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EFFECTS OF POLYPHAGOUS INVERTEBRATE PREDATORS ON CEREAL PESTS

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EFFECTS OF POLYPHAGOUS INVERTEBRATE PREDATORS ON CEREAL PESTS

by

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ABSTRACT

The objectives of this study were to examine the impact of polyphagous predatory invertebrates, notably Carabidae, Staphylinidae and Araneae, on cereal pests and to quantify this with respect to yield and quality. This was achieved by manipulating the density of these predatory groups under field conditions using exclusion techniques in wheat crops. The impact of the polyphagous predators was also compared within conventional and integrated farming systems utilising the experimental set-up at one of the sites which was part of the LINK Integrated Farming Systems Project. This large-scale project was started in 1992 to compare conventional and integrated farming through a five-course rotation of cereals and break crops. Beneficial insects were encouraged for pest control within the integrated regime and this study allowed this to be examined.

A reduction in the number of polyphagous predators by up to 80% led to a 31% increase in the number of aphids per tiller. A greater impact was found with higher aphid populations and when infestation occurred earlier in the crop's development. Carabidae and Staphylinidae were more active and abundant in May and June and would be expected to exert a greater effect on earlier infestations. In contrast Araneae were most active in July and may be more useful for controlling late aphid infestations, as found in the two years of this study. Polyphagous predators did not reduce the number of tillers infested and therefore when the recommended spray threshold was reached. Strong correlations were found between the activity/density and density of Carabidae, Staphylinidae and Araneae and cereal aphids in 1995 and to a lesser extent in 1996.

The maximum yield reduction where polyphagous predator activity and abundance was reduced was 0.37 t ha^{-1}. Aphids infesting the crop during grain filling had a negative effect on grain weight, hectolitre weight and protein although these effects varied with cultivar. For some cultivars and situations aphids also had a positive effect on thousand grain weight. However, when an insecticide was applied in 1995 at GS71 there was no increase in yield or quality compared to unsprayed areas.

Polyphagous predators were found to predate on orange wheat blossom midge before oviposition occurred in 1996 and they reduced the number of larvae per ear by an average of 1.5. Predation was greater following feeding when larvae vacated the grain and dropped to the soil to diapause. Where predators were reduced the soil populations were increased by 30% and 180% in 1995 and 1996 respectively. Mis-timed or inappropriate insecticide treatments for midge may reduce this level of predation and allow midge populations to increase in the soil.

Later drilled crops had higher aphid populations because they were infested at a relatively late growth stage and the crops remained susceptible for longer. For midge, sowing date determined the crop's suitability for oviposition. The earlier sown crops were more vulnerable in 1995 whereas the opposite occurred in 1996. Higher larval populations in the ear also resulted in a greater return to the soil.

Numbers of Staphylinidae and Araneae were sometimes greater in the IFS plots. The species composition and abundance varied considerably between fields. Low predator numbers had no effect on aphids, because when numbers were reduced further by the enclosures no increase in aphid numbers was detected. Greater measures would have to be taken to encourage beneficial invertebrates in an integrated farming system, but the results from this study indicate that this may be financially worthwhile.

1. INTRODUCTION

Two of the most recent pests to cause yield losses in wheat crops are the cereal aphids and the orange wheat blossom midge (OWBM), *Sitodiplosis mosellana* Géhin. Cereal aphids and OWBM may reduce cereal yields and grain quality (Oakley *et al.*, 1993, Oakley, 1994a). A range of invertebrate taxa may contribute towards control of these pests in cereal crops. The most studied are the polyphagous and stenophagous predators notably members of the Carabidae and Staphylinidae, and the parasitic Hymenoptera. Gut dissections (Sunderland, 1975) and ELISA tests have confirmed aphid feeding by a number of polyphagous species (Crook and Sunderland, 1984; Chiverton, 1987; Sopp, 1987) but provide no indication of their quantitative impact on pest populations. This has been addressed in a limited number of studies using predator exclusion/reduction. These experiments have shown that polyphagous predators can contribute to cereal aphid control. Where their numbers were experimentally reduced significant negative correlations were found between predator abundance and aphid density (Edwards *et al.*, 1979; Sunderland *et al.*, 1980; Chambers *et al.*, 1983; DeClerq and Pietraszko, 1983; Chiverton, 1986). However, the majority of these experiments were conducted with relatively low aphid infestation levels. More recent studies showed that an 85% reduction in ground dwelling predatory species had no effect on the aphid population, but this was attributed to the rapidity of the aphid population increase (Holland, Thomas & Hewitt, 1996a). If natural control of cereal pests is occurring it would also be expected that this would be reflected in a degree of yield or quality increase, however, this has never been investigated. Preliminary studies by Holland *et al.* (1996a) revealed a trend towards poorer grain quality from areas where polyphagous predator numbers had been reduced and thus aphid numbers were higher.

In 1993 and 1994 another cereal pest, the orange wheat blossom midge reached outbreak levels over large areas of UK cereal crops (Oakley, 1994a). This pest overwinters in the soil and adults emerge throughout June to lay their eggs on cereal ears, preferably wheat at susceptible growth stages. Larvae feed on the grain for 2-4 weeks before dropping to the ground (Walters, 1993). Polyphagous predators therefore have the opportunity to contribute towards control of this pest because there are a number of life-stages when they are vulnerable. Carabidae and Staphylinidae may feed on the larval stages in the soil (Speyer and Waede, 1956), on larvae when they pupate in the soil (Floate *et al.*, 1990) and on larvae in the crop and crop floor when they return to the soil after feeding in the ear (Basedow, 1973). Spiders may prey on the eggs and adults (Barnes, 1956) or larvae (Basedow, 1973). Research in Canada showed that fourteen carabid species were shown, using immunoelectro-osmophoresis, to have fed on *S. mosellana* larvae in the field (Floate *et al.*, 1990). Crepuscular movement of adult females from the ground surface to wheat ears may also make females vulnerable to predation by web-spinning linyphiid spiders whose webs are positioned on the ground or between wheat stems (Sunderland *et al.*, 1986). Many of these predatory species are, however, susceptible to broad-spectrum insecticides and their use may disrupt naturally occurring pest control leading to pest resurgence, secondary pest outbreaks or increased pest problems in following years. As a result of the outbreak of OWBM in 1993 the use of the broad-spectrum organophosphate insecticides chlorpyrifos and triazophos increased from 13.62 t in 1992 to 157.67 t in 1994, a 11-fold increase (Thomas, 1997).

The recent, considerable interest in Integrated Crop Management (ICM) in which control of pests by naturally occurring predatory or parasitic species is encouraged has revealed that little quantitative information is available on the potential of predatory species in arable ecosystems. There is no information on the density of predatory species which may be required to provide an acceptable level of pest control. Neither is there information on the importance of the different predatory groups. The latter is required if management practices are to be incorporated for their encouragement in ICM regimes. These questions need to be answered if farmers and advisors are to rely more on naturally occurring pest control in ICM.

In 1992 the LINK Integrated Farming Systems Project was set up to develop an integrated farming system (IFS) and to compare this with conventional farm practice (CFP) (Ogilvy *et al.*, 1994). This experimental set-up provided the opportunity to evaluate the effect of polyphagous predators on cereal pests within a conventional farming system and to make comparisons to an integrated system in which beneficial invertebrates are encouraged. A technique was adopted which involved setting up enclosures surrounded by polythene walls (exclusion barriers). These were used to reduce experimentally polyphagous predator numbers by preventing their ingress into the enclosures, whilst those already within the enclosures were trapped and removed. The subsequent effects of these predator population reductions on cereal aphids and midge populations and grain quality were determined in both farming systems and compared to adjacent non-enclosed areas.

1.1. OBJECTIVES

1. To evaluate the impact of polyphagous predators on cereal aphids and to determine the subsequent influence on cereal yield and quality.

2. To compare the quantitative and qualitative role of polyphagous predators within the IFS and CFP systems of the LINK IFS project.

3. To examine the extent to which polyphagous predators contribute to OWBM control.

2. METHODS

2.1. EXPERIMENTAL DESIGN

The experiment was conducted during 1995 and 1996 in north Hampshire in winter wheat fields which were part of the LINK IFS project based at this site. The fields were split or quartered and half the area managed using an integrated farming system (IFS) the other half using conventional farm practice (CFP). The input details for each plot are shown in Table 1. The main differences between the farming systems were that the integrated plots received less inputs of nitrogen and pesticides, and were often sown later than the conventional plots.

In 1995 four 5-ha plots in two separate fields sown with winter wheat were available. Within each field one plot was managed using an integrated farming system the other conventionally. In each of the plots five polyphagous predator reduction areas and five control areas were established, randomising their positions within each plot (Figure 1). The predator reduction areas consisted of an area (6 x 6 m) surrounded by a polythene enclosure (60 cm high, buried 30 cm). These were erected between the tramlines in February thus creating an area from which polyphagous predators could be excluded whilst existing predators within the areas were trapped out using pitfall traps. Control areas (6 x 6 m) were marked out using flexicanes.

In 1996 three fields were available; two split in half and one quartered, providing a total of four IFS and four CFP plots. In each of the plots two polyphagous predator reduction areas and two control areas were established, randomising their positions within each plot (Figure 2).

2.2. PREDATOR REDUCTION

The polythene enclosures were used to exclude ground active invertebrates. To remove existing invertebrates and those which subsequently flew into the enclosures 13 pitfall traps in 1995 and 16 pitfall traps in 1996, containing 4% formalin solution and detergent were positioned within each enclosed area. The traps remained open for the duration of the experiment and were emptied fortnightly. Plastic edging was positioned vertically over two rows pitfall traps to improve their capture efficiency. Wheat plants within 0.5 m of the exterior edge of the polythene were removed to prevent invertebrates from climbing into enclosures.

2.3. CEREAL APHID MONITORING

In each year twenty tillers were randomly selected within each enclosed and control areas and marked using coloured tape below the ear once this emerged. The number and species of adults, nymphs and mummified aphids on the ear and flag leaf were recorded twice per week for the main aphid infestation period. The crop growth stage was recorded on each occasion. From this information the total mean number of aphids per tiller, size of the aphid peak and the number of days taken to reach the peak was calculated. To obtain an indication of aphid loading the number of aphid days was calculated by multiplying the number of adults and nymphs on each sampling occasion by the number of days between the previous and following sample date divided by two. To estimate whether the rate of population increase differed between plots and treatments the regression was calculated for the rate of population growth (log x+1) to the peak for each marked tiller. These were calculated for the number of aphids on the ear and flag leaf. This data was analysed using split plot Analysis of Variance (ANOVA) in which the two farming systems and the enclosed and control areas (treatments) were compared.

Whether the percentage of tillers infested differed between the farming systems and treatments was determined by calculating the proportion of ears infested for each control and enclosed area for each sample date. The data was transformed (arc sine $\sqrt{\%/100}$) and analysed using repeated measures ANOVA. The analysis was repeated for the mean number of aphids per tiller.

The total number of aphid mummies per 20 tillers on the ear and flag leaf were compared between the farming systems and treatments using split plot ANOVA.

2.4. ORANGE WHEAT BLOSSOM MIDGE MONITORING

The number of OWBM pupae in the soil was estimated from soil cores once the enclosed and control areas had been established and immediately prior to harvest to determine the effect of predation. Twelve cores (0.15 x 0.025 m) were taken from each enclosed and control area within each plot. These were bulked to provide a sample for the enclosed and control treatments from each farming system for each field. Samples were analysed by the ADAS Plant Diagnostic Unit.

OWBM adults were counted in the Dvac samples to obtain an estimate of emergence time and density. In addition during 1996 cylindrical clear acetate sticky traps were also used to obtain an indication of time of emergence. Previous studies (unpublished) established that this trap design was the most efficient for capturing adult midge. One trap per week was placed level with the top of the crop in each enclosed and control area and left for four days.

The number of OWBM larvae per ear and number of grains infested per ear was recorded at GS83 (Tottman, 1987) on 20 ears in each enclosed and control area within each plot and compared using split plot ANOVA.

2.5. GRAIN YIELD AND QUALITY

To obtain an estimate of yield the grain from 10 x 0.096 m^2 quadrats was collected in each area. The dry weight of grain from the 20 marked tillers was also compared. Samples of grain were analysed for hectolitre weight, thousand grain weight (TGW), Hagberg falling number (HFN), and percentage grain protein and screenings. The yield and quality factors were compared for the farming systems and treatments using split plot ANOVA. For each cultivar the relationship between the mean number of aphids per marked tiller and the grain dry weight (transformed log x+1), weight of grain @14% moisture from the quadrats (transformed log x+1) and each quality parameter was calculated.

2.6. PREDATOR MONITORING

2.6.1. *Pitfall trap sampling*

To obtain an estimate of predator activity within the enclosures the invertebrates captured in a five day sampling period, in two pitfall traps located 4 m apart within the enclosed area were removed and stored in 70% alcohol. Invertebrate activity in the control area was monitored using two pitfall traps positioned 4 m apart. The sampling was repeated at intervals which covered the aphid infestation period in each year. Carabidae (ground beetles), Staphylinidae (rove beetles) and Araneae (spiders) were identified to species or genera. To determine whether there was a difference in predator activity between the farming systems and between enclosed and control areas the total number of Carabidae caught in the two pitfall traps were compared using split plot ANOVA. The analysis was repeated for Staphylinidae and Araneae.

2.6.2. *Fenced pitfall trap sampling*

Fenced pitfall traps were used to obtain an estimate of invertebrate density within each enclosed and control areas. Each fenced pitfall consisted of a wooden box (0.5 x 0.5 m) and 0.2 m high with a muslin lid. The boxes were placed over a pre-positioned pitfall trap containing 4% formalin and detergent for two weeks, thereby capturing any active invertebrates within the box confines. One fenced pitfall trap was placed within each area and sampling was repeated at monthly intervals the start coinciding with the start of the standard pitfall trap sampling regime. The total number of Carabidae, Staphylinidae and Araneae captured was analysed as above.

Only one trapping session was carried out in 1996 because hard ground conditions prevented the traps from being reliably established.

2.6.3. *Dvac suction sampling*

To obtain an estimate of some of the smaller predatory Carabidae, Staphylinidae, Araneae and cereal parasitoid densities one suction sample consisting of ten (total area sampled = 0.92 m^2), five second sucks, were taken from each area using a Dietrick (D-vac) suction sampler, at monthly intervals during 1995 and weekly intervals during 1996, from the start of recording aphid numbers. The total number of Carabidae, Staphylinidae and Araneae was analysed using the split plot ANOVA.

2.6.4. *Effect of predators on aphids*

To examine the impact of the different predatory groups on aphids, stepwise multiple regressions were carried out relating the total number of aphid days to the total numbers of each of the main predatory groups (Carabidae, Staphylinidae and Araneae). The analysis was repeated replacing the total number of aphids with the the aphid population peak. Separate analyses were carried out for the data from the pitfall traps, Dvac samples and fenced pitfall traps. All data were log transformed.

3. RESULTS

3.1. CEREAL APHIDS IN 1995

Cereal aphids were at very low densities in the experimental fields until early June when winged immigrants arrived. The predominant species was *Sitobion avenae* F. (grain aphid) which was found on the ear, few aphids were found on the flag leaf. Aphid populations exceeded ADAS thresholds (>66% of ears infested between GS61 and 73) in late June when the crop was at GS71-73 (Figs.3a & b). At the threshold there were between 6 and 13 aphids per tiller depending on the farming system and treatment (Figs. 4a & b).

The percentage of ears infested continued to increase after they reached the spray threshold and reached 100% in plot 1 (IFS) and 90% in plots 2 (CFP), 3 (CFP) and 4 (IFS). However, the number of aphids per tiller only increased after the spray threshold has been exceeded in both areas of plots 1 and 3 and the exclusion area of plot 4 (Figs. 4a and b). The percentage of tillers infested did not differ significantly between the farming systems or enclosed and control areas (treatments). As expected the percentage of tillers infested varied significantly over time ($F_{9,162}$=193, P<0.001) and there was an significant interaction effect between time and farming system ($F_{9,162}$=10.2, P<0.001). The later was significant for six of the 10 sample dates. From Figure 5a it can be seen that the percentage of tillers infested was lower initially in the IFS plots but reached a higher proportion later. The mean number of aphids per tiller differed significantly over time ($F_{9,162}$=39.8, P<0.001) and between the treatments ($F_{1,18}$=6.8, $P<0.05$) with a interaction effect between the two ($F_{9,162}$=2.3, $P<0.05$). There were less aphids in the enclosed areas with the greatest difference occurring in the IFS plots (Fig. 5b).

For all the aphid parameters measured there were no significant differences between the two farming systems and neither was there an interaction effect. There were significant differences between the enclosed and control areas for the total number of aphids on the ear and flag leaves ($F_{1,18}$=7.2, $P<0.05$), number of aphid days ($F_{1,18}$=6.9, $P<0.05$), and rate of increase to peak ($F_{1,18}$=4.6, $P<0.05$) (Table 2). More aphids and consequently a higher number of aphid infestation days were found for the enclosed compared to control areas (Table 2). The greatest difference between the control and enclosed areas occurred in plot 1 when the total number of aphids was 31% higher in the enclosed area. In the other plots the increases were 8, 21 and 15% for plots 2, 3 and 4 respectively (Figures 4a & b). The rate of increase was faster in the enclosed area. The number of aphids per tiller at the population peak was higher in the enclosed areas for both farming systems (Fig. 5b).

The number of eclosed aphid mummies on the ears did not differ significantly between the control and enclosed areas or between the farming systems (Table 2).

3.2. ORANGE WHEAT BLOSSOM MIDGE IN 1995

The number of OWBM captured using the emergence traps was similar in the four plots (16-20 $m^{2)}$.

The number of OWBM per ear ($F_{1,18}$=11.0, $P<0.01$), number of grains infested per ear ($F_{1,18}$=8.5, $P<0.01$) and percentage of ears infested ($F_{1,18}$=24.7, $P<0.001$) differed significantly between the two farming systems (Table 3). These were all greater for those plots managed conventionally. No differences were found between the enclosed and control areas and there was no interaction effect.

There was no difference in the number of OWBM in the soil between the farming systems or control and enclosed areas in early spring. In July after the OWBM had fed on the ear and returned to the soil numbers differed significantly between the farming systems ($F_{1,2}$=442, $P<0.001$) with almost four times as many in the plots managed conventionally compared to those managed using the integrated system (Table 3). There were more in the enclosed compared to the control areas especially in the CFP plots but the difference was not significant.

There was a strong correlation between the number of midge per ear and percentage of ears infested (r^2=0.58, $F_{1,38}$=52, $P<0.001$, $y=19.6(x)+30.6$) (Fig. 6). At 100% of ears infested there would be 3.5 larvae per ear.

3.3. GRAIN YIELD AND QUALITY IN 1995

3.3.1. *Effect of treatment and farming system*

The type of farming system only had a significant effect ($F_{1,18}$=23.8,P<0.001)on grain protein which was lower for the integrated system (Table 4). No yield or quality parameters differed between the enclosed and control areas.

3.3.2. *Effect of aphids on yield and quality*

For field 1, cv. Tonic and field 2, cv. Spark there was no significant relationship between total number of aphids and grain dry weight of the marked tillers (transformed log x+1) (Figs. 7a and b). No relationship was detected between the total number of aphids and weight of grain from the each area as measured using the quadrat samples (Figs. 8a and b). For Tonic there was a negative relationship between the total number of aphids and mean grain dry weight (r^2=0.38, P<0.001) (Fig. 9a) and hectolitre weight (r^2=0.38, P<0.) (Fig. 9b). Similarly the aphid population at the peak had the same effect for mean grain dry weight (r^2=0.37, P<0.01) and with hectolitre weight (r^2=0.28, P<0.05) (Figs. 10a and 10b). For Spark the number of aphids had a positive influence on hectolitre weight (r^2=0.31, P<0.05, y=6.09x+71.5) No other quality parameters were effected.

There was only one significant relationship between the number of OWBM larvae per ear and a quality parameter; for cv. Spark protein levels were positively correlated (r^2=0.35, F=9.9, P<0.01, y=2.09x+9.46). Although aphids alone had no effect on protein, there was a positive relationship when combined with the number of midge larvae per ear using multiple regression (r^2=0.52, F=9.2, P<0.01, beta=0.62 for aphids and 0.41 for midge).

The quality of grain from the sprayed areas of plots 2 and 3 was not improved compared to the control areas which remained unsprayed (Table 4).

3.4. POLYPHAGOUS PREDATORS IN 1995

3.4.1. *Pitfall trap sampling*

a. Effect of enclosures and plot

The pitfall traps monitored the activity of polyphagous predators, notably Carabidae, Staphylinidae and Araneae of which Linyphiidae (money spiders) are the most frequently captured. The combination of exclusion barrier and pitfall traps was successful in reducing the numbers of predators, so allowing their effect on the aphids to be quantified.

The number of Carabidae captured in the pitfall traps only differed significantly between the between the enclosed and control areas ($F_{1,18}$=113, P<0.001). Overall there were 88% fewer Carabidae captured in the enclosed compared to the control areas (Fig. 11). The numbers and species composition also differed between individual plots. The numbers of Carabidae differed to some extent betwen individual plots. In plots 1 and 2 numbers declined after the second sample date. This was because in the first two samples the predominant species was *Bembidion lampros* which is most active in early summer. In the latter two samples in these plots *Harpalus* species were the most active. In plots 3 and 4 the activity of Carabidae remained relatively constant because the predominant species was *Pterostichus melanarius* which is active from mid to late summer.

The activity of Staphylinidae also differed significantly ($F_{1,18}=27.9$, $P<0.001$) between the treatments. There were 43% fewer captured in the enclosed compared to the control areas (Fig. 12). Their activity was more evenly distributed between the plots. The predominant taxa in all of the sample dates were the Aleocharinae and *Tachyporus* species, both of which fly readily and would not be excluded by the enclosures. *Anotylus* spp. were frequently caught on the second date. Because of their high mobility the difference between the treatments was attributed to the trapping out rather than the effect of the barriers.

The Araneae also differed significantly between the treatments ($F_{1,18}=371$, $P<0.001$) and between the farming systems ($F_{1,18}=6.1$, $P<0.05$). Overall there was a 74% reduction of Araneae activity in the enclosed compared to the control areas. The activity increased with each sampling period (Fig. 13). Overall this group was the most active with up to 120 individuals captured per pair of pitfall traps in the final sample. *Erigone* was the predominant genus, with *Oedothorax* also appearing in the last two samples. Lycosidae were also active in the second and fourth samples.

b. Effect of predators on aphids

The stepwise multiple regression analysis indicated that only the total number of Carabidae were significantly related to the number of aphids and the aphid peak (Figs. 14a & b).

3.4.2. *Fenced pitfall trap sampling*

The fenced pitfall traps measured the absolute density of polyphagous predators. The most frequently caught species in these traps closely reflected those captured in the standard pitfall traps.

The Carabidae only differed in their density between the treatments ($F_{1,18}=12.2$, $P<0.01$). Their numbers were reduced by 67% in the enclosures (Fig. 15). Some differences occurred between the plots. Carabidae were at their most abundant in the CFP plots during May, but peaked in June in the IFS plots. On the April and May sample dates *Bembidion* spp. particularly *B. lampros* were the most abundant taxa. In the May and June samples *H. rufipes* were the most numerous especially in plots 1 and 2. *P. melanarius* was the most abundant species in plots 3 and 4 in the June sample.

Staphylinidae only differed significantly between the farming systems ($F_{1,18}=7.4$, $P<0.05$) with more in the integrated plots. Numbers in the enclosures were similar to those in the control areas (Fig. 16) and was because of their high mobility. The most abundant species were the same as those captured in the standard pitfall traps. They were most abundant in the May sample.

The Araneae differed in their density between the treatments ($F_{1,18}=71.7$, $P<0.001$) and the there was an interaction effect between farming system and treatment ($F_{1,18}=9.4$, $P<0.01$). Overall their abundance was reduced by 61% in the enclosures. Araneae preferred the conventional control plots (Fig. 17), possibly because of the denser crop structure. Few

Araneae were found in the April sample with only 1.6-2.4 m^2 but increased up to 9.5 m^2 in the June sample when they comprised mainly of *Erigone* and *Oedothorax* species.

b. Effect of predators on aphids

The total number of Araneae was correlated with the number of aphids and the population peak (Figs. 18a & b).

3.4.3. *Dvac suction sampling*

The Dvac samples provided another estimate of polyphagous predator densities but proved to under estimate drastically the density of Carabidae species compared to the fenced pitfalls.

The analysis revealed that the Carabidae did not differ significantly between the treatments or farming systems, but very few were captured, less than 1 m^2 . Their numbers peaked in May (Fig. 19) as found with the other two sampling methods. Only small species were captured, notably *Bembidion* spp. and *Trechus quadristriatus.*

The abundance of Staphylinidae differed significantly between the farming systems ($F_{1,18}$=24.0, P<0.001) and treatments ($F_{1,18}$=6.7, P<0.001). There with 25% less in the enclosed areas and fewer in the conventionally managed plots (Fig. 20). *T. hypnorum* was the most abundant species in the April and May samples, whilst the Aleocharinae predominated in the May and June samples. *Anotylus* spp. were again numerous in the May sample only.

The density of Araneae also differed significantly between the farming systems ($F_{1,18}$=4.4, P<0.05) and treatments ($F_{1,18}$=8.7, P<0.01). There was a 21% reduction in the enclosed areas (Fig. 21). Their numbers were very low in April and peaked in May when numerous immatures were found. The density of spiders estimated using this method was higher compared to the fenced pitfalls because immature spiders were collected unlike for the fenced pitfalls.

b. Effect of predators on aphids

As found for the fenced pitfall trap sampling the total number of Araneae was related to the number of aphids and the population peak (Figs. 22 a & b).

3.5. CEREAL APHIDS IN 1996

Cereal aphids were as in 1995, at very low densities in the experimental fields until mid June when winged immigrants arrived. The predominant species was *S. avenae* (grain aphid) which was found on the ear, few aphids were found on the flag leaf. Aphid populations exceeded ADAS thresholds (>66% of ears infested) on the 16 July at GS77 in plots 1 (CFP) and 2 (IFS) and on the 19 July at GS81 in the CFP plots 3, 4 and 8 (Figs. 23a-d) when the crop was at GS77-81. The threshold was not reached in IFS plots (5,6 and 7). The percentage of ears infested continued to increase after they reached the spray threshold in the CFP plots and reached 100% in plot 2 and 80-90% in plots 1, 3, 4 and 8 (Figs. 23a-d). At the threshold there were overall less than 5 aphids per tiller (Figs. 24a-d).

The percentage of tillers infested did not differ significantly between the farming systems or enclosed and control areas. As expected the percentage of tillers infested varied significantly over time ($F_{12,168}=71.9$, $P<0.001$) and there was an significant interaction effect between time and farming system ($F_{12,168}=3.2$, $P<0.001$). A higher proportion of tillers were infested at the later dates in the CFP plots (Fig. 25a). A significant three way interaction was also found between farming system, area and time ($F_{12,168}=2.4$, $P<0.01$). The number of aphids per tiller only differed significantly with time ($F_{12,168}=15.4$, $P<0.001$) (Fig. 25b).

Aphid numbers, their population peak or growth rate were unaffected by the type of farming system and there were no significant differences between the enclosed and control areas (Table 5). There were some differences in aphid numbers between plots with more aphids in plot 2 (IFS) which was sown later than the other plots and it was only in this plot that the enclosures increased aphid numbers (by 28%). The aphid populations developed slowly taking on average 36 days to reach their peak from the start of monitoring. The longest period was taken in plot 7 (42 days) and the shortest in plot 1 (33 days). The aphid population peak was highest in plot 1. The peak was considerably higher in the enclosed area of plot 2 (25 aphids/ear) compared to the an overall peak of *ca.* 9 for the other plots.

The number of eclosed aphid mummies on the ears did not differ significantly between the control and enclosed areas or between the farming systems (Table 5). Numbers of parasitised aphids remained relatively low throughout the summer but were higher in plots 1 and 2 where aphid numbers were greatest.

3.6. ORANGE WHEAT BLOSSOM MIDGE IN 1996

Midge were most abundant in the Dvac samples on June 19 when the crop was at GS67 (Fig. 26a) whereas they appeared to peak according to the sticky traps on July 5 at GS73 (Fig. 26b). However, because sampling was only carried out intermittently both methods may have missed other peak emergence periods. The difference between the two methods may have occurred because the Dvac suction samples only measure numbers at one time period whereas the sticky traps were operating for four days on each sampling occasion. There were no significant differences between the number of midge captured between the two farming systems or treatments using the two methods.

The number of OWBM per ear, the number of grains infested per ear and the percentage of ears infested did not differ significantly between the farming systems or between treatments (Table 6). There were more larvae per ear in plots 1 and 2, the second wheat crops. Although the number of larvae did not differ significantly between the enclosed and control areas there were 1.5 more larvae per ear in the enclosed areas of plots 1 and 2, a trend which was repeated to a lesser extent for plots 3-8. Approximately twice as many grains per ear were infested in the control areas of plots 3-7. Overall *ca.* one larvae per grain was found. A greater percentage of ears were infested in plots 1 and 2.

There was no difference in the number of OWBM in the soil between the plots or control and enclosed areas in early spring (Table 6). In July after the OWBM had fed on the ear and returned to the soil numbers although not significantly different there were always more in the enclosed compared to the control areas and more were found in the CFP plots.

There was a strong correlation between the number of midge per ear and percentage of ears infested ($r^2=0.79$, $F_{1,30}=109$, $P<0.001$) (Fig. 26c). At 100% of ears infested there would be 3.7 larvae per ear which was similar to the value of 3.5 found for 1995.

3.7. GRAIN YIELD AND QUALITY IN 1996

3.7.1. *Effect of treatment and farming system*

The type of farming system and treatment had no significant effect on yield or quality. There were differences between the yield and quality of grain from the second wheat cv. Spark and the two fields of first wheats cv. Ritmo. Protein was higher for Spark, compared to Ritmo (Table 7). For Ritmo protein was 1.5% higher in the CFP compared to the IFS plots in field 2. Thousand grain weight was much lower from the plots containing Spark.

3.7.2. *Effect of aphids on yield and quality*

The total number of aphids (transformed log x+1) on the marked tillers had no effect on the grain dry weight for cv. Spark or cv. Ritmo (Figs. 27a and b). Only for Ritmo was the weight of grain from the quadrats significantly related with the total number of aphids (transformed log x+1) (Figs. 28a and b). For Spark the total number of aphids had a significant negative effect on hectolitre weight (r^2=0.91, P<0.001) (Fig. 29a) and protein (r^2=0.73, P<0.01) (Fig. 29b). Similarly correlations were found between the number of aphids at the peak with hectolitre weight (r^2=0.85, P<0.01) (Fig. 30a) and protein (r^2=0.61, P<0.05) (Fig. 30b). With Ritmo the total number of aphids only had a significant negative effect on hectolitre weight (r^2=0.33, P<0.003) (Fig. 31). However, there were some significant positive effects of aphids on quality parameters for Ritmo. These were for mean dry weight of the marked tillers (r^2=0.30, P<0.006) (Fig. 32a) and TGW (r^2=0.30, P<0.006) (Fig. 32b). The aphid peak for Ritmo only had a positive effect on TGW (r^2=0.39, P<0.001) (Fig. 32c).

Number of OWBM larvae per ear was not related to any of the yield or quality parameters.

3.8. POLYPHAGOUS PREDATORS IN 1996

3.8.1. *Pitfall trap sampling*

a. Effect of treatment and farming system.

The total number of Carabidae captured in the pitfall traps differed significantly between the treatments ($F_{1,14}$=90.2, P<0.001). Overall there were 61% fewer Carabidae captured in the enclosed compared to the control areas, although the difference was sometimes more or less depending on the plot and time of sampling (Fig. 33). In the first two samples the predominant species in most plots were *Bembidion lampros* and *B. obtusum* which are most active in early summer. From the third sample onwards the predominant species in plots 1 and 2 was *Pterostichus melanarius* which is active from mid to late summer. In plots 3-8, *Trechus quadristriatus* was the only abundant species and because the activity of this species declines earlier in the summer than *P. melanarius* the total catch also declined considerably in the last two July samples. In contrast to plots 1 and 2 the aphid population in plots 3-8 continued to build throughout July.

The activity of Staphylinidae was not significantly different between the treatments although 15% fewer were captured in the enclosed compared to the control areas (Fig. 34). Numbers differed significantly ($F_{1,14}$=4.9, P<0.05) between the farming systems with more being captured in the integrated plots. The predominant taxa in all of the sample dates were *Tachyporus* species and occasionally peaks occurred in individual plots because it could not be excluded by the enclosures.

The Araneae differed significantly between the treatments ($F_{1,14}$=103.8, P<0.001). Overall there was a 56% reduction in Araneae activity/density in the enclosed compared to the control areas (Fig. 35). The activity increased with each sampling period. *Erigone* was the predominant genus, with *Oedothorax* also appearing in the last two samples. The activity period of Linyphiidae was the most closely correlated with the aphid populations.

b. Effect of predators on aphids

The stepwise multiple regression analysis indicated that neither Carabidae, Staphylinidae or Araneae were significantly related to the number of aphids or the aphid peak.

3.8.2. *Fenced pitfall trap sampling*

The fenced pitfall traps measured the absolute density of polyphagous predators. Few Carabidae were captured in the sample and the technique was discontinued after one sample because of difficulties in reliably establishing the boxes in hard ground.

The Carabidae differed in their density only between the treatments ($F_{1,14}$=9.4, P<0.01). Their numbers were reduced by 63% in the enclosures (Fig. 36). The predominant taxa which were captured were *Bembidion* spp. and *T. quadristriatus*.

Few Staphylinidae were captured and there were no significant differences between the treatments or farming systems, although overall 71% fewer Staphylinidae were captured in the enclosed areas (Fig. 37).

Significantly fewer Araneae were captured in the enclosed areas ($F_{1,14}$=24.5, P<0.001). Overall their abundance was reduced by 89% in the enclosures (Fig. 38).

3.8.3. *Dvac suction sampling*

a. Effect of enclosures and plot.

The analysis revealed that the Carabidae did not differ significantly between the treatments or farming systems but very few were captured, often less than 1 m^2 (Fig. 39). Only small species were captured, notably *Bembidion* spp. and *Trechus quadristriatus.*

The abundance of Staphylinidae differed significantly between the treatments ($F_{1,14}$=10.6, P<0.001) with 32% less in the enclosed areas (Fig. 40). They also differed significantly between the farming systems ($F_{1,14}$=11.6, P<0.01) and were most abundant in the IFS plots. *T. hypnorum* was the most abundant species in the April and May samples, whilst the Aleocharinae predominated in the May and June samples. *Anotylus* spp. were again numerous in the May sample only.

The density of Araneae also differed significantly between the treatments ($F_{1,14}=11.0$, $P<0.01$) with a 28% reduction in the enclosed areas (Fig. 41). As for the Staphylinidae numbers differed between the farming systems ($F_{1,14}=5.2$, $P<0.05$) being higher in the integrated plots. Their numbers peaked in May compared to July for the pitfall traps. This was because the Dvac sampled immature spiders which were most numerous in May.

b. Effect of predators on aphids:

The stepwise multiple regression showed that neither the Carabidae, Staphylinidae or Araneae were correlated with the number of aphids or the population peak.

4. DISCUSSION

The first objective of this study was to examine the contribution which polyphagous predators made towards cereal pest control and whether this subsequently affected cereal yield and quality. Exclusion techniques were adopted because these allowed inherent populations of polyphagous predators to be manipulated under field conditions in conjunction with the naturally occurring pest infestations. Although all polyphagous predators cannot be excluded completely from the enclosed areas by manipulating their density an indication can be obtained on their impact and whether they should be encouraged through manipulation of the crop environment and surrounding non-crop habitat. A few similar exclusion studies (Edwards *et al.*,1979; Sunderland *et al.*, 1980; Chambers *et al.*, 1983; DeClerq & Pietraszko, 1983; Chiverton, 1986) have been conducted previously but these were with relatively low aphid levels and never for orange wheat blossom midge. Neither was the effect on cereal yield and quality incorporated in such investigations.

4.1. EFFECT OF ENCLOSURES

4.1.1. *Cereal aphids*

In the first year of this two year study cereal aphids were the most prolific cereal pests in the experimental fields. The predominant species was the grain aphid (*S. avenae*) and this was first recorded in crop in mid-June at GS61-65. Initially the aphids were evenly distributed on the ear and flag leaf but rapidly moved to the ear as the crop ripened and the flag leaf deteriorated. The aphids reached spray threshold levels in approximately 15 days from the first recordings at the later stages of crop development (GS73). Aphids were encouraged by the long, hot dry weather in which temperatures regularly exceeded 30°C and only 34 mm of rain fell between 20 April and the 10 July 1995. Conversely the activity of ground beetles declined during these relatively extreme conditions. With such conditions it was not surprising that aphid predators failed to prevent aphid populations reaching spray threshold levels, although this occurred relatively late in the crop's development. Where polyphagous predator density and activity were reduced in the exclusion areas the total number of cereal aphids recorded increased and the number of aphid days to which the tillers were subjected was also increased, therefore polyphagous predators were having some impact on aphid populations. However, in the enclosed and control areas the proportion of tillers infested were similar. Consequently, in this instant the predators were therefore not having sufficient impact to prevent a spray recommendation.

In the second year of the study the grain aphid was again the most predominant pest but first appeared later in the season (GS67) than in 1995. Aphid populations took much longer to reach the spray threshold, 25 days in field 1 and up to 33 days in the other fields, when the crop was at GS77 or GS81 respectively. This was probably because of the cooler temperatures compared to 1995. The numbers of aphids per tiller when thresholds were reached was lower in 1996 (<5 aphids/tiller) compared to 1995 (6-13 aphids/tiller). The longer infestation period but lower aphids per tiller in 1996 resulted in the tillers being subjected to less aphid days compared to 1995. The slower aphid population development in 1996 should have allowed the predatory insects a greater opportunity to exert an effect but this was not found. Only in the IFS plot 2 was there greater aphid numbers in the enclosed compared to the control areas.

4.1.2. *Orange wheat blossom midge*

In the spring of each year the densities of midge in the soil were similar in all plots, although more would have been expected for the fields in second wheats, and were at relatively low levels. This was also confirmed by the emergence traps in 1995 where 16-20 adult midge per m^2 were found which was equivalent to approximately one adult midge per 25 tillers. This was well below the recommended spray threshold of one midge per 6 tillers. Approximately one midge larvae per ear was found in both years, therefore, assuming 50% of the emerging adult midges were female and there was no ingress from outside the field then each female produced 50 larvae. This was similar to that derived by Oakley (1994b) of 84 eggs per female.

There was no significant difference in the number of midge larvae per grain between the enclosed and control areas, although 1.5 fewer midge per ear were found in some enclosed areas in 1996, indicating that polyphagous predators may predate on midge adults from when they emerge until oviposition. The effect of polyphagous predators between the enclosed and control areas may have been masked by adult midges moving into the enclosures from other areas. On evenings when conditions for flight were suitable, females have been observed to fly long distances, in search of crops at susceptible growth stages, especially if emergence occurs in non-suitable crops (J. Oakley pers. comm. 1995). Perhaps this phenomenon explained why the more dramatic effect observed by Basedow (1975) was not found in this study. He found that predation was reduced by 84% when ground-dwelling predators were excluded from emergence cages.

Where polyphagous predators were reduced the number of larvae returning to the soil was increased by 30% in 1995 and by 180% in 1996. Floate *et al.* (1990) also found that Carabidae and Staphylinidae were likely to predate more extensively on larvae when they vacate the ear and seek over-wintering sites in the soil than when they emerge from the soil in June. This highlights the importance of only using insecticides when midge thresholds are exceeded and ensuring they are correctly timed so that beneficial insects are preserved. A mis-timed insecticide may reduce only the beneficial insects and subsequently allow more midge larvae to return to the soil. An even larger reduction in the number returning to the soil was found in the IFS compared to the CFP plots in 1995. This may have been partly because the number in the ear was 30% lower in the IFS plot and because the ear ripened later in these plots allowing the soil surface to harden: thus larvae may have been prevented from entering the soil exposing themselves to predation and desiccation.

A strong correlation was found between the number of midge larvae per ear and percentage of ears infested. This was used to predict the number of midge per ear at 100% infestation of ears, which was approximately 3.6. This confirms results from 1994 where a value of 4 was obtained (Holland et al., 1996a). Such a strong correlation was expected because midge prefer not to oviposit in already infested wheat ears (Pivnick and Labbé, 1992). This value was within the average egg batch size range of 0.3 to 6 per ear found in the UK by Oakley (1994b). The average number of midge per grain was one and at this level the reduction in grain size would be 22-48% depending on the earliness of ear emergence (Kurppa, 1989). With an average of 4 larvae per grain with 100% of ears infested the expected yield reduction, if all 4 grains were lost, would be 8%, assuming 50 grains per ear as was found for the cultivars used in this study. If the maximum damage of 48% per grain occurred then the yield loss would only be 4%. In most of the plots the proportion of tillers infested rarely reached 100% and therefore the expected yield loss would be considerably lower. This may explain why in 1994 no correlation between number of midge per ear and grain dry weight could be detected even with up to 12 midge per ear (Holland, Thomas and Hewitt, 1996).

4.1.3. *Grain yield and quality*

The damage caused by grain aphids was estimated from field experiments and modelling to be 2.5 kg ha^{-1} per aphid day for an infestation between GS71 and 79, but decreased during grain filling to 0.8 kg ha^{-1} per aphid day (Roermund *et al.*, 1986). This was because the majority of damage was caused by the honeydew on the leaves interfering with photosynthesis, rather than by the withdrawl of phloem sap. In 1995 when the main infestation period was between GS71-79 the maximum difference between enclosed and control areas (plot 1) was 130 aphid days which would be equivalent to a yield loss of 0.325 t ha^{-1} (2.5/1000 x 130) or £39 ha^{-1} at a value of £120 t. The actual recorded difference was 0.368 t ha^{-1} (0.04 kg m^{-2} x 10000 - 800 m^{2} for tramlines). The main aphid infestation period in 1996 was much later (GS77-85) therefore the impact of each aphid day would be lower according to Roermund *et al.* (1986). The maximum difference between enclosed and control areas (plot 2) of 50 aphid days was equivalent to a yield loss of 0.04 t ha^{-1} (0.8/1000 x 50) or £5 ha^{-1} at a value of £120 t. The actual recorded yield was, however, greater from the enclosed areas.

Late aphid infestations have been shown to reduce baking quality in caging experiments (Lee *et al.*, 1981). Field trials have revealed that this is extremely rare in the absence of a yield effect, even when aphids are controlled using insecticides (Oakley *et al.*, 1993). Furthermore, the increases in quality where insecticides were applied were only small compared to untreated controls; an increase in hectolitre weight of 2.7% and TGW of 4. In this study there was some evidence of an effect on quality when relationships were examined for aphid infestation levels and quality parameters. These effects were often specific to individual cultivars. The hectolitre weight of Tonic in 1995 and Spark and Ritmo in 1996 was reduced by aphids, as was protein for Spark in 1996. In contrast some positive effect of aphids were found on the hectolitre weight of Spark in 1995 and TGW of Ritmo in 1996. When, however, areas of plots 2 and 3 were sprayed in 1995 and quality compared to the control areas (unsprayed) of these plots grain quality was unaffected. Although polyphagous predators appeared to have no impact on quality because there was little difference between the enclosed and control areas in either year using the split plot Analysis, they were affecting aphid numbers. Therefore, because aphids were shown to reduce some yield and quality parameters and aphid numbers increased when predators were reduced, predators can have an affect on these factors.

The effects found which were caused by aphids were in agreement with previous studies. The relatively low impact of cereal aphids in 1995 and the virtual absence of an effect in 1996 could be attributed to the timing of the infestations. Although aphids were first recorded in the crop at GS61 in 1995, they did not reach the threshold until GS71-73 which is at the end of the period when control is recommended. In 1996 the spray thresholds were not exceed until GS83. Furthermore, the poor relationship between aphids and yield confirm the impact predicted by Roermund *et al.* (1986). Lee, Wratten and Kenyi (1981) also found no yield loss from aphid infestations peaking after GS71. More recent studies with naturally occurring aphid infestations found that sprays at GS73 only produced a yield response at 2 out of 15 sites, and only one of these was for an infestation of grain aphids (Oakley and Walters, 1994). The other response was for an infestation of rose-grain aphids which are known to cause greater yield loss during grain filling than grain aphids (Holt *et al.*, 1984). In contrast, yield increases were detected in response to treating an aphid infestations at GS83 (Young *et al.*, 1986).

4.1.4. *Polyphagous predators*

The activity/density of Carabidae was best measured using the pitfall traps whilst the fenced pitfall traps gave an indication of a density alone. Only the smaller species were captured using the Dvac suction sample and this gave extremely varied results. The activity and density of Carabidae was effectively reduced within the enclosures by exclusion and trapping out, thus creating areas of different population density which allowed the effect of the Carabidae to be examined. In 1995 Carabidae were found to have a negative effect on the aphid populations but the degree of influence varied between the plots, the greatest effect occurring in plot 1. This plot was the latest sown crop and suffered the highest aphid levels indicating that predation may be more important as aphid numbers increase. Plots 3 and 4 contained more Carabidae until later in the summer because the predominant species was *P. melanarius,* which is active from mid to late summer. In contrast the *Bembidion* species were the most active in plots 1 and 2, earlier in the course of the experiment. Coincidentally plots 3 and 4 had fewer aphids indicating that species composition as well as predator density may be an important component of the aphid/predator relationship. Further evidence supporting this was found in 1996 because little difference in aphid numbers between the enclosed and control areas was found in plots 3-8 where predator numbers and diversity were low. It is unlikely that Carabidae actively search for fields containing aphids because they are limited to some extent, depending on the species, in their mobility and often populations are persistent within fields from year to year (G. Thomas *pers. comm.*), therefore it is the inherent, resident population which will be responsible for controlling aphids. This may in turn, for example, determine whether they better control an early or late infestation. The predation rate of Carabidae may have been inhibited in 1995 because during the unusually hot, dry weather the beetles bury into the soil during the day to avoid desiccation. Furthermore the aphid fall off rate may have been lower because of the absence of rainfall and wind which encourage dislodging and therefore fewer aphids were available on the ground. Winder (1990) demonstrated that ground predation was an important method by which ground beetles controlled aphids.

In contrast for 1996 there was no correlation between the activity/density of Carabidae and aphids but this was probably because Carabid diversity and activity was so low in plots 3-8 that they were having no effect on the aphids. Furthermore the aphids infested the crop later in the season compared to 1995, by which time the activity/density of Carabidae had declined. There was only a large effect of predator exclusion in plot 2 where the aphid peak was reached 10 days earlier and aphid populations were naturally higher. The dominant species in this plot was *P. melanarius*, and because this was active later in the summer may explain the effects found.

The exclusion barriers were less effective in reducing the population of Staphylinidae because the most numerous taxa, the Aleocharinae and *Tachyporus* species readily fly. The reductions in activity/density and density measured by the pitfall traps and Dvac suction samples respectively were similar, as was the species composition sampled by the two methods. The Staphylinidae appeared to have no effect on aphids in 1995 but there was a correlation in 1996. The correlations may not be a result of true predation but a reflection of syncronisation between predator abundance and aphid decline. Gut dissections or ELISA tests would be needed to confirm these relationships.

In contrast the activity of spiders increased during the course of the experiment coinciding with the aphid outbreak. Their numbers were, therefore, inversely proportional to those of the aphids indicating that they are one of the more important groups of predators later in the year. The Linyphiidae were the most abundant taxon of spiders.

Overall the predators only had an effect in some plots on the aphid populations, despite the relatively slow population build up. Previous studies have shown that polyphagous predators should exert the greatest effect when aphid populations develop slowly (Burn, 1992) and before the peak is reached (Chambers *et al.*, 1982; Carter *et al.*, 1982). However this study revealed that predation is poorer later in year, even when populations develop slowly because less polyphagous predators, with the exception of most Linyphiidae, are active and abundant at this time. As temperatures increase they became less active whilst warm, dry weather encourages aphids. The rate of population increase is still, however, important because polyphagous predators are unable to prevent rapidly developing aphid populations from reaching spray thresholds (Holland *et al.*, 1996). If aphids had arrived earlier in the year larger differences between the enclosed and control areas may have been found.

The inherent polyphagous predator populations at this site were relatively high compared to the other LINK IFS Project sites (Holland *et al.*, 1996b), probably having been encouraged for many years by the same policies adopted to encourage invertebrate food for gamebird chicks. These have included Conservation Headlands (Sotherton, 1991), care of field margins and no application of insecticides to cereal crops during the summer. The results would, therefore indicate that little control of cereal pests is occurring at the other LINK IFS sites given their invertebrate populations. Moreover, if these sites are representative of much of the arable farmland in the UK which have no policy to encourage invertebrates, then control of cereal pests by polyphagous predators is likely to be very low. If farmers wish to adopt ICM practices within which integrated pest management is a key component, then considerable measures will have to be taken to encourage their predatory invertebrates if they are to be relied upon for pest control.

The sampling method was found to be important when interpreting the results because their capture efficiency varies depending on the species size and habit (Sunderland *et al.*, 1996). However, by using range of sampling techniques these were overcome. The pitfall traps were probably the most suitable method for sampling Carabidae and Araneae, whilst Staphylinidae were best sampled using the Dvac suction sampler. Although the latter method only samples a single time period, this is of less consequence for day active species or for those which do not shelter in the soil during daylight.

4.2. EFFECT OF FARMING SYSTEMS

There were some differences in aphid population development, midge infestation and predator activity between the conventional and integrated farming systems.

4.2.1. *Cereal aphids*

The aphid populations reached their highest levels in both years in the later sown integrated plots (Plot 1in 1995 and plot 2 in 1996). The crops in these plots were behind in development and remained at a more susceptible stage for aphid infestation longer into the summer. This was a disadvantage when the aphids infested the crops relatively late. This effect was also found to a lesser extent in plot 4 (IFS) during 1995. It was also within these plots that the predators exerted the greatest effect. In summary although sowing date influence the number of aphids per tiller it had no effect on the percentage of tillers infested and consequently whether spray thresholds were reached, but because the timing of initial infestations varies from year to year this cannot be used as a management tool.

The type of farming system did appear to have an effect both on the level of aphid infestation per tiller and the percentage of tillers infested during 1996. Fewer aphids were found in the integrated plots of fields 2 and 3 and the spray threshold was not reached in these fields. This may be attributed the nitrogen inputs. The integrated compared to the conventional plots received less nitrogen (27 or 29 kg ha^{-1}) on the last application. Less nitrogen was also applied to the integrated plots during 1995 but because both plots were sown later thereby increasing the crops susceptible period any effects may have been overcome.

4.2.2. *Orange wheat blossom midge*

More midge larvae were found in the grain from the CFP plots in 1995, probably because these plots were sown earlier and subsequently the ear was at a more vulnerable stage when the adults were ovipositing. Midge prefer to infest crops between GS53 to 59. A similar effect was also found in 1994 (Holland *et al.*, 1996a). The greater midge infestation also led to more midge returning to the soil of the CFP plots. In 1996 the later sown second wheat crops were more heavily infested than the first wheat crops. Sowing date therefore appears to be critical in determining the likely susceptibility of each crop.

4.2.3. *Polyphagous predators*

The Carabidae were unaffected by the type of farming system, however, the activty/density and density of Staphylinidae and Araneae differed. The activity/density and density of spiders was higher for the CFP plots in 1995. Staphylinidae were more abundant in the integrated plots for both years. These two groups may have been responding to the higher aphid numbers found in some of the integrated plots. In addition the Staphylinidae species which were most numerous are also fungal feeders and may have been responding to the higher disease levels found in the integrated plots. Some taxon of the Linyphiidae, which formed the majority of the spiders collected, may also respond to soil surface structure and crop density as this determines the number of sites suitable for webs.

At three of the other LINK IFS Project sites no difference has been detected betweeen the farming systems (Holland *et al.*, 1996b). There was little difference in carabid activity and density between the two farming systems because the husbandry practices in cereal crops which have been shown to directly effect carabids in the field are insecticide treatments

(Vickerman and Sunderland, 1979; Basedow *et* al., 1985; Powell *et al.*, 1985; Vickerman *et al.*, 1987) and type of soil tillage (Blumberg and Crossley, 1983; Hance and Gregoire-Wibo, 1987). The integrated and conventional plots were all established by ploughing, no autumn insecticides were required and no summer insecticides could be applied because they would have disrupted the experiment. The establishment of `Beetle Banks' can also encourage polyphagous predators (Thomas, Wratten and Sotherton, 1991) but the experimental layout of the LINK IFS fields prevented these from being evaluated in this study.

5. CONCLUSIONS

In conclusion the objectives proposed were addressed. These were:

1. To evaluate the impact of polyphagous predators on cereal aphids and to determine the subsequent influence on cereal yield and quality.

    - The experiment demonstrated that polyphagous predators can reduce aphid infestations but the effect was greater when aphid populations were higher and when infestation occurred earlier in the crops development.

    - The effect of reducing polyphagous predators by approximately 80% can increase the number of aphids per tiller by up to 33%. However, the proportion of tillers infested were unaffected by reducing polyphagous predators..

    - There were some strong correlations between aphid levels and predator activity and density for Carabidae, Staphylinidae and Araneae.

    - Greater effects on aphids would be expected for earlier aphid infestations because polyphagous predator activity and abundance was greater earlier in the year, although this needs to be verified.

    - Climatic conditions influenced the activity of predators and the development rate of aphid populations.

    - It is likely that the species composition of the predators will also influence the effect on aphids because of their activity period and abundance relative to the aphids. Species composition varied between fields on a single farm.

    - Correlations were found between cereal aphids and grain dry weight, hectolitre weight, percentage protein and TGW although results varied with cultivar. This occurred despite the aphids infesting the crops at a relatively late growth stage.

    - Grain yield and quality were unaffected when polyphagous predator numbers were reduced but aphids numbers were higher and therefore grain yield and quality may be lower

2. To compare the quantitative and qualitative role of polyphagous predators within the IFS and CFP systems of the LINK IFS project.

   - There were some differences in the activity/density and abundance of the predatory guilds between the IFS and CFP systems. Staphylinidae and Araneae were often more numerous in the IFS plots.

   - The later sown IFS crops were more heavily infested with aphids. This was because aphids appeared relatively late in the season and these crops remained at a more susceptible stage for longer.

   - In fields 2 and 3 in 1996 fewer aphids per tiller were recorded in the IFS plots an numbers remained below the spray threshold unlike for the CFP plots.

   - The quality of grain differed from the two farming systems. Protein was lower from some of the IFS plots in 1995 and 1996, probably as result of the lower nitrogen inputs.

3. To examine the extent to which polyphagous predators contribute to OWBM control.

   - Polyphagous predators were found to feed on OWBM prior to oviposition but to a greater extent after they vacate the ear and return to the soil to diapause.

   - Reducing polyphagous predators led to an increase in midge larvae per ear and more ears infested in 1996.

   - The number of midge pupae in the soil was increased by 30% in 1995 and by 180% in 1996 when polyphagous predator numbers were reduced.

   - Sowing date was critical in determining the susceptibility of the crop for oviposition by midge. The earlier sown conventional crops were more heavily infested in 1995. Grain infestation levels also influenced the subsequent return to the soil.

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TABLES

Table 1. Treatment differences for Integrated Farming System (IFS) and Conventional Farm Practice (CFP) plots in 1995 and 1996.

Treatment	IFS	CFP
Field 1-1995, cv. Tonic	*Plot 1*	*Plot 2*
Sowing date	24/11/94	26/10/94
Nitrogen (kg ha^{-1})	198	230
Herbicides (ha^{-1})	Wildcat (fenoxyprop-p ethyl) 1.27 l, 13/4/95; Jubilee (metsulfuron-methyl) 31 g, 1/5/95	CMPP 570 (mecoprop) 2.87 l & Jubilee 29 g, 4/4/95; Starane (fluroxypr) 0.5 l, 2/5/95
Fungicides (ha^{-1})	Folicur (tebuconazole) 0.3 l & BAS 464 (fenpropimorph and tridemoph) 0.25 l, 26/5/95; Jupital (chlorothalonil) 0.74 l, 30/5/95; Decade 500 (fenpropimorph and propiconazole) 0.55 l, 20/6/95	Folicur 0.3 l & BAS 464 0.3 l, 30/5/95 BAS 464 0.25 l, Jupital 0.75 l & Folicur 0.5 l, 30/5/95
Plant growth regulator (ha^{-1})	Cycocel 1.2 l	Cycocel 1.3 l
Field 2-1995, cv. Spark	*Plot 4*	*Plot 3*
Sowing date	18/10/94	3/10/94
Nitrogen (kg ha^{-1})	224	188
Herbicides (ha^{-1})	Jubilee 32 g, 21/3/95; Starane 0.5 l, 19/6/95	IPU (isoproturon) 4.14 l & Jubilee 31 g, 20/3/95; Starane 0.5 l, 3/5/95
Fungicides (ha^{-1})	Jupital 1.0 l & Folicur 0.5 l, 31/5/95	Pointer (flutriafol) 0.46 l & Jupital 0.55 l, 3/5/95; Jupital 1.0 l & Folicur 0.5 l, 31/5/95
Plant growth regulator (ha^{-1})	Cycocel 0.5 l, 31/5/95	Cycocel 0.5 l, 31/5/95
Field 1-1996, cv. Spark	*Plot 2*	*Plot 1*
Sowing date	12/10/95	26/10/95
Nitrogen (kg ha^{-1})	212	235
Herbicides (ha^{-1})	IPU 3.06 l, Stomp (pendimethalin) 2.55 l, Duplosan (mecoprop-p) 1.0 l, 7/3/96	IPU 3.06 l, Stomp (pendimethalin) 2.55 l, Duplosan (mecoprop-p) 1.0 l, 7/3/96
Fungicides (ha^{-1})	Folicur 0.6 l, 6/6/96	Jupital 1.0 l & Folicur 0.6 l, 4/6/96
Plant growth regulator (ha^{-1})	Cycocel 1.25 l, 6/4/96	Cycocel 1.25 l, 6/4/96
Field 2-1996, cv. Ritmo	*Plots 9 & 10*	*Plots 7 & 8*
Sowing date	3/10/95	3/10/95
Nitrogen (kg ha^{-1})	158	185
Herbicides (ha^{-1})	Duplosan 1.0 l & Jubilee, 21 g, 20/4/96	IPU 1.08 l & Stomp 2.71, 2/11/95
Fungicides (ha^{-1})	Genie (flusilazole) 0.4 l & Folicur 0.6 l, 6/6/96	Genie 0.4 l & & Jupital 1.0 l, 13/5/96; Folicur 0.6 & Jupital 1.0 l, 4/6/96; Ashlade mbc 0.3 l, BAS464 0.5 l & Manex (maneb & zinc) 1.0 l, 21/6/96
Plant growth regulator (ha^{-1})	Cycocel 1.25 l, 20/4/96	Cycocel 1.75 l, 16/4/96
Field 3-1996, cv. Ritmo	*Plot 11*	*Plot 12*
Sowing date	3/10/95	3/10/95
Nitrogen (kg ha^{-1})	180	209
Herbicides (ha^{-1})	IPU 3.06 l, Duplosan 1.0 l & Stomp 2.71, 7/3/96	IPU 1.08 l & Stomp 2.71, 2/11/95
Fungicides (ha^{-1})	Genie 0.4 l, 9/5/96; Folicur 0.6 l, 6/6/96	Genie 0.4 l & & Jupital 1.0 l, 13/5/96; Folicur 0.6 & Jupital 1.0 l, 4/6/96; Ashlade mbc 0.3 l, BAS464 0.5 l & Manex (maneb & zinc) 1.0 l, 21/6/96
Plant growth regulator (ha^{-1})	Cycocel 1.25 l, 20/4/96	Cycocel 1.75 l, 16/4/96

Table 2. Effect of farming system and treatment on the aphid parameters measured in 1995 (±SE).

System and treatment	Aphids/tiller	Aphid days/tiller	Aphid peak	Number of days to peak	Rate of increase to peak	Mummified aphids/tiller
CFP-enclosed	61.9 (8.0)	203 (26)	17.9 (3.0)	19.0 (1.1)	0.064 (0.005)	0.69 (0.1)
CFP-control	51.1 (5.9)	168 (18)	14.2 (1.5)	19.8 (1.2)	0.056 (0.004)	0.83 (0.2)
IFS-enclosed	84.3 (14.3)	280 (46)	24.1 (3.5)	21.0 (1.1)	0.064 (0.003)	1.04 (0.1)
IFS-control	60.7 (7.5)	206 (26)	19.2 (2.9)	21.4 (0.8)	0.058 (0.002)	0.88 (0.1)

Table 3. Effect of farming system and treatment on the orange wheat blossom midge (OWBM) parameters measured in 1995 (±SE).

System and treatment	OWBM/ear	Grains infested with OWBM/ear	% tillers infested	OWBM/kg soil during February	OWBM/kg soil during July
CFP-enclosed	1.3 (0.2)	1.2 (0.2)	62 (4)	2.0	3.70 (0.20)
CFP-control	1.2 (0.1)	1.1 (0.1)	56 (3)	2.0	2.40 (0)
IFS-enclosed	0.7 (0.1)	0.6 (0.1)	42 (2)	0.25	0.75 (0.15)
IFS-control	0.8 (0.2)	0.8 (0.2)	40 (3)	0.25	0.65 (0.25)

Table 4. Effect of farming system and treatment on the yield and quality parameters measured in 1995 (±SE).

System and treatment	Weight of grain (kg/m^2 @14% moisture)	Dry weight of marked tillers (g)	Hectolitre weight	HFN	% protein
CFP-enclosed	0.63 (0.03)	2.17 (0.05)	83 (1)	355 (5)	10.3 (0.1)
CFP-control	0.57 (0.03)	2.13 (0.05)	83 (1)	352 (5)	10.5 (0.1)
IFS-enclosed	0.58 (0.03)	2.05 (0.06)	82 (1)	357 (7)	9.9 (0)
IFS-control	0.60 (0.03)	2.13 (0.12)	82 (1)	363 (5)	10.0 (0.1)
Plot 2 CFP-sprayed			79.0	330	10.10
Plot 3 CFP-sprayed			81.4	363	10.50

Table 5. Effect of farming system and treatment on the aphid parameters measured in 1996 (±SE).

System and treatment	Aphids/tiller	Aphid days/tiller	Aphid peak	Number of days to peak	Rate of increase to peak	Mummified aphids/tiller
CFP-enclosed	31.4 (4.4)	110 (16)	9.3 (1.5)	36.3 (0.9)	0.025 (0.003)	0.16 (0.06)
CFP-control	37.3 (4.8)	130 (17)	10.9 (2.0)	34.5 (0.5)	0.037 (0.009)	0.18 (0.08)
IFS-enclosed	35.7 (11.4)	125 (40)	9.3 (3.6)	35.9 (0.9)	0.021 (0.006)	0.18 (0.08)
IFS-control	33.9 (9.4)	119 (33)	8.2 (2.6)	38.4 (1.1)	0.021 (0.004)	0.18 (0.08)

Table 6. Effect of farming system and treatment on the orange wheat blossom midge (OWBM) parameters measured in 1996 (±SE).

System and treatment	OWBM/ear	Grains infested with OWBM/ear	% tillers infested	OWBM/kg soil during February	OWBM/kg soil during July
CFP-enclosed	1.1 (0.5)	0.9 (0.4)	34 (10)	0.3 (0.3)	2.1 (1.0)
CFP-control	1.0 (0.2)	0.9 (0.2)	48 (8)	0	0.9 (0)
IFS-enclosed	1.1 (0.5)	1.0 (0.5)	42 (11)	0	2.2 (1.2)
IFS-control	0.9 (0.3)	0.8 (0.3)	41 (10)	0	1.5 (0.6)

Table 7. Effect of farming system and treatment on the yield and quality parameters measured in 1996 (±SE).

System and treatment	Weight of grain (kg/m^2 @14% moisture)	Dry weight of marked tillers (g)	Hectolitre weight	HFN	% protein	TGW (g)
CFP-enclosed	0.73 (0.04)	2.21 (0.11)	78 (2)	370 (5)	8.9 (0.3)	47 (2)
CFP-control	0.80 (0.03)	2.19 (0.13)	78 (1)	366 (10)	9.0 (0.3)	47 (2)
IFS-enclosed	0.85 (0.08)	2.18 (0.11)	77 (2)	341 (9)	8.3 (0.3)	46 (2)
IFS-control	0.82 (0.09)	2.22 (0.08)	77 (2)	352 (11)	8.4 (0.4)	46 (2)

Figure 1. Layout of enclosed (E) and control (C) areas in fields 1 and 2 in 1995.

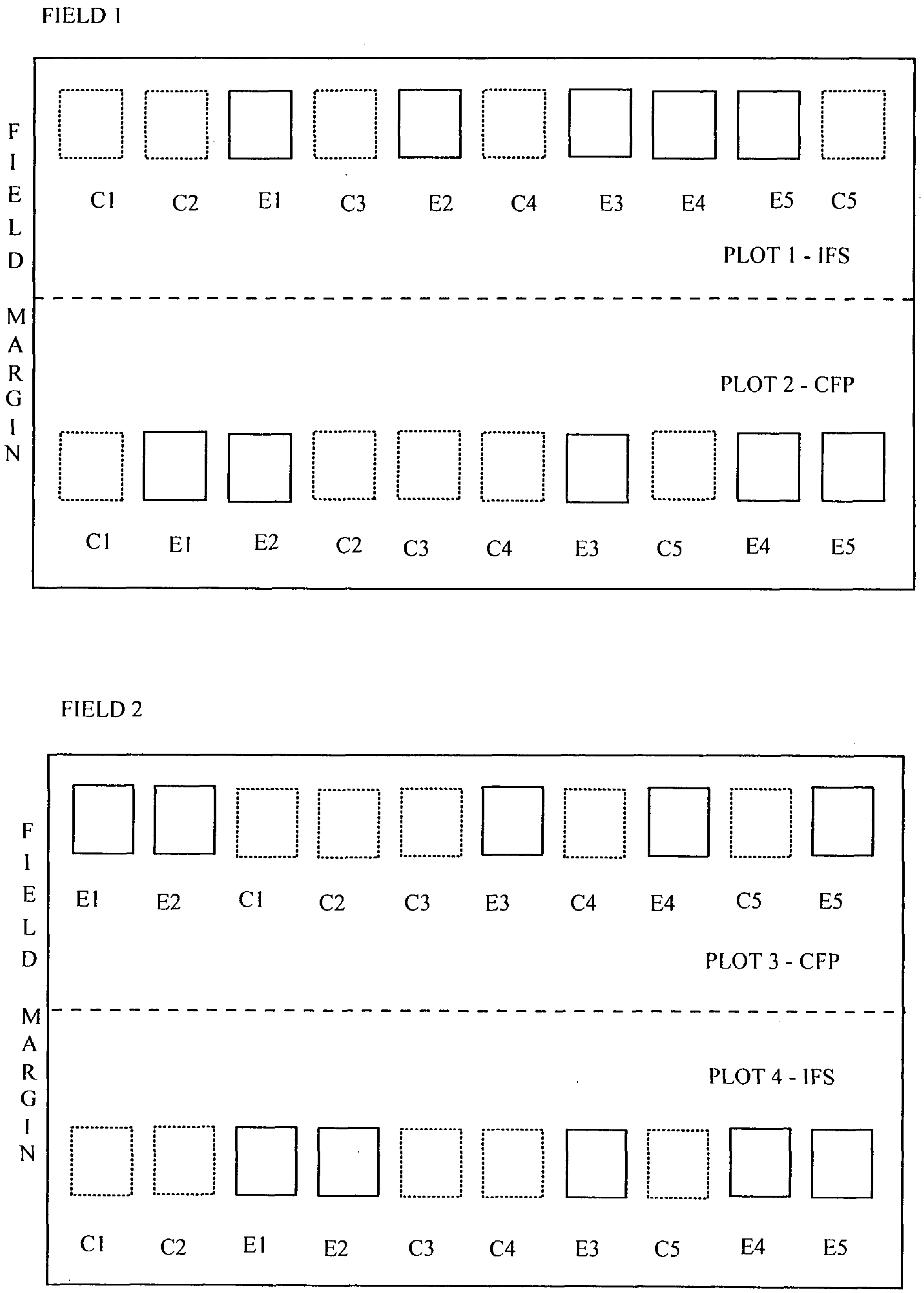


Figure 2. Layout of enclosed (E) and control (C) areas in fields 1, 2 and 3 in 1996.

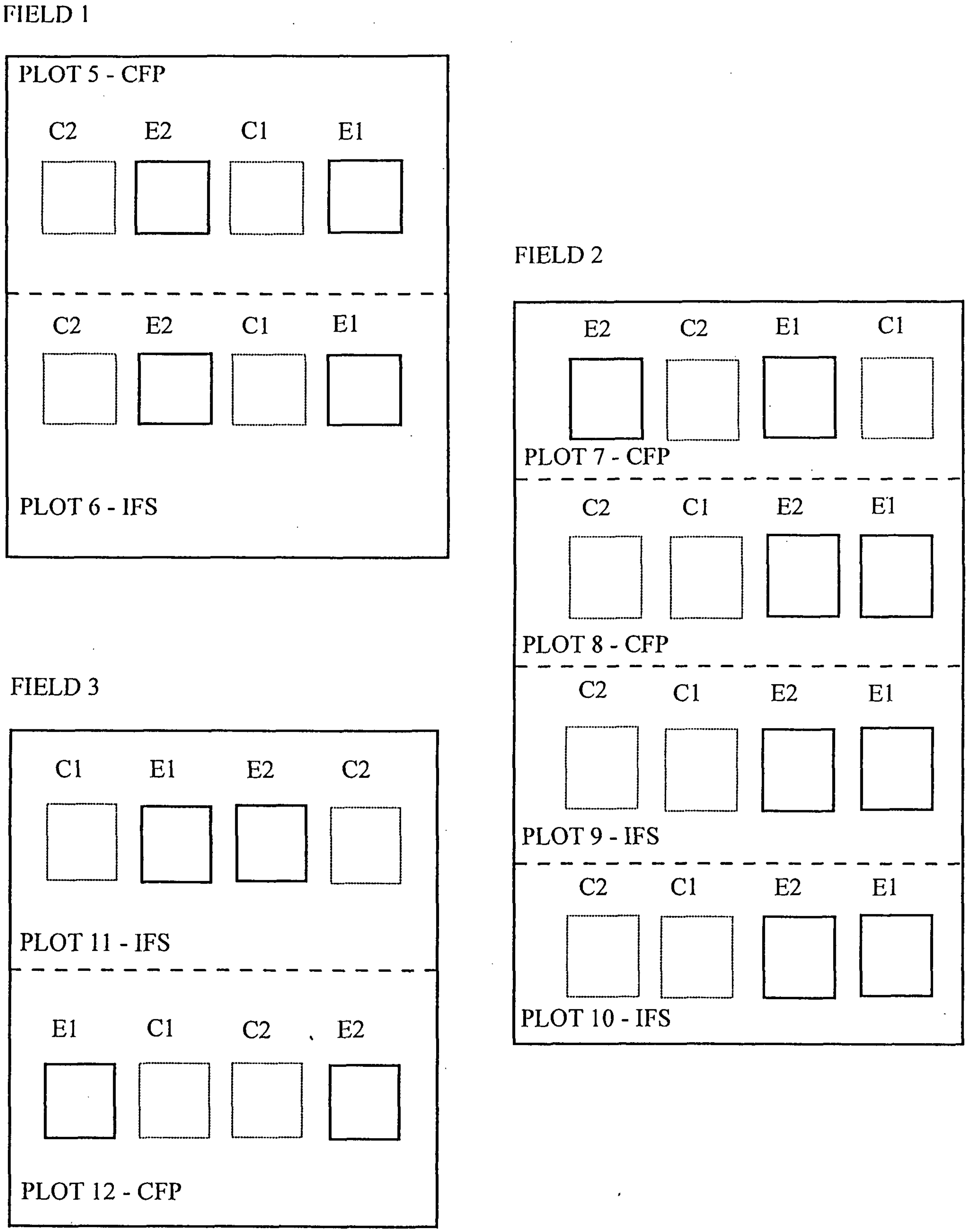


Figure 3a. Percentage of tillers (±SE) infested in enclosed (E) and control (C) areas within plots 1 and 2 in 1995.

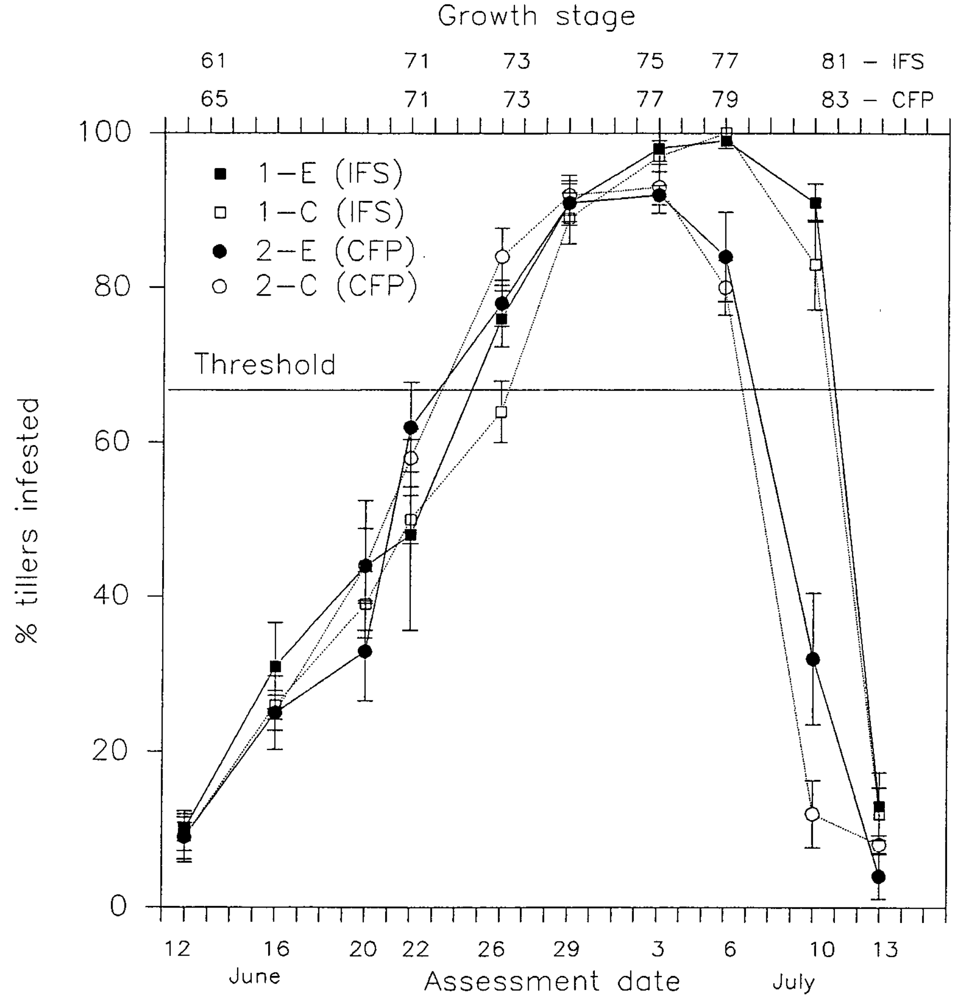


Figure 3b. Percentage of tillers (±SE) infested in enclosed (E) and control (C) areas within plots 3 and 4 in 1995.

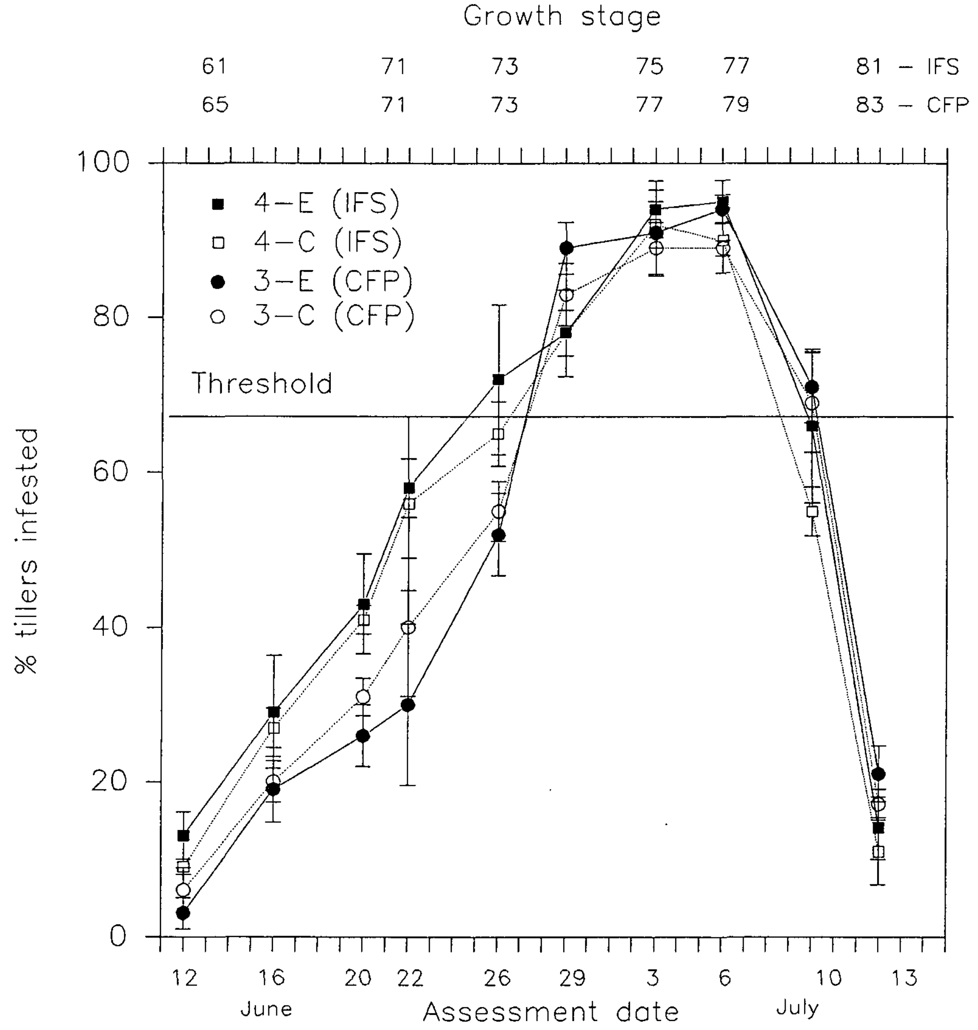


Figure 4a. Mean number of grain aphids per tiller (±SE) in the enclosed (E) and control (C) areas within plots 1 and 2 in 1995.

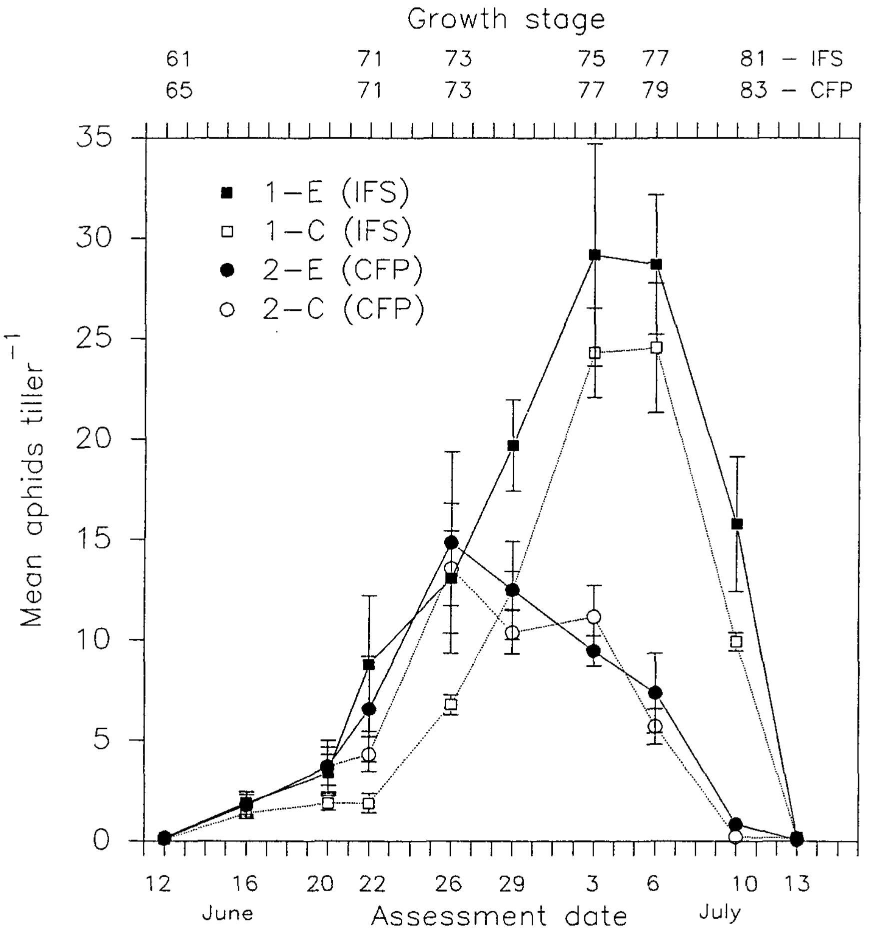


Figure 4b. Mean number of grain aphids per tiller (±SE) in the enclosed (E) and control (C) areas within plots 3 and 4 in 1995..

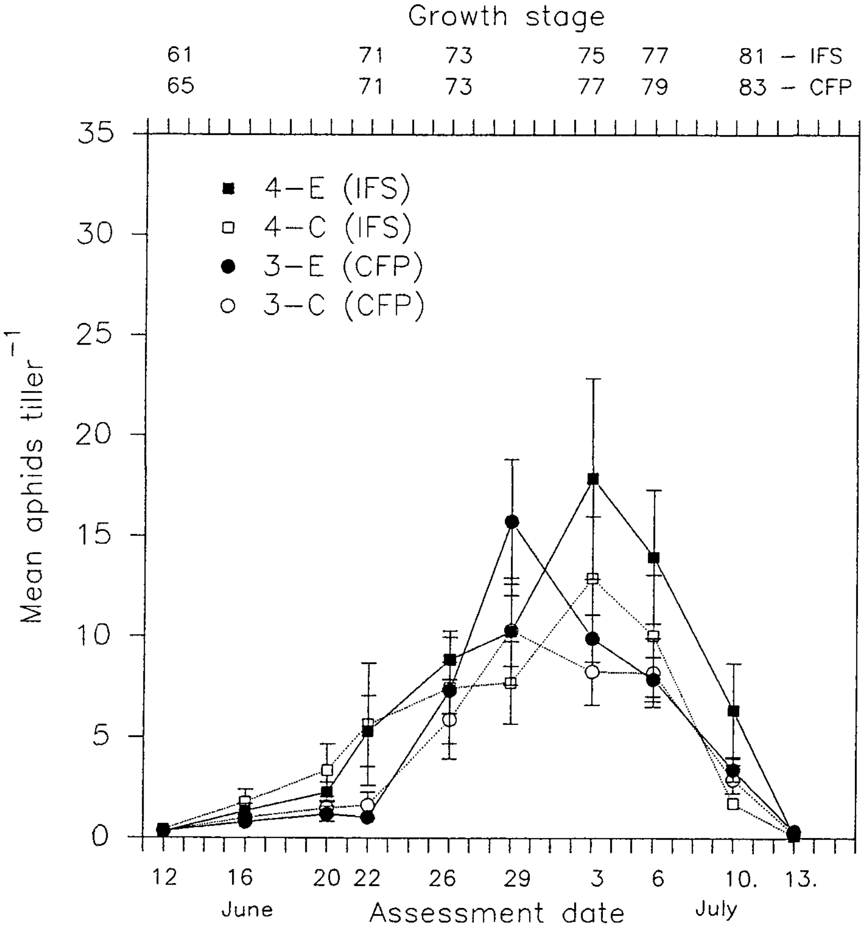


Figure 5a. Proportion of tillers infested with aphids for the enclosed (E) and control (C) areas in the IFS and CFP plots during 1995

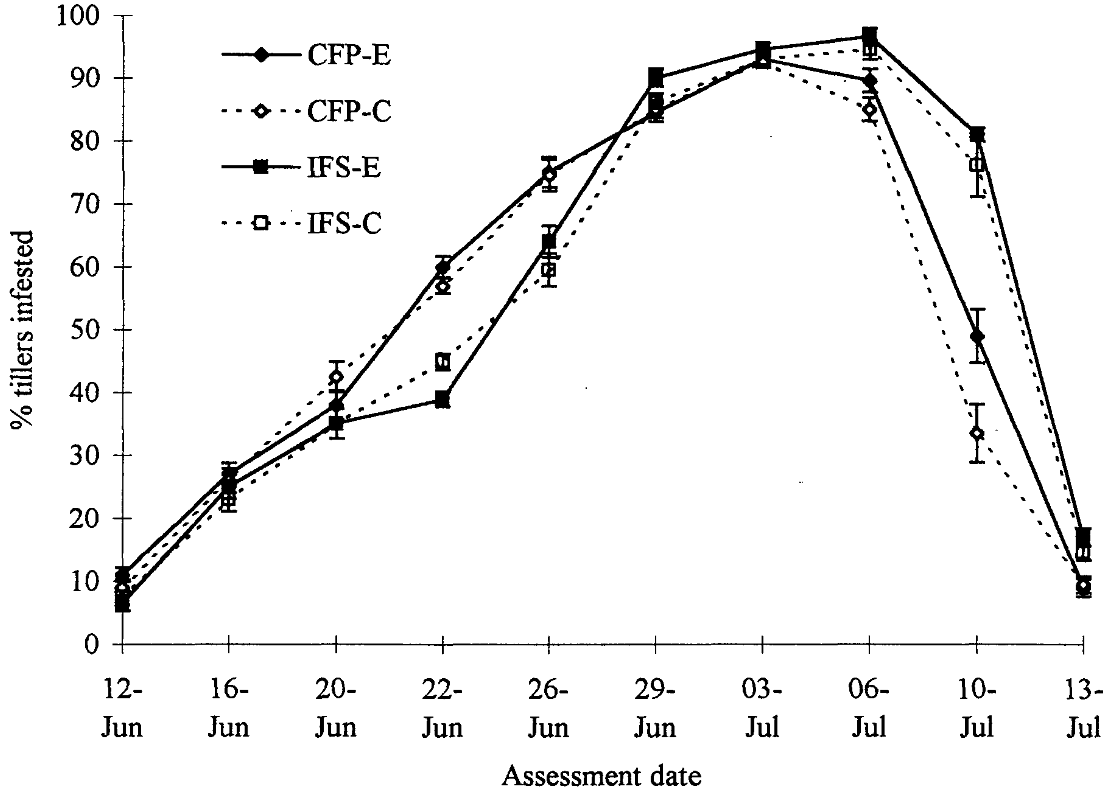


Figure 5b. Mean number of aphids per tiller for the enclosed (E) and control (C) areas in the IFS and CFP plots during 1995

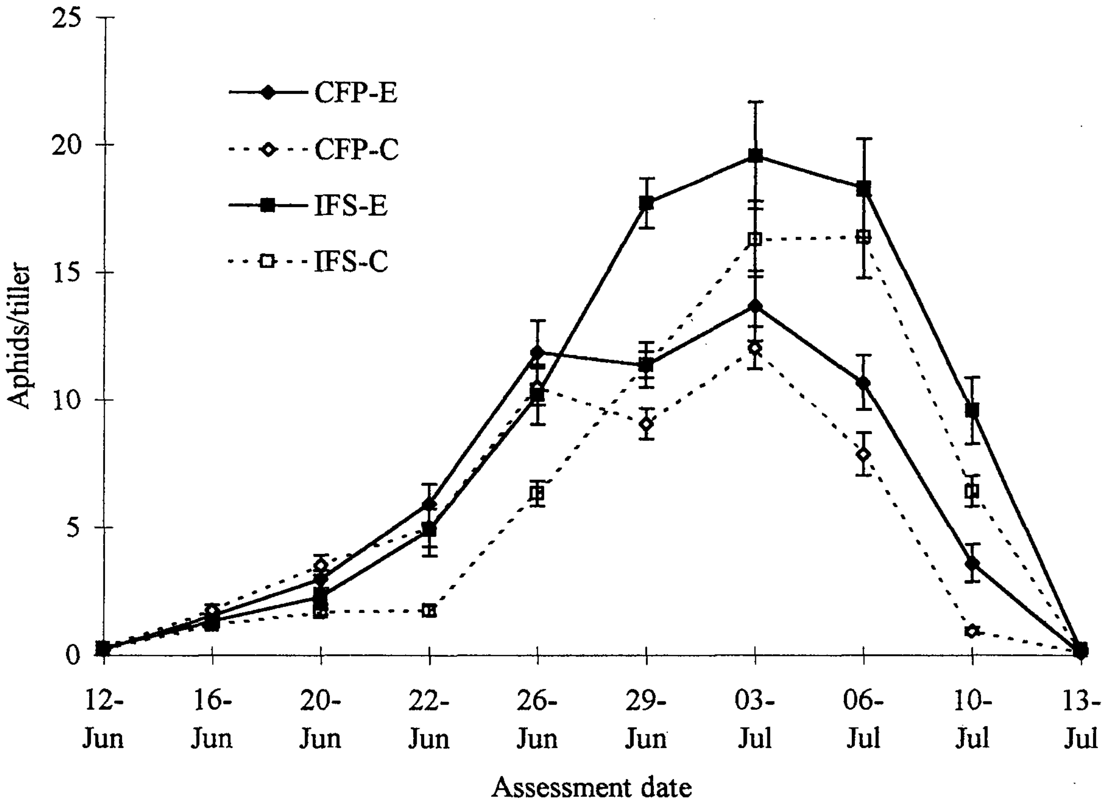


Figure 6. Relationship between number OWBM larvae per ear and the proportion of ears infested during 1995 ($y=96.4x+22.5$)

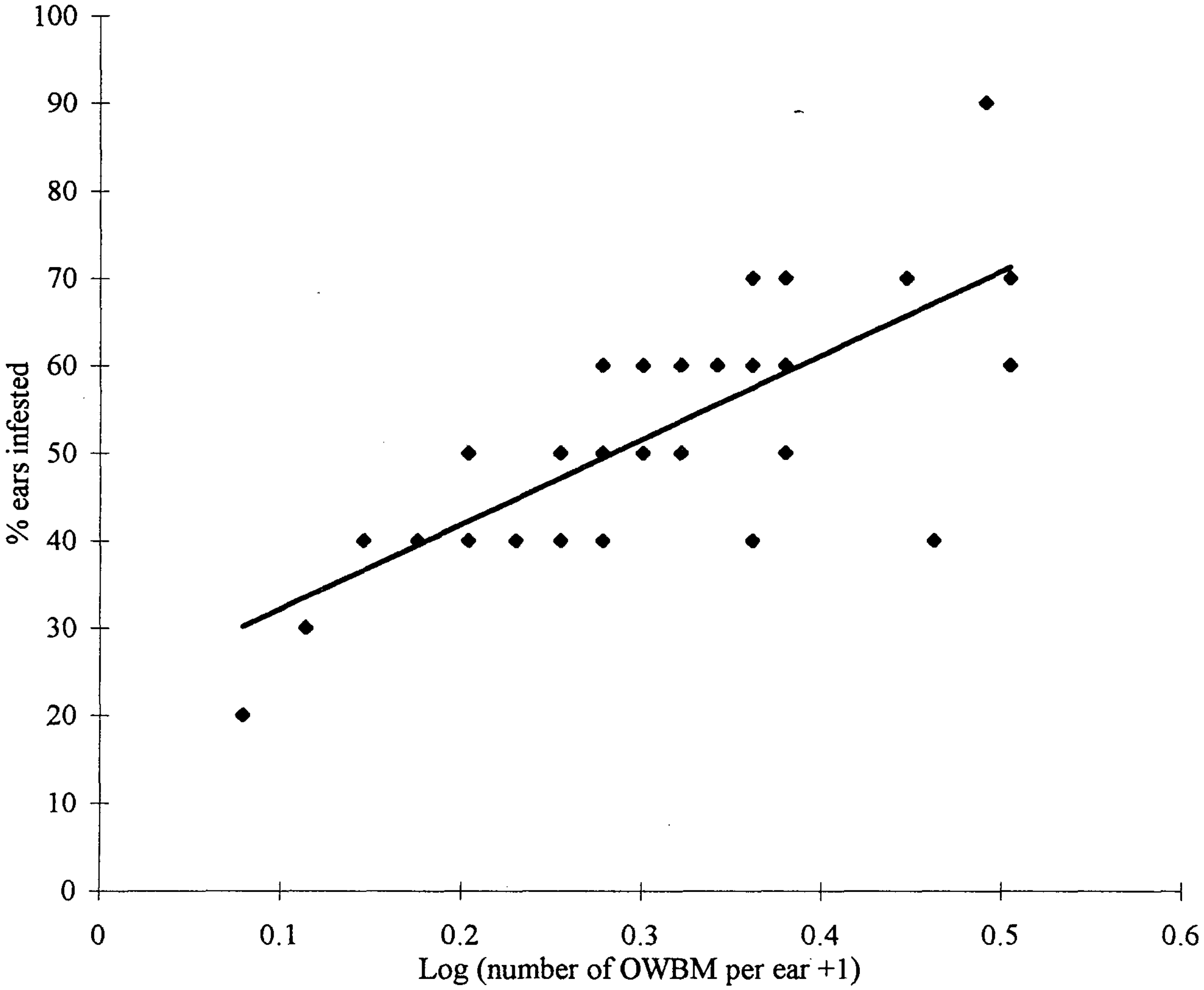


Figure 7a. Relationship between total aphids and marked ear dry weight for field 1, cv. Tonic.

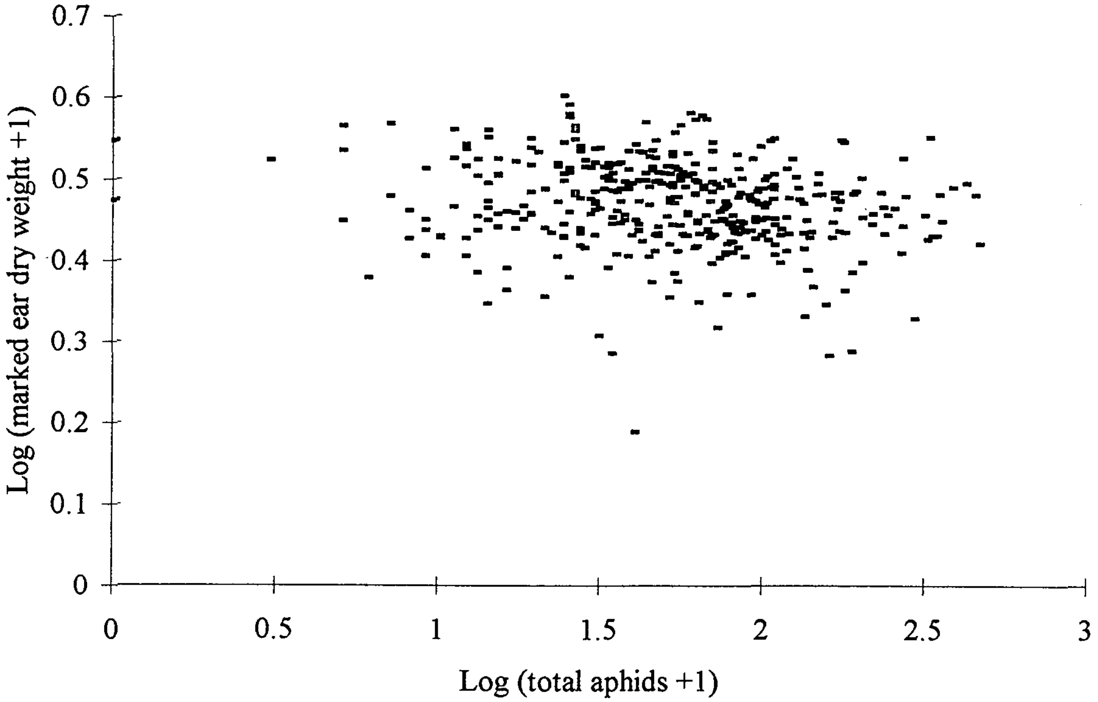


Figure 7b. Relationship between total aphids and marked ear dry weight for field 2, cv. Spark.

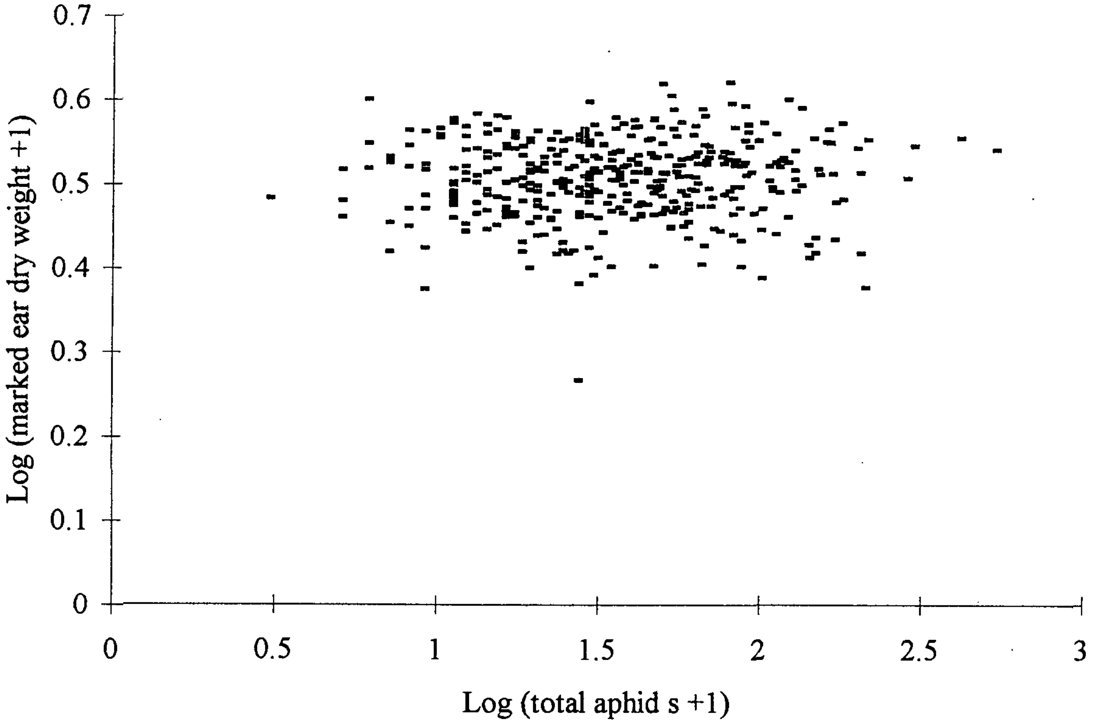


Figure 8a. Relationship between mean total aphids and grain yield per m2 for each area in field 1, cv. Tonic.

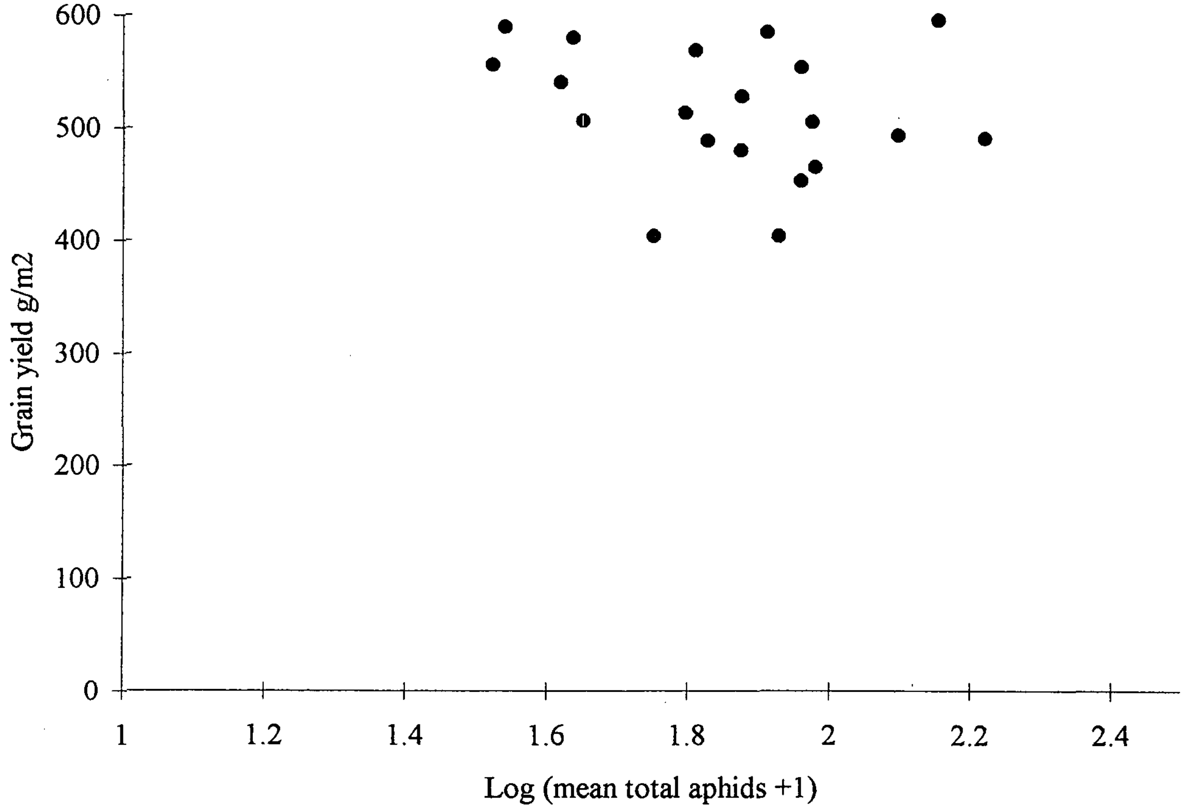


Figure 8b. Relationship between mean total aphids and grain yield per m2 for each area in field 2, cv. Spark.

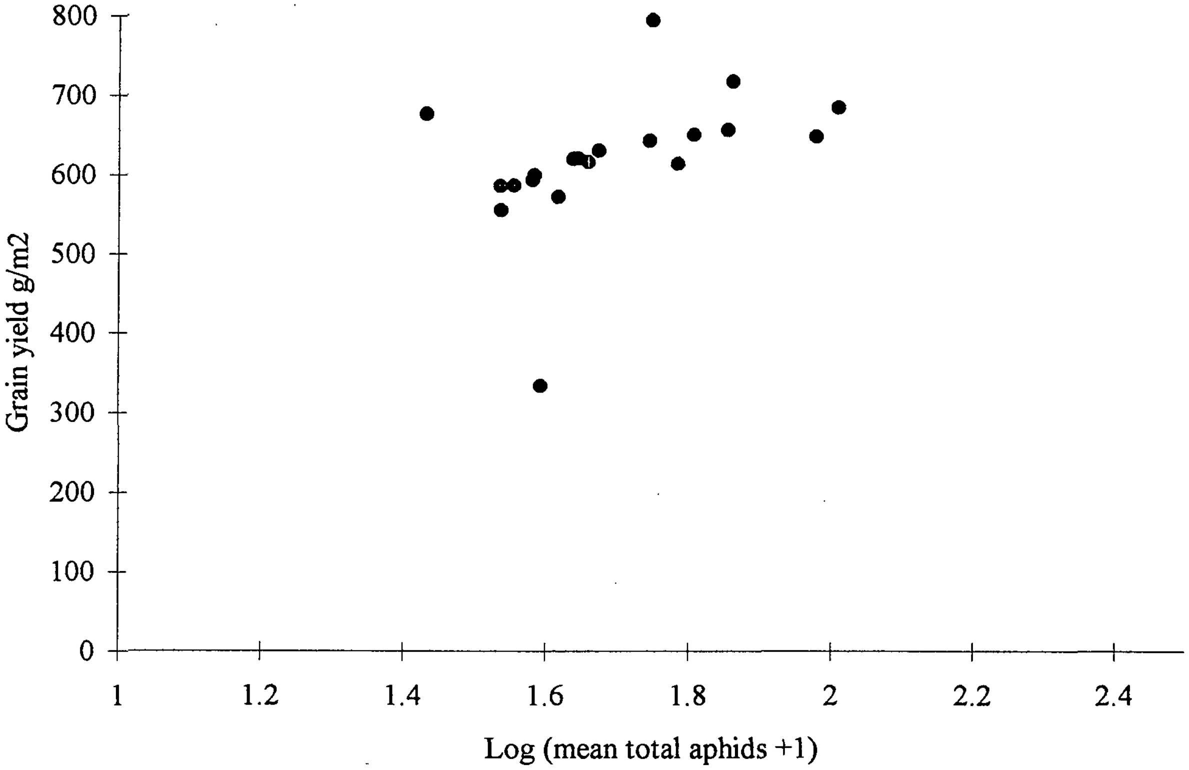


Figure 9a. Relationship between mean total aphids and mean grain dry weight in each area for field 1, cv. Tonic (y=-0.46x+2.82)

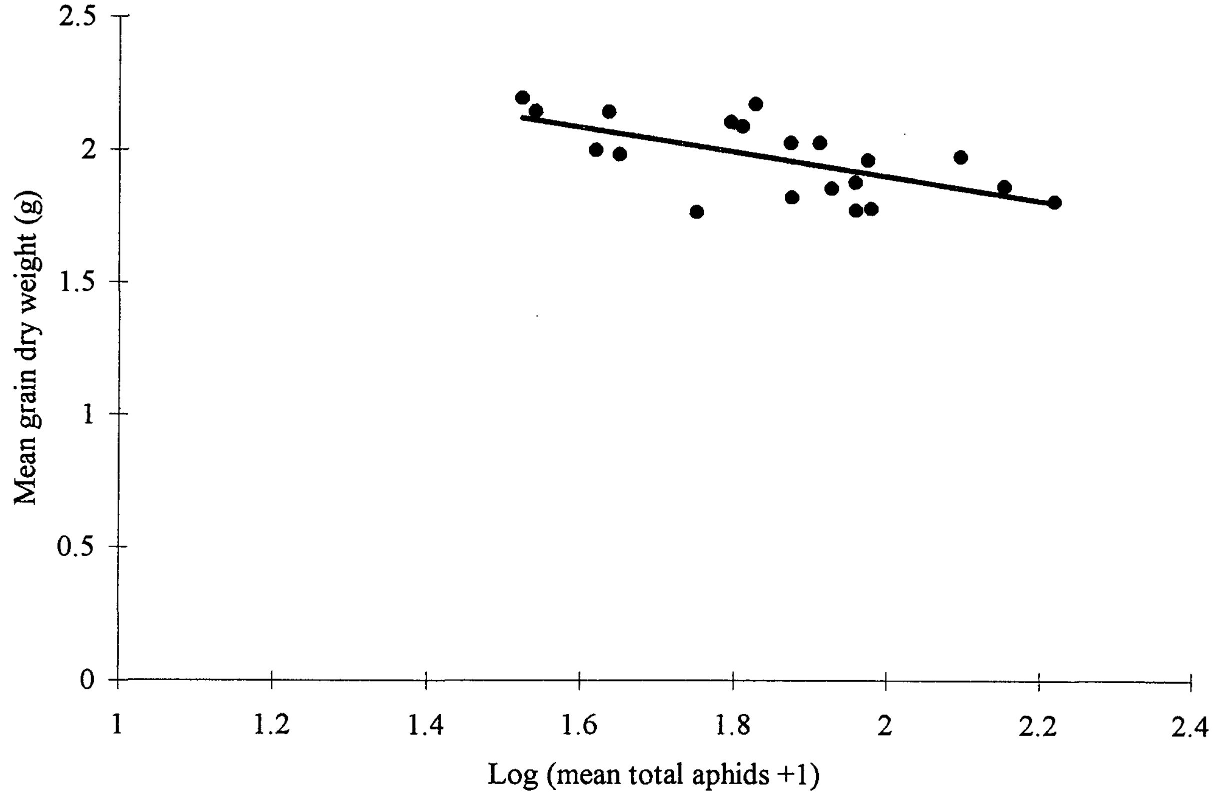


Figure 9b. Relationship between mean total aphids and hectolitre weight in each area for field 1, cv. Tonic (y=-5.52x+89.6)

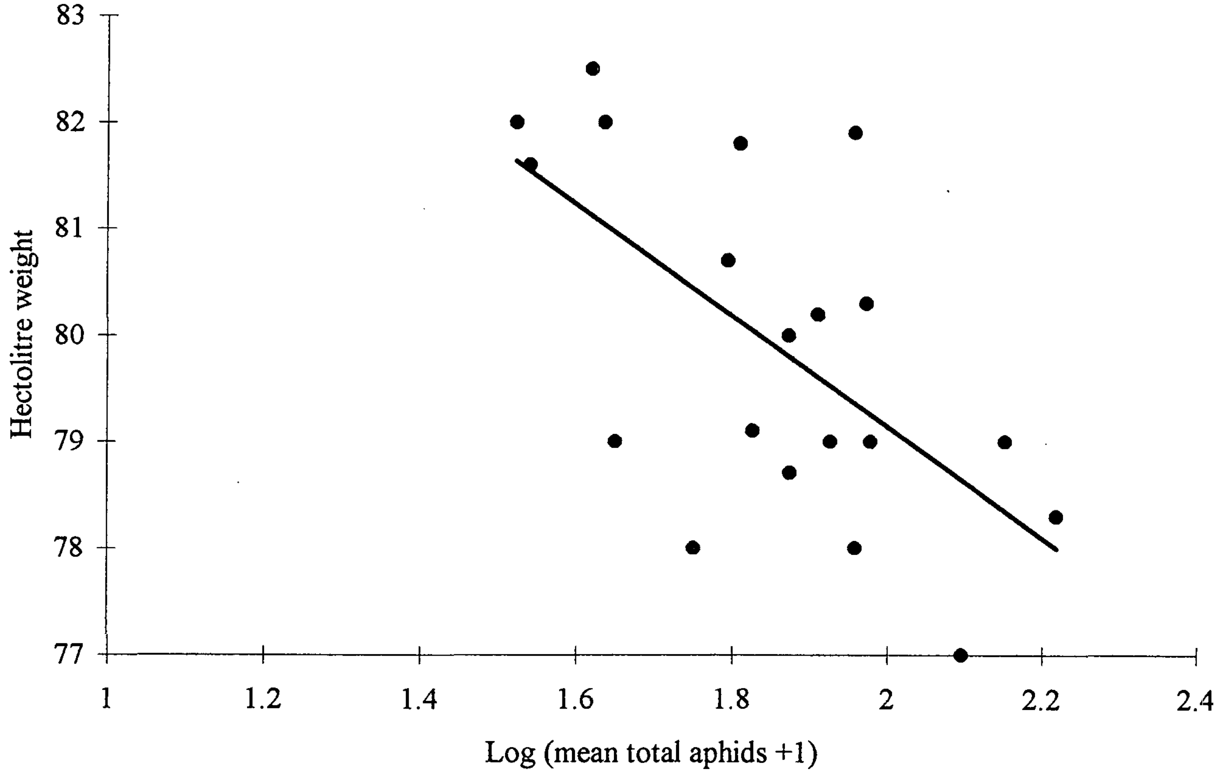


Figure 10a. Relationship between aphid peak and mean grain dry weight for field 1, cv. Tonic (y=-0.08x+2.15)

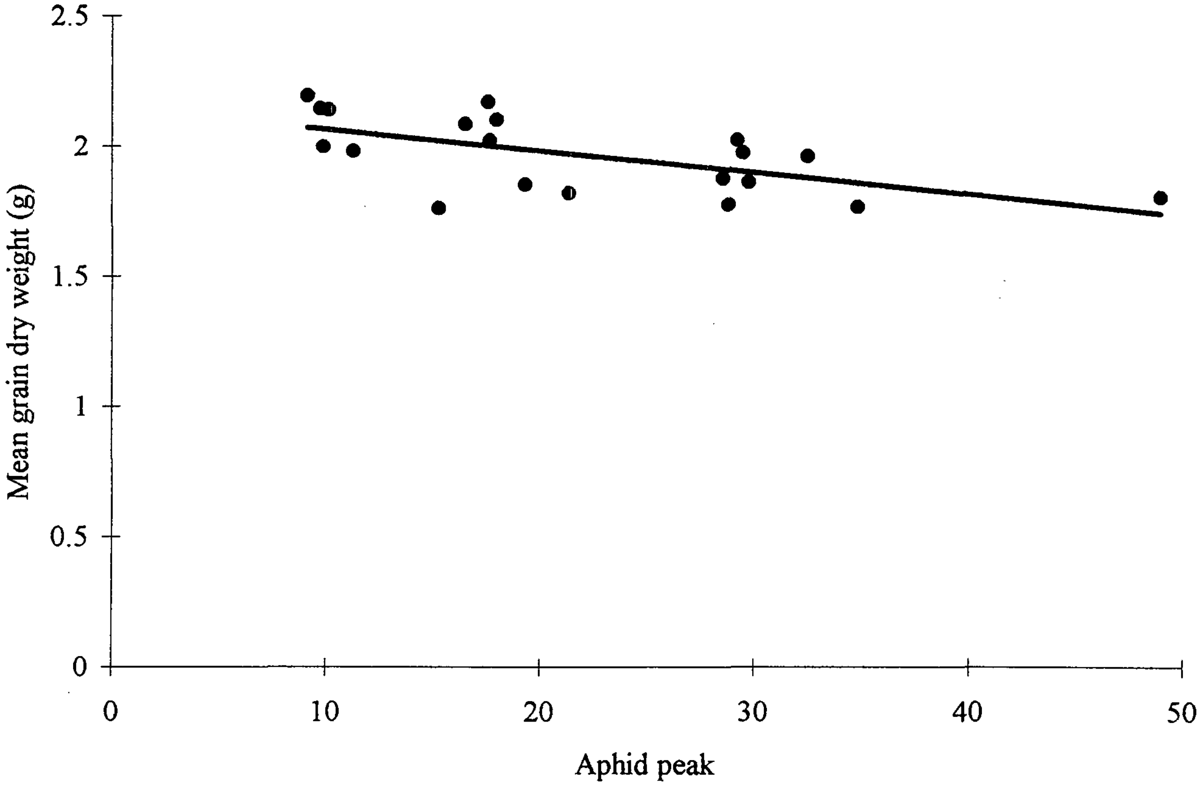


Figure 10b. Relationship between aphid peak and hectolitre weight for field 1, cv. Tonic (y=-0.08x+8.17)

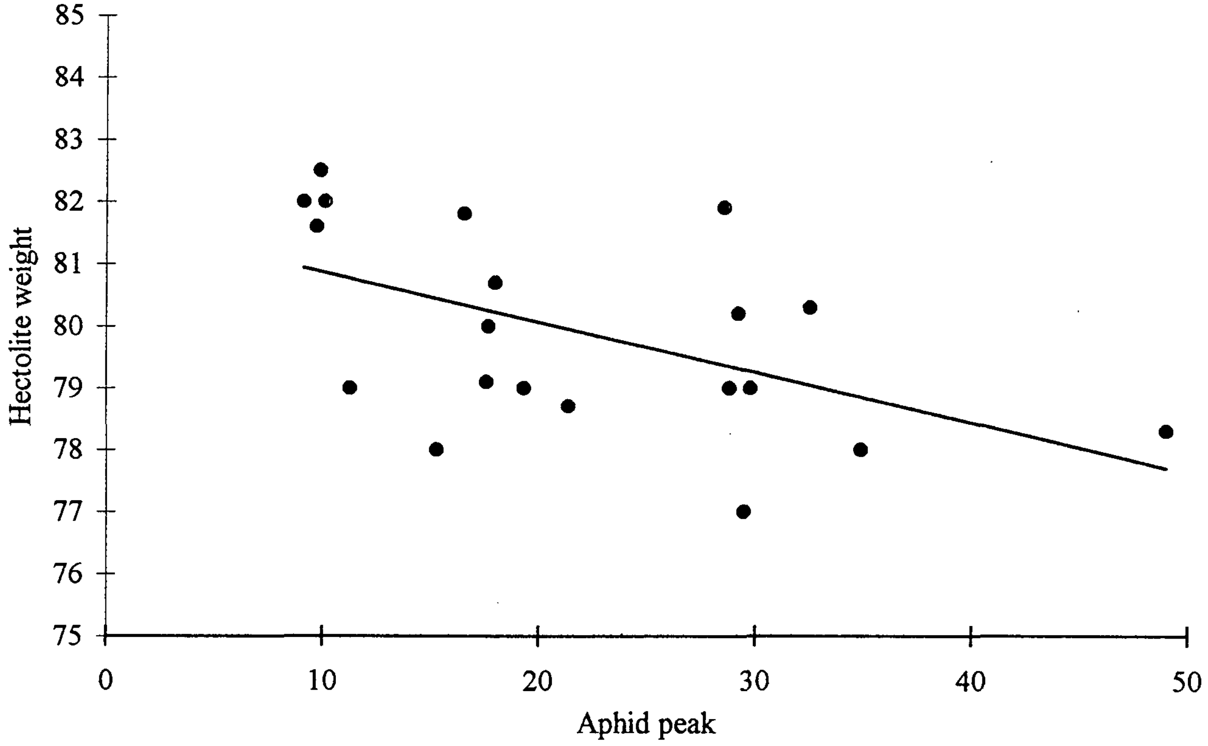


Figure 11. Mean number of Carabidae per pitfall trap in the enclosed (E) and control (C) areas for the IFS and CFP plots in 1995

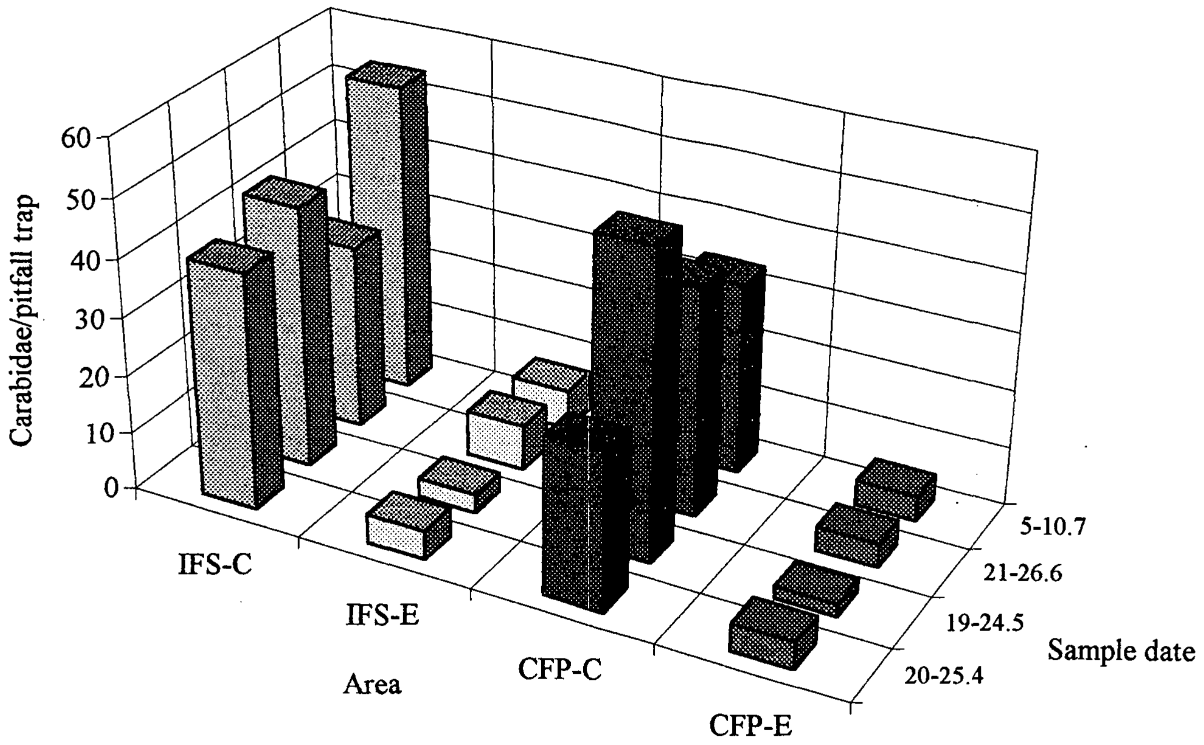


Figure 12. Mean number of Staphylinidae per pitfall trap in the enclosed (E) and control (C) areas for the IFS and CFP plots in 1995

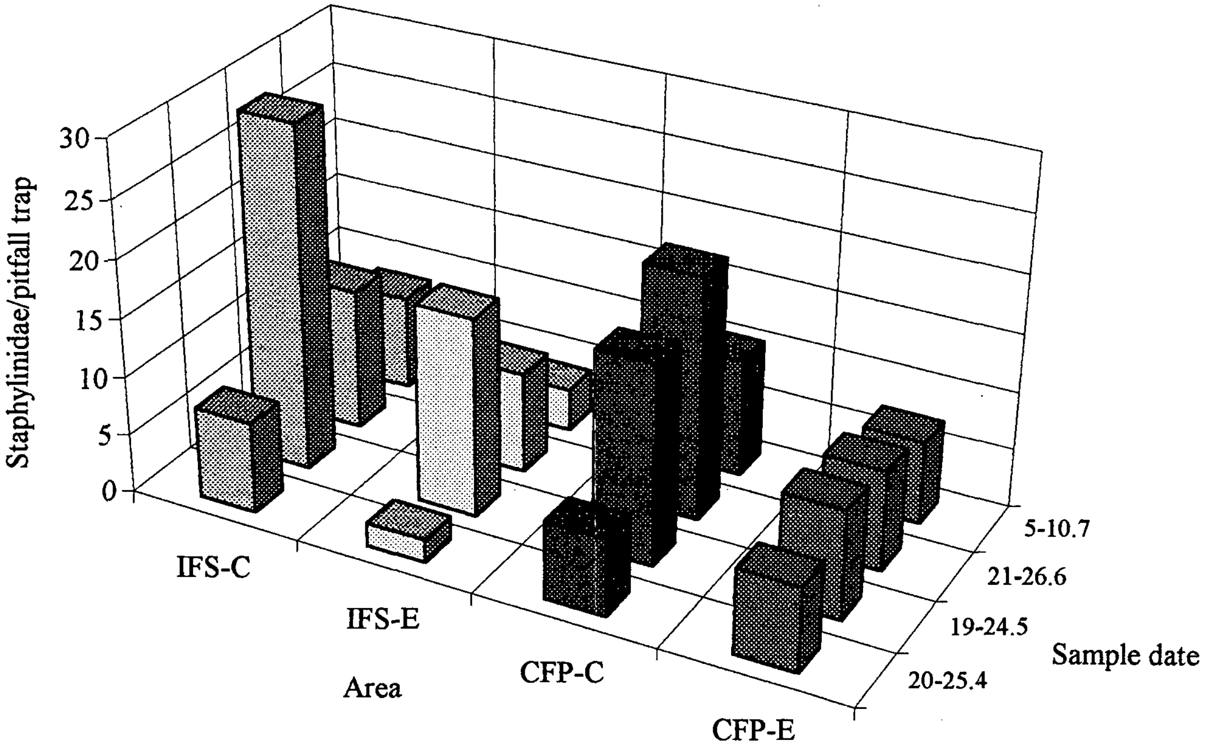


Figure 13. Mean number of Araneae per pitfall trap in the enclosed (E) and control (C) areas for the IFS and CFP plots in 1995.

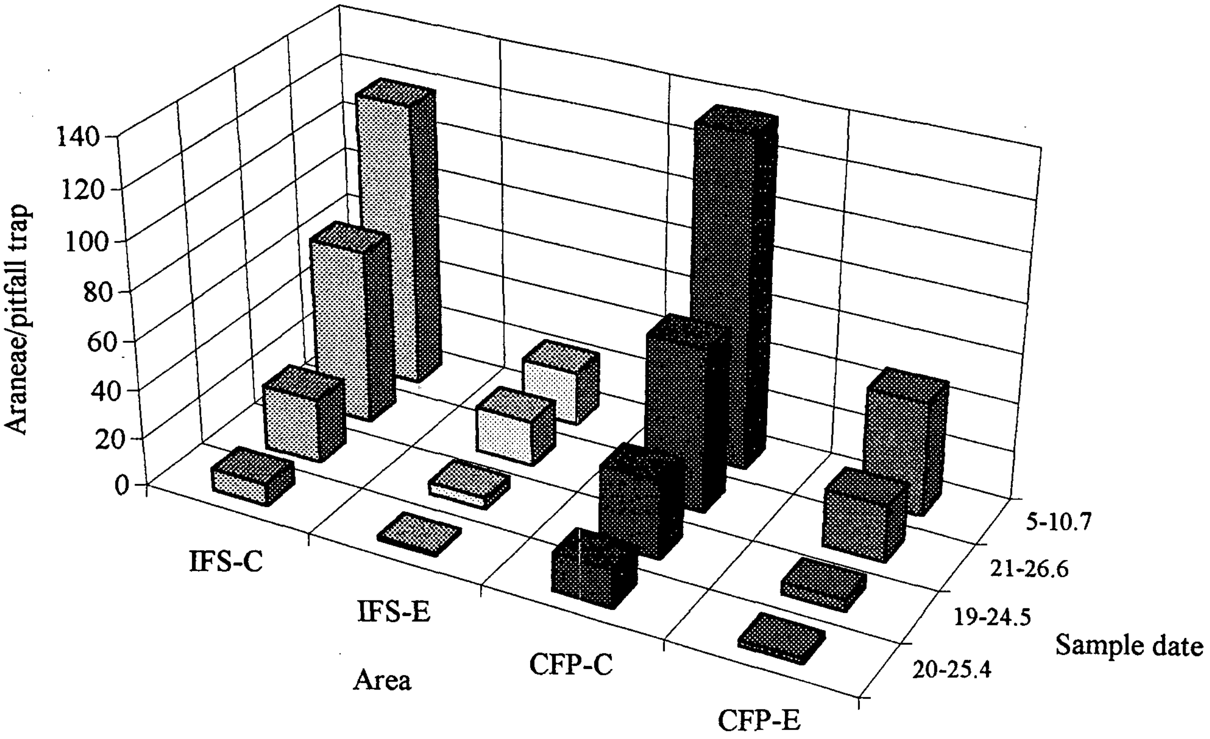


Figure 14a. Relationship between total number of Carabidae captured in the pitfall traps and total aphids per tiller for each enclosed and control area in 1995 (y=-0.20x+2.12)

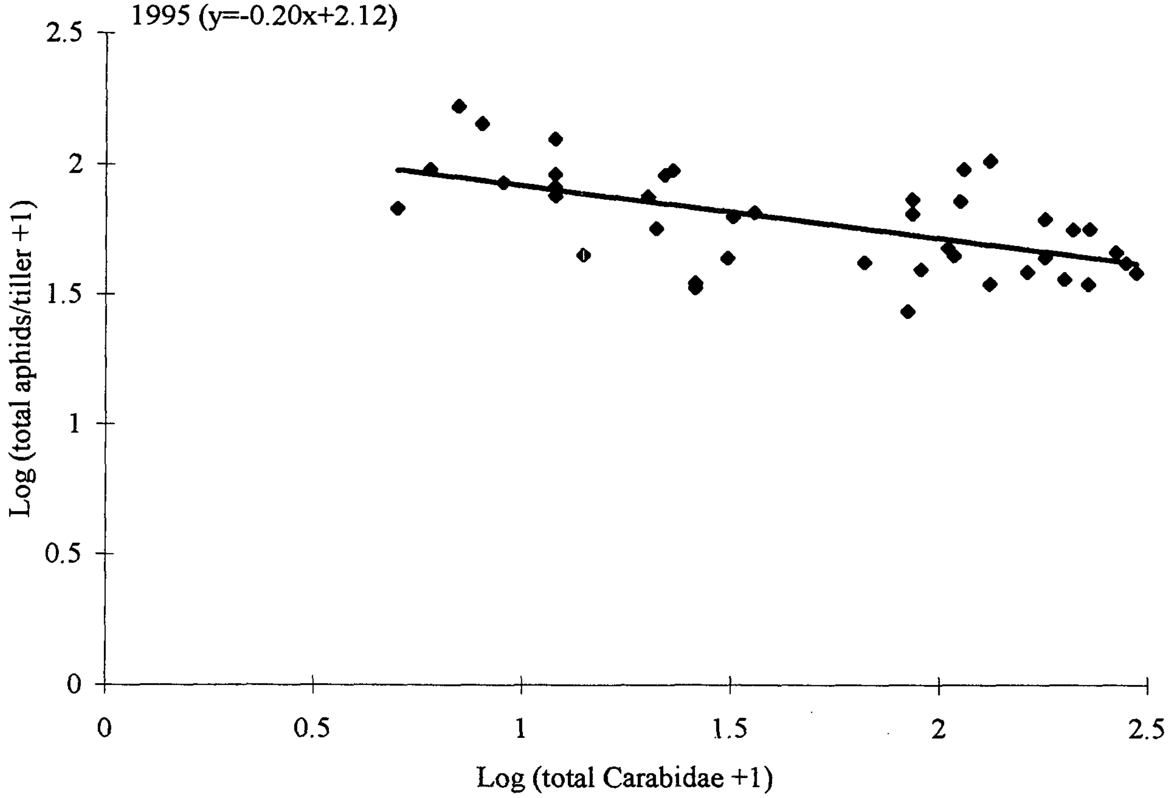


Figure 14b. Relationship between total number of Carabidae captured in the pitfall traps and aphid peak for each enclosed and control area in 1995 (y=-0.16x+1.53)

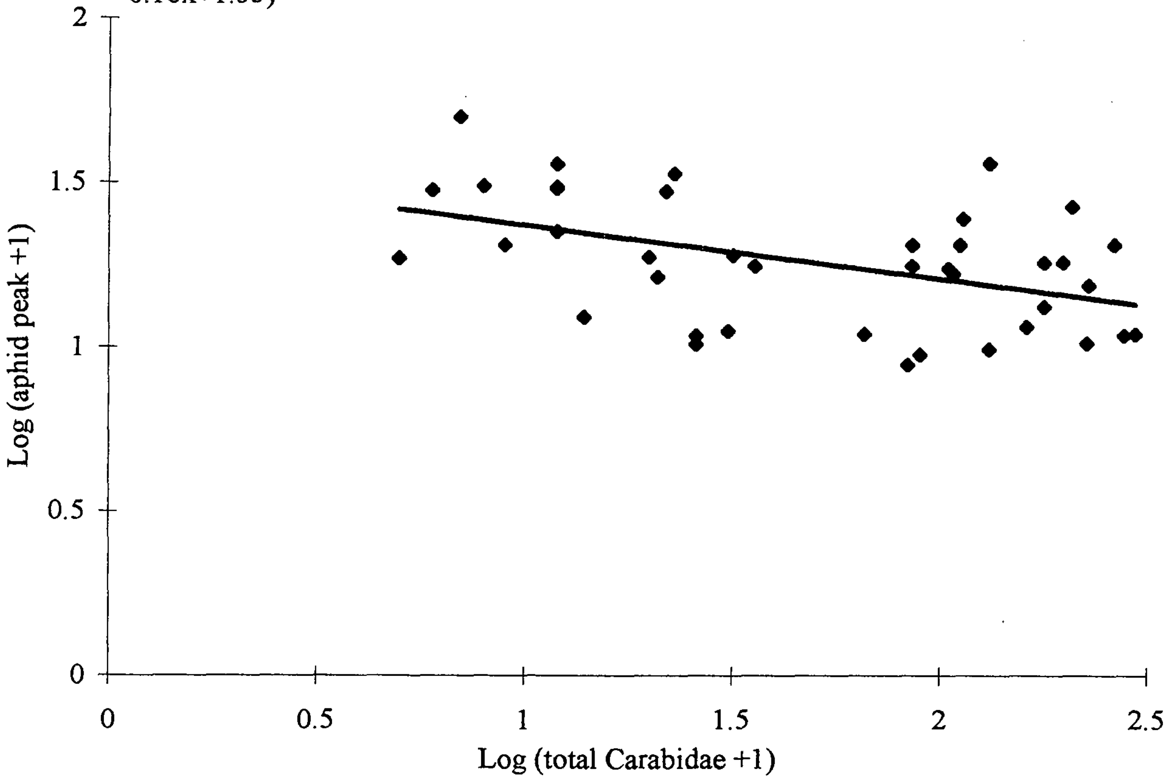


Figure 15. Mean number of Carabidae from fenced pitfall traps in the enclosed (E) and control (C) areas for the IFS and CFP plots in 1995

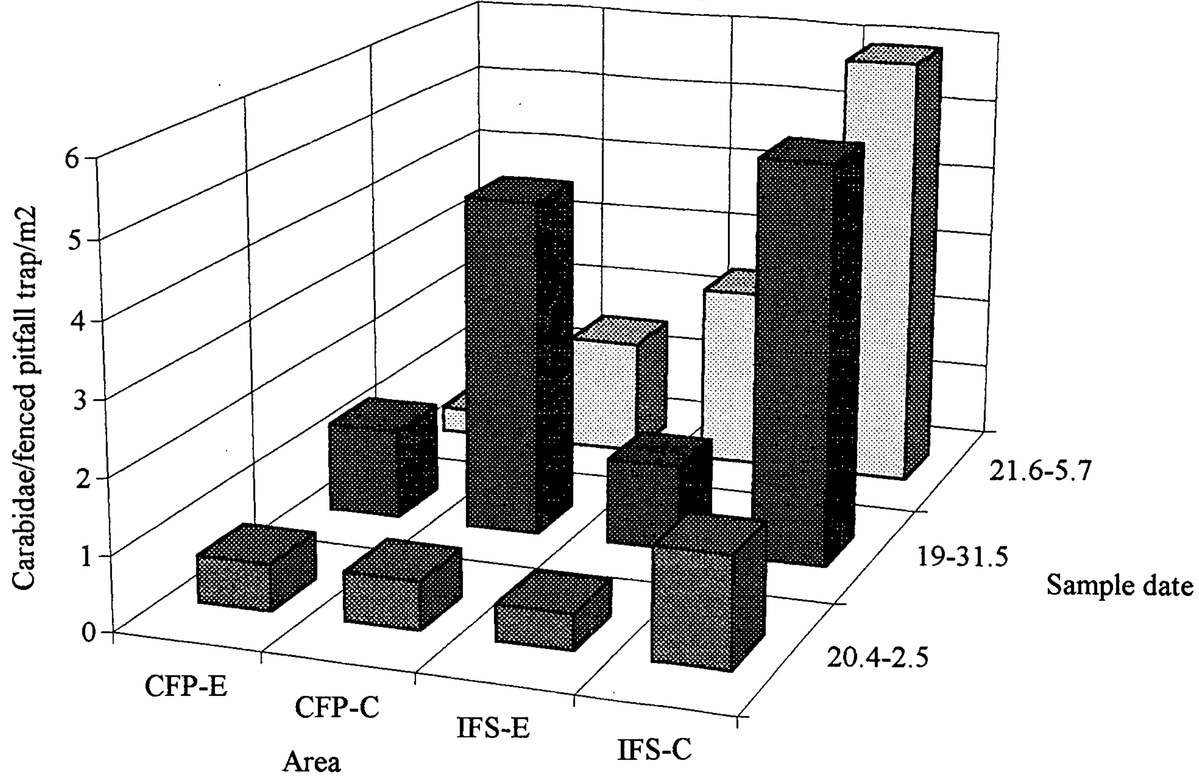


Figure 16. Mean number of Staphylinidae from the fenced pitfall traps in the enclosed (E) and control (C) areas for the IFS and CFP plots in 1995

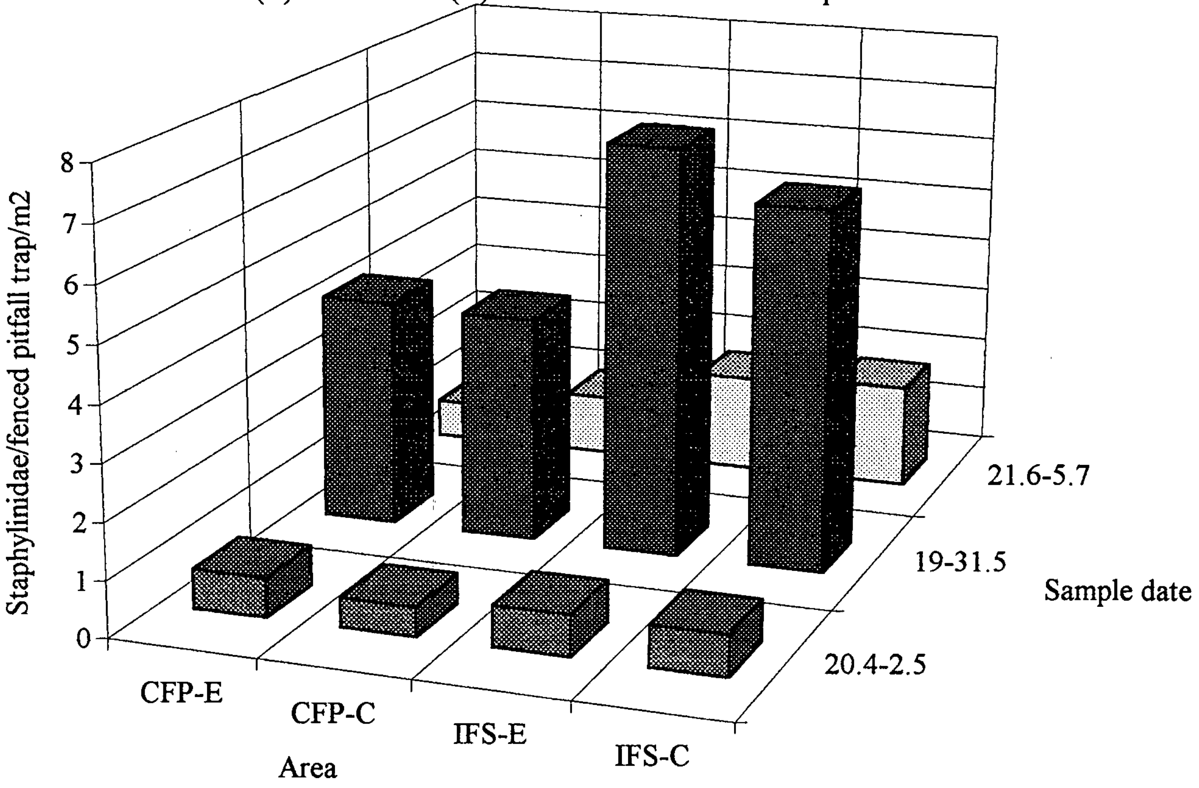


Figure 17. Mean number of Araneae from the fenced pitfall traps in the enclosed (E) and control (C) areas for the IFS and CFP plots in 1995

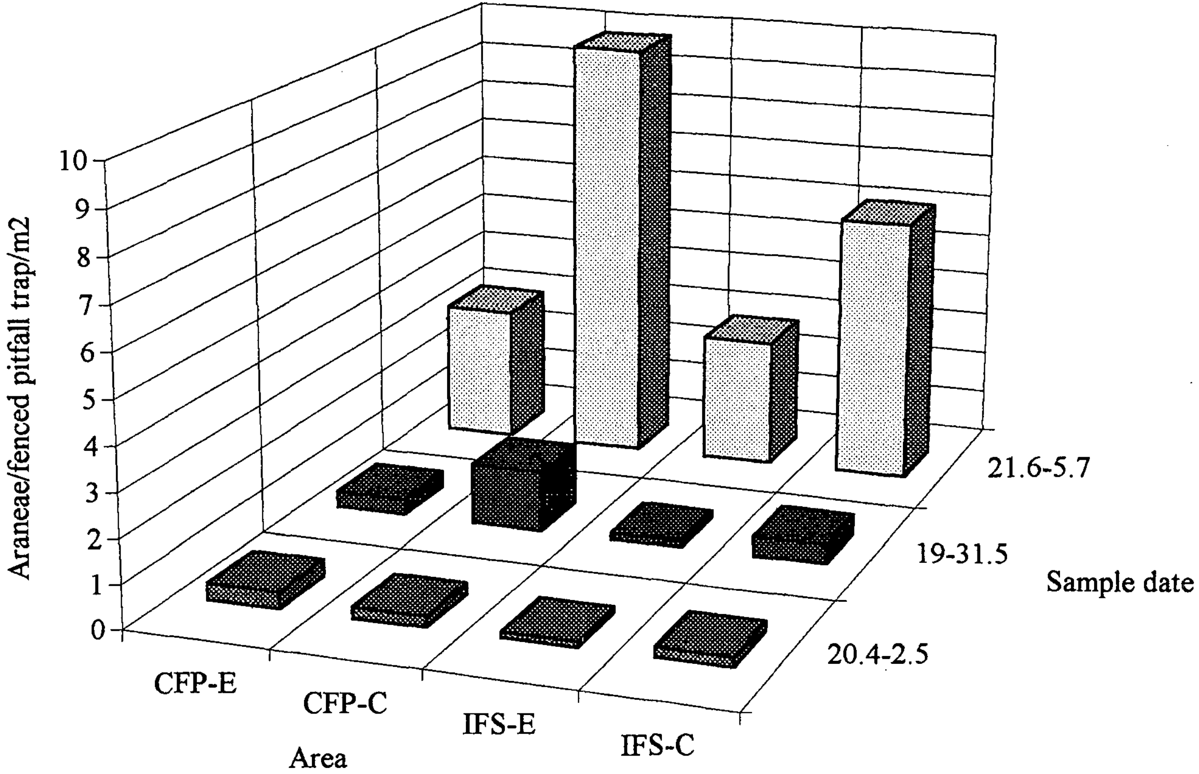


Figure 18a. Relationship between total number of Araneae captured in the fenced pitfall traps and total aphids per tiller for each enclosed and control area in 1995 (y=-0.31x+2.18)

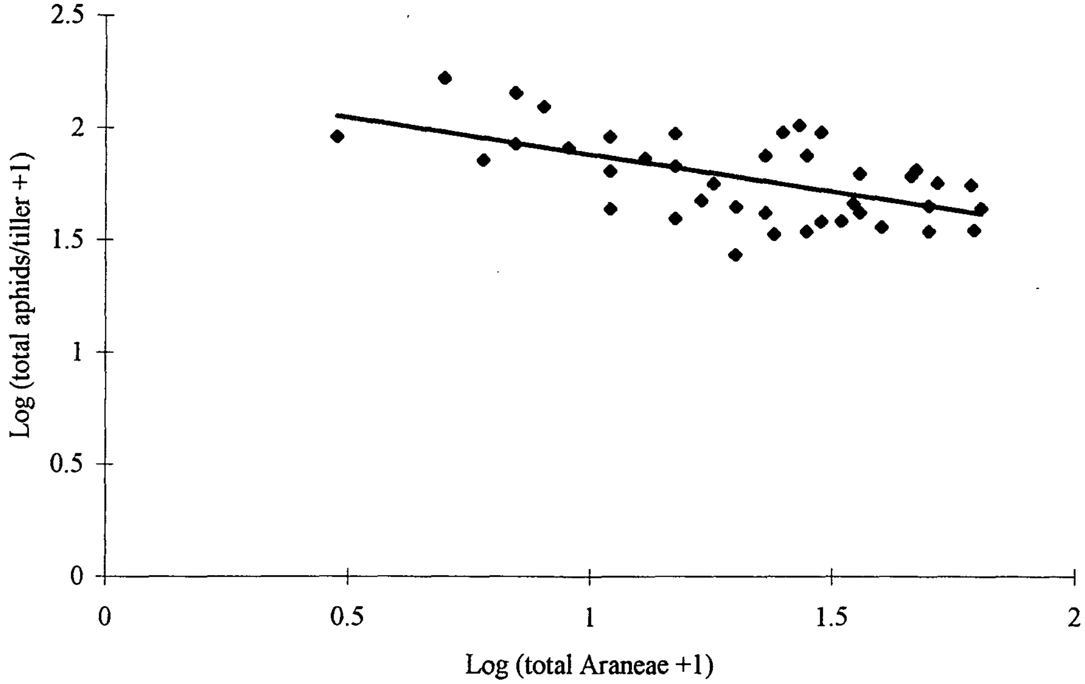


Figure 18b. Relationship between total number of Araneae captured in the fenced pitfall traps and aphid peak for each enclosed and control area in 1995 (y=-0.25x+2.21)

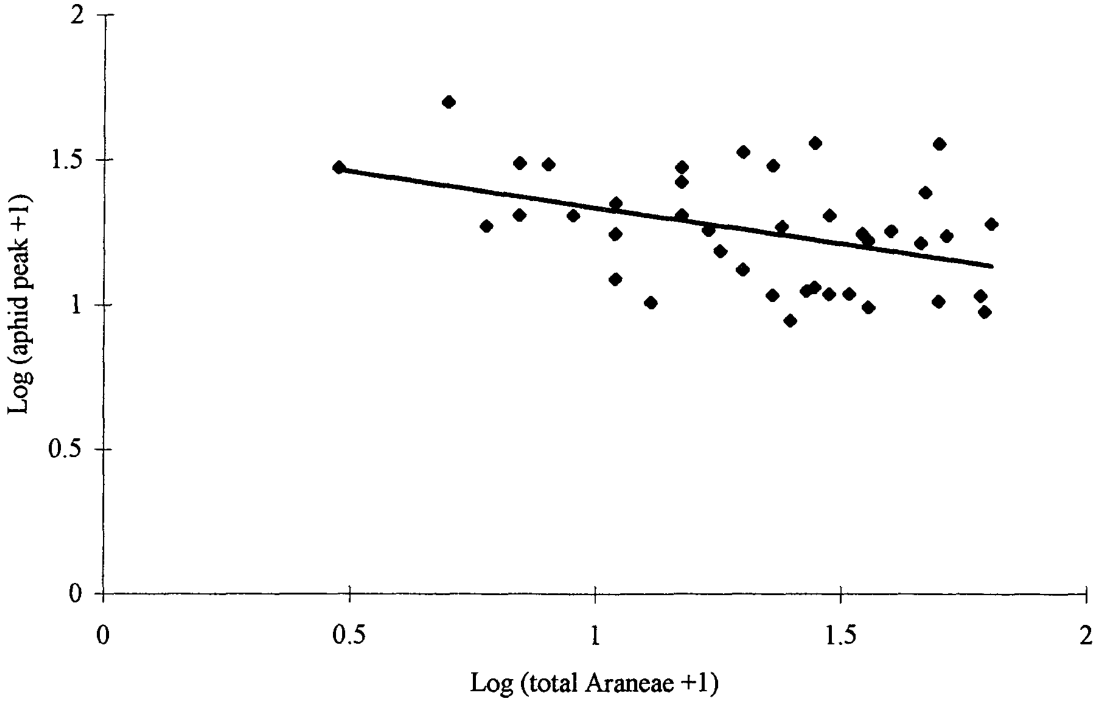


Figure 19. Mean number of Carabidae from the Dvac samples in the enclosed (E) and control (C) areas for the IFS and CFP plots in 1995

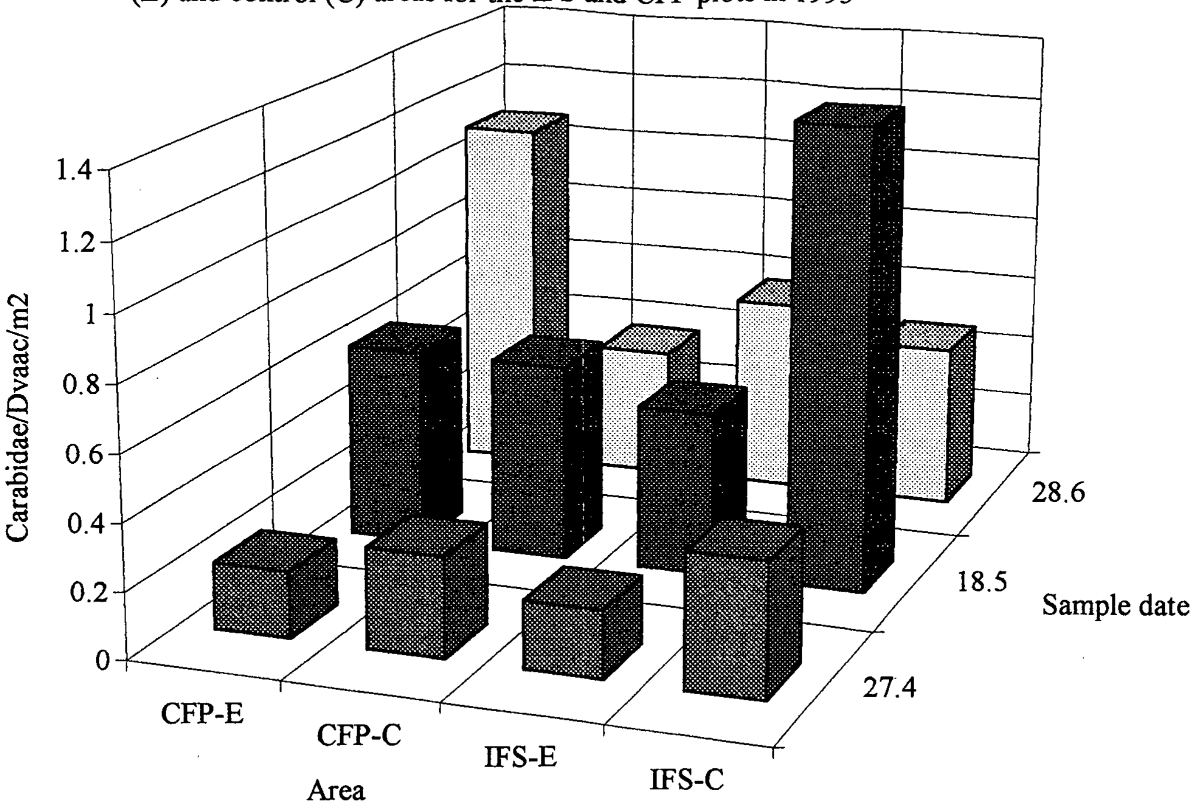


Figure 20. Mean number of Staphylinidae from the Dvac samples in the enclosed (E) and control (C) areas for the IFS and CFP plots in 1995

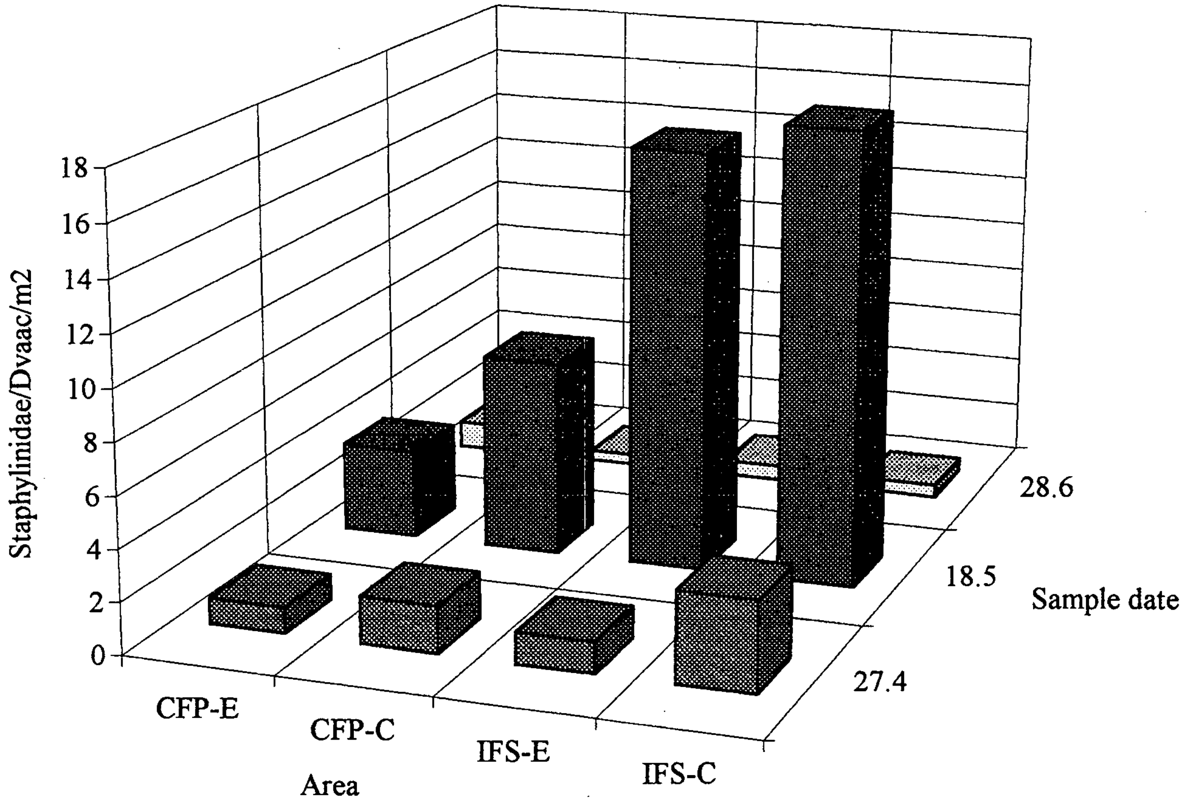


Figure 21. Mean number of Araneae from the Dvac samples in the enclosed (E) and control (C) areas or the IFS and CFP plots in 1995

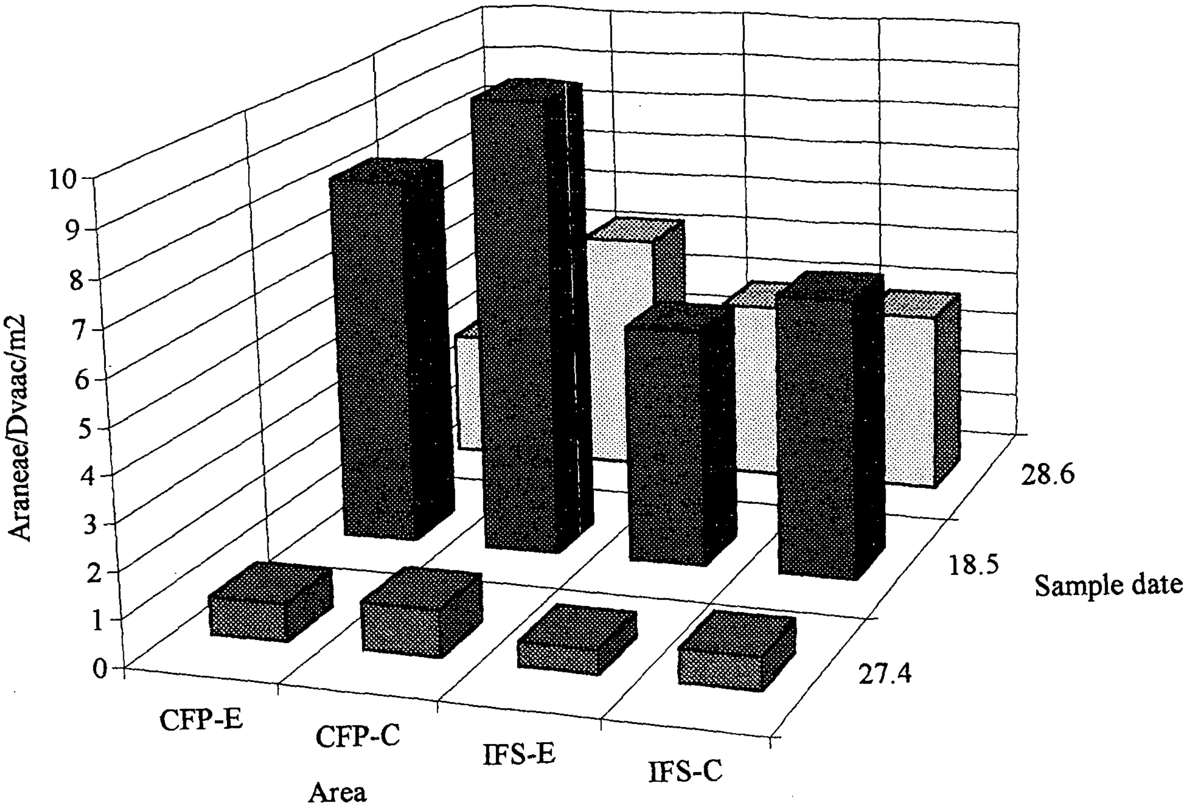


Figure 22a. Relationship between total number of Araneae captured in the Dvac suction samples and total aphids per tiller for each enclosed and control area in 1995 (y=-0.48x+2.29)

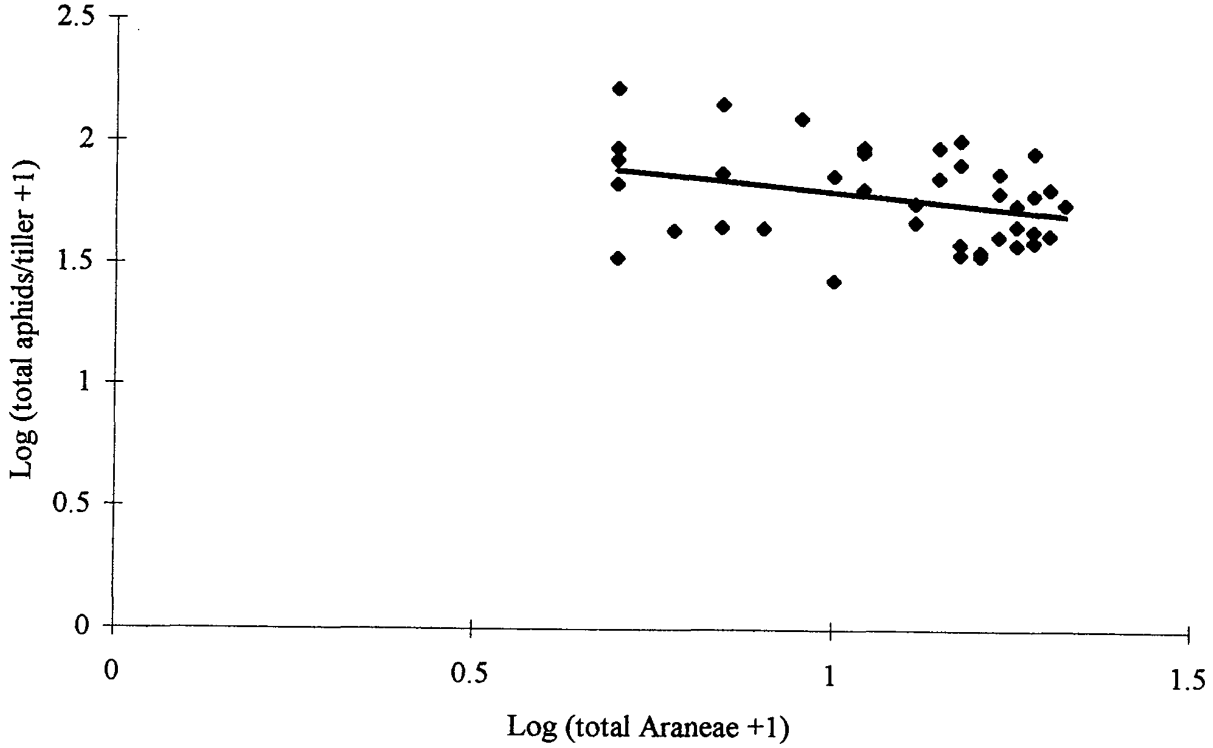


Figure 22b. Relationship between total number of Araneae captured in the Dvac suction samples and the aphid peak for each enclosed and control area in 1995 (y=-0.44x+1.73)

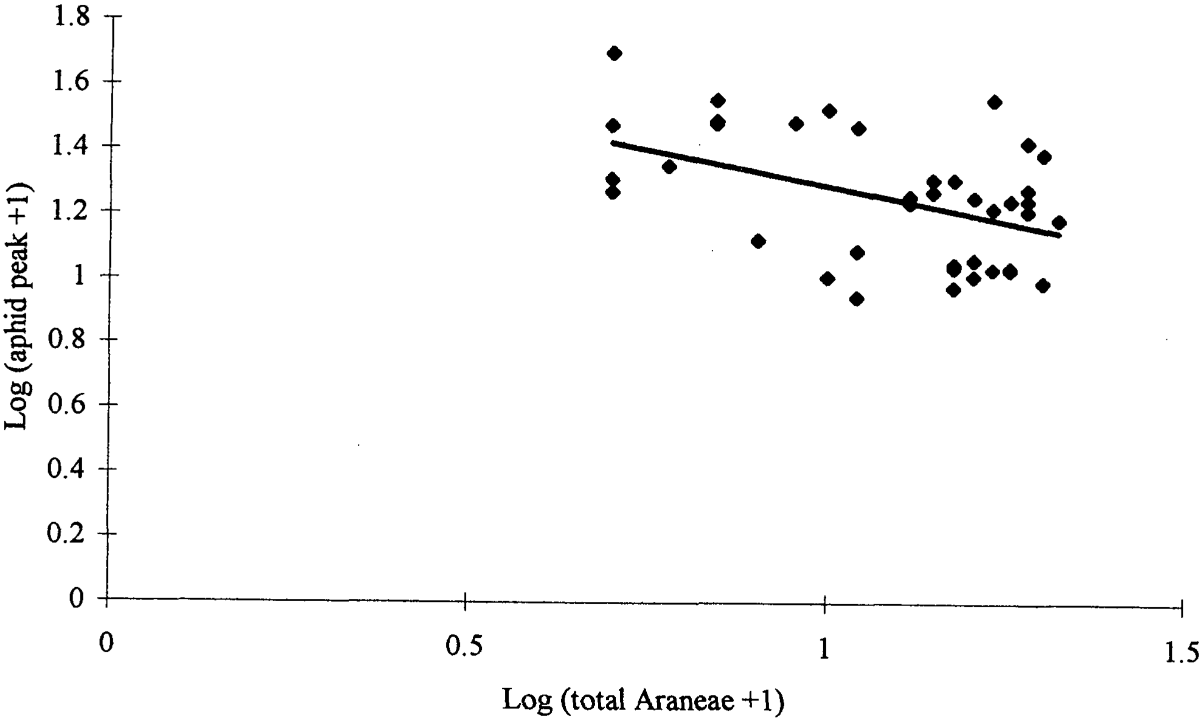


Figure 23a. Percentage of tillers (±SE) infested in enclosed (E) and controll (C) areas in plots 1 and 2 in 1996.

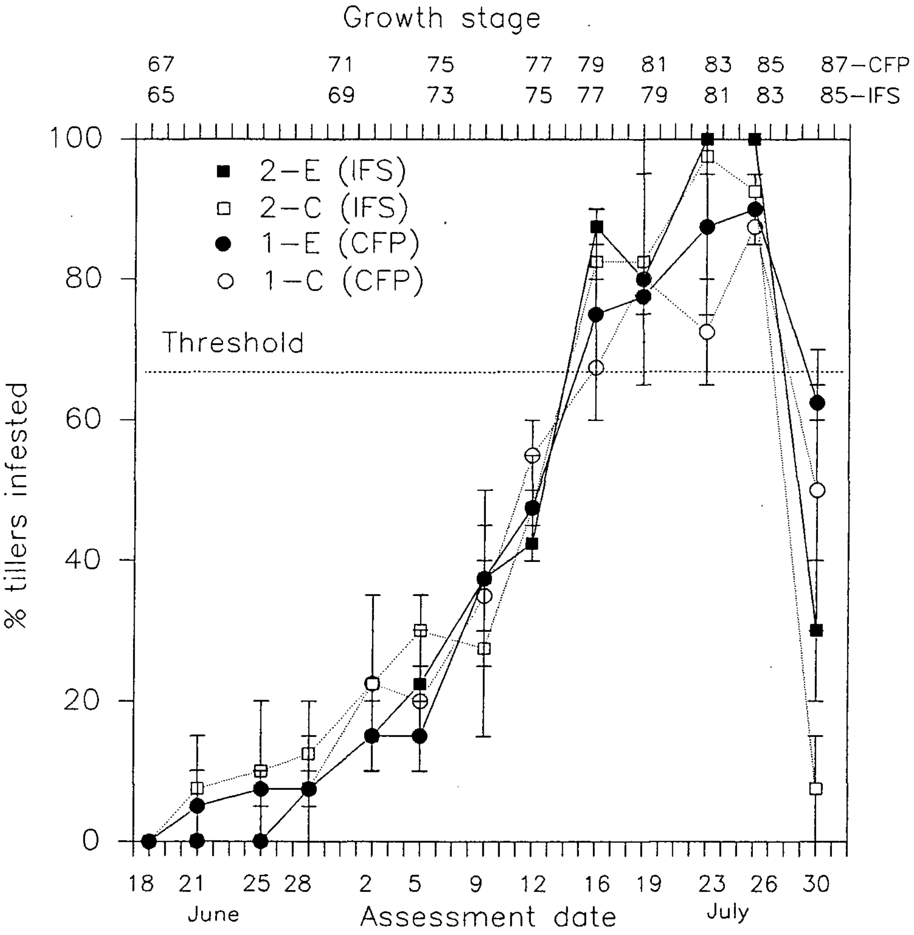


Figure 23b. Percentage of tillers (±SE) infested in enclosed (E) and control (C) areas in plots 3 and 6 in 1996.

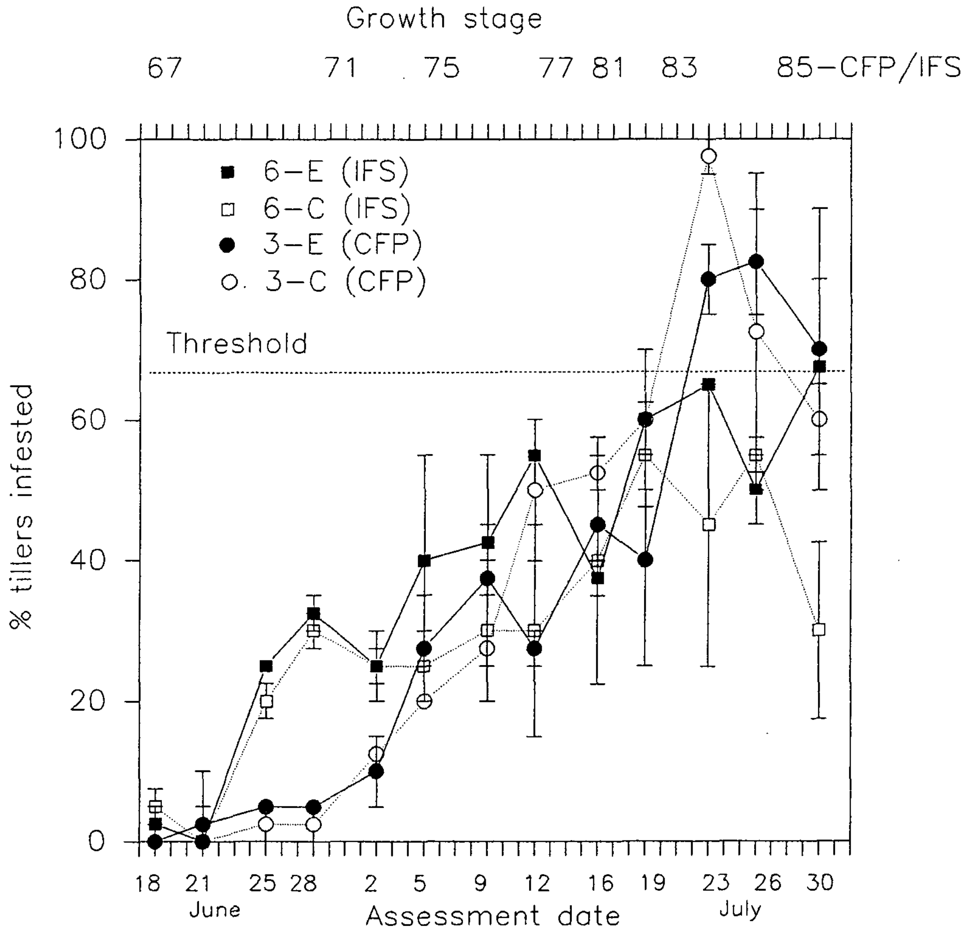


Figure 23c. Percentage of tillers (±SE) infested in enclosed (E) and control (C) areas in plots 4 and 5 in 1996.

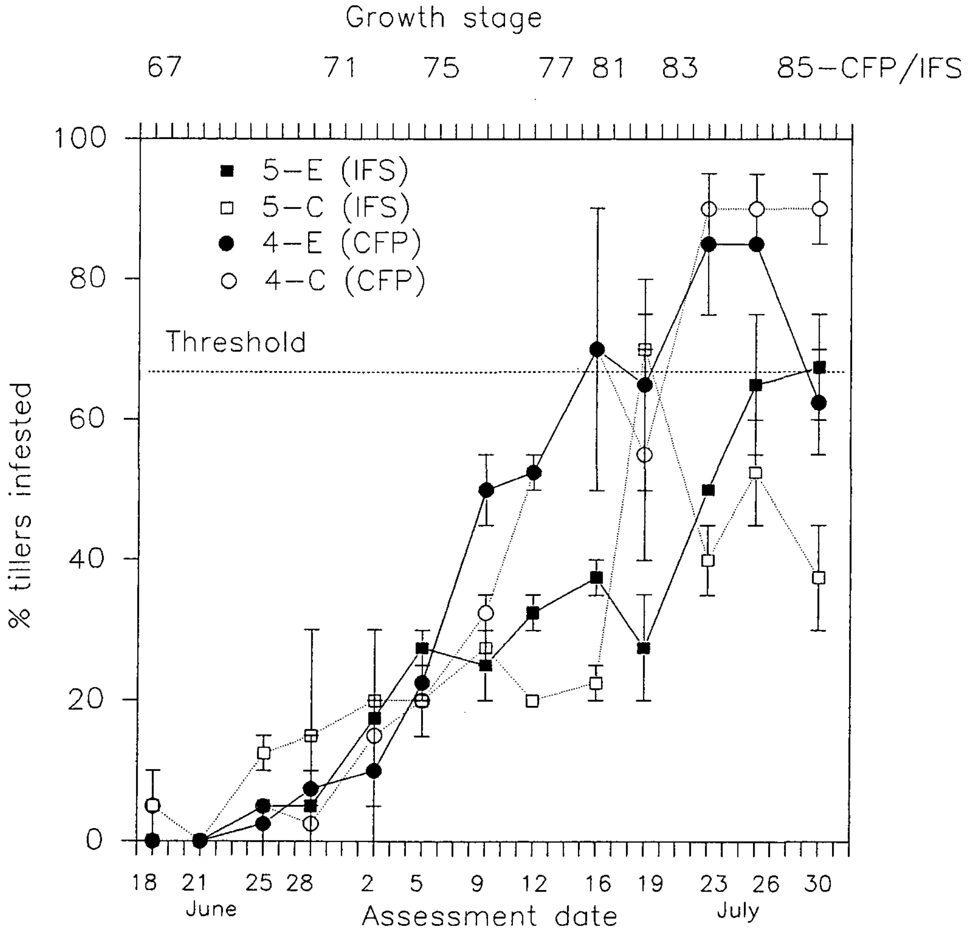


Figure 23d. Percentage of tillers (±SE) infested in enclosed (E) and control (C) areas in plots 7 and 8 in 1996.

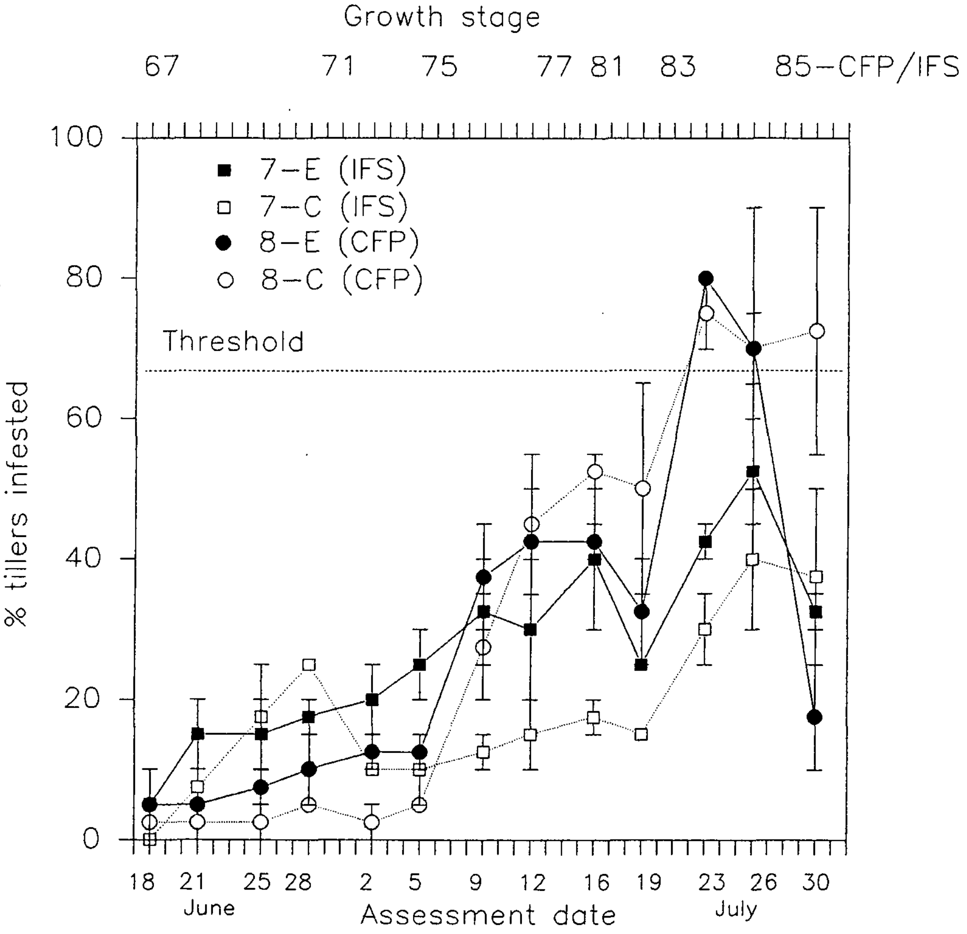


Figure 24a. Mean number of grain aphids per tiller (±SE) in the enclosed (E) and control (C) areas within plots 1 and 2 in 1996..

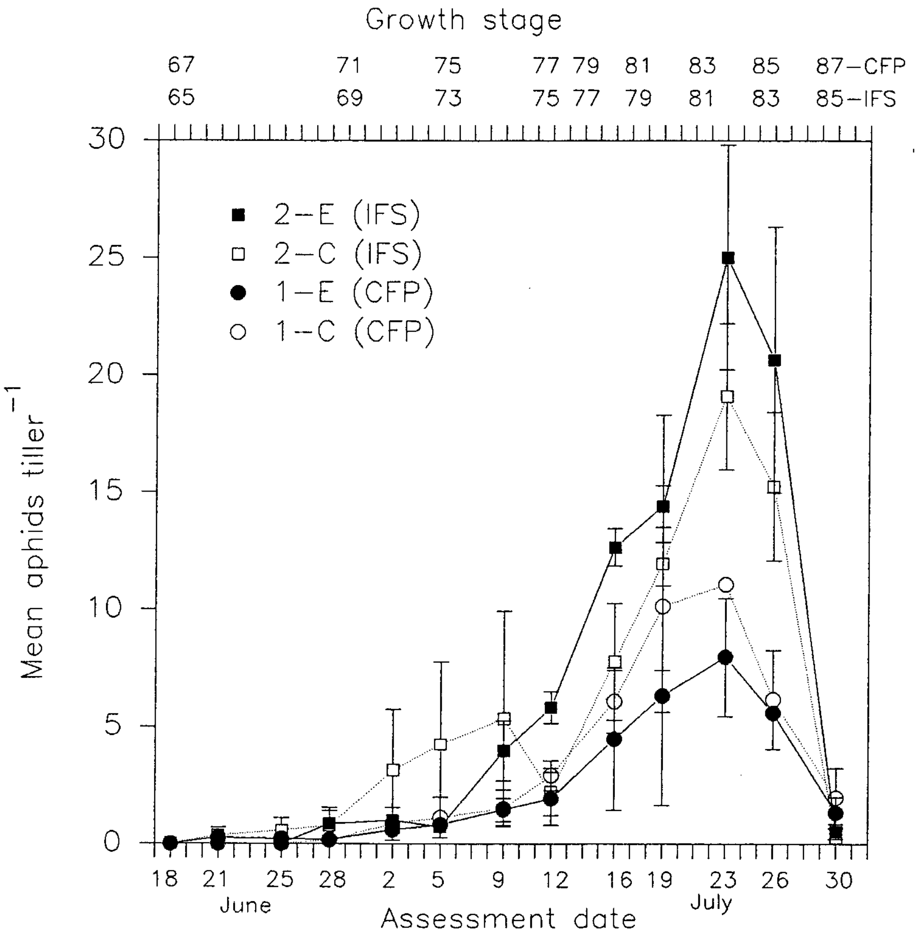


Figure 24b. Mean number of grain aphids per tiller (±SE) in the enclosed (E) and control (C) areas within plots 3 and 6 in 1996.

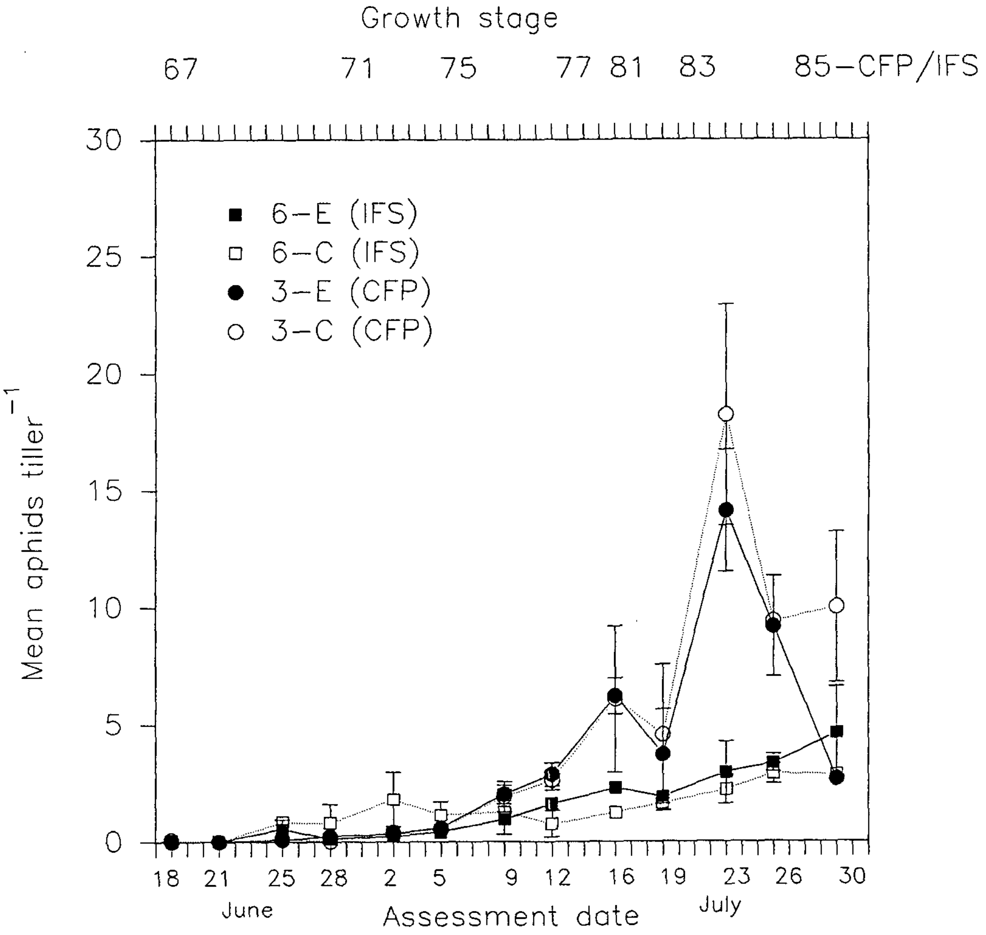


Figure 24c. Mean number of grain aphids per tiller (±SE) in the enclosed (E) and control (C) areas within plots 4 and 5 in 1996.

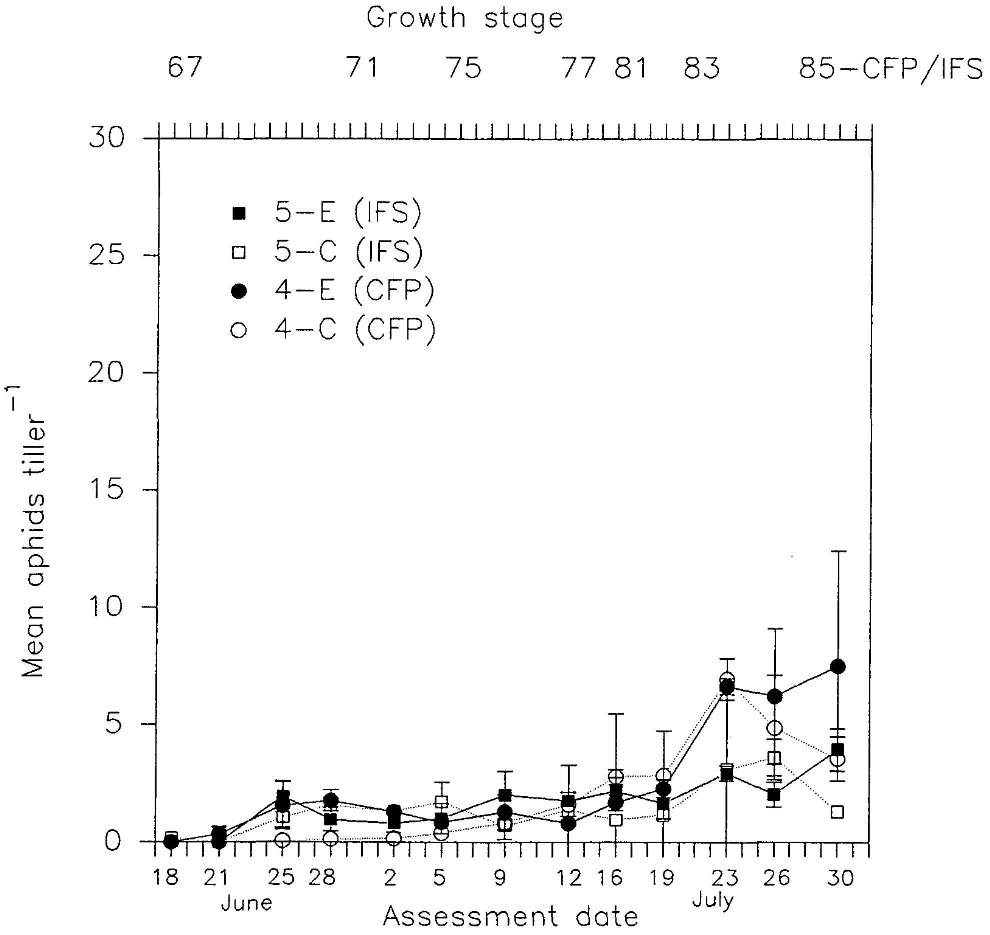


Figure 24d. Mean number of grain aphids per tiller (±SE) in the enclosed (E) and control (C) areas within plots 7 and 8 in 1996.

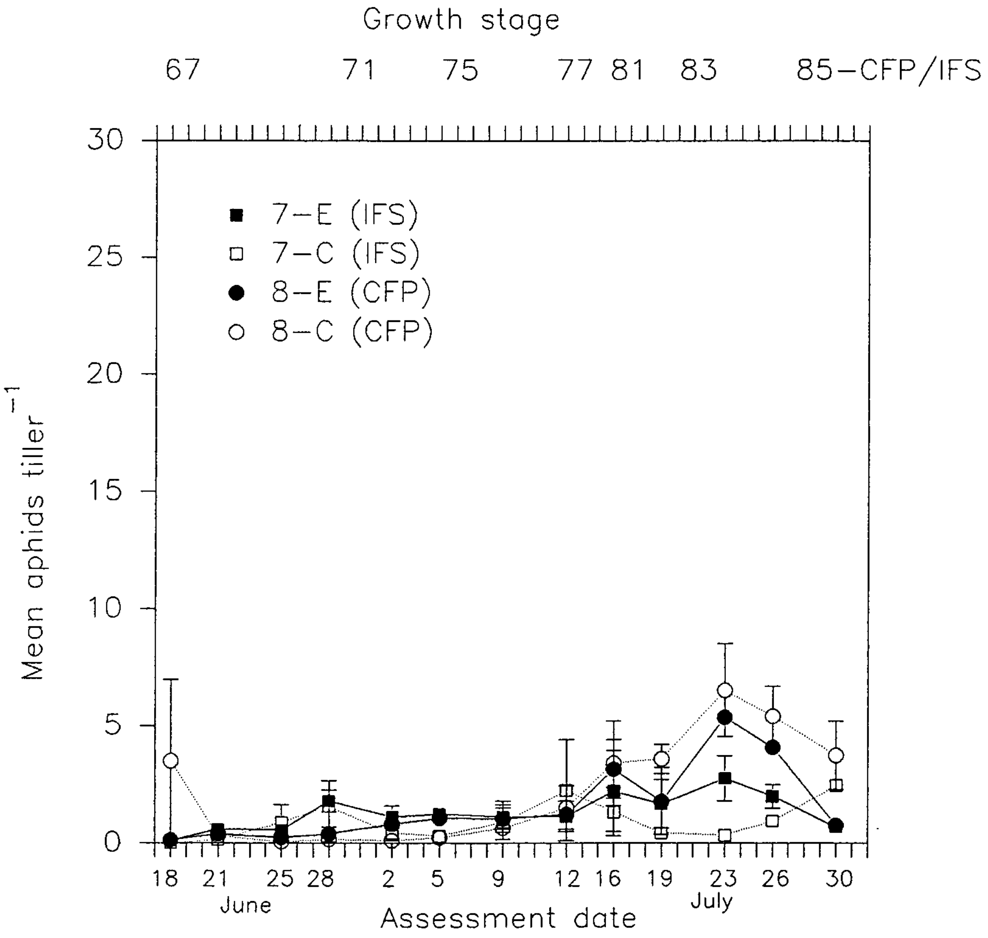
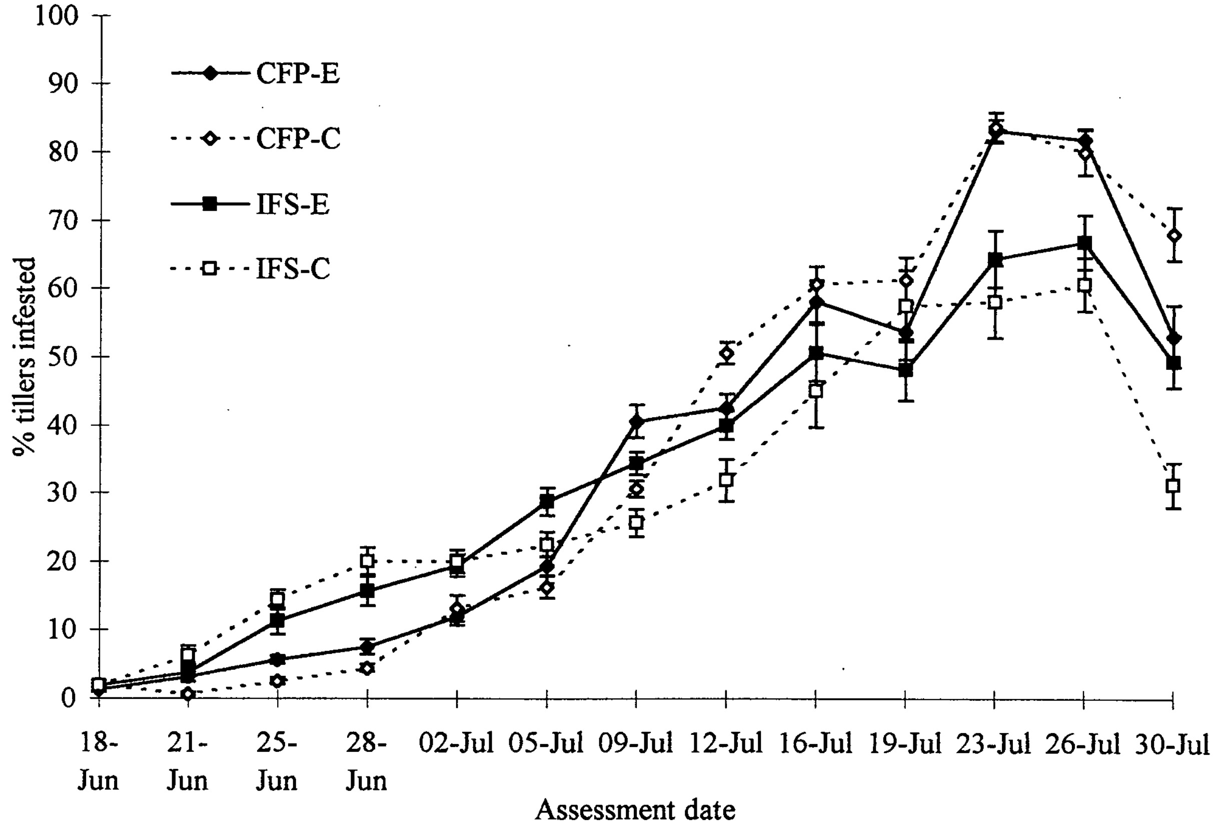


Figure 25a. Proportion of tilles infested with aphids for the enclosed (E) and control (C) areas in the IFS and CFP plots during 1996



Figue 25b. Mean number of aphids per tiller for the enclosed (E) and control (C) areas in the IFS and CFP plots during 1996

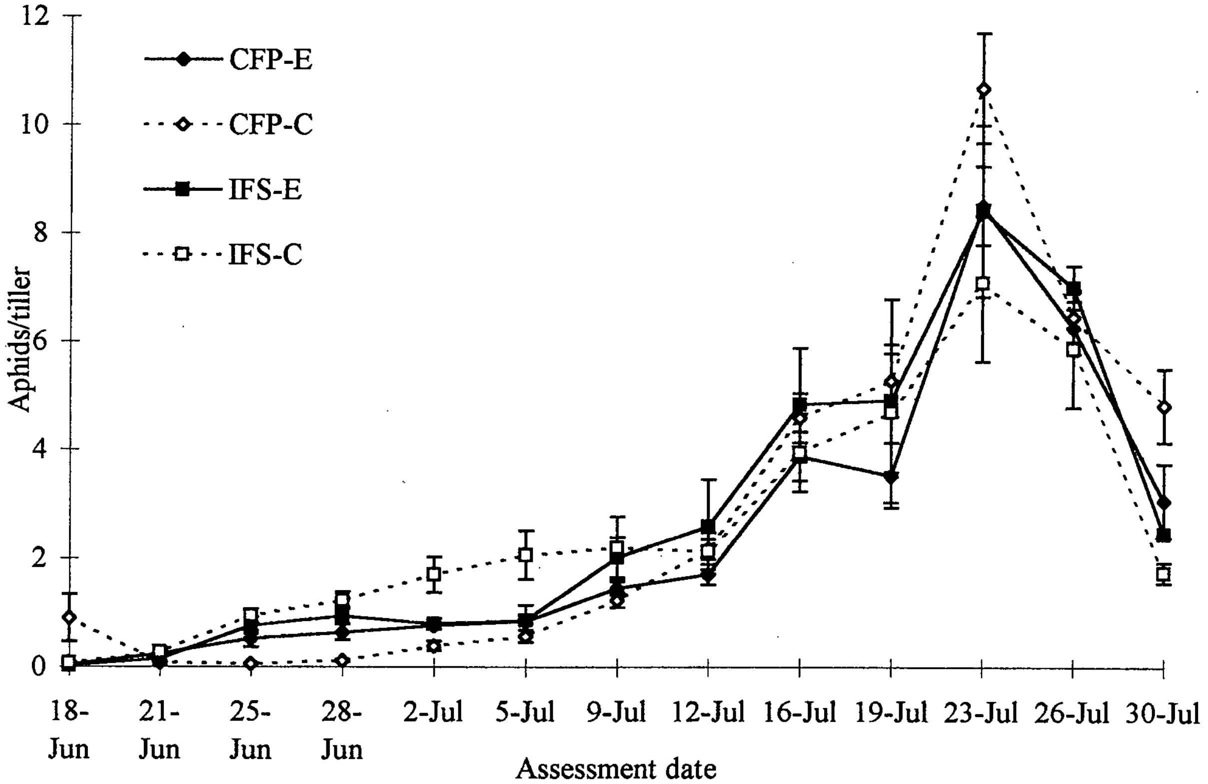


Figure 26a. Number of OWBM captured in the Dvac samples for the enclosed (E) and control (C) areas in the IFS and CFP plots during 1996

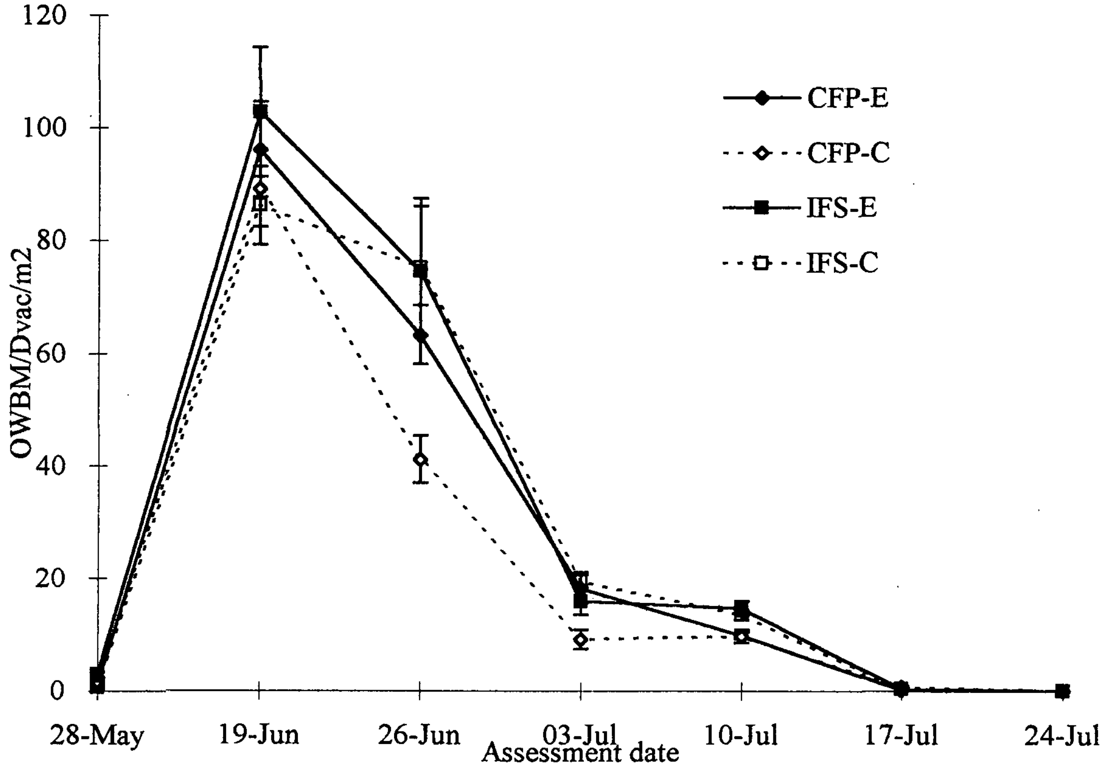


Figure 26b. Number of OWBM captured on the sticky traps for the enclosed (E) and control (C) areas in the IFS and CFP plots during 1996

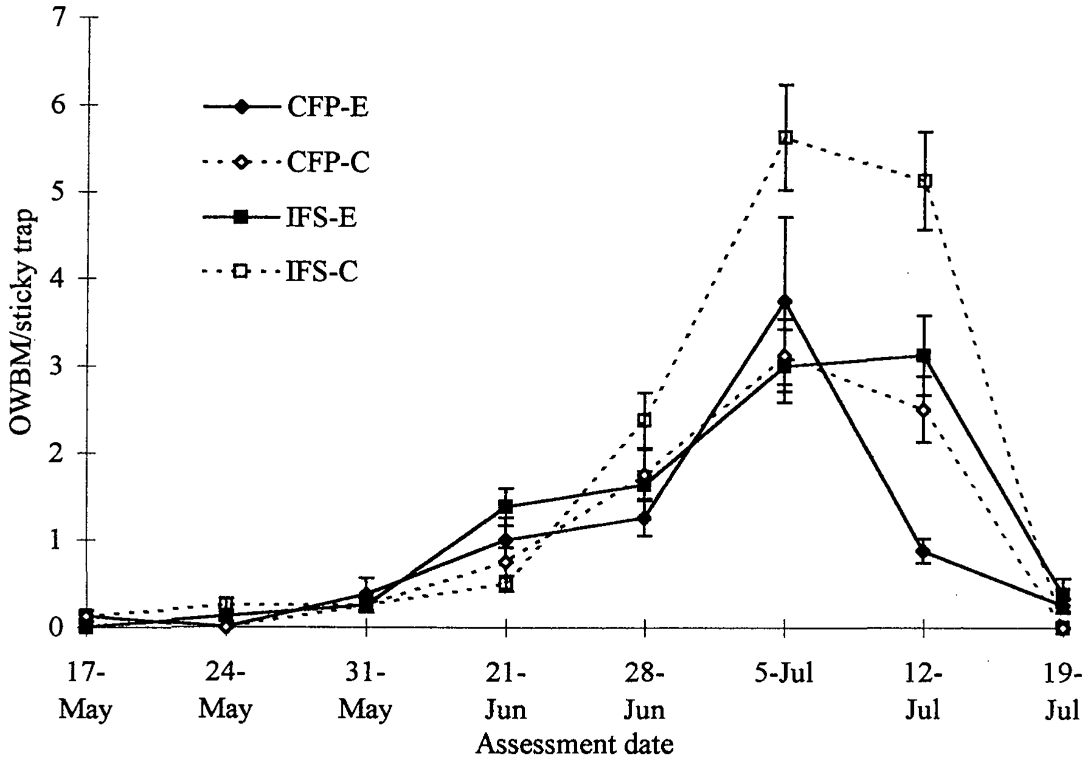


Figure 26c. Relationship between number OWBM larvae per ear and the proportion of ears infested during 1996 (y=130.6x+8.3)

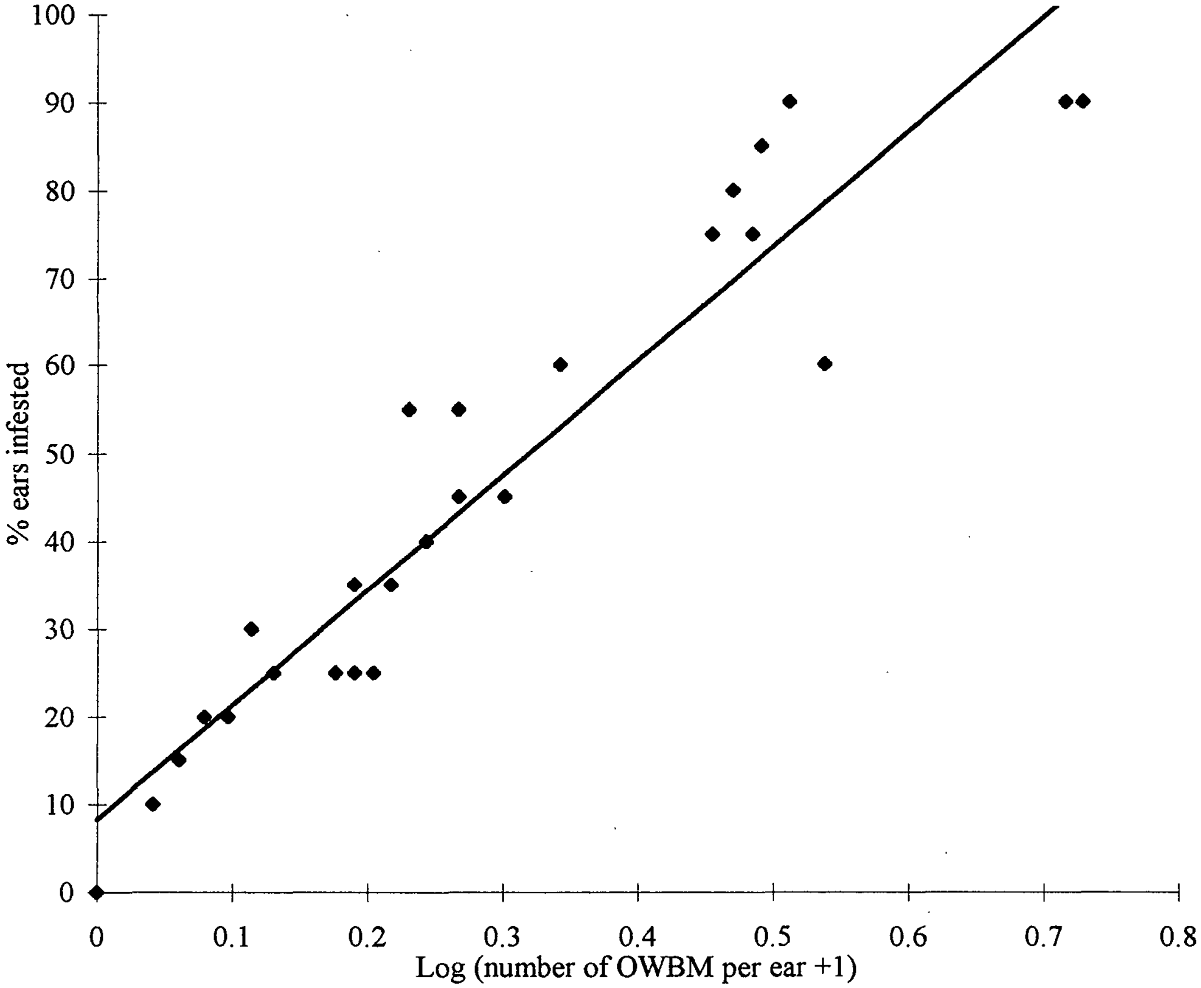


Figure 27a. Relationship between total aphids and marked ear dry weight for field 1, cv. Spark in 1996.

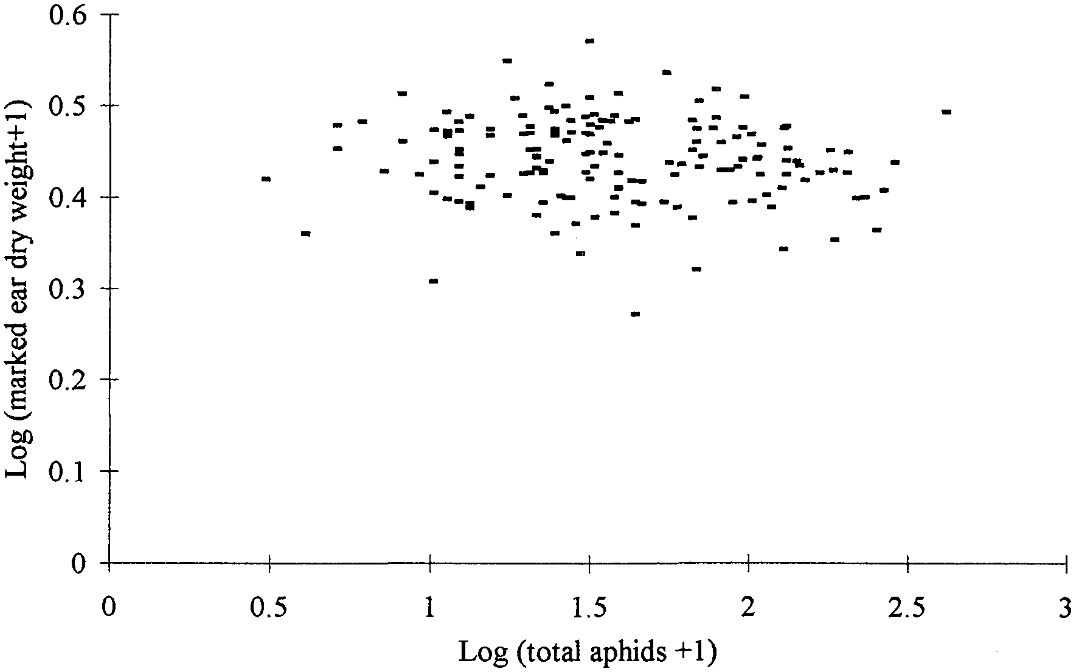


Figure 27b. Relationship between total aphids and marked ear dry weight for fields 2 & 3, cv. Ritmo in 1996.

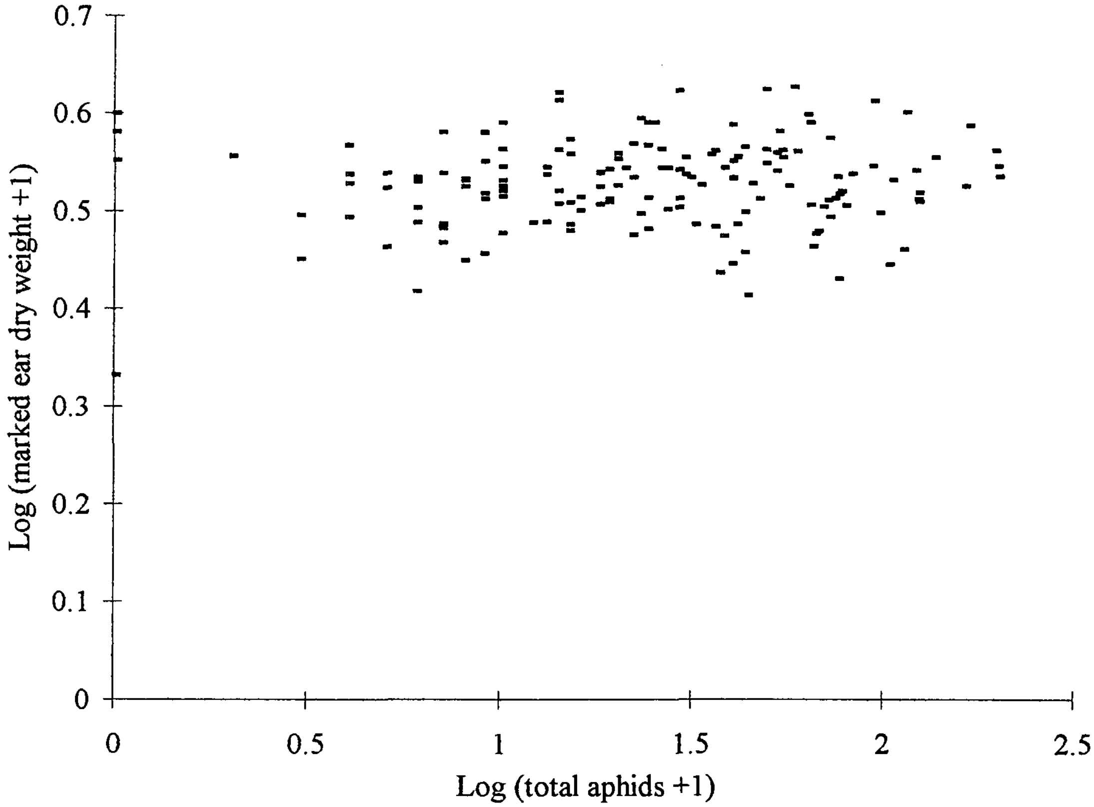


Figure 28a. Relationship between mean total aphids and grain yield per m2 for each area in field 1, cv. Spark in 1996.

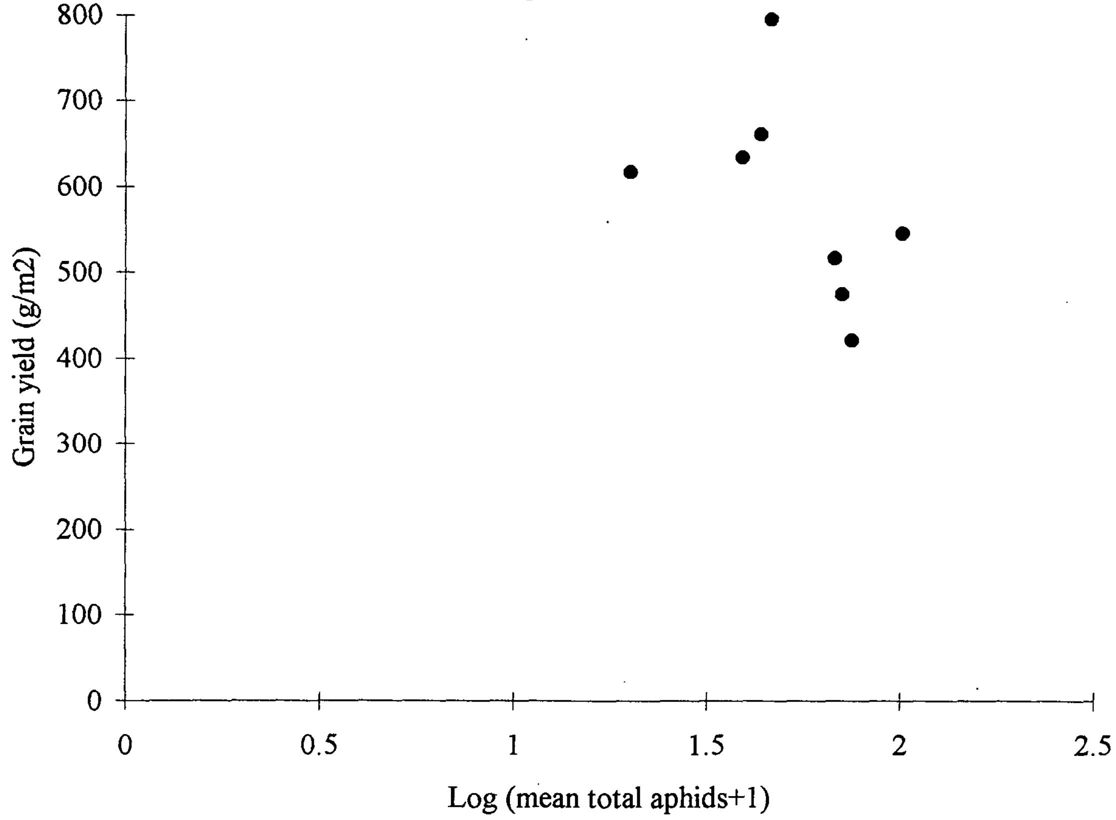


Figure 28b. Relationship between mean total aphids and grain yield per m2 for each area in fields 2 and 3, cv. Ritmo in 1996 (y=-263x+1242)

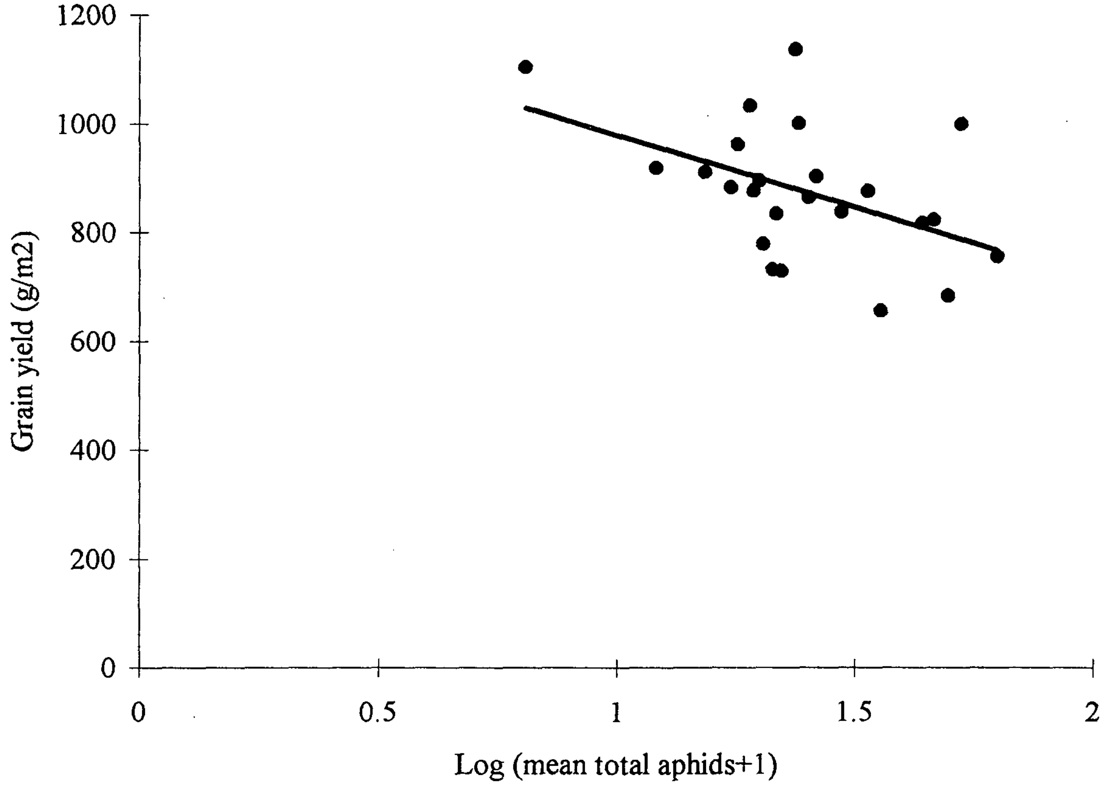


Figure 29a. Relationship between total aphids and hectolitre weight for each area in field 1, cv. Spark in 1996 (y=-29.9x+127)

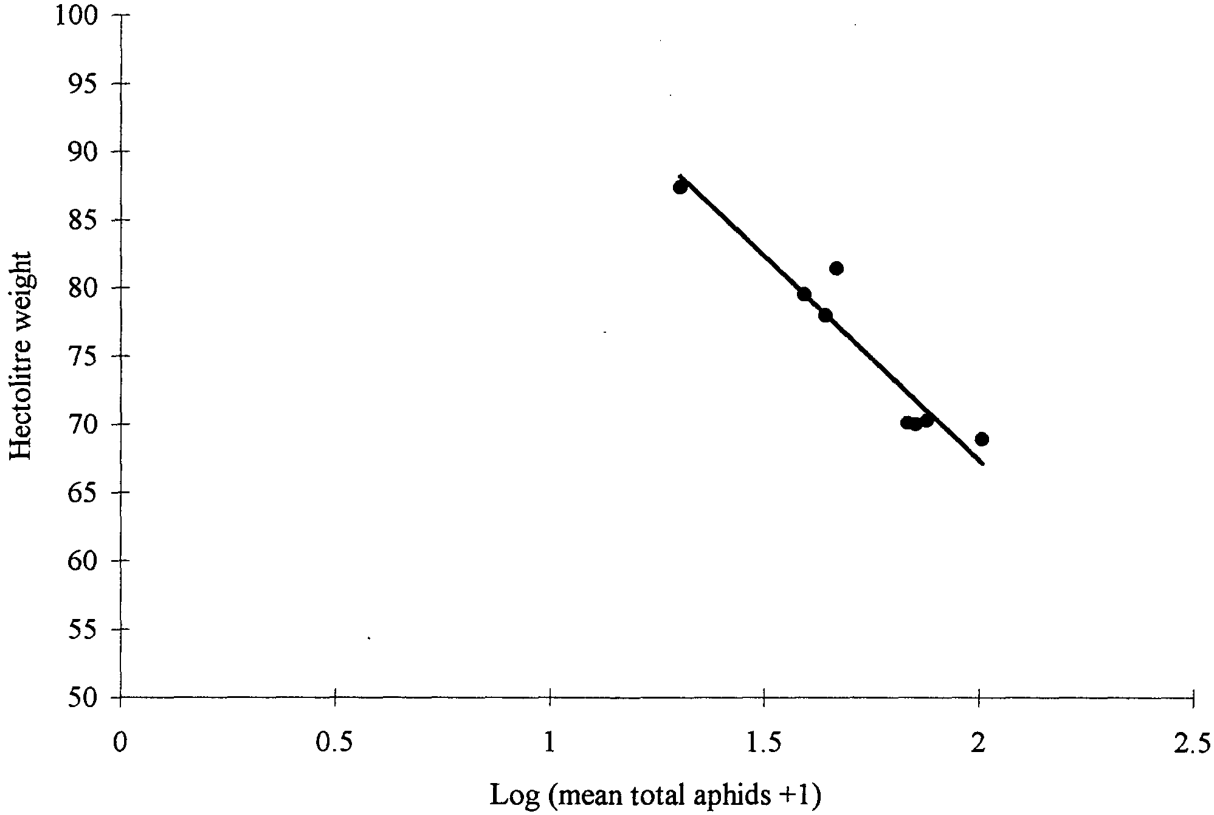


Figure 29b. Relationship between total aphids and grain protein for each area in field 1, cv. Spark in 1996 (y=-1.42x+12.5)

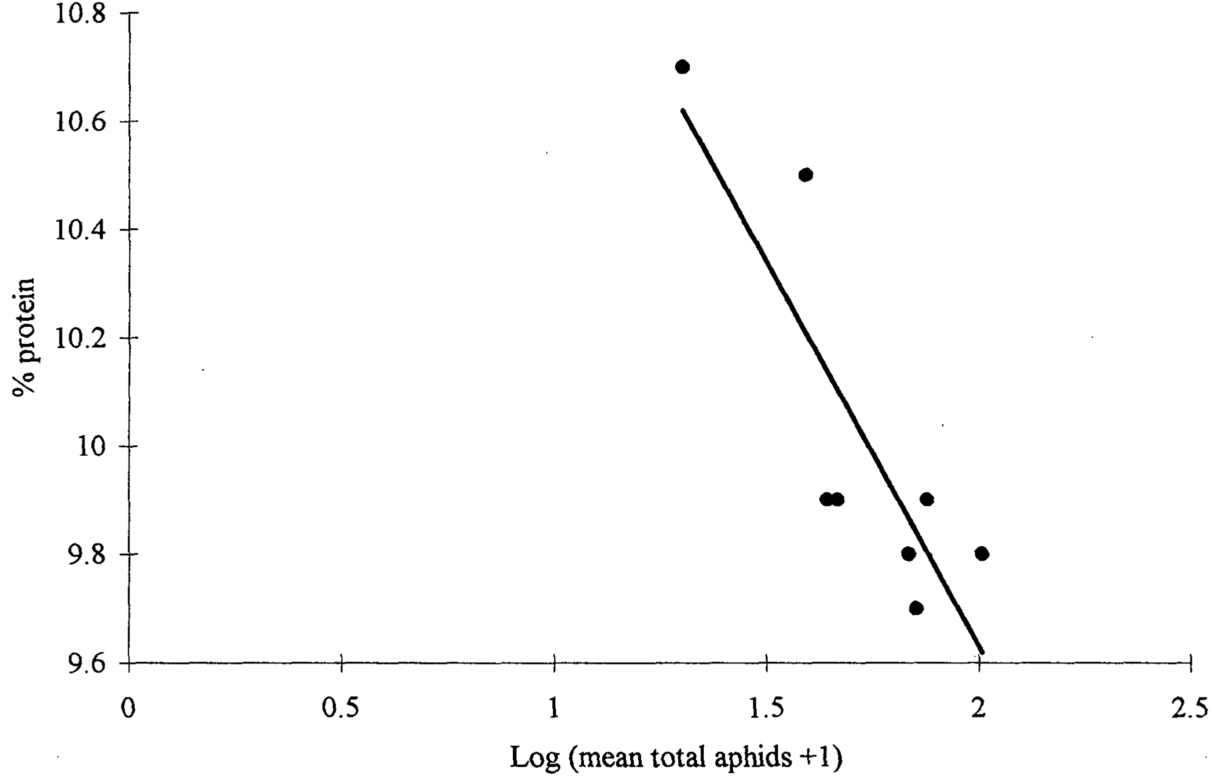


Figure 30a. Relationship between aphid peak and hectolitre weight for each area in field 1, cv. Spark in 1996 (y=-30.6x+112)

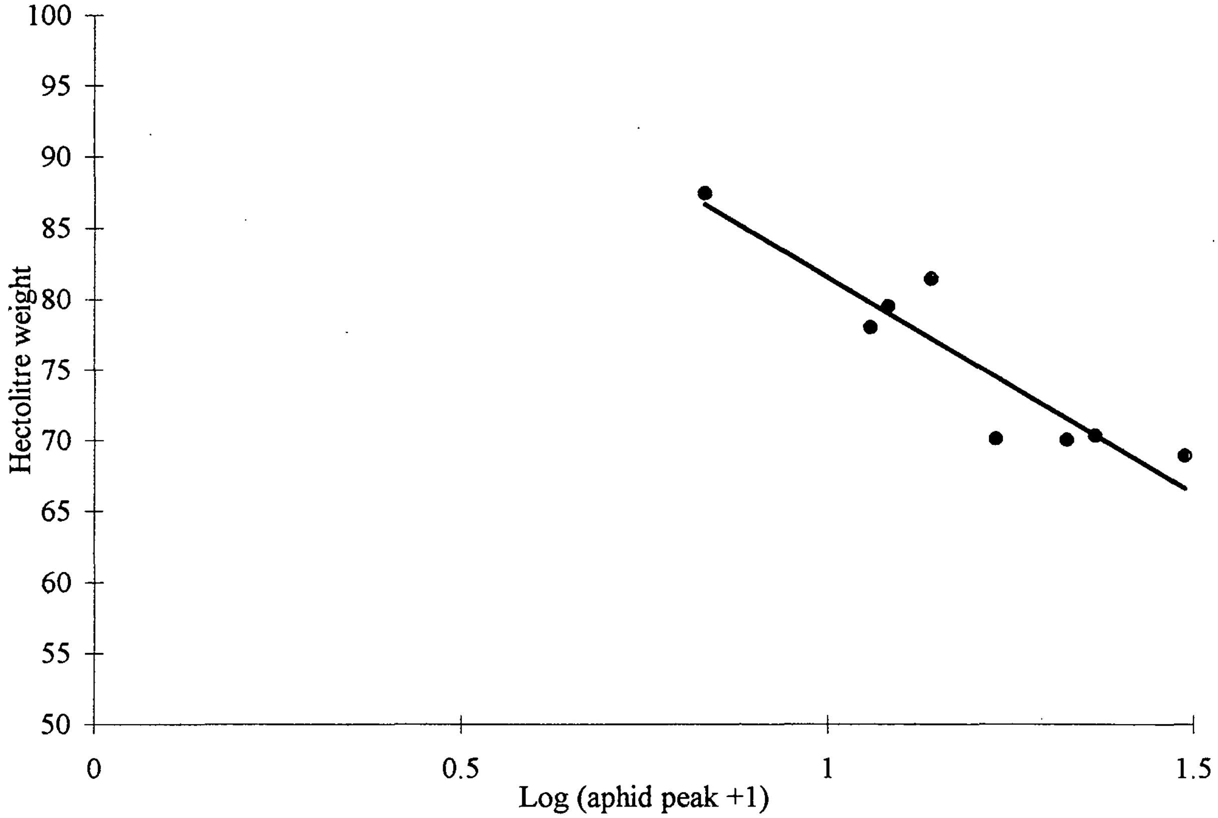


Figure 30b. Relationship between aphid peak and grain protein for each area in field 1, cv. Spark in 1996 (y=-1.4x+11.7)

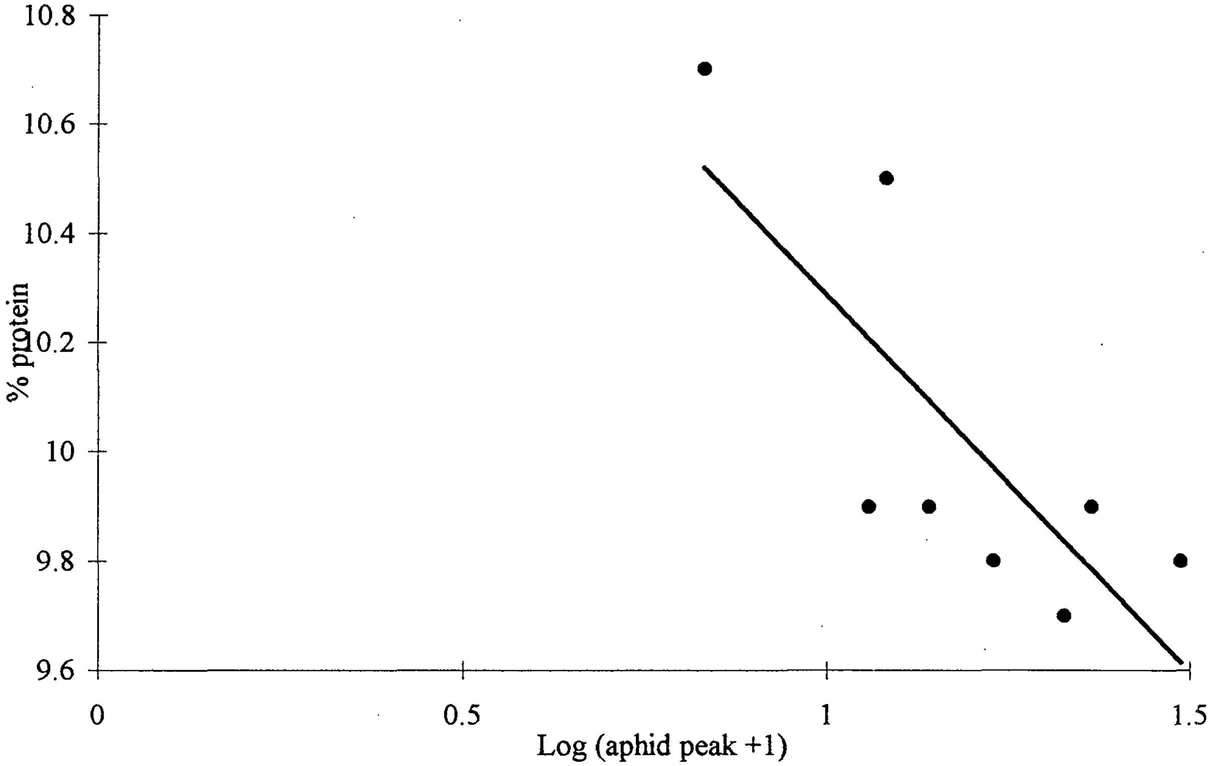


Figure 31. Relationship between total aphids and hectolitre weight for each area in fields 2 and 3, cv. Ritmo in 1996 (y=-6.62x+87.4)

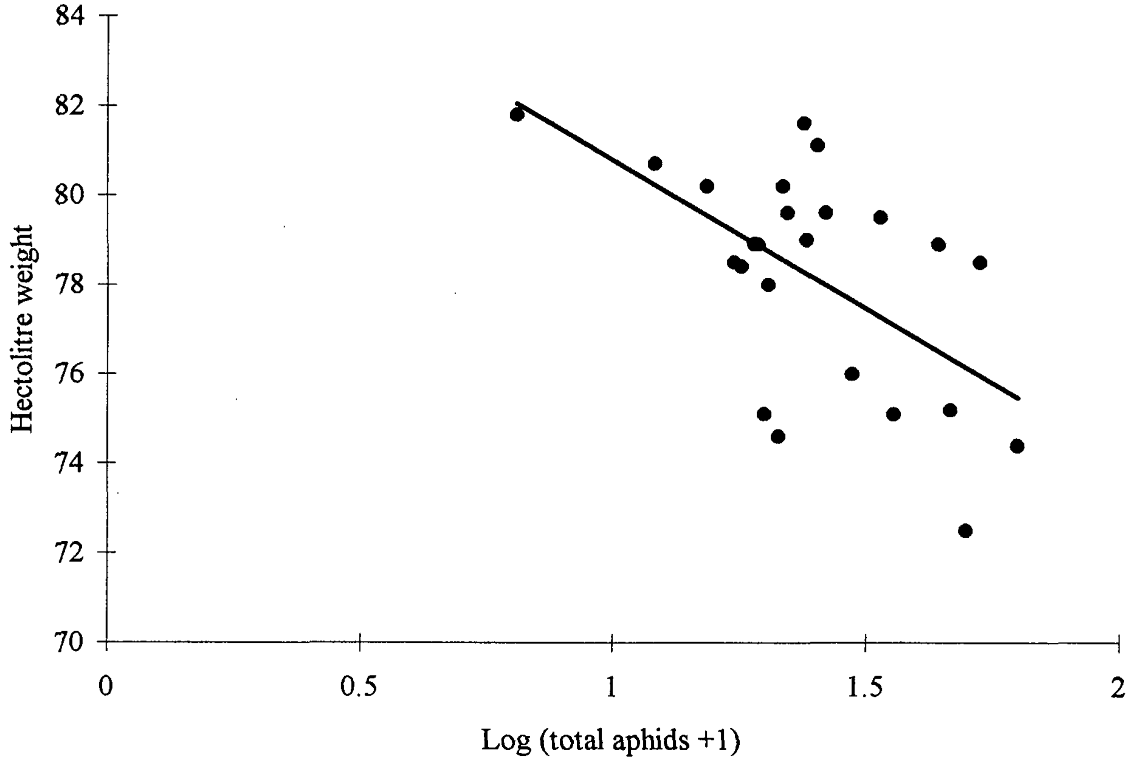


Figure 32a. Relationship between total aphids and mean grain dry weight for each area in fields 2 and 3, cv. Ritmo in 1996 (y=0.32x+1.9)

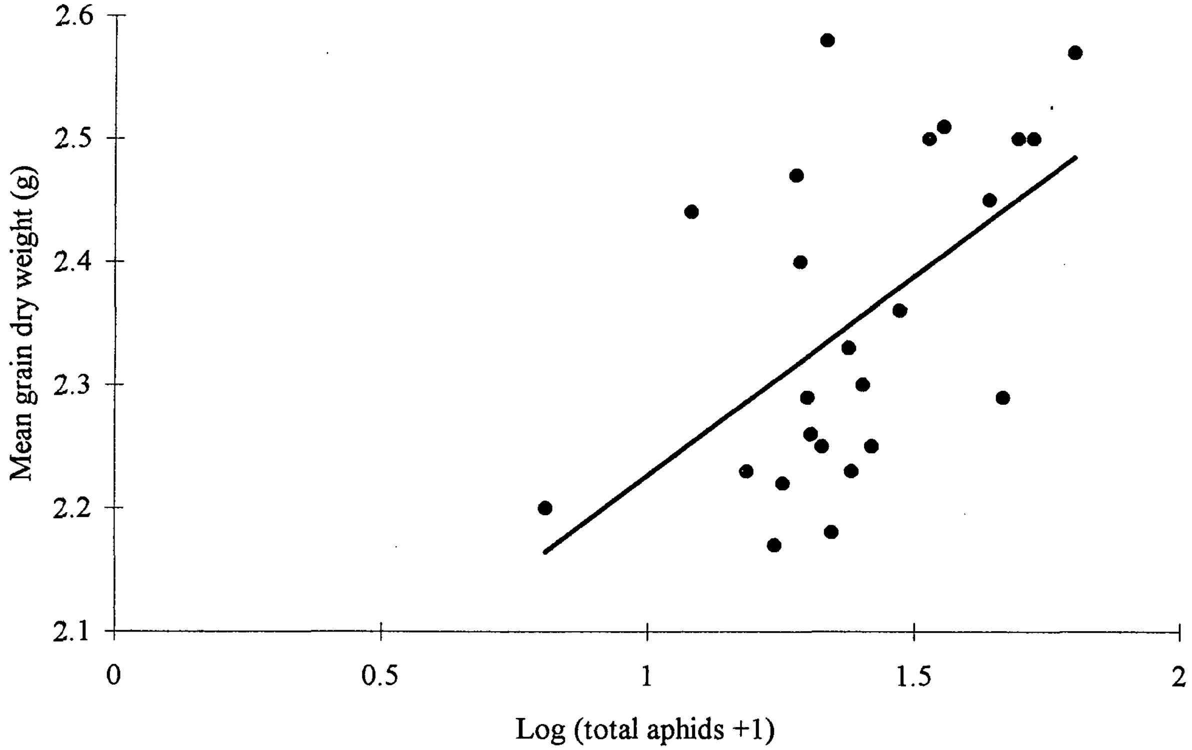


Figure 32b. Relationship between total aphids and thousand grain weight for each area in fields 2 and 3, cv. Ritmo in 1996 (y=3.9x+45.8)

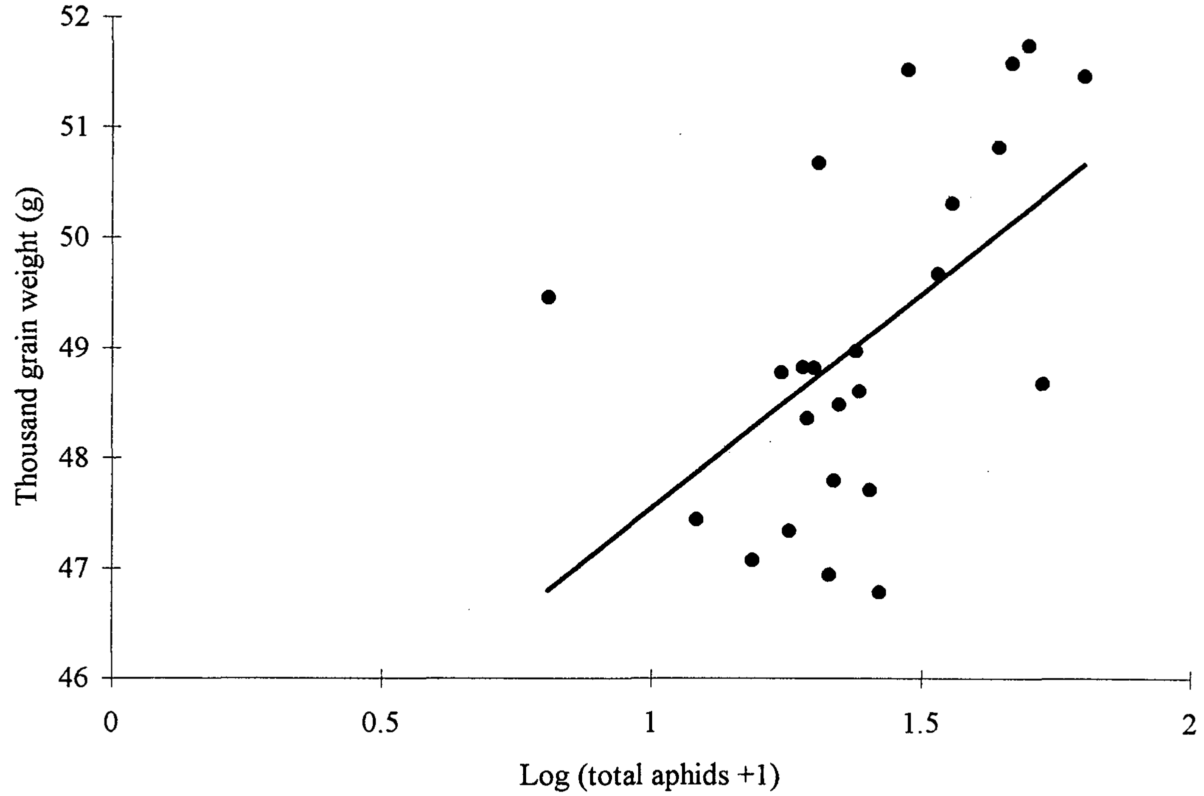


Figure 32c. Relationship between aphid peak and thousand grain weight for each area in fields 2 and 3, cv. Ritmo in 1996 (y=4.0x+45.8)

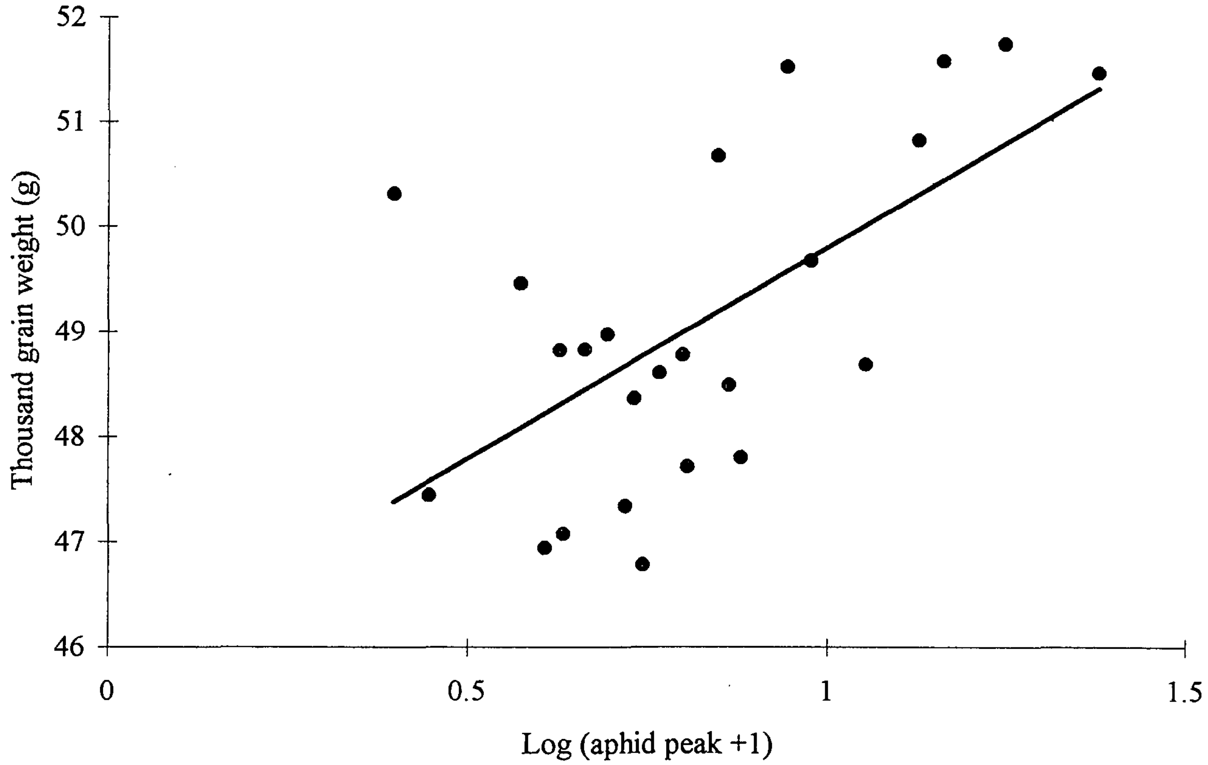


Figure 33. Mean number of Carabidae per pitfall trap in the enclosed (E) and control (C) areas for the IFS and CFP plots in 1996

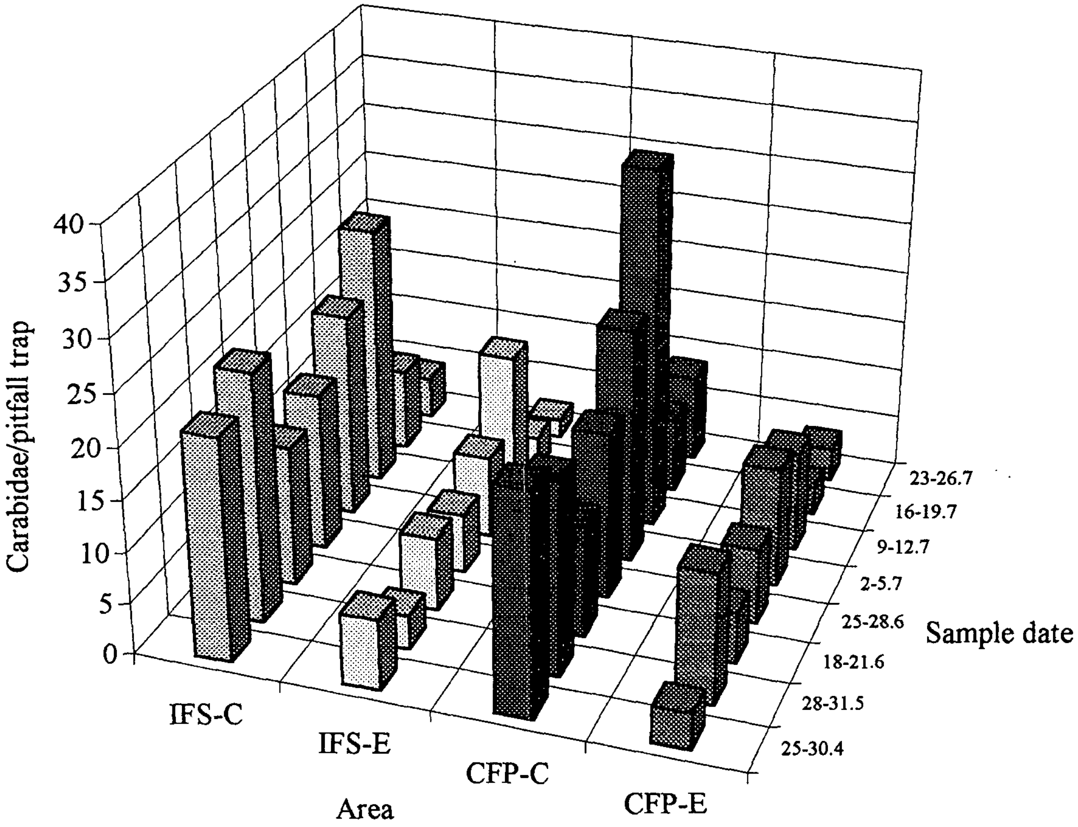


Figure 34. Mean number of Staphylinidae per pitfall trap in the enclosed (E) and control (C) areas for the IFS and CFP plots in 1996

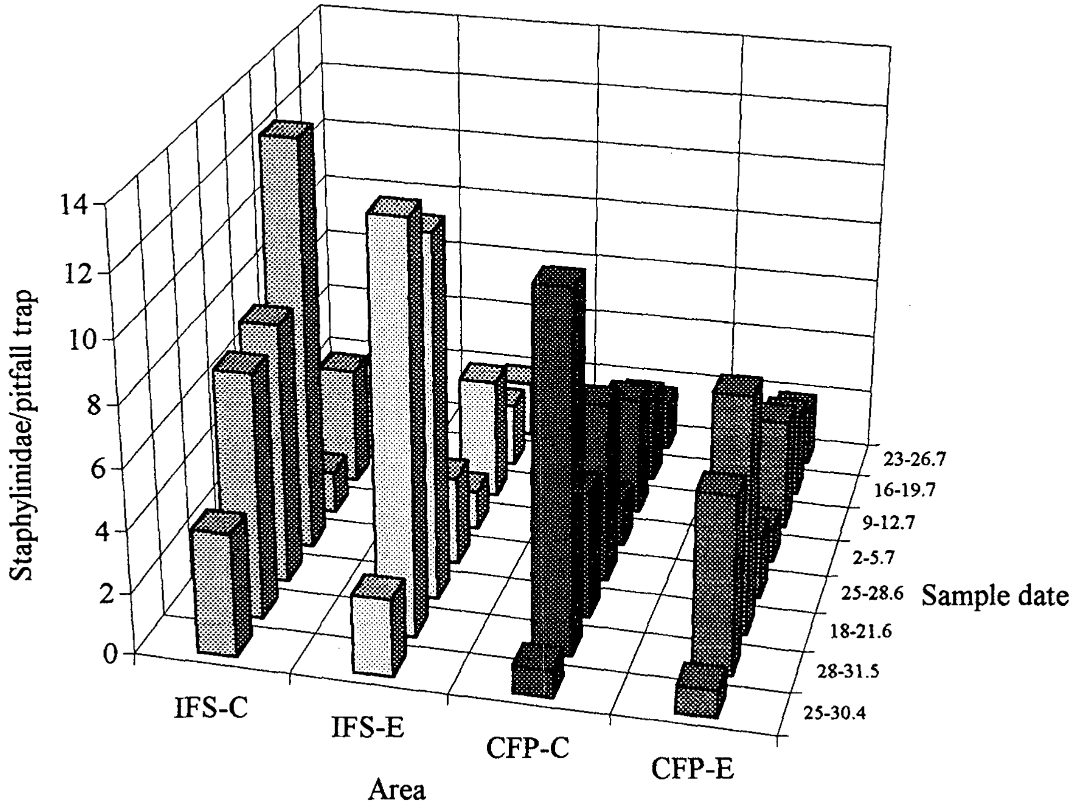


Figure 35. Mean number of Araneae per pitfall trap in the enclosed (E) and control (C) areas for the IFS and CFP plots in 1996

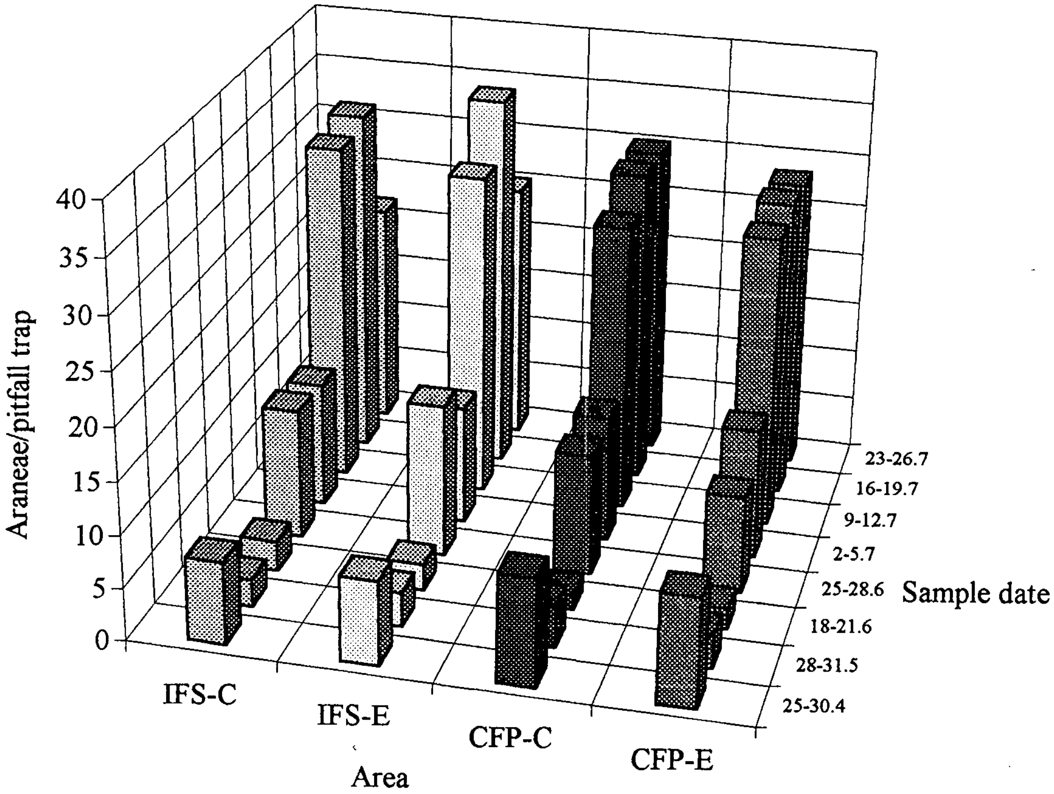


Figure 36. Mean number of Carabidae per fenced pitfall trap/m2 in the enclosed (E) and control (C) areas within each plot in 1996.

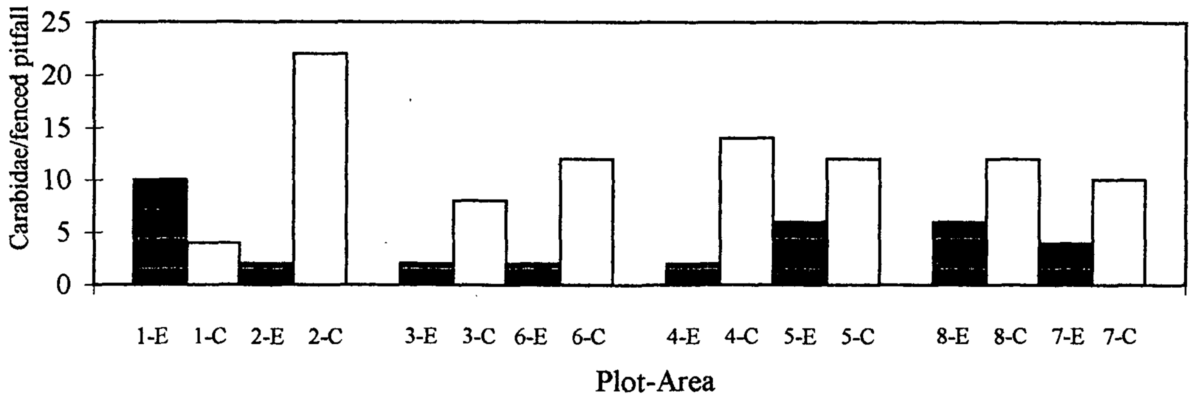


Figure 37. Mean number of Staphylinidae per fenced pitfall trap/m2 in the enclosed (E) and control (C) areas within each plot in 1996.

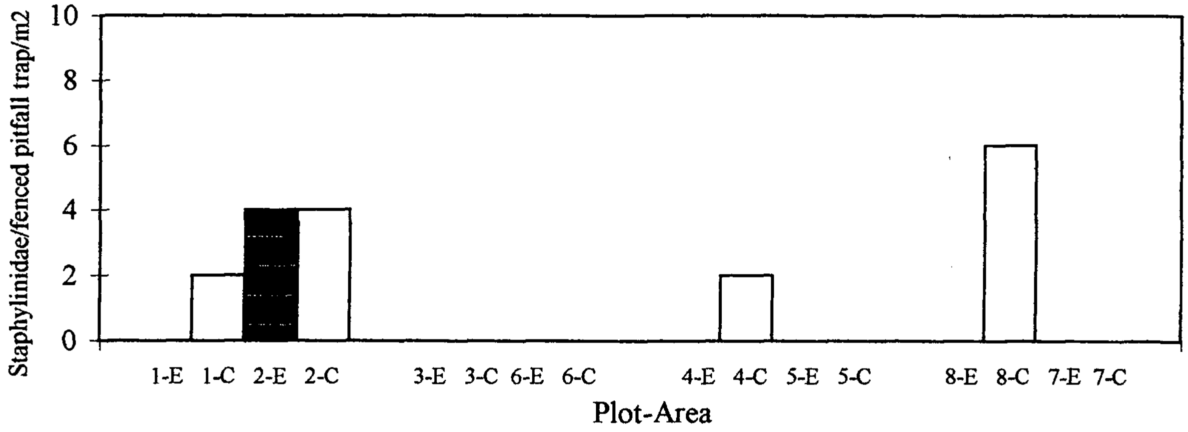


Figure 38. Mean number of Araneae per fenced pitfall trap/m2 in the enclosed (E) and control (C) areas within each plot in 1996.

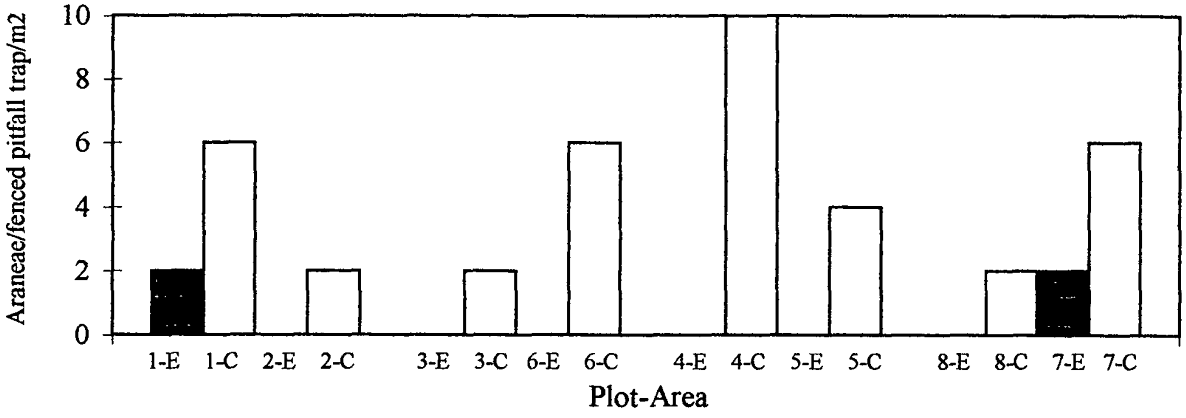


Figure 39. Mean number of Carabidae per Dvac sample/m2 in the enclosed (E) and control (C) areas for the IFS and CFP plots in 1996

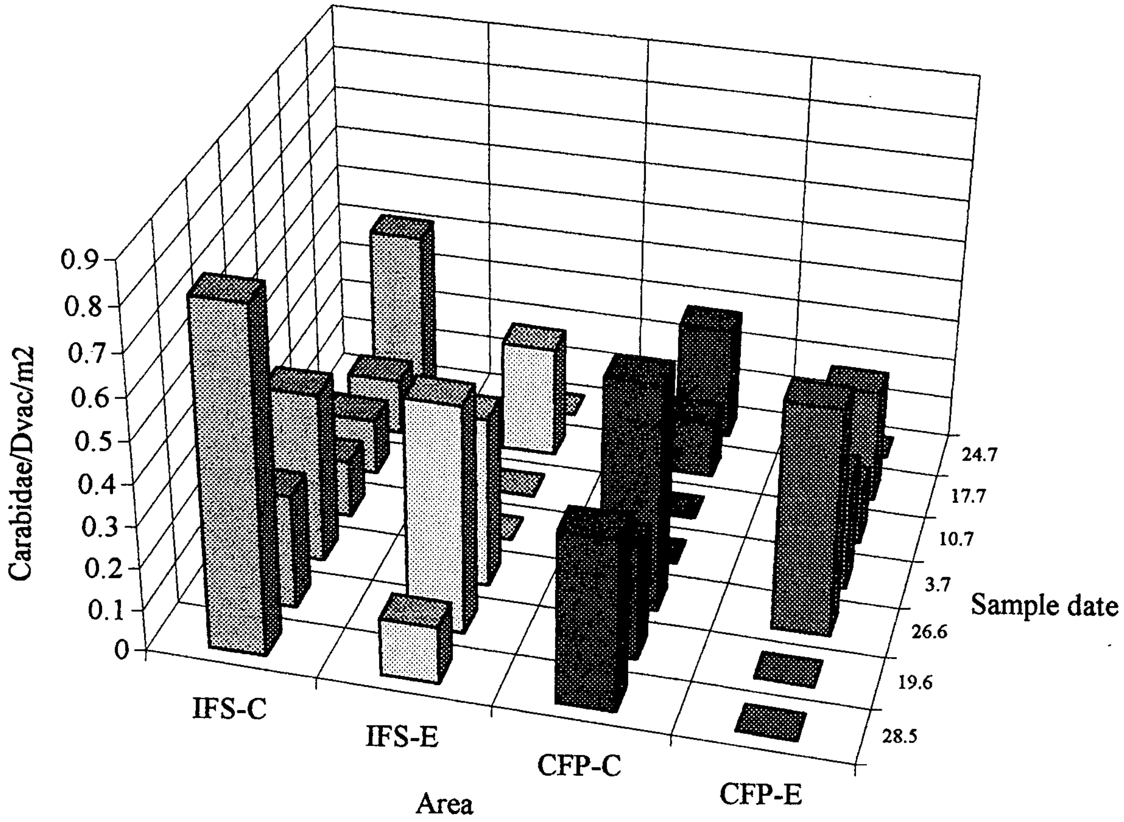


Figure 40. Mean number of Staphylinidae/m2 in the enclosed (E) and control (C) areas for the IFS and CFP plots in 1996

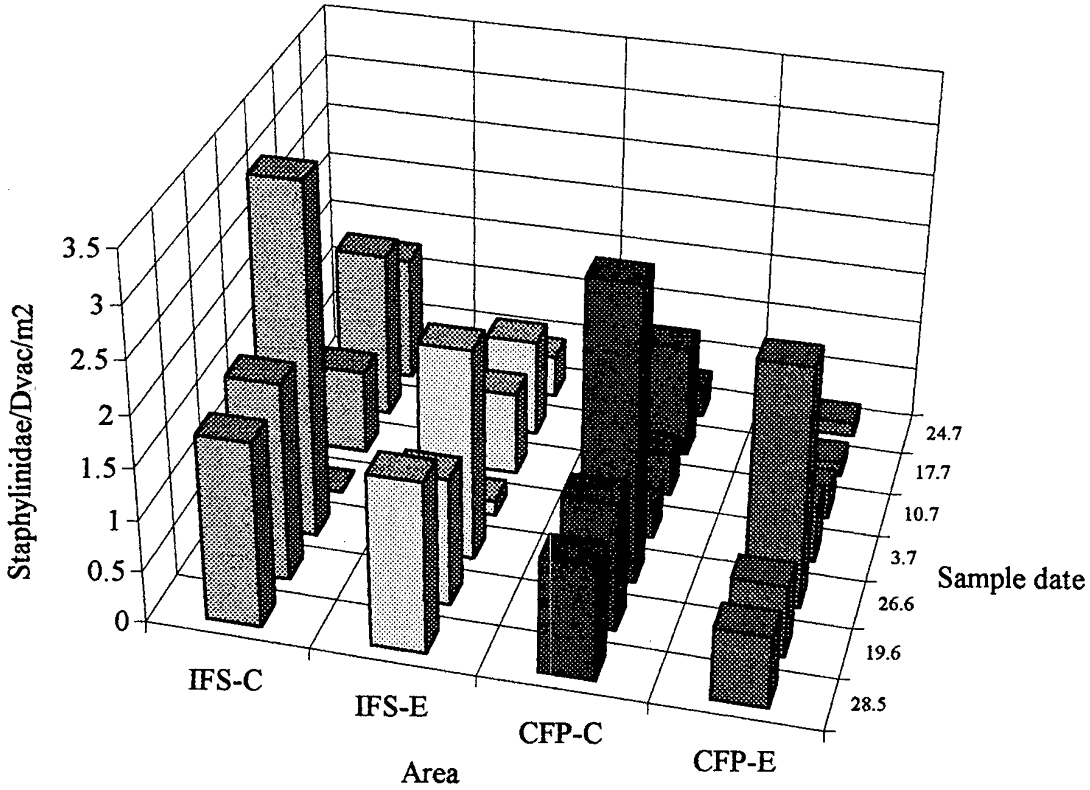


Figure 41. Mean number of Araneae per Dvac sample/m2 in the enclosed (E) and control (C) areas for the IFS and CFP plots in 1996