.12	9	6.1 (0.5)	7.5 (0.4)	5.9 (0.6)	6.7 (0.5)	6.1 (0.9)	6.8 (0.4)	7.3 (1.0)	6.8 (0.7)
28.12	10	6.7 (0.6)	8.1 (0.3)	6.1 (0.5)	7.5 (0.4)	6.1 (0.5)	7.1 (0.3)	7.3 (0.5)	7.5 (0.4)
2.1	11	5.3 (0.2)	6.9 (0.5)	5.1 (0.3)	6.5 (0.3)	5.1 (0.1)	6.4 (0.3)	5.6 (0.6)	6.9 (0.5)
12.1	12	6.0 (0.3)	7.3 (0.3)	6.0 (0.3)	7.1 (0.4)	6.2 (0.3)	7.1 (0.3)	7.3 (0.6)	7.4 (0.6)
15.1	13	5.7 (0.4)	7.3 (0.3)	5.6 (0.2)	7.3 (0.3)	5.8 (0.1)	7.2 (0.3)	7.0 (0.5)	7.5 (0.4)
23.1	14	6.5 (0.4)	8.0 (0.3)	6.5 (0.6)	7.8 (0.2)	7.0 (0.7)	7.9 (0.1)	7.9 (1.0)	8.2 (0.4)
30.1	15	6.0 (0.2)	7.1 (0.4)	6.1 (0.2)	7.3 (0.3)	6.3 (0.2)	7.6 (0)	7.1 (0.7)	7.6 (0.4)
7.2	16	6.9 (0.4)	8.1 (0.2)	7.2 (0.4)	8.0 (0)	7.7 (0.4)	8.3 (0.1)	8.4 (0.7)	8.5 (0.2)

Table 2 cont'd

date	week	0.5m t	0.5m u	1.0m t	1.0m u	1.5m t	1.5m u	2.0m t	2.0m u
14.2	17	7.3	8.2	7.5	8.5	7.8	8.7	7.6	8.8
		(0.3)	(0.2)	(0.5)	(0.3)	(0.6)	(0.4)	(0.5)	(0.30
21.2	18	7.7	8.3	7.7	8.1	7.8	8.1	8.1	8.1
		(0.2)	(0.2)	(0.3)	(0.2)	(0.6)	(0.2)	(0.8)	(0.2)
28.2	19	9.1	9.4	8.5	8.9	8.3	9.0	7.9	8.7
		(0.2)	(0.4)	(0.2)	(0.3)	(0.2)	(0.3)	(0.2)	(0.4)
7.3	20	7.9	8.8	7.9	8.5	7.7	8.5	7.7	8.2
		(0.2)	(0)	(0.3)	(0.2)	(0.6)	(0.2)	(0.9)	(0.4)
14.3	21	9.4	10.1	8.9	9.5	8.7	9.5	8.5	9.1
		(0.2)	(0.3)	(0.3)	(0.3)	(0.4)	(0.2)	(0.5)	(0.2)
21.3	22	10.1	11.1	9.9	10.3	9.7	10.2	9.6	10.1
		(0.3)	(0.3)	(0.4)	(0.3)	(0.6)	(0.2)	(0.7)	(0.1)
28.3	23	9.7	9.6	9.3	9.0	8.9	8.8	8.6	8.4
		(0.2)	(0.3)	(0.2)	(0.4)	(0.4)	(0.5)	(0.4)	(0.7)
4.4	24	9.9	9.6	9.7	9.2	9.7	8.9	9.1	8.8
		(0.4)	(0.7)	(0.3)	(0.7)	(0.3)	(0.8)	(0.6)	(0.7)
11.4	25	8.9	7.9	8.7	7.5	7.9	6.9	7.4	6.0
		(0.4)	(0.7)	(0.2)	(0.7)	(0.4)	(0.7)	(0.7)	(0.5)
18.4	26	9.1	8.5	8.7	7.5	7.9	7.0	7.3	6.6
		(0.2)	(0.8)	(0.3)	(1.1)	(0.6)	(0.9)	(0.5)	(0.9)
25.4	27	9.5	9.3	9.2	8.3	8.9	7.9	8.9	7.9
		(0.3)	(0.4)	(0.7)	(0.5)	(0.9)	(0.6)	(0.9)	(0.4)
2.5	28	12.7	12.3	11.9	10.7	11.9	10.4	12.0	10.4
		(0.9)	(0.4)	(0.7)	(0.2)	(0.9)	(0)	(1.1)	(0)
9.5	29	17.1	16.8	15.3	14.3	14.7	13.7	14.2	13.4
		(0.7)	(0)	(1.1)	(0.6)	(1.1)	(0.3)	(1.2)	(0.2)
16.5	30	13.7	14.7	12.9	13.5	12.5	12.7	13.1	12.7
		(0.5)	(0.4)	(0.5)	(0.5)	(0.8)	(0.3)	(1.3)	(0.3)
23.5	31	14.3	14.3	13.5	12.7	12.9	11.7	12.9	11.7
		(0.6)	(0.9)	(0.7)	(1.5)	(0.5)	(1.7)	(0.7)	(1.3)
31.5	32	15.3	16.3	14.4	14.8	14.1	14.0	14.7	13.7
		(0.6)	(0.2)	(0.9)	(0.3)	(0.9)	(0.5)	(1.3)	(0.4)

Table 3
Hours run each week by fans cooling six 25 tonne bins of wheat. (1989-90)

date	week	hours	cumulative
25.10	1	0	0
1.11	2	0	0
8.11	3	0	0
15.11	4	78	78
23.11	5	58	136
30.11	6	88	224
8.12	7	7	231
13.12	8	0	231
22.12	9	0	231
28.12	10	0	231
3.1	11	0	231
10.1	12	0	231
17.1	13	4	235
24.1	14	3	238
30.1	15	0	238
7.2	16	1	239
14.2	17	27	266
21.2	18	52	291
1.3	19	2	293
8.3	20	20	313
14.3	21	0	313
21.3	22	0	313
28.3	23	0	313
4.4	24	39	332
11.4	25	25	357
18.4	26	8	365
25.4	27	0	365
2.5	28	0	365
9.5	29	0	365
16.5	30	0	365
23.5	31	0	365
31.5	32	4	369

Table 4
1990-91 A comparison of weekly mean spot readings (and s.e.) of temperatures (°C) at the centre of surface treated (t) and untreated (u) aerated bins of wheat (n=3).

date	week	0.5 t	0.5 u	1.0 t	1.0 u	1.5 t	1.5 u	2.0 t	2.0 u
19.10	1	14.0 (0.4)	13.6 (0.4)	12.3 (0.4)	12.0 (0)	11.6 (0.3)	11.2 (0)	12.1 (0.5)	11.5 (0.3)
26.10	2	13.7 (0.5)	13.2 (0)	12.7 (0.4)	12.1 (0.2)	12.1 (0.3)	11.6 (0)	12.7 (0.4)	12.0 (0)
1.11	3	12.8 (0.3)	12.3 (0.2)	12.4 (0.3)	12.3 (0.2)	12.3 (0.4)	12.0 (0)	12.7 (0.2)	12.0 (0)
8.11	4	9.1 (0.6)	8.8 (0.5)	7.9 (0.5)	7.5 (0.4)	7.2 (0.4)	6.4 (0)	6.0 (0.4)	5.3 (0.4)
19.11	5	9.5 (0.6)	9.2 (0.2)	8.0 (0.7)	7.5 (0.4)	7.5 (0.6)	6.7 (0.2)	7.9 (0.5)	7.5 (0.4)
23.11	6	8.4 (0.4)	8.3 (0.1)	8.2 (0.4)	8.1 (0.2)	6.7 (0.6)	5.9 (0.5)	5.1 (0.4)	4.7 (0.1)
29.11	7	7.3 (0.7)	7.3 (0.5)	7.1 (0.6)	6.8 (0.4)	7.1 (0.6)	6.1 (0.2)	4.9 (0.4)	5.3 (0.8)
5.12	8	7.3 (0.5)	6.8 (0.4)	7.1 (0.6)	6.9 (0.6)	5.6 (0.3)	4.9 (0.2)	4.8 (0.5)	4.4 (0)
12.12	9	6.1 (0.5)	5.6 (0.2)	4.7 (0.4)	3.7 (0.2)	3.3 (0.5)	2.7 (0.2)	3.3 (0.3)	3.1 (0.3)
19.12	10	4.9 (0.5)	3.9 (0.2)	4.3 (0.4)	3.4 (0.3)	3.3 (0.3)	2.0 (0)	0.5 (0.3)	0.1 (0.2)
26.12	11	5.1 (0.4)	4.7 (0.4)	4.4 (0.4)	3.7 (0.3)	3.5 (0.4)	2.7 (0.2)	4.3 (1.0)	3.5 (0.5)
2.1	12	4.9 (0.3)	4.5 (0.3)	4.5 (0.3)	4.0 (0.3)	4.1 (0.5)	3.5 (0.2)	6.1 (1.1)	4.9 (0.6)
9.1	13	4.9 (0.3)	4.4 (0.3)	4.7 (0.5)	4.1 (0.2)	5.4 (0.9)	4.3 (0.5)	6.9 (1.3)	5.7 (0.6)
16.1	14	4.8 (0.4)	4.0 (0.3)	5.1 (0.8)	4.3 (0.2)	6.0 (1.1)	4.8 (0.5)	7.3 (1.1)	6.0 (0.5)
23.1	15	7.2 (0.8)	6.1 (0.2)	6.1 (0.5)	5.3 (0.2)	5.2 (0.4)	4.8 (0.3)	5.2 (0.3)	4.4 (0)
30.1	16	4.4 (0.4)	4.1 (0.3)	4.1 (0.5)	3.8 (0.2)	3.3 (0.3)	2.5 (0.1)	1.3 (0.4)	0.7 (0.2)

Table 4 cont'd

date	week	0.5m t	0.5m u	1.0m t	1.0m u	1.5m t	1.5m u	2.0m t	2.0m u
6.2	17	2.9 (0.5)	2.5 (0.3)	-1.2 (0.5)	0.5 (0.4)	0.3 (0.6)	0 (0.3)	-0.5 (0.4)	0 (0.6)
13.2	18	-2.3 (0.5)	-2.4 (0.3)	-2.9 (0.7)	-3.2 (0.4)	-1.6 (0.4)	-1.7 (0.5)	-1.2 (0.4)	-1.3 (0.2)
20.2	19	-1.2 (0.4)	-1.2 (0.4)	-2.0 (0.4)	-2.4 (0.3)	-1.5 (0.3)	-1.6 (0.3)	0 (0.4)	-0.1 (0.4)
27.2	20	0.3 (0.4)	0.9 (1.1)	-1.6 (0.4)	-1.9 (0.3)	-1.3 (0.5)	-1.5 (0.1)	1.5 (1.1)	0.5 (0.4)
6.3	21	2.5 (0.3)	2.8 (0.9)	-0.7 (0.3)	-0.7 (0.3)	-0.7 (0.5)	-0.9 (0.2)	1.2 (0.7)	0.9 (0.1)
13.3	22	4.0 (0.4)	4.1 (1.0)	0 (0.4)	-0.1 (0.4)	-0.4 (0.7)	-0.5 (0.2)	1.3 (0.9)	1.1 (0.1)
20.3	23	5.5 (0.1)	5.9 (1.1)	1.6 (0.4)	1.6 (0.4)	0.5 (0.5)	0.3 (0.2)	2.7 (0.9)	2.3 (0.6)
27.3	24	5.2 (0.3)	5.7 (0.5)	2.5 (0.3)	2.7 (0.4)	1.5 (0.5)	1.5 (0.3)	3.6 (0.4)	3.9 (0.1)
3.4	25	5.9 (0.4)	6.3 (0.9)	3.4 (0.4)	3.3 (0.4)	2.8 (0.4)	2.7 (0.3	4.4 (0.5)	4.5 (0.2)
11.4	26	6.1 (0.4)	6.7 (0.8)	4.1 (0.4)	4.1 (0.4)	3.5 (0.4)	3.7 (0.3)	4.9 (0.6)	5.1 (0.5)
18.4	27	7.6 (0.8)	7.7 (0.7)	4.9 (0.5)	4.7 (0.3)	4.3 (0.4)	4.4 (0.3)	5.8 (0.4)	5.9 (0.2)
24.4	28	6.4 (0.7)	6.7 (0.6)	5.5 (0.4)	5.5 (0.3)	5.6 (0.3)	5.3 (0.2)	5.3 (1.1)	4.5 (0.8)
1.5	29	7.3 (0.7)	7.5 (0.4)	6.1 (0.3)	6.1 (0.4)	6.0 (0.4)	5.9 (0.3)	6.1 (0.3)	6.3 (0.4)

Table 5
1990-91 A comparison of weekly mean spot readings (and s.e.) of temperatures (°C) at the edge of surface treated (t) and untreated (u) aerated bins of wheat (n=3).

date	weeks	Surface		0.5		1.0		1.5	
		t	u	t	u	t	u	t	u
19.10	1	15.2 (0)	14.8 (0.3)	14.9 (0.5)	14.9 (0.2)	14.5 (0.6)	13.9 (0.3)	14.1 (0.6)	13.9 (0.3)
26.10	2	13.2 (0)	12.6 (0.4)	14.1 (0.7)	13.5 (0.2)	13.7 (0.7)	13.1 (0.1)	13.5 (0.6)	12.9 (0.1)
1.11	3	11.1 (0.6)	10.7 (0.5)	11.9 (0.6)	11.6 (0.3)	11.7 (0.8)	11.5 (0.2)	11.3 (0.8)	11.2 (0)
8.11	4	8.3 (0.9)	7.7 (0.2)	9.8 (1.0)	9.2 (0.5)	8.9 (0.8)	8.5 (0.4)	8.3 (0.8)	8.1 (0.4)
19.11	5	7.7 (0.5)	7.6 (0.5)	10.9 (0.5)	10.3 (0.2)	10.4 (0.5)	9.7 (0.2)	10.3 (0.5)	9.5 (0.3)
23.11	6	6.7 (0.6)	6.0 (0)	8.9 (0.7)	8.5 (0.2)	8.8 (0.7)	8.7 (0.2)	8.8 (1.1)	8.9 (0.3)
29.11	7	7.3 (0.7)	6.5 (0.6)	7.1 (0.5)	6.9 (6.9)	6.5 (0.6)	6.8 (0.7)	4.9 (0.4)	6.5 (0.8)
5.12	8	6.0 (0.7)	5.6 (0.3)	6.8 (0.7)	6.4 (0.7)	6.8 (0.7)	6.7 (0.5)	7.2 (0.9)	6.9 (0.6)
12.12	9	4.9 (0.5)	4.4 (0)	5.7 (0.8)	5.2 (0.5)	5.6 (0.7)	5.1 (0.4)	5.2 (0.7)	4.4 (0.5)
19.12	10	2.1 (0.7)	1.3 (0.4)	4.4 (0.9)	3.7 (0.4)	4.1 (0.7)	3.3 (0.4)	4.0 (0.9)	3.6 (0.3)
26.12	11	4.8 (0.4)	4.4 (0.3)	5.6 (0.4)	4.8 (0.3)	5.5 (0.4)	4.5 (0.3)	5.5 (0.4)	4.5 (0.4)
2.1	12	8.3 (0.4)	7.6 (0.7)	5.4 (0.3)	5.1 (0.1)	5.3 (0.5)	4.8 (0.3)	5.2 (0.4)	4.8 (0.3)
9.1	13	4.4 (0.4)	4.3 (0.4)	5.3 (0.5)	4.7 (0.2)	5.4 (0.5)	4.7 (0.2)	5.5 (0.6)	4.9 (0.2)
16.1	14	0.1 (0.5)	0.7 (1.1)	4.4 (0.7)	4.0 (0.3)	4.4 (0.9)	3.9 (0.2)	4.3 (1.1)	4.1 (0.2)
23.1	15	5.1 (0.6)	4.3 (0.2)	5.6 (0.7)	4.9 (0.3)	6.2 (0.9)	5.5 (0.2)	6.4 (0.7)	5.9 (0.3)
30.1	16	3.6 (0.7)	3.2 (0.3)	4.8 (0.7)	4.3 (0.4)	4.4 (0.7)	4.0 (0.4)	4.4 (0.7)	4.1 (0.3)

Table 5 cont'd

date	week	Surface t	Surface u	0.5m t	0.5m u	1.0m t	1.0m u	1.5m t	1.5m u
6.2	17	1.7 (0.8)	0.9 (0.3)	2.8 (0.9)	2.3 (0.6)	2.8 (0.9)	2.4 (0.7)	2.3 (1.0)	2.0 (0.8)
13.2	18	-0.7 (0.5)	-1.3 (0.5)	-1.2 (0.7)	-1.7 (0.4)	-1.5 (0.5)	-2.0 (0.4)	-1.5 (0.5)	-1.9 (0.5)
20.2	19	4.3 (0.4)	3.9 (0.5)	0.5 (0.5)	0.1 (0.3)	0 (0.5)	-0.4 (0.3)	-0.1 (0.4)	-0.3 (0.3)
27.2	20	7.1 (0.6)	6.8 (0.5)	3.6 (0.5)	3.6 (0.3)	3.1 (0.6)	2.7 (0.3)	3.6 (0.7)	2.9 (0.3)
6.3	21	10.1 (0.5)	10.1 (0.6)	5.3 (0.4)	5.2 (0.3)	4.7 (0.6)	4.4 (0.3)	5.1 (0.8)	4.3 (0.2)
13.3	22	8.4 (0.3)	8.4 (0.5)	7.1 (0.8)	6.9 (0.4)	6.0 (0.9)	5.7 (0.2)	6.2 (0.9)	5.7 (0.2)
20.3	23	11.7 (0.3)	11.3 (0.4)	8.7 (0.5)	8.5 (0.2)	7.7 (0.8)	7.3 (0.3)	7.7 (0.9)	6.9 (0.4)
27.3	24	10.7 (0.9)	10.3 (1.1)	7.6 (0.5)	7.7 (0.2)	6.9 (0.6)	6.8 (0.4)	6.5 (0.6)	6.4 (0.3)
3.4	25	10.3 (0.5)	10.0 (0.9)	8.4 (0.4)	8.4 (0.3)	7.7 (0.6)	7.7 (0.2)	7.7 (0.7)	7.2 (0.4)
11.4	26	14.3 (1.1)	15.2 (1.6)	8.4 (0.4)	8.4 (0.3)	7.9 (0.6)	8.0 (0.3)	8.0 (0.7)	7.9 (0.3)
18.4	27	8.0 (0.7)	8.0 (0.7)	10.1 (0.6)	9.9 (0.3)	9.3 (0.8)	9.0 (0.2)	9.0 (0.7)	8.8 (0.3)
24.4	28	10.4 (0.9)	10.0 (1.1)	8.0 (0.7)	8.0 (0.3)	7.6 (0.7)	7.5 (0.4)	7.7 (0.5)	7.7 (0.2)
1.5.	29	8.3 (0.4)	8.4 (0.3)	8.8 (0.7)	8.4 (0.3)	8.5 (0.5)	8.1 (0.2)	8.3 (0.4)	8.1 (0.2)

Table 6
Hours run each week by fans cooling six 25 tonne bins of wheat 1990- 91.

date	week	hours	cumulative
19.10	1	0	0
26.10	2	0	0
1.11	3	0	0
8.11	4	88	88
19.11	5	2	90
23.11	6	30	120
29.11	7	25	145
5.12	8	52	197
12.12	9	35	232
19.12	10	18	250
26.12	11	0	250
2.1	12	0	250
9.1	13	0	250
16.1	14	0	250
23.1	15	55	305
30.1	16	84	389
6.2	17	85	474
13.2	18	107	581
29.2	19	0	581
27.2	20	0	581
6.3	21	0	581
13.3	22	0	581
20.3	23	0	581
27.3	24	0	581
3.4	25	0	581
11.4	26	0	581
18.4	27	0	581
24.4	28	0	581

Table 7
Comparison of mean moisture content (s.e.) of wheat (%) at 3 depths in treated (t) and untreated (u) aerated bins of wheat (n=15)

date	week	Surface t	Surface u	1m t	1m u	2m t	2m u
a) 1989-90							
8.11	3	15.4 (0.03)	15.5 (0.09)	14.9 (0.07)	15.0 (0.03)	15.0 (0)	15.0 (0.15)
6.12	7	16.9 (0)	16.6 (0.03)	14.5 (0.03)	14.7 (0.07)	14.6 (0.09)	14.8 (0.13)
4.1	11	16.7 (0.24)	16.2 (0.22)	14.6 (0.03)	14.6 (0.10)	14.6 (0.07)	14.8 (0.15)
31.1	15	16.7 (0.19)	16.8 (0.22)	14.5 (0.07)	14.6 (0.03)	14.7 (0.12)	14.8 (0.15)
28.2	19	16.3 (0.15)	16.4 (0.15)	14.5 (0.09)	14.6 (0.09)	14.7 (0.06)	14.7 (0.15)
28.3	23	15.4 (0.35)	15.6 (0.15)	14.5 (0.06)	14.5 (0.12)	14.6 (0.03)	14.7 (0.17)
25.4	27	14.7 (0.47)	14.8 (0.43)	14.4 (0.06)	14.5 (0.09)	14.6 (0.07)	14.7 (0.12)
23.5	31	13.0 (0.31)	13.2 (0.25)	14.4 (0.07)	14.5 (0.12)	14.6 (0.07)	14.7 (0.09)
b) 1990-91							
7.11	4	14.8 (0.03)	14.7 (0.03)	14.3 (0.03)	14.3 (0.09)	14.6 (0.09)	14.8 (0.06)
12.12	9	15.1 (0.17)	15.3 (0.09)	14.3 (0)	14.3 (0.09)	14.9 (0.06)	14.9 (0.03)
14.1	14	15.3 (0.10)	15.5 (0.20)	14.3 (0.09)	14.4 (0.07)	14.8 (0.19)	14.9 (0.07)
11.2	18	14.6 (0.13)	14.8 (0.06)	14.3 (0.09)	14.3 (0.09)	15.1 (0.13)	15.1 (0.15)
11.3	22	15.4 (0)	15.6 (0.17)	14.3 (0.07)	14.3 (0.03)	14.9 (0.18)	15.2 (0.09)
8.4	26	14.9 (0.09)	15.0 (0.23)	14.2 (0.03)	14.4 (0.10)	14.9 (0.07)	15.1 (0.07)
8.5	30	14.1 (0.25)	14.2 (0.21)	14.2 (0.07)	14.3 (0.07)	15.0 (0.12)	15.0 (0.13)

Table 8
A comparison of the mean nos of <u>Glycyphagus</u> / kg (s.e.) at 3 depths in treated (t) and untreated (u) bins of wheat (n=15)

date	weeks	Surface t	Surface u	1m t	1m u	2m t	2m u
a) 1989-90							
8.11	3	28 (11)	79 (23)	21 (6.7)	48 (20)	25 (6.7)	32 (3.8)
6.12	7	4.9 (1.7)	576 (158)	0.9 (0.5)	25 (5.2)	1.1 (0.6)	20 (12)
4.1	11	0	347 (63)	0	10 (5.3)	3.9 (3.0)	33 (14)
31.1	15	1.6 (1.6)	536 (53)	2.7 (1.1)	20 (11)	33 (29)	67 (24)
28.2	19	11 (10)	449 (210)	1.0 (1.0)	(52) (31)	43 (33)	64 (29)
28.3	23	1.0 (1.0)	555 (260)	3.4 (1.6)	48 (14)	68 (38)	92 (40)
25.4	27	1.0 (1.0)	100 (12)	1.9 (1.0)	63 (28)	105 (42)	257 (107)
23.5	31	3.0 (1.0)	14 (5.0)	70 (32)	91 (49)	163 (66)	241 (89)
b) 1990-91							
7.11	4	1.3 (0.9)	61 (31)	0.6 (0.3)	3.1 (2.2)	5.8 (2.0)	36 (23)
12.12	9	3.0 (2.1)	66 (50)	0	2.3 (1.5)	15 (7.8)	35 (6.1)
14.1	14	0	26 (14)	0	4.0 (2.7)	8.4 (3.9)	22 (10)
11.2	18	0.3 (0.3)	33 (27)	0.9 (0.9)	0.6 (0.3)	13 (6.2)	20 (1.9)
11.3	22	0	23 (15)	0	1.2 (0.6)	8.4 (3.9)	8.7 (4.5)
8.4	26	0	4.8 (2.4)	0	0.3 (0.3)	5.6 (1.8)	5.8 (1.2)
6.5	30	0	0.9 (0.5)	0	0	4.9 (0.8)	7.9 (1.6)

Table 9
A comparison of the mean nos of <u>Acarus</u> / kg. (s.e.) at 3 depths in surface treated (t) and untreated (u) aerated bins of wheat (n=15)

		Surface		1m		2m	
date	week	t	u	t	u	t	u
a) 1989-90							
8.11	3	1.3 (0.4)	4.7 (4.7)	0.3 (0.3)	3.7 (3.2)	4.3 (2.4)	1.7 (1.2)
6.12	7	6.2 (4.0)	342 (331)	0	3.0 (3.0)	0	6.3 (6.3)
4.1	11	5.2 (0.8)	186 (136)	0	2.3 (1.9)	0	0.9 (0.5)
31.1	15	9.8 (7.6)	748 (571)	0.6 (0.6)	5.6 (5.2)	4.7 (4.7)	4.0 (4.0)
28.2	19	0	1084 (1027)	0	29 (26)	20 (20)	36 (36)
28.3	23	4.7 (4.7)	845 (715)	0.6 (0.6)	33 (30)	72 (69)	47 (42)
25.4	27	0.3 (0.3)	248 (114)	0	29 (22)	93 (89)	21 (13)
23.5	31	1.0 (0.6)	15 (13)	21 (7.4)	849 (742)	403 (213)	916 (781)
b) 1990-91							
7.11	4	0	0.7 (0.7)	0	0	1.3 (0.7)	1.6 (1.6)
12.12	9	0	0	0	0.6 (0.6)	1.6 (0.4)	75 (74)
14.1	14	0	0	0	0	0	2.4 (2.4)
11.2	18	0	0	0	0	12.6 (12.2)	0
11.3	22	0.3 (0.3)	0	0	0	0.3 (0.3)	0
8.4	26	0	0	0	0.3 (0.30)	0.9 (0.9)	0.6
6.5	30	0.3 (0.3)	0	0	0	1.2 (0.8)	0

Table 10
A comparison of the mean nos of Cheyletus / kg. at 3 depths in treated (t) and untreated (u) aerated bins of wheat (n=15)

		Surface		1m		2m	
date	week	t	u	t	u	t	u
a) 1989-90							
8.11	3	0	0	0	1.3 (0.9)	1.3 (0.7)	2.7 (1.7)
6.12	7	1.8 (1.8)	0.6 (0.6)	0	2.0 (0.8)	0.6 (0.6)	0.9 (0.5)
4.1	11	6.1 (5.2)	3.9 (1.6)	0.6 (0.3)	0.9 (0)	0.6 (0.3)	2.6 (1.3)
31.1	15	3.6 (2.4)	6.2 (4.4)	0.3 (0.3)	0.9 (0.5)	0	0.6 (0.3)
28.2	19	1.0 (1.0)	2.3 (0.9)	0.6 (0.6)	0	0	0
28.3	23	3.0 (3.0)	4.2 (1.7)	0.3 (0.3)	0.6 (0.3)	0	0
25.4	27	3.3 (2.8)	15 (3.5)	0	0.3 (0.3)	0	0
23.5	31	1.3 (0.9)	21 (4.9)	0	5.7 (1.5)	0.3 (0.3)	6.0 (2.7)
b) 1990-91							
7.11	4	105 (22)	60 (12)	12 (2.0)	20 (14)	144 (63)	151 (23)
12.12	9	131 (43)	110 (60)	10.2 (2.4)	9.3 (6.6)	119 (45)	85 (6.4)
14.1	14	79 (17)	49 (24)	9.9 (2.1)	5.8 (4.1)	58 (37)	85 (29)
11.2	18	42 (13)	18 (9)	6.6 (2.1)	1.8 (1.3)	221 (113)	66 (34)
11.3	22	58 (9.2)	48 (17)	8.3 (3.9)	5.8 (4.1)	124 (58)	27 (8.5)
8.4	26	67 (10)	26 (8.7)	6.2 (4.1)	6.4 (4.6)	156 (49)	26 (1.2)
6.5	30	3.8 (1.4)	3.1 (1.7)	2.7 (1.4)	0.6 (0.4)	85 (11)	19 (8.6)

Table 11
Comparison of mean nos of S.granarius / kg (and nos alive) in spear samples at 3 depths in treated (t) and untreated (u) aerated bins of wheat (n=15).

date	week	Surface t	Surface u	1m t	1m u	2m t	2m u
a) 1989-90							
8.11	3	0.3 (0)	0.3 (0.3)	2.6 (1.8)	1.8 (1.8)	3.0 (2.1)	2.4 (2.0)
6.12	7	0.3 (0.3)	0.3 (0.3)	1.7 (0.6)	1.7 (0.6)	2.0 (0.6)	1.8 (0.3)
4.1	11	0.6 (0)	0.6 (0.3)	1.7 (0.3)	1.2 (0)	1.2 (0)	2.0 (2.0)
31.1	15	0.6 (0)	0.6 (0)	2.4 (0)	2.4 (0)	4.9 (0)	1.5 (0)
28.2	19	1.3 (0)	1.0 (0)	1.5 (0)	6.2 (0)	2.8 (0)	2.5 (0)
28.3	23	0.7 (0)	0 (0)	2.2 (0)	2.4 (0)	2.8 (0)	3.4 (0)
28.4	27	1.6 (0)	0.3 (0)	1.9 (0)	1.6 (0)	2.8 (0)	2.9 (0)
23.5	31	0.7 (0)	0.3 (0.3)	6 (0)	2.5 (0)	1.6 (0)	0.9 (0)
b) 1990-91							
7.11	4	0.3 (0)	0.3 (0)	1.7 (0)	1.7 (0)	3 (0)	2 (0)
12.12	9	0.3 (0)	0.7 (0.7)	6 (0)	2.3 (0)	2.3 (0)	3.3 (0)
14.1	14	0.6 (0)	1.0 (0.3)	4.8 (0)	2.4 (0)	0.9 (0)	1.2 (0)
11.2	18	0.9 (0)	1.9 (0.6)	1.2 (0)	0.6 (0)	2.1 (0)	0.3 (0)
11.3	22	0.3 (0)	0.3 (0)	3.0 (0)	3.1 (0)	2.2 (0)	1.2 (0)
8.4	26	2.2 (0)	1.0 (0)	2.1 (0)	2.1 (0)	2.1 (0)	0.6 (0)
8.5	30	1.9 (0)	0.3 (0)	1.5 (0)	2.4 (0)	0.9 (0)	1.5 (0)

Table 12
Comparison of the mean nos of <u>O.surinamensis</u> / kg. (and nos. alive) in spear samples from 3 depths in treated (t) and untreated (u) aerated bins of wheat (n=15)

date	week	Surface t	Surface u	1m t	1m u	2m t	2m u
a) 1989-90							
8.11	3	0.3 (0.3)	0.3 (0)	6.0 (4.6)	2.3 (2.3)	0.6 (0.6)	0.9 (0.6)
6.12	7	0.3 (0)	0 (0)	0.3 (0)	0.3 (0.3)	0.3 (0.3)	0 (0)
4.1	11	0.3 (0)	0.9 (0)	0 (0)	0 (0)	0 (0)	0 (0)
31.1	15	0.6 (0)	0.3 (0)	0.6 (0)	0 (0)	0.3 (0.3)	0 (0)
8.2	19	1.3 (0)	0 (0)	0 (0)	0 (0)	0.6 (0.3)	0 (0)
28.3	23	0.7 (0)	1.0 (0)	0 (0)	0.3 (0)	0.3 (0)	0 (0)
28.4	27	1.6 (0.3)	1.0 (0.7)	0.3 (0)	0.3 (0.3)	0.6 (0.3)	0.3 (0)
23.5	31	1.3 (0)	2.7 (2.7)	0 (0)	0.3 (0.3)	0 (0)	0.3 (0.3)
b) 1990-91							
7.11	4	1.7 (0)	1.3 (0.3)	0.7 (0)	0.7 (0.7)	1.3 (1.0)	0 (0)
12.12	9	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.3 (0)
14.1	14	0.3 (0)	1.3 (0.3)	0 (0)	0.6 (0)	0 (0)	1.3 (0)
11.2	18	0 (0)	0 (0)	1.3 (0)	0.6 (0)	0 (0)	0 (0)
11.3	22	0.3 (0)	0.3 (0)	0.3 (0)	0 (0)	0 (0)	0 (0)
8.4	26	1.3 (0.3)	1.6 (0.3)	1.2 (0)	0.9 (0)	0.9 (0)	0 (0)
8.5	30	1.3 (0)	1.9 (0.3)	0 (0)	1.2 (0)	0.6 (0)	0.6 (0)

Table 13
Comparison of the mean nos of C.ferrugineus / kg (and nos. alive) in spear samples from 3 depths in treated (t) and untreated (u) aerated bins of wheat.

date	week	Surface t	Surface u	1m t	1m u	2m t	2m u
a) 1989-90							
8.11	3	0 (0)	0 (0)	0.9 (0.6)	1.2 (1.2)	0.6 (0.6)	0.6 (0.6)
6.12	7	0 (0)	0.9 (0.6)	0 (0)	0 (0)	0.6 (0.3)	0.3 (0)
4.1	11	0.3 (0)	0.3 (0.3)	0 (0)	0.6 (0.3)	0 (0)	0.3 (0)
31.1	15	0.3 (0)	1.2 (1.2)	0.3 (0.3)	0.3 (0.3)	0 (0)	0.3 (0)
28.2	19	0.3 (0)	0.3 (0)	1.0 (0)	1.9 (0.6)	0.3 (0.3)	0 (0)
28.3	23	0 (0)	0 (0)	0.6 (0)	0 (0)	0.9 (0)	0.3 (0)
28.4	27	0 (0)	0.3 (0.3)	0 (0)	0.6 (0)	0 (0)	1.3 (0)
23.5	31	0 (0)	0 (0)	0.3 (0)	0.9 (0.3)	0 (0)	0 (0)
b) 1990-91							
7.11	4	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0.3 (0)
12.12	9	0 (0)	0 (0)	0 (0)	0.7 (0)	0 (0)	0 (0)
14.1	14	0.3 (0)	0 (0)	0.3 (0)	0 (0)	0.3 (0)	0 (0)
11.2	18	0 (0)	0 (0)	0 (0)	0.6 (0)	0 (0)	0.3 (0)
11.3	22	0 (0)	0 (0)	0.9 (0)	0.6 (0)	0 (0)	0.3 (0.3)
8.4	26	0 (0)	0 (0)	0.9 (0)	0 (0)	0 (0)	0 (0)
6.5	30	0.6 (0)	0 (0)	0.3 (0)	0 (0)	0.3 (0)	0.9 (0)

Table 14
1989-90 Mean nos of O.surinamensis per bin in probe traps (s.e.) at 3 depths (n= 27) in surface treated (t) and untreated (u) aerated bins of wheat.

		Surface		1m		2m	
date	week	t	u	t	u	t	u
1.11	2	45.3 (5.70)	32.7 (9.24)	1208.3 (220.90)	539.3 (113.30)	109.7 (28.01)	128.0 (52.20)
7.11	3	20.3 (5.84)	26.0 (2.65)	358.7 (50.96)	669.3 (159.62)	53.0 (19.52)	122 (26.16)
15.11	4	192.3 (87.46)	109.0 (15.95)	418.0 (163.37)	309.7 (58.47)	73.0 (5.51)	62.0 (7.00)
22.11	5	136.0 (22.55)	204.7 (35.63)	20.7 (5.84)	23.00 (14.01)	10.7 (4.33)	12.3 (5.24)
29.11	6	130.7 (110.79)	62.3 (9.02)	12.0 (5.03)	12.0 (2.31)	4.0 (2.00)	5.7 (1.86)
6.12	7	0.7 (0.67)	7.0 (0.58)	0	0.7 (0.33)	1.7 (1.20)	0.7 (0.67)
4.1	11	1.0 (0)	0.3 (0.33)	0.7 (0.33)	0.7 (0.67)	5.0 (4.04)	1.0 (1.00)
31.1	15	0	2.7 (1.67)	1.0 (1.00)	2.0 (1.15)	3.3 (1.20)	3.0 (1.00)
28.2	19	1.7 (1.20)	4.0 (0.58)	1.0 (1.00)	0.7 (0.3)	1.3 (0.67)	1.7 (0.33)
28.3	23	2.7 (1.33)	24.0 (4.73)	0.7 (0.33)	3.0 (1.00)	3.0 (1.53)	2.7 (1.67)
25.4	27	0	12.7 (3.71)	0	1.7 (1.2)	0.3 (0.33)	1.3 (0.88)
23.5	31	8 (3.46)	225.0 (25.70)	0	4.3 (1.67)	0	2.0 (1.00)

Table 15
1989-90 The mean number per bin (s.e.) of 3 spp of insects captured in pitfall traps (n= 16) in surface treated (t) and untreated (u) bins of wheat.

		O.surinamensis		S.granarius		C.ferrugineus	
date	week	t	u	t	u	t	u
1.11	2	43.7 (2.60)	31.0 (3.21)	24.0 (7.55)	29.0 (4.93)	1.3 (0.67)	0
7.11	3	22.6 (4.98)	9.7 (2.33)	17.3 (4.06)	8.7 (2.96)	0.7 (0.67)	0
15.11	4	31.7 (7.22)	39.3 (9.17)	11.3 (2.60)	15.3 (2.91)	0.7 (0.67)	0.3 (0.3)
22.11	5	46.0 (3.06)	77.3 (9.84)	4.7 (2.91)	18.3 (3.48)	0	0
29.11	6	10.3 (3.53)	14.3 (5.21)	2.3 (0.33)	14.7 (3.38)	0	0
6.12	7	2.67 (2.19)	2.3 (1.5)	3.3 (1.33)	14.0 (6.11)	0	0
4.1	11	1.0 (0.58)	9.7 (2.73)	1.3 (0.67)	23.7 (6.39)	0	0
31.1	15	8.7 (2.33)	19.3 (5.93)	0.7 (0.33)	13.0 (4.0)	0	0.5 (0.3)
28.2	19	2.0 (0.58)	9.7 (2.91)	0.7 (0.67)	6.0 (2.00)	0	0.5 (0.3)
28.3	23	3.0 (1.53)	23.7 (6.44)	0.7 (0.33)	11.0 (2.08)	0	0.3 (0.3)
25.4	27	2.0 (0.58)	34.7 (9.39)	1.0 (0.58)	16.3 (2.96)	0	1.9 (1.20)
23.5	31	10.0 (0.58)	57.3 (12.14)	0.7 (0.33)	8.3 (1.76)	0	0

Table 16
1989-90 Mean no of S.granarius per bin in probe traps (and s.e.) at 3 depths in surface treated (t) and untreated (u) aerated bins of wheat (n=27).

		Surface		1m		2m	
date	week	t	u	t	u	t	u
1.11	2	7.7 (5.17)	5.0 (1.15)	81.7 (13.9)	56.0 (5.29)	15.0 (4.16)	29.0 (2.00)
7.11	3	6.0 (2.52)	6.3 (4.37)	74.3 (26.87)	30.7 (2.40)	13.7 (2.33)	29.3 (8.41)
15.11	4	1.3 (0.33)	5.3 (0.33)	46.7 (2.91)	49.3 (7.9)	16.0 (4.16)	18.0 (1.15)
22.11	5	5.3 (3.33)	11.0 (2.89)	11.0 (5.03)	23.0 (12.50)	10.0 (1.15)	16.7 (3.71)
29.11	6	4.3 (2.40)	7.7 (1.76)	32.7 (15.94)	41.3 (25.10)	7.0 (2.00)	10.0 (3.06)
6.12	7	2.0 (1.53)	4.7 (2.03)	2.3 (0.88)	3.3 (0.88)	7.0 (4.04)	4.7 (2.33)
4.1	11	0.7 (0.33)	2.0 (1.53)	2.7 (1.20)	1.0 (0.58)	0.3 (0.33)	0.3 (0.33)
31.1	15	0 (0)	0.3 (0.33)	0.7 (0.67)	0.3 (0.33)	0.7 (0.67)	0.3 (0.33)
28.2	19	0 (0)	0 (0)	1.7 (0.33)	0 (0)	2.0 (1.00)	0.7 (0.67)
28.3	23	0.3 (0.33)	1.3 (0.33)	0.3 (0.33)	0.3 (0.33)	0.3 (0.33)	1.0 (0.58)
25.4	27	0 (0)	1.0 (0.58)	1.3 (0.33)	0.7 (0.33)	0.3 (0.33)	0.7 (0.33)
23.5	31	0 (0)	0.3 (0.33)	0 (0)	0 (0)	0 (0)	0 (0)

Table 17
1989- 90 Mean no. of C.ferrugineus per bin (and s.e.) captured in probe traps at 3 depths in surface treated (t) and untreated (u) aerated bins of wheat (n=27).

		Surface		1m		2m	
Date	Week	t	u	t	u	t	u
1.11	2	1.0 (1.00)	0.3 (0.33)	62.3 (41.91)	17.0 (2.08)	4.7 (2.19)	6.3 (2.73)
7.11	3	1.0 (0)	0.3 (0.33)	19.7 (3.53)	20.3 (6.89)	1.3 (0.67)	7.3 (2.19)
15.11	4	17.0 (5.13)	15.3 (2.03)	7.7 (5.24)	7.3 (2.40)	0.3 (0.33)	2.0 (1.53)
22.11	5	8.3 (1.86)	11.0 (7.21)	4.0 (4.00)	1.3 (0.67)	0 (0)	0.7 (0.33)
29.11	6	2.7 (1.20)	2.3 (1.45)	1.3 (0.88)	0.3 (0.33)	0.7 (0.33)	0 (0)
6.12	7	0.3 (0.33)	0.7 (0.67)	0 (0)	0.3 (0.33)	0 (0)	0 (0)
4.1	11	0 (0)	0.7 (0.67)	0.7 (0.33)	0 (0)	0 (0)	0.3 (0.33)
31.1	15	0.3 (0.33)	0 (0)	0 (0)	0.3 (0.33)	0.3 (0.33)	0 (0)
28.2	19	0.3 (0.33)	0 (0)	0.3 (0.33)	0.3 (0.33)	0.7 (0.67)	0 (0)
28.3	23	0 (0)	0.7 (0.33)	0 (0)	0 (0)	0 (0)	0 (0)
25.4	27	0 (0)	0.3 (0.33)	0 (0)	0 (0)	0 (0)	0 (0)
23.5	31	0 (0)	0.7 (0.67)	0 (0)	0.3 (0.33)	0 (0)	0 (0)

Table 18
1989-90 The number of insects of 3 species trapped in bait bags around aerated bins of wheat (n=50).

	O.surinamensis	S.granarius	Cryptophagus
19.10	0	0	9
20.10	2	0	39
23.10	1	0	31
25.10	2	0	82
1.11	4	1	147
8.11	2	1	123
15.11	6	0	152
22.11	5	1	133
29.11	0	0	102
6.12	0	0	79
13.12	0	0	52
20.12	2	0	54
28.12	1	0	19
11.1	0	1	19
18.1	3	1	52
25.1	3	1	32
31.1	4	1	40
8.2	3	0	48
15.2	3	0	58
22.2	4	1	49
1.3	10	0	44
19.4	8	2	43
26.4	10	0	13
3.5	21	0	17
10.5	10	0	48
17.5	14	0	145
24.5	1	0	70

Table 19
1990-91 Mean no. of S.granarius per bin in probe traps (and nos. alive) at 3 depths in surface treated (t) and untreated (u) aerated bins of wheat. (n=27)

		Surface		1m		2m	
date	week	t	u	t	u	t	u
17.10	1	0 (0.00)	0.3 (0.30)	0 (0.00)	0 (0.00)	0 (0.00)	0.3 (0.00)
24.10	2	0 (0)	1.7 (1.7)	0 (0)	0.3 (0.33)	1.3 (0.67)	1.0 (0)
1.11	3	0.6 (0.33)	2.7 (2.19)	0.7 (0.33)	0.7 (0.33)	0.7 (0.33)	1.3 (0.67)
7.11	4	0 (0)	1.3 (0.88)	1.0 (0)	1 (0.58)	0 (0)	0.7 (0.67)
14.11	5	0.7 (0.33)	0.7 (0.33)	1.3 (0.67)	0.3 (0.33)	0.3 (0.33)	1.0 (1.0)
21.11	6	0.3 (0.33)	1.7 (1.7)	0.3 (0.33)	0.3 (0.33)	0.3 (0.33)	0 (0)
12.12	9	0 (0)	0.3 (0.33)	0 (0)	0 (0)	0 (0)	0.7 (0.67)
10.1	13	0 (0)	1.0 (0.58)	0 (0)	0.3 (0.33)	0 (0)	0.3 (0.33)
6.2	17	0 (0)	0.3 (0.33)	0 (0)	0 (0)	0.3 (0.33)	0.3 (0.33)
6.3	21	0 (0)	2.3 (1.86)	0.3 (0.33)	0.3 (0.33)	0 (0)	1.0 (0)
3.4	25	0.3 (0.33)	1.7 (1.20)	0 (0)	0.7 (0.33)	0.7 (0.33)	0.33 (0.33)
6.5	30	0.7 (0.67)	0.7 (0.67)	0 (0)	0 (0)	0.7 (0.33)	0 (0)

Table 20
1990-91 Mean no. of <u>C.ferrugineus</u> per bin (and se.) captured in probe traps at 3 depths in surface treated (t) and untreated (u) aerated bins of wheat (n=27).

		Surface		1m		2m	
date	week	t	u	t	u	t	u
17.10	1	0	0	0	0	0	0
24.10	2	0	0.3 (0.33)	0	0	0.3 (0.33)	0
1.11	3	0	0	0	0	0	0
7.11	4	0	0	0	0.7 (0.67)	0	0
14.11	5	0	0.3 (0.33)	0	0	0	0
21.11	6	0	0	0	0	0	0
12.12	9	0	0	0	0	0	0
10.1	13	0	0	0	0.3 (0.33)	0	0
6.2	17	0	0	0	0	0	0
6.3	21	0	0	0	0	0	0
3.4	25	0.3 (0.28)	0	0	0.3 (0.33)	0.3 (0.33)	0
6.5	30	0	0	0	0	0	0

Table 21
1990-91. Mean nos. of <u>O.surinamensis</u> per bin in probe traps (s.e.) at 3 depths (n=27) in surface treated (t) and untreated (u) aerated bins of wheat.

		Surface		1m		2m	
		t	u	t	u	t	u
17.10	1	1.7 (0.88)	12.0 (6.03)	1.3 (0.88)	7.0 (3.6)	1.0 (1.00)	5.3 (1.33)
24.10	2	1.7 (0.33)	11.3 (1.76)	1.3 (1.33)	3.7 (2.19)	0.7 (0.67)	7.3 (4.37)
1.11	3	2.0 (0.58)	19.6 (5.49)	1.3 (0.88)	26.3 (3.76)	2.7 (1.20)	11.7 (0.67)
7.11	4	2.3 (1.33)	25.3 (7.45)	1.0 (0.58)	7.0 (2.52)	0.7 (0.67)	8.3 (2.40)
14.11	5	1.0 (0.58)	10.7 (1.33)	0	2.3 (1.3)	1.00 (1.00)	2.3 (2.33)
21.11	6	1.3 (0.88)	4.7 (0.88)	0.7 (0.67)	3.0 (1.53)	0.3 (0.33)	2.0 (0.58)
12.12	9	1.3 (0.33)	1.7 (0.67)	0.7 (0.67)	0.3 (0.33)	0	0.7 (0.33)
10.1	13	0	1.0 (0)	0	0.3 (0.33)	0	0
6.2	17	0	0.3 (0.33)	0	0	0	0.3 (0.33)
6.3	21	0.3 (0.3)	0.7 (0.33)	0	0.7 (0.67)	0.3 (0.33)	0
3.4	25	0	2.7 (1.7)	0.7 (0.67)	1.7 (0.33)	0.3 (0.33)	7.7 (2.67)
6.5	30	0.7 (0.33)	4.7 (1.45)	0.7 (0.67)	5.0 (2.52)	1.0 (1.00)	4.3 (1.76)

Table 22
1990-91 Mean number per bin (s.e.) of 3 spp. of insects captured in pitfall traps (n=16) in surface treated (t) and untreated (u) aerated bins of wheat.

		O.surinamensis		S.granarius		C.ferrugineus	
date	week	t	u	t	u	t	u
17.10	1	4.3 (1.20)	28.0 (8.72)	9.3 (5.84)	38.7 (11.8)	0	1.3 (0.33)
24.10	2	7.0 (2.52)	24.0 (5.03)	6.0 (2.08)	34.3 (3.48)	0	0
1.11	3	6.7 (2.96)	21.3 (2.40)	24.7 (19.68)	58.3 (17.25)	0	0
7.11	4	3.7 (1.20)	17.7 (0.67)	13.0 (5.69)	48.7 (16.05)	0	0
14.11	5	5.7 (4.18)	41.7 (19.1)	10.7 (8.69)	50.3 (23.21)	0	0.3 (0.3)
21.11	6	3.7 (0.7)	14.7 (4.67)	12.7 (3.5)	50.3 (27.16)	0	0
12.12	9	0.7 (0.33)	7.0 (2.52)	13.0 (9.02)	35.0 (12.9)	0	0
10.1	13	1.0 (0)	10.7 (1.9)	15.7 (9.68)	100.0 (40.50)	0	0
6.2	17	0	1.0 (0.58)	10.0 (4.62)	77.0 (4.58)	0	0
6.3	21	3.3 (1.86)	14.3 (3.78)	16.3 (8.11)	103.3 (39.3)	0	0
3.4	25	3.7 (1.33)	20.0 (5.69)	4.0 (1.73)	32.7 (7.27)	0	0
6.5	30	0.7 (0.67)	11.7 (2.96)	5.0 (2.08)	5.7 (0.88)	0	0

Table 23
1989- 90 Response of <u>O.surinamensis</u> to a discriminating dose of 0.6 % Pirimiphos- methyl. Percent knockdown and numbers tested () in surface treated (n=3) and untreated (n=3) bins of wheat.

	All depths		Sur		1 & 2m	
a) 1989-90	t	u	t	u	t	u
7.11	90.8	90.8				
	(229)	(271)				
15.11	85.3	89.0	86.2	88.1	85.1	89.5
	(307)	(474)	(58)	(168)	(249)	(306)
29.11	90.0	95.7	89.2	96.2	92.9	94.3
	(130)	(184)	(102)	(131)	(28)	(53)
31.1	*	*	-	*	*	*
	(5)	(30)	(0)	(21)	(5)	(9)
28.2	*	100	-	100	*	*
	(1)	(21)	(0)	(16)	(1)	(6)
28.3	**	86.2	-	91.7	**	**
	(6)	(87)	(0)	(72)	(1)	(5)
25.4	***	83.9	-	86.3	***	**
	(1)	(56)	(0)	(51)	(1)	(5)
22.5	***	91.4	***	91.3	-	92.9
	(3)	(232)	(3)	(218)	(0)	(14)
b) 1990-91						
17.10	-	89.6				
	(0)	(48)				
24.10	+	93.2				
	(3)	(73)				
1.11	**	86.3				
	(9)	(102)				
7.6.91	+	95.4				
	(6)	(22)				

* all knocked down
** 2 survivors out of those tested
*** all survived
+ one survivor of those tested

3. DIFFERENCES IN CLIMATE, TEMPERATURES ACHIEVED AND HOURS BLOWN AFFECTING GRAIN AERATED AT SLOUGH IN 1987-8, 1989-90 AND 1990-91

i. Introduction

In the integrated control experiments carried out during the grain storage seasons of 1987-88 and 1989-91, one important observed difference was that, while all insects were killed in aerated bins in the initial experiment, there were survivors in the subsequent test. It is obviously important that a method of control is universally reliable and therefore, these differences require clarification.

The two explanations forwarded for these inconsistencies were the varying ability of different strains of insects to survive at low temperature in the various years and the differences in ambient temperatures. This section examines the latter and attempts to discover whether the experimental years were greatly different from each other and whether they were warmer than the warmest year on which the calculations underpining the technique, were based.

ii. Methods

To make the required comparisons, records were acquired for Heathrow Airport, the nearest Meteorological station to Slough, in the years concerned, for hours in each month between October and May (the storage season) that were below 15 °C, 10 °C and 5 °C. In Table 24 these are compared with those of the warm winter of 1974-5 in Exeter which was used as the basis of calculations for the slowest winter cooling (Wilkin et al., 1990).

The effects of ambient conditions on the hours that the aeration fans operated are compared in Table 25 for the 3 years in which the farm-scale integrated control experiments were carried out.

Finally, the consequences of the combination of the hours aeration and the ambient conditions on the grain temperature in each of the 3 years are compared in Table 26.

iii. Results and discussion

Of all the years examined, the hours below 10 °C were lower for Exeter than Heathrow, between November and April and the hours below 5 °C were lowest for Exeter between November and January. This shows that the slowest winter cooling previously calculated (Wilkin et al., 1990) has not been undermined by recent warm years, as these are the months during which most cooling is expected to occur.

However, compared to the other years of the experiments, the year of 1989-90 had fewer hours below 10 °C and 5 °C in

January and February and the hours below 5 °C were even less than the warm Exeter year of 1974-5.

The consequences of these ambient conditions were that the warm conditions of 1989-90 did not affect hours aeration or temperatures until January, but in that month the hours blown were much reduced which allowed notably higher temperatures in February and March 1989 than in 1987-88 (or in 1990-91).

The recent warm years have not undermined the basis of calculations performed previously concerning the speed of cooling (Wilkin et al., 1990). However, the warm weather early in the New Year of 1989-90 has highlighted the importance of intermittent aeration after 5 °C has been achieved. This need not be important in large, commercial stores, where peripheral warming affects only a small proportion of the bulk but is more so in smaller farm stores with a larger surface area. This effect was quite marked in the small 20 t bins used in the experiments at Slough.

The differences observed may have been a factor in permitting enhanced insect survival in 1989-90 compared with 1987-88.

Table 24
Comparison of temperatures during cooling years 1987-88, 89-90 and 90-91 (Heathrow) with warmest predicted year, Exeter 1974-5 (Wilkin et al., 1990)

a) Hours below 15 °C

Month	10	11	12	1	2	3	4	5	Tot.
87-88	668	720	744	744	696	744	678	518	5512
89-90	567	714	744	744	665	704	636	426	5200
90-91	530	711	744	744	672	731	683	597	5412
Ex 74-75	221	720	744	744	672	744	672	667	5184

b) Hours below 10 °C

87-88	277	572	521	670	674	623	433	126	3886
89-90	101	555	608	573	457	456	421	115	3286
90-91	150	519	760	715	634	464	491	291	3944
Ex 74-75	441	468	354	459	431	424	304	279	3160

c) Hours below 5 °C

87-88	35	155	283	238	309	135	108	5	1268
89-90	0	188	244	178	91	108	131	0	940
90-91	15	152	360	410	466	108	160	22	1633
Ex 74-75	82	47	58	108	211	289	157	24	976

Table 25
Comparison of temperature range (°C) at 1 m depth in the centre of 20 t bins of wheat during 3 years of experiments at Slough.

a) Centre

Month		10	11	12	1	2	3	4	5
87-88	max	11.8	9.2	4.0	7.6	6.0	5.2	6.6	9.2
	min	10.0	6.6	3.0	4.8	4.4	3.2	4.8	6.8
89-90	max	18.6	10.0	4.4	6.0	9.0	8.2	7.2	10.0
	min	16.8	6.8	2.8	4.4	6.8	6.4	3.2	9.0
90-91	max	12.8	8.8	4.8	6.0	-1.6	2.0	5.8	6.8
	min	11.6	6.8	3.0	3.6	-2.8	0.8	4.0	5.6

b) Side

87-88	max	13.2	9.8	8.4	6.8	8.2	8.8	11.2	14.8
	min	10.4	8.2	6.4	5.6	6.4	6.4	9.2	11.2
89-90	max	19.6	10.8	7.6	8.0	8.4	10.8	9.6	14.8
	min	14.8	8.6	4.8	5.8	7.2	9.2	6.4	10.0
90-91	max	15.8	11.6	5.6	6.8	1.2	9.6	11.2	9.2
	min	14.4	10.0	2.8	4.4	-0.4	8.0	9.2	8.0

Table 26
Comparison of hours blown and proportion of the total in each month by aeration fans during the 3 years of experiments at Slough.

a) Hours

Year	Differential	Month 10	11	12	1	2	3	4	5
87-88	2C	160	263	131	77	70	66	39	10
	4C	81	58	63	17	38	33	12	5
89-90	4C	0	224	7	7	55	20	52	4
90-91	4C	0	145	53	139	192	0	0	0

b) Proportion (%)

Year	Differential	10	11	12	1	2	3	4	5
87-88	2C	19.6	32.2	16.1	9.4	8.6	8.1	4.8	1.2
	4C	26.4	18.9	20.5	5.5	12.4	10.7	3.9	1.7
89-90	4C	0	60.7	1.9	1.9	14.9	5.4	14.1	1.1
90-91	4C	0	27.4	10.0	26.3	36.3	0	0	0

4. COMPARISON OF COLD HARDINESS AND INSECTICIDE RESISTANCE OF THE INSECT STRAINS USED IN THE FARM-SCALE EXPERIMENTS

i. Objectives.

1. To see if the insects used in experiments during 1987-88 were less cold hardy than those used in 1989-91.

2. To see if the resistance to pirimiphos-methyl of Sitophilus granarius collected from surface treated bins differed from that of those from the untreated bins.

ii. Introduction.

It has already been established in Part 3, that differences existed in ambient temperature during the 3 years of the farm scale experiment. These could account, at least partly, for the fact that some insect survival occurred in 1989-91 but not in 1987-88. Another contributing factor is the ability of the insects themselves to withstand cold weather. Fortunately, the original strains had been retained in culture so this comparison could still be made. The aim of the experiments descibed here was to compare the probable survival of the insects used in the farm scale experiments, so no attempt to select for known age adults, was made.

Attempts were made to compare the resistance to pirimiphos-methyl of O.surinamensis from treated and untreated bins as they were trapped during the course of the test. However, a similar procedure could not be carried out using S.granarius, as no discriminating dose for pirimiphos methyl had been established at that time. Cultures had been set up and maintained of the original insects placed in the bins in 1989, as well as of the survivors from both the treated and untreated bins. It therefore seemed worthwhile carrying out a comparison of their response to different doses of pirimiphos methyl, to see if that of the different strains varied.

iii. Methods

a. Cold hardiness.

Two strains of O.surinamensis were used in this test. One was collected in 1981, and used in our experiments in 1987-88, the other was the strain created by uniting a number of cultures collected in 1989 and used in our tests starting in that year. Three strains of S.granarius were used. The first had been in culture since 1952 and was used in our tests starting in 1987. The second was set up by uniting a number of cultures collected in 1989 and was used in our tests that started in that year. The final strain was set up by collecting the survivors from the last 3 samplings in Spring 1991 of the untreated bins from the farm scale experiment. The tests described here were set up in July 1991.

Adults of O.surinamensis and S.granarius were harvested after 8 weeks from cultures initially set up with 100 adults. The S.granarius were on whole wheat, the O.surinamensis on a ratio of 5:5:1 of wheatfeed, oats and brewer's yeast. Both were maintained at 25 C, 70% r.h. This was the same procedure as that adopted in producing the insects for the farm scale experiment, and hopefully produced populations of comparable, if unknown, age composition to those used in the farm scale experiment.

Batches of 50 insects were counted out and placed in an 80 x 25 mm tubes on about 15g of wheat, previously conditioned to 70% r.h., by the addition of water . Ten percent of the wheat was coarsely kibbled as the ground grain enhances the survival of insects at low temperature (Granovsky and Mills, 1982). The tubes were then placed in plastic dessiccators over potasium hydroxide of appropriate specific gravity (Solomon, 1951) in a cooled incubator, initially at 20 C.

The temperature of the incubator was reduced to 5 C, at a rate of about 1 C/day by turning the temperature down by 2 C, every other day. In practice, it took 18 days to reduce the temperature by 15 C. When this temperature had been achieved, 5 replicates of each species and strain thereof were withdrawn, and allowed to stand overnight at room temperature, before the live and dead were counted. This procedure was repeated at fortnightly intervals.

b. Resistance to pirimiphos methyl.

Three strains of S.granarius were used in this experiment. One was the strain of weevil resulting from collections in commercial stores in 1989. The second was that collected from untreated bins in 1991 and already referred to above. The third was based on the survivors collected from the treated bins in 1991. Batches of 25 adults of mixed age were counted out and starved overnight for exposure on filter papers.

A range of doses of pirimiphos-methyl were made up as follows. An upper dose was diluted in 5 ml oil (Shell Risella oil) and this was diluted in turn to 25 ml using 5 ml acetone and 15 ml petroleum ether (boiling point, 60 C - 80 C). Serial dilutions were then made up to give a range of 4 doses. Twenty five ml of solvent was used as a control. Five filter papers were treated with 0.5 ml for each dose and for the control. These were left overnight to dry on pin points at 20 C/50% r.h.

Four papers for each dose and the controls were placed on glass plates with a fluon treated ring on top. Twenty five insects were placed in each and they were left in darkness at 25 C/70% r.h. for 24h.

After 1 day the response was measured as knock-down which was defined as the inability of the insect to make coordinated movements.

iv) Results and Discussion.

a. Cold hardiness

It is evident that, at 5 C, O.surinamensis survived longer than S.granarius (Table 34). This confirms the finding of Armitage and Llewellin (1987) and confounds the opinions of some authors (e.g. Wohlgemuth, 1989) who suggested a reverse order of hardiness and attributed results suggesting the contrary, to the peculiarly susceptible laboratory strain of S.granarius used at Slough.

The strain of O.surinamensis used in 1987 was less cold hardy than that used in 1989 as shown by the survival at 28 and 42 days.

At 28 and 29 days, the S. granarius survivors from the farm scale experiment were hardier than the laboratory strain, used in 1987 and the original strain introduced into the bin in 1989. However there was no clear hardiness ranking between the earlier strains.

The survival obtained in these experiments was less than that obtained earlier by Armitage (unpublished) and used in calculations of insect population decline for the previous integrated control report (Wilkin et al., 1990). For instance, ET50s of 113 and 138 days were obtained for O.surinamensis and S.granarius respectively in the earlier calculations. It is possible that there are seasonal differences in the ability of a given species to withstand cold, as well as the differences between strains, investigated here. The assumed loss of a strain's cold hardiness with prolonged culture is also worth investigating further.

b. Resistance to pirimiphos methyl

Probit analysis of the data (Table 35) indicated a very good fit between the observed responses and the fitted lines ($p >> 0.05$). There was no significant difference between the three strains either in terms of the LD50 or the slope of the regression line. This was confirmed by fitting a common slope to all 3 sets of data.

Thus, although there was evidence from the farm scale tests that S.granarius may have completed a generation during the experiment in the treated bins, there was no evidence that the surface treatment had increased the resistance to pirimiphos methyl of the S.granarius.

Table 34
Comparison of the percentage survival (and s.e.) at 5 C of the different strains of <u>O.surinamensis</u> and <u>S.granarius</u> used in integrated control experiments in 1987-8 and 1989-91.

Day		O.surinamensis		S.granarius		
		1987	1989	1987	1989 original	survivors
1	Mean	93	98	90	89	97
	Range	(91-95)	(94-100)	(89-92)	(84-96)	(95-98)
	n	311	267	251	280	276
14	Mean	92	93	77	67	78
	Range	(90-98)	(89-95)	(72-80)	(61-75)	(69-90)
	n	277	296	283	290	280
28	Mean	61	94	4	11	37
	Range	(49-78)	(86-98)	(2-6)	(0-22)	(16-66)
	n	285	293	251	271	281
29	Mean			13	16	37
	Range			(4-27)	(7-25)	(33-42)
	n			273	271	262
42	Mean	43	79			
	Range	(25-61)	(66-89)			
	n	391	384			

Table 35
Analysis of probit lines from the comparison of 3 strains of *S.granarius* against pirimiphos methyl.

Strain	LD50	95% limits	LD99	Slope+s.e.	p(doses)
Original	0.074	0.059,0.081	0.134	8.92+2.01	0.72
Untreated	0.070	0.064,0.074	0.127	9.03+1.28	0.91
Treated	0.070	0.063,0.075	0.136	8.09+1.17	0.62

5. COMMERCIAL-SCALE TRIAL

i. Objectives

a. To apply the integrated strategy in a commercial store.
b. To meet the strictest quality standards applied therein.

ii. Introduction

In the first phase of the integrated control project for grain stores (Wilkin et al., 1990), aeration disinfested grain without resort to chemicals. However, Armitage and Llewellin (1987) had shown consistent survival of insects at the surface and Armitage (1984) found that in dry grain surface infestations of mites were inevitably present. Field trials in the first phase of the integrated control project showed surface infestations of insects could be effectively eradicated by surface treatments with contact pesticides.

In the second phase of the project described in Part 2 of this report, a surface treatment prevented mite infestations developing until spring and prevented insects reappearing in surface layers as the grain warmed. In untreated bins mites were present in the surface layers.

The surface treatment has therefore proved to be a useful adjunct to the aeration system and the various monitoring devices as part of the integrated control strategy. In order to test this strategy to the utmost, it was decided to apply it in a commercial store, where the strictest quality standards applied.

iii. Method

<u>Store</u>

The floor store, holding 2.5 thousand tonnes of grain at a depth of 3 m (but peaked to 6 m) measured approximately 35 x 25 m.

<u>Aeration</u>

Two main ducts, each 60 x 90 cms ran down each side of the store. These supplied numerous under-floor ducts which ran half way across the store. Air was supplied by two 45 kW fans which were operated by time clock using off-peak electricity and these were estimated to give 35,000 - 53,000 cfm (28-42 cu m/h/t) at an approximate cost of 0.1 p/t/h (assuming night tariff of 2 p/kWh and 66% efficiency).

A differential thermostat operated the fans via relays. The sensors for the thermostats were installed 1m below the surface of a peak with the ambient sensors close to the fan inlet.

Hours of fan operation were recorded by site personnel from the hours meters which were incorporated in the fans.

Airflow Measurement

The depression into the fan inlet was measured with a 'Solomat' electronic manometer. This was used to provide an independent check on the air volume flow rate. The static pressure in the main duct after the fan was also measured with an electronic manometer.

The temperature rise across the fan was estimated by making separate measurements of the ambient temperature outside the fan house and in the main duct, after the fan. All temperature measurements were made with a platinum resistance thermometer.

Grain reception

The grain was taken into the store directly from farms without drying because of the exceptionally warm and dry year of 1990. The test commenced in early September.

Initial sampling

In order to establish the quality of the grain before the integrated strategy was applied, the grain was sampled for mites and moisture content (m.c.). Twenty equidistant samples were taken, both at the surface and 1m depth (n=40), sieved over an 0.7 mm mesh and live mites counted and identified to genus under a binocular microscope. Representative specimens were mounted onto slides and identified to species. The m.c. of the sieved grain was determed using a 'Sinar' meter.

Surface treatment

All of the grain surface was treated with 2% active ingredient Etrimfos dust (Satisfar) at 50 g/sq. m. For the estimated surface area of 819 sq.m, this was 41 Kg which cost £ 100 and took 1 man day, (not more than £ 100)

Sections of the surface were staked, into a 2x5 m grid, using bamboo canes and 0.5 kg Satisfar was weighed out into polythene bags and sprinkled evenly into each square.

Samples of grain were taken from the initial sampling positions, immediately after treatment and on 4 subsequent occasions and analysed for chemical residues.

Temperature measurement

Two 'Squirrel' data loggers were used. They recorded the readings from duplicate sets of thermocouples. Temperatures were measured in 5 equidistantly spaced rows, running across the width of the store in a line from one a trough at one side, through the grain peak, to the other side. They were inserted at depths of 0.5 m, 1.5 m and 2.5 m from the grain surface.

These measurements were supported by spot readings using a thermistor probe and meter, taken at a depth of 1.0 m in the sampling positions. The purpose of these was to check that there were no 'hot spots' in areas not monitored by thermocouples.

Insect sampling

Probe and pitfall traps were inserted into the surface sampling positions to monitor insect numbers. However, the slope of the grain limited the use of pitfall traps.

Sampling intervals

The site was visited initially, to treat the grain and set up the experiment, after 1 and 2 weeks and thereafter monthly, for sampling and data collection. On each occasion the 'Squirrel' data was transferred to a portable computer, the traps emptied and any insects within counted, the spear samples taken and moistures and mites assessed and aeration data collected.

The experiment ended in June when the grain was sold.

On - site monitoring

The condition of the grain was monitored independently by on-site personnel, with the option to stop the experiment at any stage, if their quality expectations were not being met.

iv. Results

Temperatures and hours blowing

The mean grain temperature at the start of the trial in early September, was initially around 20 °C; ranging from 19 - 26 °C (Table 29). Temperatures were not all reduced to below 15 °C until after 9 weeks of storage, on 6.11 at a cost of 14 p/t after 72 h aeration from the right hand and 183 h from the left hand fan (Table 37). The disparity in hours blown was due to problems with one of the controlling differential thermostats.

Grain temperatures were reduced to 10 °C or below (8-10 °C) after 12 weeks, on 27.11 after 112 and 231 h blowing from the right and left fans respectively at a cost of 19 p/t.

Temperatures below 5 °C (1-3 °C) were achieved after 24 weeks on 12.2 after 375 and 534 hours aeration from the right and left fans respectively at a cost of nearly 50 p/t.

Moisture contents

At the start of the experiment, the grain at the surface of the store and at 1m was initially at a mean of about 13% m.c., within the range 12-14% (Table 38). There was no consistent change up to the 17th week (1.1) but by the 23rd week, the m.c.s had increased by about 0.5 - 1.0%.

The irregularly taken deep samples also showed an increase of up to 1.5% m.c. after 23 weeks, with maximum increases near the floor (Table 39).

Airflow measurements

The static pressures at the fan were 3.0-3.3 kN/sq.m and airflow of the fans into the store was estimated at about 38 m3/s (32 cfm/t), or about 6 times the normally recommended rates. The fans heated the air by 1.3-1.5 °C. Allowing 66 % efficiency for the fans and night tariffs at 2 p/kWh, the cost was estimated at 135 p/h run by each fan.

Insect and mite numbers

One psocid and one Ptinus sp. were all that was found throughout the test in the probe and pitfall traps. The numbers of mites recovered from the 10 kg of samples were also insignificant. One tydeid mite was found in week 8, 4 Glycyphagus destructor in the 4th week, 1, 4 and 8 Cheyletus eruditus were found in weeks 1, 2 and 8 respectively and 17 Acarus siro were found in week 42.

Chemical analyses

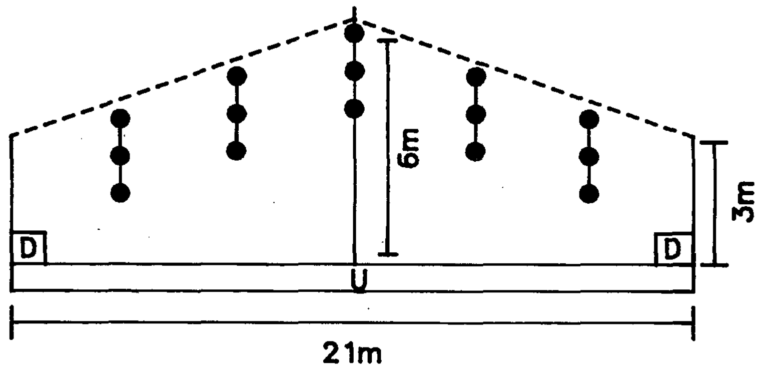
The residues of Etrimfos fell from an initial level of about 2.1 mg/kg. at the surface, to about 0.2 mg/kg. at the last sampling in March. There was considerable variation between samples taken on one date and between sampling occasions (Table 40).

v. Discussion

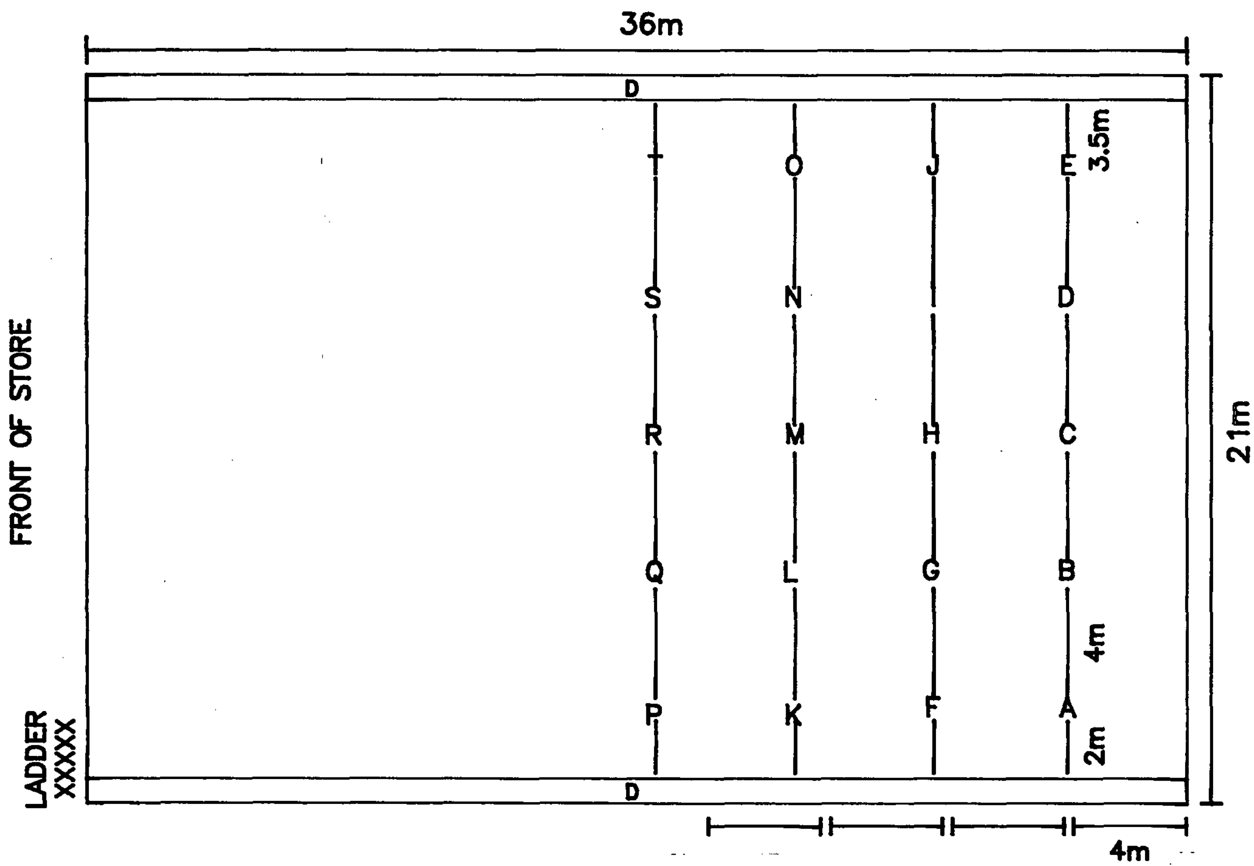
Despite the length of storage and the apparent uneveness of the chemical treatment, the trials in the commercial store achieved nearly pest-free grain storage at low temperatures. Some of the decline in residues of Etrimfos, detected during the course of the test, must be attributed to the activities during sampling which will have caused treated grain to roll down the considerable slope. This would presumably not occur so markedly during a non-experimental storage process.

The grain took much longer to cool and consequently at greater cost than estimates and records from other commercial stores suggest (Wilkin et al., 1990). The grain should have been cooled to 15 °C after less than 20 h aeration, to 10 °C after 40 h and to 5 °C after a total of about 60 h. These values were considerably exceeded. One reason for the slow cooling is that only one fan operated during the early part of the test because of problems with the thermostat. Other possible explanations include re-circulation and diversion of the air through shallow layers of grain or unrecognised problems associated with deep grain, high airflows and small differential settings (Current trials in the same store suggest the latter). It is also possible that these very high airflows do not allow air and grain temperatures to come to equilibrium so that, in effect, much of the air is wasted.

Fig 10
(Above) Store cross section showing duct and thermocouple positions.
(Below) Plan showing sampling points



Position of sampling points for pests and moisture contents



D = duct plenum
U = underfloor lateral

Fig 11
(Above) Applying the surface treatment in a commercial store.
(Below) Raking in

Table 29
Temperatures recorded (°C) by thermocouples (n=5) at 3 depths in a 2500 t commercial aerated store (Spot readings at midnight)

Date	Week	Amb.	Temps at depth (m) 2.5			1.5			0.5		
			mean	max	min	mean	max	min	mean	max	min
4.9	0	20.4	21.7	26.4	19.6	19.9	20.4	19.6	22.2	25.6	19.2
11.9	1	12.8	17.1	18.0	16.8	16.8	16.4	17.2	16.7	17.6	16.4
18.9	2	17.2	16.8	18.8	15.6	17.3	18.8	16.4	16.7	18.0	16.0
25.9	3	8.8	15.0	17.6	12.0	15.6	18.4	13.6	15.8	17.6	12.0
2.10	4	15.6	14.4	16.8	13.2	15.3	18.0	13.6	14.8	16.8	12.8
9.10	5	13.6	13.4	16.4	10.4	14.2	16.8	10.4	14.0	16.0	12.4
16.10	6	12.8	13.3	15.6	10.8	14.6	16.8	10.8	13.9	15.6	12.8
23.10	7	12.8	13.5	14.8	12.0	13.9	16.0	12.0	14.0	16.4	11.6
30.10	8	9.2	13.4	14.8	11.6	13.8	15.6	12.4	13.4	14.8	11.2
6.11	9	9.2	10.8	11.6	9.2	11.6	12.4	10.4	11.5	12.4	10.8
13.11	10	13.6	13.6	12.4	9.6	11.8	13.2	10.0	11.5	12.8	10.4
20.12	11	2.8	10.8	11.2	10.0	11.4	12.4	10.8	11.0	12.0	10.4
27.11	12	3.2	9.3	9.6	8.4	9.8	10.0	9.2	9.7	10.0	9.2
4.12	13	6.4	9.2	8.4	9.6	9.8	10.0	9.2	9.4	9.6	9.2
11.12	14	9.6	8.6	9.6	6.8	9.0	10.0	8.0	9.4	9.6	9.2
18.12	15	2.8	8.1	9.2	6.8	8.3	9.2	7.6	8.3	9.2	7.6
25.12	16	5.2	7.8	8.8	6.8	8.2	9.2	7.6	8.2	8.8	8.0
1.1	17	10.1	8.7	9.2	8.4	9.0	9.6	8.4	8.8	8.8	8.8
8.1	18	8.0	9.4	10.4	8.0	9.7	10.0	9.2	9.1	10.0	8.0
15.1	19	-0.4	6.5	9.2	5.2	7.1	9.2	5.6	7.9	9.6	6.8
22.1	20	5.2	6.1	6.8	5.6	6.2	6.4	5.6	6.0	6.8	5.2
29.1	21	2.8	7.3	8.0	6.4	7.3	8.4	6.8	7.3	8.0	6.4
5.2	22	2.0	5.2	6.8	3.6	5.8	8.0	4.0	6.6	7.6	5.6
12.2	23	1.2	2.4	3.2	1.2	2.5	2.8	1.2	3.0	4.8	1.2
19.2	24	3.6	2.7	3.2	2.0	3.0	4.0	2.4	3.1	4.0	2.4
26.2	25	8.4	2.8	3.2	2.0	3.0	3.6	2.4	3.7	5.6	3.2
5.3.	26	10.0	1.8	2.4	0.4	1.8	2.8	0.8	3.2	4.8	2.4
12.3	27	9.2	1.8	2.8	0	1.8	2.8	0.8	4.6	6.8	2.8
19.3	28	11.2	2.2	3.2	-0.4	2.4	3.2	0.8	6.0	9.6	3.2
26.3	29	6.0	1.8	3.6	0	2.1	3.2	0.8	5.5	8.4	2.8
2.4	30	13.6	3.3	4.8	2.4	3.8	6.0	3.2	7.4	10.4	4.8
9.4	31	6.4	3.1	7.6	0.8	2.8	3.2	2.4	5.4	8.0	2.8
16.4	32	6.0	3.3	6.8	1.2	3.0	3.6	2.8	7.8	10.4	4.4
23.4	33	4.0	2.9	6.4	1.2	3.3	4.4	2.8	6.8	8.4	5.2
30.4	34	6.4	3.3	6.4	2.0	3.6	4.8	3.2	7.8	9.6	5.6
7.5	35	10.3	3.3	6.0	2.4	4.1	5.6	3.2	10.3	9.2	7.6
14.5	36	10.2	3.4	6.0	2.4	4.6	6.0	3.6	10.2	12.4	7.6
25.11	37	10.9	3.5	5.6	2.8	5.1	6.4	4.4	10.9	13.2	8.4
28.5	38	13.1	3.8	6.4	2.8	5.7	8.4	3.2	13.1	16.4	9.2
4.6	39	12.2	3.8	5.6	2.8	6.6	8.8	5.2	12.2	13.2	10.8
11.6	40	11.2	3.9	5.2	3.2	7.3	9.6	6.0	11.2	12.8	9.0
18.6	41	11.2	4.0	6.8	3.2	6.2	8.8	4.8	11.2	12.4	9.2

Table 30
Hours run by fans and cost (£) of aerating a 2500 t commercial grain store

Date	Right side Hours	Total	Cost	Left side Hours	Total	Cost	Overall Cost/t
4.9	0	0	0	0	0	0	0
11.9	16.9	16.9	22.9	34.7	34.7	46.9	0.03
18.9	13.0	29.9	40.4	24.3	59.0	79.7	0.05
25.9	4.6	34.5	46.6	47.1	106.1	143.2	0.08
2.10	0	34.5	46.6	7.1	113.2	152.8	0.08
9.10	8.8	43.3	58.5	18.4	131.6	177.7	0.09
16.10	0	43.3	58.5	0	131.6	177.7	0.09
23.10	0	43.3	58.5	14.6	146.2	197.4	0.10
30.10	0	43.3	58.5	0	146.2	197.4	0.10
6.11	28.5	71.8	96.9	37.2	183.4	247.6	0.14
13.11	0	71.8	96.9	0	183.4	247.6	0.14
20.11	8.3	80.1	108.1	9.1	192.5	259.9	0.15
27.11	31.8	111.9	151.1	38.8	231.3	312.3	0.19
4.12, 11.12, 18.12	Readings not taken						
25.12	69.1	184.0	248.4	78.9	313.3	423.0	0.27
1.1	0	184.0	248.4	3.1	316.4	427.1	0.27
8.1	0	184.0	248.4	0	316.4	427.1	0.27
15.1	27.3	211.3	285.3	42.6	359.0	484.7	0.31
22.1	30.3	241.6	326.2	32.5	391.5	528.5	0.34
29.1	41.3	282.9	381.9	44.6	436.1	588.7	0.39
5.2	54.6	337.5	455.6	50.0	486.1	656.2	0.44
12.2	37.6	375.1	506.4	48.0	534.1	721.0	0.49

NO FURTHER AERATION - FANS SWITCHED OFF.

Table 31
Moisture content (%) of grain in the upper layers of a commercial 2500 t aerated store.

Date	Week	Sur mean	max	min	1m mean	max	min
4.9	0	13.2	14.1	12.2	13.0	14.4	12.0
11.9	1	13.3	14.5	12.5	13.2	14.4	12.5
18.9	2	12.6	14.0	11.8	12.7	13.9	12.0
2.10	4	13.0	14.1	12.3	13.0	14.1	12.2
30.10	8	13.4	14.2	12.5	12.9	14.0	12.2
27.11	12	12.8	13.9	12.4	12.8	14.2	12.3
1.1	17	13.3	14.4	12.5	12.9	14.0	12.2
12.2	23	14.4	15.4	13.0	13.7	15.0	12.9
19.3	28	13.1	14.0	12.5	13.3	14.6	12.5
30.4	34	13.5	14.0	13.0	13.2	14.5	12.4
10.6	40	13.9	14.6	12.4	13.3	14.8	12.0

Table 32
Temperatures (°C) measured at 1m using a hand probe and moisture contents (%) at depth in an aerated 2500 t store.

Date		18.9	2.10	30.10	27.11	1.1	12.2	19.3	30.4	10.6
Week		2	4	8	12	17	23	28	34	40
<u>a. Temperatures</u>										
	mean	15.4	13.0	11.9	7.5	6.9	1.1	2.0	3.9	6.8
	max	17.4	16.4	13.6	8.5	8.1	2.1	4.1	8.0	9.7
	min	12.5	11.0	9.6	6.2	5.8	0.3	0.9	2.7	5.2
<u>b. Moisture contents</u>										
Floor	mean		13.8	13.9		14.1	14.9			
	max		14.1	14.4		15.0	15.1			
	min		13.6	13.4		12.7	14.5			
1m up	mean		13.3	13.3		14.0	14.6			
	max		13.7	13.8		14.7	14.9			
	min		12.8	13.0		13.7	14.2			
2m up	mean		13.0	13.0		13.6	14.5			
	max		12.5	12.5		13.9	14.1			
	min		12.3	12.5		12.8	14.7			
3m up	mean		12.5	12.5		13.9	14.1			
	max		13.7	13.4		14.9	14.6			
	min		11.8	11.8		12.9	13.7			

Table 33
Residues of Etrimfos (mg/kg) from surface treated grain in a 2500 t commercial store (n=5)

		12.9	5.10	30.11	26.2	27.3
Surface	mean	2.1	1.5	0.2	1.1	0.2
	max	4.4	2.7	0.9	3.8	0.7
	min	0.1	0.02	<0.05	0.05	0.02
1m	mean	0.14	0.39	0.04	0.04	0.17
	max	0.40	0.39	0.14	0.14	0.72
	min	0.05	0.02	<0.05	<0.01	<0.01

6. CONCLUSIONS AND RECOMENDATIONS FOR FURTHER WORK

This report has extended the integrated strategy outlined by Wilkin et al. (1990) in several important ways. It has shown the low cost of farm-scale aeration by fitting fans of 20 W (output) to the 20 t experimental bins and demonstrated that effective cooling to below 5 °C still occurred. The limitations of using cooling alone, to deal with existing infestations, were demonstrated by the surface populations of mites that occurred in the first winter, by the upsurge in numbers of O. surinamensis in the late spring and by the detection of S. granarius in the second winter. The remedy for these limitations was a surface insecticidal application applied at the start of storage, which was shown to be effective. The essential nature of using insect traps to monitor infestations, is demonstrated by the fact that conventional sampling was unable to detect the changes referred to.

The importance of repeating, even such a well-regulated farm-scale test as this, was highlighted by the survival of some insects in the bins that were cooled only. In the test previously reported, no survival had occurred due to harsher winter conditions and due to the different cold-hardiness of the strains used. The variation in biological properties of different insect strains is still little studied and a greater range of data is required because the speed of cooling depends on the insects' rate of multiplication and death. The loss of cold-hardiness of insects after prolonged culture is assumed but not proven. Future experiments should always therefore use recently-collected field strains (as was done in the experiment reported here).

The commercial-scale trial showed that the strategy, combining automatically controlled aeration with trapping and surface treatment, could be applied on a much larger scale and still achieve pest-free storage. The advantages were the achievement of lower than usual temperatures and hence prolonged storage and sale at a higher market price. The reservations of the trial, were the slow cooling rate and the high cost, compared with that calculated. These may well be associated with the unusually high airflow used and the atypical nature of the hybrid cooling/ drying system used. However, there are many stores that rely on ambient drying systems to cool grain and this demonstrates the increasing costs that can be incurred if fan running hours are not strictly controlled. Thus, although the trial showed the strategy is applicable, the results may be unrepresentative and further trials of this nature are required, carried out over a number of years and in a variety of stores.

The nature of the farm and commercial-scale experiments dictate that only a limited number of fan control strategies can be tested at one time. We have already demonstrated that a 4 °C differential thermostat setting can offer 3-fold savings over a 2 °C differential. In the commercial-scale test we used a time clock to select only off-peak electricity, offering further 3-fold savings at least. It is thus not inconceivable that much grain is cooled at 9x the necessary cost. However, further theoretical studies need to be done, for instance to ensure that choosing night air only will allow the grain to be cooled sufficiently quickly to prevent insect development. It may well be that different thermostat settings would be appropriate at different stages of the cooling strategy. To test all these possibilities on a practical scale would be impracticable in the short term so it is important that an interactive model is developed for cooling grain in the British climate, combining meteorological data, grain cooling physics, insect and mite biology.

In this experiment, the effect of the strategy on insecticide resistance was given only cursory attention. No increase in resistance of S. granarius was detected, presumably mainly due to the low temperatures prevailing, which prevented the insects completing a generation (although there was slight evidence of a selection of increased frequency of resistant O.surinamensis). Nevertheless, the strategy needs to be able to deal with infestations of resistant insects and should not encourage the selection of resistant insects by the partial insecticide treatment. Attention should therefore be given to using resistant insects in future tests.

As it stands, the strategy depends on lengthy storage at low temperatures. Occasions will arise when a quick kill of the infestation is required or an infestation will be discovered in the summer, when no lethally cold air is available. There are also a number of solutions in such a case; admixture of the bulk being one form of 'last resort' treatment. There are a number of less-researched alternatives, such as grain cleaning and conveying which offer the possibility of removing and killing over 90% of the pests without resort to chemicals.

Fumigation is another alternative. Fumigation of the entire bulk with aluminium phosphide formulations is a proven, but costly solution. Novel fumigant treatments that allow localised application (in the manner formerly produced with the now withdrawn liquid fumigant mixture of carbon tetrachloride and ethylene dichloride) are based on a 3% v/v mixture of phosphine in carbon dioxide in cylinders. However these need development to match flow rates to hot spots of various sizes and to obtain complete mortality of insects at the low temperatures encountered in British grain. Controlled atmosphere disinfestation using carbon dioxide or nitrogen generators is also applicable in this context and have the advantage of leaving no chemical residues.

The strategy has been devised mainly for grain and tested using stores of feed wheat but it is appropriate to modify it for other commodities or for grain used for different purposes. For instance, rapeseed and linseed offer different storage problems to grain; they have greater resistance to airflow and must be stored at lesser depth or else will cool more slowly than grain. Insects are rarely a problem with oilseeds but mites present a greater problem and the seed must be stored at lower moisture contents than grain.

Malting barley requires an altogether different strategy. It must be stored at high temperature for a time to break dormancy. The length of storage during this stage depends on temperature; the higher the temperature, the shorter the storage time. Obviously grain is very vulnerable to infestation during this time and it is desirable to design a strategy that allows minimum pest development during the warm phase and then cools quickly afterwards. Dormancy, once broken, is unlikely to be re-imposed by low temperature storage. An alternative strategy would use Desmarchelier's (1988) wet bulb temperature hypothesis. This states that insect development is linearly related to wet bulb temperature. When grain is dry, as is malting barley, a relatively high dry bulb temperature may relate to a low wet bulb temperature. For instance, grain at 9% m.c. and 27 °C (dry bulb) is at a wet bulb temperature of 14 °C, unsuitable for many grain store beetles. Thus a limited amount of cooling can achieve very effective control results.

Although the strategy is still under development, many aspects can be applied immediately. Most stores have aeration systems and the installation of automatic fan control systems should cut costs appreciably. Surface treatments applied at the start of storage, or when infestations are detected, using insect traps, should provide protection from mites, providing the grain is stored at or below 15%, m.c. and also protect from insects invading from nearby harbourages. This can be done at a fraction of the cost of admixing the entire bulk. These measures should ensure U.K. grain retains its reputation for low levels of infestation and low chemical residues.

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GLOSSARY OF TERMS

B.S.	British Standard
° C	Degrees Celsius
cfm/T	Cubic feet per minute per Ton
cu m/h	Cubic metres per hour
cu m/h/t	Cubic metres per hour per tonne
cm	Centimetres
df	Degrees of freedom
g	Gram
g/sq. m	Grams per square metre (insecticide application rate)
h	Hours
kg	Kilograms
kN/sq.m	Kilonewtons per square metre (pressure)
kW	Kilowatts
kWh	Kilowatt-hour (energy)
LD50	Lethal dose 50 (dose to achieve 50% mortality)
LD99	Lethal dose 99 (dose to achieve 99% mortality)
m	Metre (length)
mm	Millimetre (0.001m) (length)
m.c.	Moisture content
mg/kg	Milligrams/kilogram (chemical residue)
ml	Millilitre (0.001 litre)
p/kWh	Pence per kwh (energy cost)
p/t	Pence per tonne (cost)
p/t/h	Pence per tonne per hour (cost)
p>0.05	Probability less than 5%
r.h.	Relative humidity
s.e.	Standard error (measure of variation)
t	Tonne (1000 kg) (weight/mass)
v/v	Volume of fumigant per volume of fumigant mixture
W	Watts (0.001 kW) (power)

bait bags	Mesh traps to catch wandering insects
discriminating dose	A test pesticide dose, the survivors of which are deemed to be resistant
knockdown	An early effect of the pesticide- to immobilise the pest (an indication of efficacy)
pitfall trap	Trap designed to catch surface insects.
probe trap	Trap designed to catch insects within the bulk

<u>Cryptolestes</u> <u>ferrugineus</u> (Steph.)	Rust-red grain beetle
<u>Oryzaephilus</u> <u>surinamensis</u> L.	Saw-toothed grain beetle
<u>Sitophilus</u> <u>granarius</u> L.	Grain weevil

<u>Acarus</u> <u>siro</u> L.	Flour/grain mite
<u>Cheyletus</u> <u>eruditus</u> (Schrank)	No common name, a predator
<u>Glycyphagus</u> <u>destructor</u> (Schrank)	Grocers' itch mite