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DURATION OF CEREAL APHID POPULATIONS AND THE EFFECTS ON WHEAT YIELD AND QUALITY

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Summary The effects of three levels of field-caged populations of Sitobion avenae on winter wheat (cv. Maris Widgeon) were compared with control (uninfested) wheat. All populations began at G.S. 10.2 (Feekes Scale); they were removed by spraying with pirimicarb at G.S. 10.5.4., 11.1-11.2 and 11.2-11.3 respectively. Mean peak aphid units per ear (one unit = one adult or 4th instar aphid or 3 early instar aphids) were: 11, 28, and 57 respectively. All populations significantly affected mean weight per grain and grain sieving fraction composition. However, the longest infestation did not significantly further reduce yield compared with the second-longest infestation. The two longer treatments significantly reduced proportional and total flour yield and significantly darkened the flour compared with that from the control wheat.

The field cages markedly reduced wind speed and light intensity and raised the mean temperature slightly when compared with un-caged plots. However, although flag leaf area was significantly slightly greater, no grain metrics were significantly changed by the cages.

Résumé On faisait la comparaison entre le blé d'hiver (Maris Widgeon) qui avait éprouvé les effets de trois populations encagées de Sitobion avenae au point de vue de l'intensité, et le blé témoin (non-infesté). Toutes les populations commencaient a G.S. 10.2 (echelle de Feekes); on les éffacait en les passant au vaporisateur de pirimor respectivement à G.S. 10.5.4., 11.1-11.2 et 11.2-11.3. Les unités moyennes d'aphides par épi atteignaient respectivement un maximum de 11, 28 et 57 (une unité = un adulte ou un aphis au quatrième étage ou trois aphides d'un étage précoce). Toutes les populations influaient d'une manière significative le poids moyen par grain et la composition de chaque fraction vannée. Cependent la population la plus prolongée ne reduisait beaucoup davantage le rendement auprès de celle qui passait seconde au point de durée. Les deux populations les plus prolongées réduisaient considérablement le rendement proportionnel et total de farine et le foncaient considérablement en comparaison du blé temoin. Les cages abaissaient d'une facon marquée la velocité du vent et l'intensité lumineuse, et haussaient un peu la température moyenne en comparaison des terrains pas-encagés. Néanmoins, bien que la surface des feuilles I fusse un peu plus grande, les cages ne modifiaient aucune mesure de grain d'une manière significative.

INTRODUCTION

The English grain aphid (Sitobion avenae) has frequently been shown to reduce the yield of wheat, barley and oats in Europe (Vickerman and Wratten, 1979). Many studies have shown the efficacy of a single insecticide application in preventing or limiting yield losses (e.g. Kolbe, 1969 et seq., George, 1974) and experimental manipulation of aphid populations in field cages has also given information on yield reduction (e.g. Rautapää, 1966 et seq; Wratten, 1975; Wratten and Redhead, 1976). The contribution to yield loss of aphid infestations at varying stages during the crop's growth has received less attention although this type of information is important for rational aphid control. Qualitative changes in the grain and flour from aphid-infested wheat have also received little attention; percentage grain protein has been shown to be affected but this does not always change in parallel with yield losses (Wratten, 1975, 1978; Freier and Wetzel, 1976) and is only a crude measure of the flour's potential baking quality.

This paper presents results of experiments in field cages where the effects on wheat of three infestations of S.avenae of different durations were assessed. Five components of grain yield were measured together with grain germination percentage, percentage flour extraction and flour colour. (Chemical changes in the grain and flour were also recorded and these will be reported elsewhere) To help relate these field-cage results to open-field conditions effects of the cages on micro-environment, leaf area and senescence, and grain yield are also reported.

METHODS AND MATERIALS

All references to plant growth stage (G.S.) in this paper are those of Feekes (Large, 1954) followed, in parentheses, by those of Zadoks (Zadoks et al. 1974).

Field-Cage Experiments

In October 1977, seven plots of winter wheat (cv. Maris Widgeon), each measuring 20m x 2m x 2m, were sown (154 kg/ha) at the National Institute of Agricultural Botany Trial Grounds at the Hampshire College of Agriculture. (The cultivar Maris Widgeon was chosen because of its suitability for bread-making). On May 26, 1978, when the crop was at G.S. 4 (34), twelve cages were erected over the wheat, four cages on each of three of the seven plots. Each cage was 2m x 2m x 2m, constructed of steel scaffolding and covered with Tygan (1mm mesh). To remove any aphids already on the crop, each of the twelve caged areas was sprayed with one litre of pyrethrum (with piperonyl butoxide) at a dilution of 1%. During the first three weeks of June, nine of the cages (selected randomly) were infested with a clonal, virus-free, laboratory culture of S.avenae. This was done by introducing aphid-infested leaves and aphids in clip-on cages (Noble, 1958) to the leaves of the crop. The other three cages were left uninfested as controls.

In each cage, immediately following ear emergence, G.S. 10.5 (59), 50 main-stem ears bearing 19 or 20 spikelets were selected randomly and labelled. Once aphids had begun to colonize the plants, the clip-on cages were removed and the aphids on ears of labelled stems were counted twice per week. The aphids were classified into five categories: apterous (wingless) adults, alate (winged) adults, apteriform fourth instars, alatiform fourth instars and nymphal instars 1-3. Of the nine infested cages three were allocated randomly to each of three treatments and were sprayed with pirimicarb (21/cage at a dilution rate of 0.25g a.i. per 1) at the following growth stages:

Treatment 1 : Control, uninfested
Treatment 2 : G.S. 10.5.4 (71)
Treatment 3 : G.S. 11.1-11.2 (77)
Treatment 4 : G.S. 11.2-11.3 (85)

For the ear of each labelled stem on each counting date an aphid index was calculated by giving adults and fourth instars a value of 1 and earlier instars a value of $^1/3$. For each cage a cumulative index of infestation was computed as below:

Cumulative index of infestation = $\Sigma_{n=1}^{n=k-1}\left(\frac{t_n}{2} \cdot (x_n + x_{n+1})\right)$ aphid unit days where k is the number of occasions on which the aphids were counted; x_n, x_{n+1} are consecutive indices; t_n is the time, in days, between the consecutive indices x_n, x_{n+1}.

When the wheat was ripe, G.S. 11.4 (93), the labelled ears were harvested and dried at 40°C for three days. After drying, the ear weight, total grain weight, and grain number were recorded. All grain from the same ear was kept together as one sample. These samples were used for the following analyses:

Sieving Fraction Composition Between five and nine single ears were combined to produce a bulked sample. From each cage two replicate bulked samples were sieved for 30 s (amplitude: 2.5 cm, frequency: 217 min^{-1}) into the following fractions: <2.01 mm, 2.01 - 2.80 mm, 2.81 - 3.50 mm and >3.50 mm diam.

Germination Grain from each of the two sieved fractions 2.01 - 2.80 mm and 2.81 - 3.50 mm diam from each bulked sample (see above) was grown in 25 mm of Bedford Sand No. 21 (58% water-holding capacity). "Normal germination" was assessed in accordance with the method of the Official Seed Testing Station, Cambridge.

The quantity of grain obtained from labelled main-stem ears was insufficient for some tests (see below). For these, two samples per cage, each of 50 ears, were selected randomly at harvest. The following characteristics were then measured:

Milling Samples were milled into flour using a hybrid system comprising the roller-milling stages only of a small-scale laboratory milling/sifting device (Brabender Quadrumat) followed by a separate and more efficient sifting procedure. Flour yield, expressed as % extraction rate, was calculated from the weight of material passing a 195 µm-aperture sieve as a percentage of the total weight of all sieved fractions.

Flour Colour This was determined by measuring the reflectance of a flour/water slurry in a commercial instrument (Kent-Jones et al. 1956). The capacity of the optical cell was reduced by means of a suitable insert in order to deal with the limited amounts of samples available. Results are given in arbitrary units of Grade Colour Figure (GCF), higher values indicating increasing bran content of the flour sample.

Effects of Field Cages

From the erection of the cages until harvest ear weight, total grain weight, grain number and leaf senescence were recorded on six to ten randomly chosen main stems per plot. This was done for two of the control cages and for two aphid-free plots outside the cages. On July 11, when the crop was at G.S. 11.1 (75) the length and maximum width of both the flag leaf and leaf two were recorded for each of six main stems/plot or cage. The product of these two measurements (previously shown to be very highly correlated with leaf area) was calculated. These data supplemented recordings made in field cage experiments in 1977.

Microclimate components investigated were light intensity and temperature (in 1977) and wind speed (in 1978). Simultaneous light intensities inside and outside the cages were recorded both at ear level and at the height of the flag-leaf auricle. Temperatures inside and outside cages were recorded by thermographs. Wind-run recordings were taken simultaneously inside and outside cages; each recording was made at ear level and taken over a period of 30s. This procedure was carried out both for a cage sheltered by other cages and for one exposed to the wind.

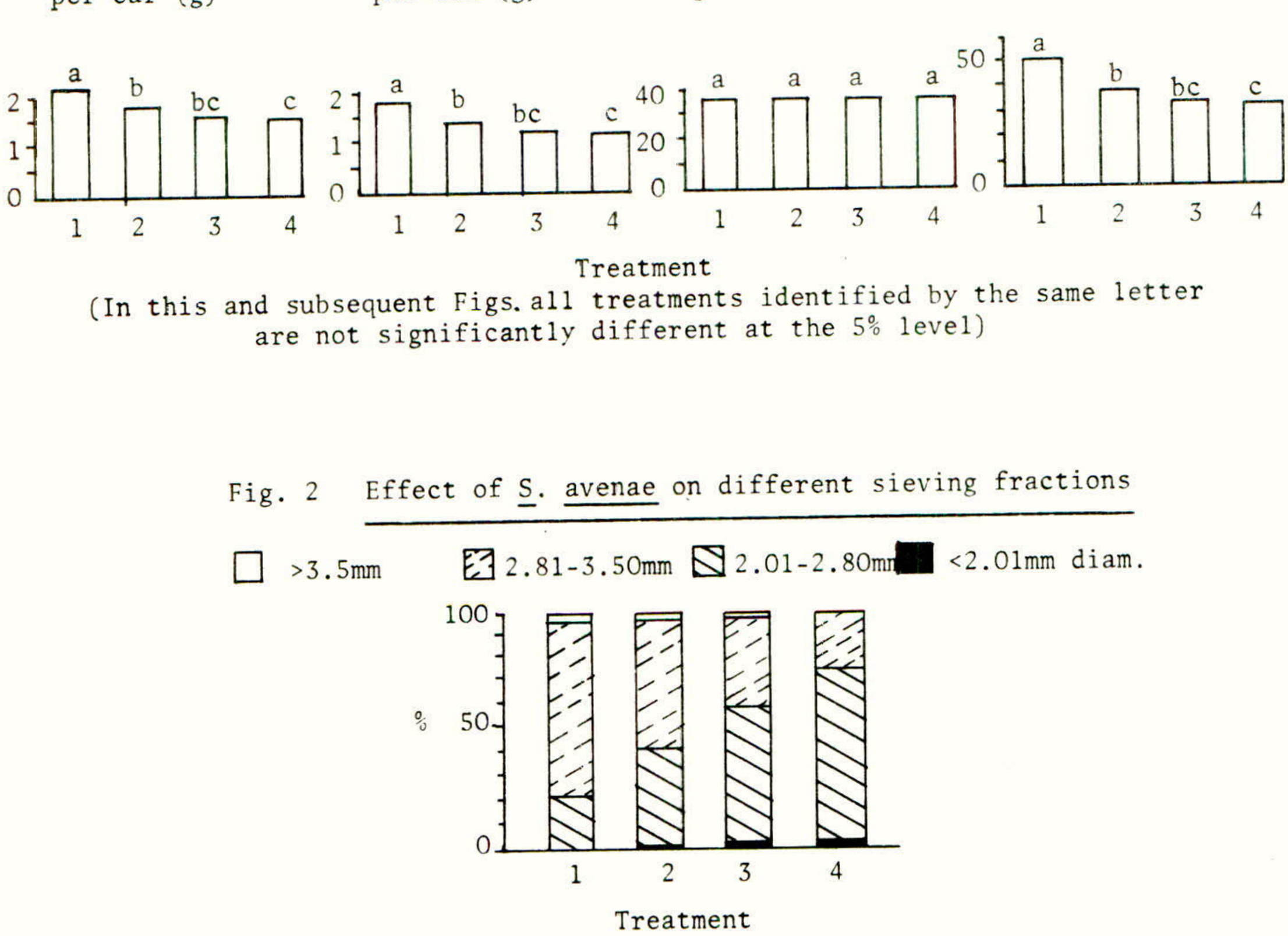
RESULTS

The mean number of aphid unit days and peak aphid index (in brackets) for treatments 2, 3 and 4 were: 43 (11), 306 (28) and 789 (57) respectively; corresponding mean weight per grain (mg) with percentage reduction from control in brackets was: 39.1 (23.8), 34.6 (32.6) and 32.2 (37.2). Control mean weight per grain was 51.3 mg. All infested treatments were significantly different from the control but treatment 3 did not differ significantly from treatments 2 or 4. This pattern was repeated for total ear weight and total grain weight per ear. Results of the analysis of variance (arc sin $\sqrt{p}$ transformation) are given in Fig. 1.

In all treatments more than 95% of sieved grain was in the two fractions 2.01 - 2.80 mm and 2.81 - 3.50 mm diam. but there was an increasing proportion in the smaller of these two fractions with increasing mean cumulative index of infestation (Fig. 2).

"Normal germination" was high in all treatments in each of the two fractions investigated. The rate varied from 92.8% to 99.7% and there were no significant differences between treatments.

Fig. 1 Effect of S. avenae on yield components

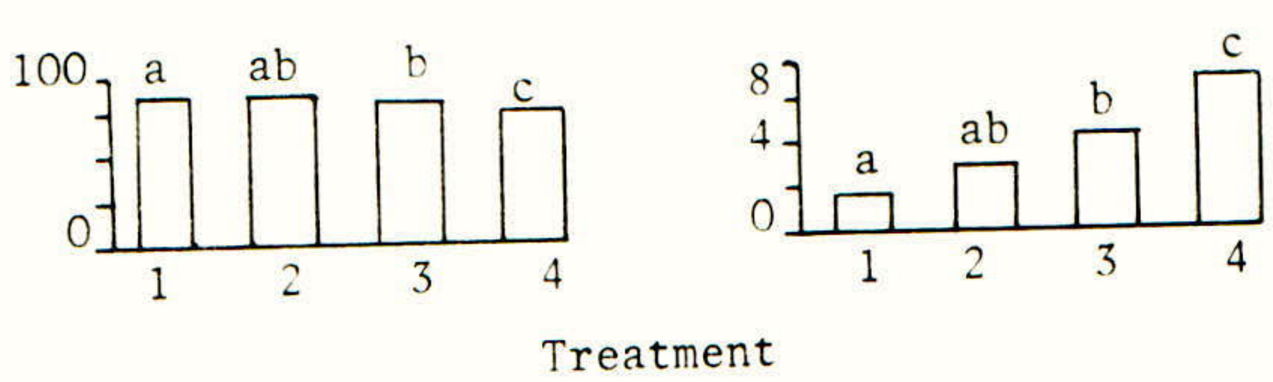


(In this and subsequent Figs. all treatments identified by the same letter are not significantly different at the 5% level)

Fig. 2 Effect of S. avenae on different sieving fractions

The percentage flour extraction from milling and sieving decreased from 68.1 in the control to 62.7 in treatment 4. Results of the analysis of variance are given in Fig. 3.

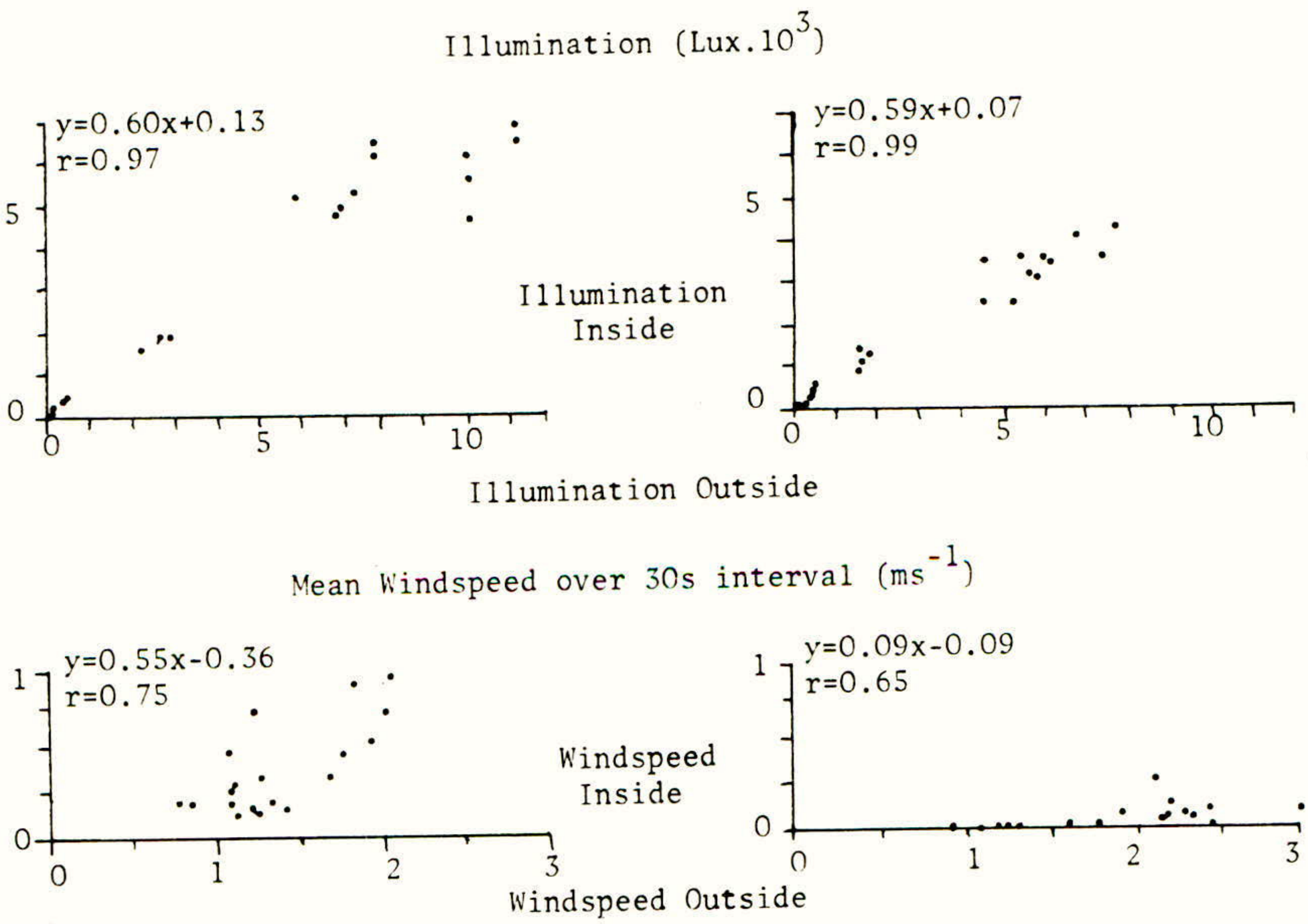
Fig. 3 Effect of S. avenae on flour extraction and colour



The mean percentage flour extraction was multiplied by the mean total grain wt/ear to give the mean total flour yields (g) per ear. These were: treatment 1 (Control): 1.29; treatment 2: 0.96; treatment 3: 0.84; treatment 4: 0.75. Flour from aphid-infested ears was darker than that from control ears: the darkness increased as the mean cumulative index of infestation increased (Fig. 3).

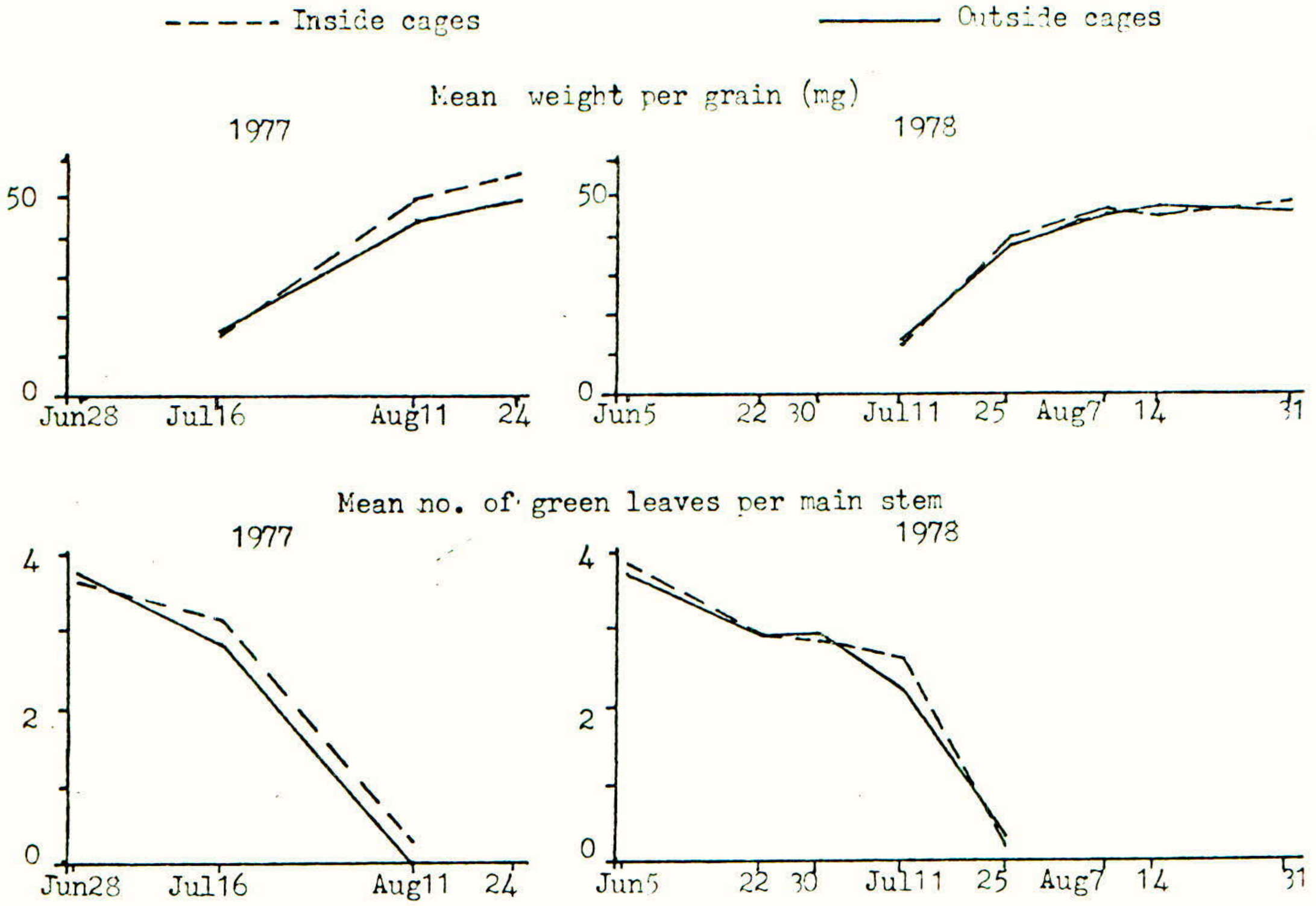
The field cages had a marked effect on all measured aspects of microclimate. They reduced illumination to 60% of that outside. Windspeed was reduced to 55% of that outside if the cage was unsheltered by other cages and was reduced to 9% if the cage was sheltered by others (Fig. 4). The temperature range was 3.1°C lower inside cages ($p < 0.001$) and the mean accumulated d°C/d was 2.1°C greater ($p < 0.01$).

Fig. 4 Effect of cages on illumination and windspeed



The cages had no significant effect, however, on total grain weight/ear nor on mean weight/grain. This was the case both during development of the grain and at harvest. Leaf senescence rate was similarly unaltered by the presence of cages (Fig. 5). Flag leaf area was greater inside the cages (34.8 cm^2) than outside (30.2 cm^2) ($p < 0.05$); the area of leaf two did not differ, however: inside, 38.5cm^2; outside, 39.7 cm^2 ($p > 0.05$).

Fig. 5 The effect of cages on plant growth



DISCUSSION

Although all three aphid-infested treatments significantly reduced yield (total grain weight per ear and mean weight per grain) with respect to control, the rate of yield reduction declined through the post-anthesis period. Feeding up to G.S. 10.5.4 (71) reduced mean weight per grain at a rate of 28.4 mg/100 aphid unit dayš. The rate for subsequent aphid-feeding in the periods G.S. 10.5.4 (71) to G.S. 11.1-11.2 (77) and G.S. 11.1-11.2 (77) to G.S. 11.2-11.3 (85) were, respectively, 1.7 mg/100 aphid unit days and 0.5 mg/100 aphid unit days. The mean weight per grain from treatment four did not significantly differ, in fact, from that of treatment three ($p > 0.05$). This was despite aphids having fed on the ears of treatment four for fourteen days longer than on those of treatment three and the cumulative index of infestation being 483 units greater. On the basis of this experiment, therefore, spraying with insecticide beyond G.S. 11.1 - 11.2 (77) does not increase yield significantly.

In contrast to mean weight per grain, the proportion of the grain which could be extracted as flour was significantly lower in treatment four compared with treatment three; flour colour, too, was significantly darker in treatment four. Consideration of all four treatments shows that the percentage extraction decreased

with each increase of mean cumulative index of infestation. Whereas flour colour is usually lighter (an improvement) when percentage extraction decreases, in this case it was darker. In all aphid-infested plots the flour colour had a GCF value greater than three, the upper limit normally accepted for bread-making flour.

In experiments of this type other factors potentially affecting yield cannot all be fully excluded. The large yield reduction in treatment two, for instance, could have been influenced by the handling of the ears during aphid counting and by the effects of soil compaction in visiting these cages. However, they were visited on three occasions only, so these factors seem unlikely to have been very important. No other pests were recorded in the field cages but this does not exclude the possibility that larvae of Diptera in the ears were killed by the pirimicarb spray. The role of the aphids' saliva in adding to the damage caused by sap removal could also have been involved but there is no information on these effects in S.avenae. Barley Yellow Dwarf Virus, on the other hand, did not contribute to yield loss. Aphids were collected from each cage and used to infect oat (cv. Blenda) plants in a growth room; no virus symptoms appeared during the subsequent seven weeks, after which the plants were discarded.

S.avenae on cereals in the U.K. in June and July 1978 were generally at a very low density; mean peak populations in Sussex, for instance, did not exceed three per ear (G.P. Vickerman, pers. comm.). The use of field cages makes work on such species possible in years of low numbers, but results have to be interpreted with care (Vickerman and Wratten, 1979). This experiment and others (Woodford, 1973) have shown that such enclosures markedly reduce light intensity and wind speed and change the temperature regime at crop level. The plants may have compensated, at least partly, for the reduced light in that they produced larger flag leaves. The wind reduction could have increased the CO_2 boundary layer resistance to photosynthesis (Austin and Jones, 1975), while the small temperature increase may have accelerated photosynthesis. The relative roles of these changes in crop environment in affecting the way in which the crop grew is unknown. Senescence rate was unaffected, however, and yield was unchanged relative to un-caged plots both in 1977 and 1978. In such cages, aphid populations can be readily established, probably because colonization is made easier by the reduced frequency of contact between tillers and leaves in the lower wind speeds. Other advantages of the cages are that experiments involving single-species, clonal, virus-free aphid populations can be carried out and population density and timing of development can be more easily manipulated than in the open field.

The results presented in this paper indicate that yield and quality can change differentially with respect to the duration of aphid-feeding. Thus, all three factors (i.e. yield, quality and duration) need to be considered in developing and implementing rational aphid control on wheat.

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CONTROL OF BARLEY YELLOW DWARF VIRUS WITH PERMETHRIN ON WINTER BARLEY IN FRANCE

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Summary Barley Yellow Dwarf Virus (BYDV) was recently recognised in France as a serious problem in early sown winter cereals. Yield losses up to 3.5 t/ha were reported. The use of permethrin was investigated for the control of the aphid vector of BYDV. Applied at the 2 - 3 leaf stage to crops at risk this insecticide gave persistent control of the bird cherry aphid (Rhopalosiphum padi), significant reduction in disease incidence, and up to 90% increase in yield. Factors contributing to the aphicidal activity of permethrin are discussed. The optimum rate of application of permethrin was 40g a.i./ha, based on the tentative conclusion that 5% crop yellowing will significantly reduce yield. Application at the 2 - 3 leaf stage, when aphids first appeared in the crop, was compared with treatment 7 - 8 days later. In no trial was yield decreased when treatment was delayed.

Resume Le virus de la jaunisse nanissante de 1'orge (V I N O) a été recémment reconnu en FRANCE comme un danger certain pour les céréales d'hiver semées précocement. Des pertes allant jusqu'à 35 q/ha ont été signalees. La Perméthrine, utilisée contre le puceron, principal vecteur de la J N O, a été mise en essai. Appliqué au stade 2 - 3 feuilles, dans les zones les plus exposées, cet insecticide a permis une lutte efficace avec suffisamment de rémanence, contre le Rhopalosiphum (R. padi), une réduction significative de l'incidence de la maladie et jusqu'à 90% d'augmentation de rendement. Les facteurs favorisant l'activité aphicide de la Perméthrine sont étudiés. La dose optimum de Perméthrine à appliquer est de 40g m.a./ha, dans la mesure ou les résultats suggèrent qu'à partir de 5% de jaunissement de la culture, le rendement est significativement réduit. L'application au stade 2 - 3 feuilles au tout début de l'apparition des pucerons dans la culture, a été comparee a une application 7 à 8 jours plus tard. Dans aucun des essais, le rendement n'a été affecte par un traitement retarde.

INTRODUCTION

Barley Yellow Dwarf Virus (BYDV) is a disease of cereals transmitted by aphids. In France, the full economic significance of this disease was not recognised until 1977, when Bayon and Ayrault (1977) recorded yield losses of 2 - 3.5t/ha on winter barley. BYDV is now considered endemic on early sown winter cereals in the west (Brittany, Poitou-Charentes), south-west (Toulouse) and north-east (Paris-Reims axis). During 1978 1.4 million hectares of winter barley were sown in France (Statistique du Ministere de l'Agriculture). This crop is normally the first winter cereal to be planted, and it is this early sowing that is at risk from BYDV. (Bayon and Ayrault, 1977).

The most important vector of the virus in autumn sown cereals is the bird cherry aphid (Rhopalosiphum padi) (Leclant, 1974; Lapierre and Moreau, 1974). This aphid is commonly found on maize and it is believed that the maturing and harvesting of this crop results in the migration of the aphid on to early sown winter cereals. Maize is known to be a reservoir of BYDV (Panayotou, 1977) and Moreau and Lapierre (1977) have demonstrated transmission by R. padi from maize to cereals.

BYDV is a persistent, circulative virus and a degree of control has been achieved by the use of insecticides, which kill the aphid vector (Smith, 1963; Plumb, 1973; A'Brook, 1974).

This paper describes field experiments carried out between 1977-1979 using permethrin, a photostable pyrethroid (Elliot et al, 1973), to control the aphid vectors of BYDV.

These trials were designed to :

i) demonstrate that disease incidence could be decreased and yield increased by applying permethrin (Experimental Series 1)

ii) define the optimum rate for permethrin application (Experimental Series 2)

iii) devise a recommendation for the timing of application (Experimental Series 3)

METHODS AND MATERIALS

In all trials permethrin was applied as a 25% w/v e.c.

The results presented are selected from a programme of fully replicated small plot trials on early sown winter barley.

Trials were located in regions where BYDV is endemic. All trials were attacked by aphids, and 9 out of 11 developed symptoms of BYDV. Disease incidence ranged from 7.5% to 68%.

Treatments in 500 l/ha were applied with a horizontal boom passed over the crop. This application was designed to simulate tractor application in normal farm practice. Treatments were applied at the 2 - 3 leaf stage and this coincided with the appearance of aphids in the trials described. In one series of trials an application at the 2 - 3 leaf stage was compared with an application delayed 7 - 8 days. Assessments of aphid control, per cent crop yellowing (visual assessment) and yield were made. A number of yield parameters were measured. In all trials the farmers' normal regime of fungicide treatments was applied throughout the season.

RESULTS

In all experiments R. padi was the predominant aphid species. In all tables the abbreviation DAT is used for days after treatment. Where figures are suffixed by the same letter (A,B,C,E) they are not significantly different at the 5% level.

(a) Experimental series 1.

The results presented in Table 1 and Table 2 are from a trial located in the Compiegne area (north-east), barley cv. Robur, sown on 4 October, 1977, treated on 29 October, 1977, at the 2-leaf stage.

Table 1

Control of R. padi

		pre-treatment		8 DAT		20 DAT	
treatment	rate g a.i./ha	% plants attacked	aphids/ plant	% plants attacked	aphids/ plant	% plants attacked	aphids/ plant
Dimethoate	400	34.3	1.1	9.6	0.2	21.9	0.5
Permethrin	50	30.9	1.0	0.6	0.01	0.1	0.01
Control	-	29.5	0.8	48.5	2.5	81.1	3.4

to

Aphid assessments were only made up/20 days after treatment. Permethrin gave better initial aphid control than the standard dimethoate and was more persistent.

Table 2

Per cent Barley Yellow Dwarf Virus Infection* and yield

treatment	rate g a.i./ha	% yellows 138 DAT	yield ears/metre	t/ha
Dimethoate	400	11.6 B	52.6 A	4.7 B
Permethrin	50	6.6 A	56.1 A	5.0 A
Control	-	51.6 C	28.9 B	3.3 C

*Visual assessment of percent of crop showing symptoms of yellowing.

A very severe attack of BYDV developed in this trial and both treatments gave a significant reduction in the level of disease producing significant yield increases over the control. Permethrin at 50g a.i./ha was significantly more effective than dimethoate, giving a yield increase of 53% over control.

(b) Experimental series 2

The results presented in Fig. 1 and Table 3 are from a trial located in Toulouse, barley cv. Thibault, sown on 12 October, 1978, treated on 15 November, 1978, at the 2-leaf stage.

Figure 1

Incidence of BYDV

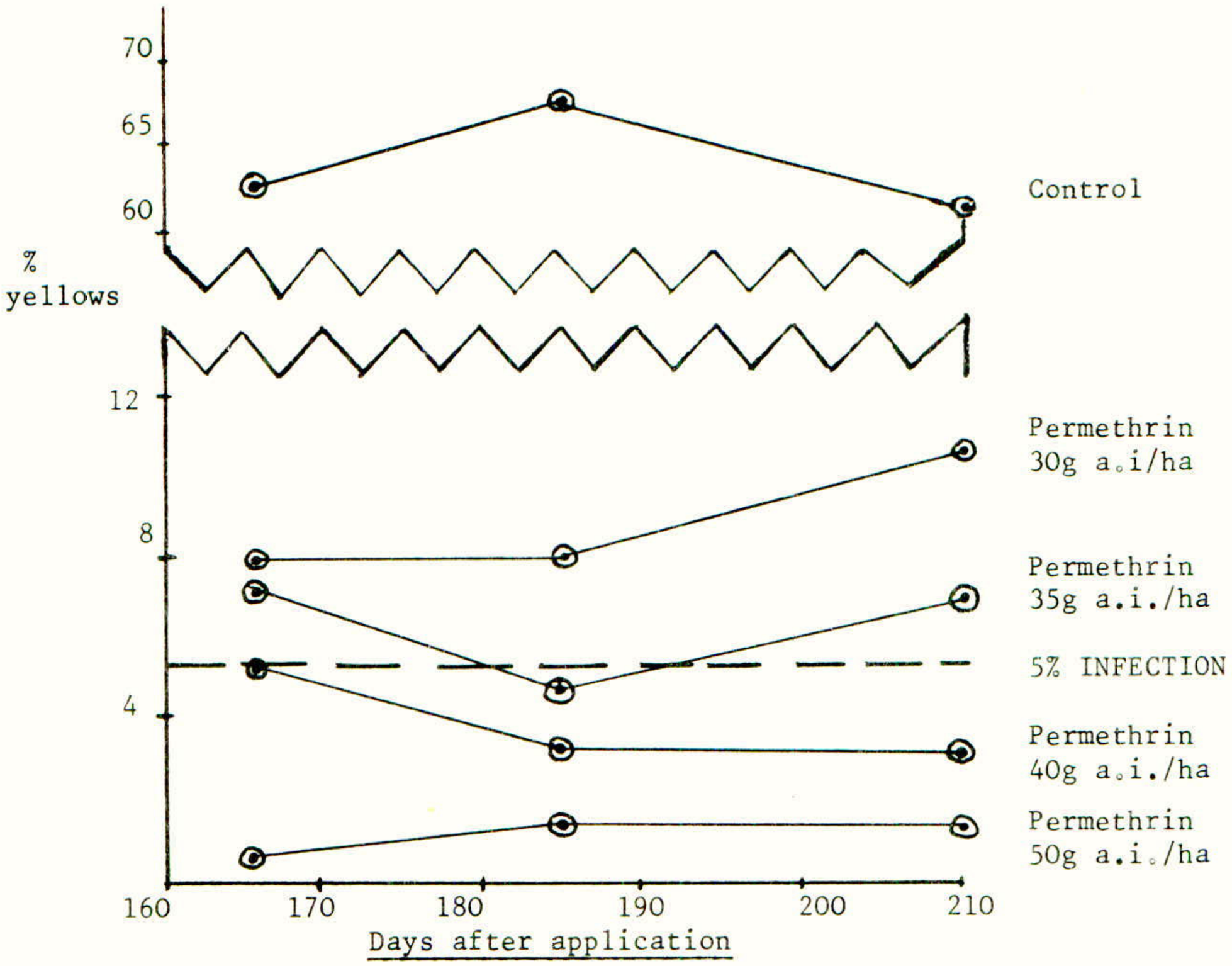

Table 3

Control of R. Padi and the yield response to a range of permethrin rates.

		pre-treatment		8 DAT		
treatment	rate g a.i./ha	% plants attacked	aphids/ plant	% plants attacked	aphids/ plant	yield t/ha
Control	-	53	0.9	16	0.4	2.5 C
Permethrin	30	46	0.9	1.3	0.01	4.1 B
	35	43.5	1.1	1.5	0.02	4.5 A
	40	50.5	1.5	0.5	0.005	4.6 A
	50	49	0.8	0	0	4.7 A

The aphid population collapsed after eight days and no further assessments were made. All permethrin treatments gave good aphid control, and a clear dose response relationship for both per cent yellowing (Fig. 1) and yield (Table 3) was established. The difference in disease level of 12.5% between permethrin 30g a.i./

ha and permethrin 50g a.i./ha at 18 days after treatment produced a significant difference in yield. A single application of permethrin at 50g a.i./ha gave a yield improvement over control of 90%.

(c) Experimental series 3

The results presented in Table 4 and Table 5 are from a trial located in Tours, barley cv, Robur, sown on 29 September, 1978, treated on 19/26 October, 1978, at the one to two leaf stage, and a trial located at Compiegne, barley cv, Ager, sown 20 September, 1977, treated 11/19 October, 1977, at the two-leaf stage.

Table 4

Development of the aphid population

	Tours			Compiegne		
aphids	pre-treatment	7DAT*	14DAT	pre-treatment	8DAT*	20DAT
Number of aphids/plant	0.6	0.8	1.0	0.2	0.1	0.2
% plants attacked	4.7	45	39	7.5	8.1	8.8

*i.e. after 2nd application date.

Table 5

Comparison of per cent yellowing and yield at two application dates.

treatment	rate	application date	location	% yellowing	yield t/ha
Control	-	-		15.8 B	5.7 B
Permethrin	40g a.i./ha	19 October '78	Tours	0.5 A	6.7 A
Permethrin	40g a.i./ha	26 October '78		2.2A	6.3 A
Control	-			61.6 E	4.1 C
Permethrin	50g a.i./ha	11 October '77	Compiegne	17.5 B	5.0 B
Permethrin	50g a.i./ha	19 October '77		0 A	5.8 A

With one exception, throughout this series of trials, there were no significant differences between treatment dates as illustrated by the Tours result. The exception was at Compiegne where a significant difference was found, although aphid numbers at this site were very low during the time they were recorded.

DISCUSSION

The objective of this research programme was to devise practical cost/effective recommendations for the use of permethrin to control BYDV in autumn sown cereals. The approach to this objective has been of necessity highly empirical, since most of the basic biological research has yet to be completed.

The first series of trials clearly showed that permethrin gave persistent control of bird cherry aphid (Table 1). Furthermore, control of this aphid at the 2-leaf stage reduced disease incidence and produced a large increase in yield over the controls (Table 2).

Although in direct contact tests in the laboratory permethrin has high intrinsic activity on aphids, in the field, where the insect is normally not exposed on the leaves, control with the compound has been poor due to its lack of fumigant and translaminar activity (Ruscoe, 1977). Thus the superiority of permethrin over the standard dimethoate was unexpected.

The good control achieved in these experiments can be explained by the following factors :-

i) R. padi on barley at the 2 - 3 leaf stage is exposed to direct contact with spray application.

ii) Permethrin has good persistence (Ruscoe, 1977), which may be needed to control R. padi migrating into the crop over a period of time.

iii) Permethrin has been shown to have a negative temperature coefficient, i.e. it is more toxic at lower temperatures for some insects. This may be important for treating autumn cereals. For example, Reims (close to Compiegne), had an average November temperature of 6.8°C in 1977 (Resume Mensuel du Temps en France).

iv) Permethrin has anti-feeding/repellant activity against a range of insect species (Ruscoe, 1977). These behavioural effects are likely to be significant in the control of aphids on barley, especially alate aphids migrating into the crop.

Experiments using a range of permethrin rates showed a dose response, both for disease level and yield. Clear guidelines on aphid thresholds for treatment and the disease level tolerable without yield loss are not yet available, and further research on a range of parameters (Plumb, 1977) is needed before they can be established. In our experience only low levels of aphid establishment at the two-leaf stage (Tables 3 and 4) and yellowing (Tables 2 and 5) can be tolerated. No clear definition of an aphid threshold was derived from these trials.

From the overall field programme it was tentatively concluded that 5% yellows is likely to produce significant yield losses, and with this criterion the optimum rate of permethrin is 40g a.i./ha (Fig. 1).

Trials to study the timing of application were aimed at preventing the infection of young barley plants (2 - 3 leaf) when they are most susceptible to disease (Watson and Mulligan, 1960). In no trial was there an increase in disease, or significant loss of yield, when treatment was delayed seven days after the first appearance of aphids. This would suggest that it is not the initial virus transmission that is critical but the in-crop aphid multiplication and consequent virus spread. On one trial (Table 5) a significant yield improvement was obtained

with a seven day delay in application. This might be explained by a later aphid migration into the crop, with the delayed application giving better control due to the higher level of insecticide residues remaining.

As a result of these trials, it was concluded that application should be made within seven days of any aphids appearing in the crop at the 2 - 3 leaf stage. It is possible that viruliferous aphids will migrate into barley later than the 2 - 3 leaf stage, and further research is required to establish the latest date at which permethrin treatment can usefully be made. However, our trials have shown that if permethrin is used as recommended on barley crops at risk, then significant yield improvements can be achieved.

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