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Foliar insect pest management on cowpea (*Vigna unguiculata* Walpers) in simulated varietal mixtures. I. The suitability of partial insecticide applications

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Abstract

This research described in this paper examined the impact of varietal mixtures on pest management utilising a model system of partial insecticide applications. In six field experiments conducted in 1995 and 1996 in Igalaland, Kogi State, Nigeria varietal mixtures were simulated through the application of systemic insecticide (carbofuran or furathiocarb) to a pre-determined percentage of a cowpea (*Vigna unguiculata*) crop. The objective was to examine and compare the pest damage on untreated cowpea plants grown in plots in which varying percentages of the cowpea plants were treated with insecticide. A secondary objective was to determine whether action of the foliage pests influenced flower production. The results showed that the presence of insecticide-treated plants reduced the level of leaf damage by *Ootheca mutabilis* Sahlberg and the densities of *Aphis craccivora* Koch populations on untreated plants. The greater the percentage of insecticide-treated plants the greater this reduction on the untreated plants. Meanwhile, the number of flowers found on the untreated plants increased suggesting the foliage pest damage reduced flower production.

Keywords: Cowpea; Pest management; Insecticide; Varietal mixture; *Aphis craccivora*; *Ootheca mutabilis*; Nigeria

1. Introduction

Cowpea is a grain legume grown widely in West Africa. Annual production is hard to accurately estimate as cowpea is predominantly grown as a subsistence crop or is sold in internal markets. Annan et al. (1994) estimate that 80% of African cowpea production is in West Africa and half of this is centred in Nigeria. The biggest constraint to increasing cowpea seed yield in Africa is the insect pest complex (Booker, 1965; Singh and van Emden, 1979; Singh and Allen, 1980; Muleba and Ezumah, 1985; Jackai and Daoust, 1986; IITA, 1992). Every part of the cowpea plant has an adapted pest species that can cause substantial damage (Jackai and Daoust, 1986), and of these the flower and pod pests have the greatest impact on yield. However, it is the foliage pests that are present over a greater percentage of the cowpea's life span.

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Resource-poor farmers in Nigeria mostly employ methods of cultural control to control pests (Kitch et al., 1997), including crop rotation and inter-cropping. However, the effectiveness of these methods is somewhat limited and variable. Adoption of synthetic insecticides has been variable largely due to problems with availability and cost of inputs and the required changes in cropping strategy (Jackai and Daoust, 1986). A further alternative is the use of resistant varieties, which has been an attractive option to resource-poor farmers when varieties are agronomically and phenologically acceptable to the farmer (McNamara and Morse, 1996). The International Institute of Tropical Agriculture (IITA) maintains the world germplasm store for cowpea, with approximately 15,200 cultivated and 1646 wild accessions (Ehlers and Hall, 1997). They have identified fairly high sources of resistance to leafhoppers, aphids and bruchids, and moderate resistance to thrips and *Maruca vitrata* Fabricius (Lepidoptera: Pyralidae) (Singh and van Emden, 1979). In addition, biotechnologists are developing transgenic insect resistant cowpea, e.g. resistance to *M. vitrata* and *Callosobruchus masculatus* Fabricus (Coleoptera: Bruchidae) (Moar et al., 1995; Ortiz, 1998).

The deployment of transgenic resistant varieties, and the extreme antibiotic resistance that they could incorporate, has raised fears over the development and spread of resistant genotypes of insect pest, a phenomenon well documented with insecticides. Given that the insect genes that code for resistance (to insecticides or plant resistance) in insects (R-genes) are usually recessive, one approach is to maintain a significant population of susceptible individuals in the population and thereby slow the exhibition of resistance (Denholm and Rowland, 1992; Alstad and Androw, 1995). This can be achieved by ensuring that there is a proportion of susceptible plants in the environment. Two of the most commonly cited forms for achieving this are the use of refuges and varietal mixtures.

Computer simulations suggest that refuges offer the most effective strategy for the management of insect resistance. The required proportion of susceptible plants will vary from pest to pest depending upon population dynamics and the genetics involved (Gould, 1986; Mallet and Porter, 1992). However, the voluntary cultivation of a susceptible refuge may be a contentious issue with farmers (Kimsky and Wrubel, 1996). Gould (1998) felt that farmers would not accept refuges of more than 4–10% of the crop. Anecdotal evidence from Igalaland, Nigeria (Ward, 2000) suggests that S:R varietal mixtures would be a more farmer acceptable cropping strategy than the planting and cultivation of refuges. Varietal mixtures (or multilines) are commonly found in subsistence agriculture in the tropics (Smithson and Lenne, 1996). Smithson and Lenne (1996) suggest that the advantages of varietal mixtures may include yield increase, yield stability and the prolonging of harvest and income flow. Crop mixtures have been shown to benefit crop protection. Multilines have been utilised in pathogen control (Browning and Frey, 1969; Wolfe, 1985; Jensen, 1988; Smithson and Lenne, 1996), but their successful use in controlling insect pests has been less well documented (Cantello and Sanford, 1984; Wolfe, 1985; Altieri and Schmidt, 1987; Gold et al., 1991; Bush et al., 1991; Nault et al., 1995). It has been postulated that mixtures are unlikely to be as effective in insect pest control because, unlike pathogens, insect pests have a greater propensity to determine the direction of their movement (Mallet and Porter, 1992; Dixon, 1998).

The relative paucity of strong insect resistance, as distinct from partial resistance, has limited research into S:R mixtures. One approach to overcome this has been to use 'simulated resistance' by the application of synthetic insecticides. Ward and Morse (1995) simulated an S:R mixture (with strong resistance) in field bean (*Vicia fabae*) using aldicarb to provide resistance to bean weevil (*Sitona lineatus* Linnaeus [Coleoptera: Curculionidae]) and bean aphid (*Aphis fabae* Scopoli [Homoptera: Aphididae]). Their results suggested that the pest numbers on the S component was influenced by the proportion of plants that had received insecticide (i.e. those simulating strong resistance). As the proportion of insecticide-treated plants in the mixture increased then the densities of both pests on the susceptible plants declined. However, although the results of these studies clearly indicated that infestation on susceptible plants was related to the proportion of the insecticide-treated plants in the mixture, the experiments could not provide an explanation of the mechanism involved.

The experiments described in this paper were intended to build on the results achieved by Ward and Morse (1995) using cowpea (*V. unguiculata*) instead of *V. fabae*. The experiments utilised simulated resistance provided by the application of a systemic insecticide (carbofuran as Furdan 3G, 3% a.i. FMC Corporation). The research aimed to determine whether the presence of a simulated-resistant component resulted in reduction in the pest infestation on the untreated component and to determine whether this had any impact on flower production.

2. Materials and methods

2.1. Location

The six experiments reported here took place between 1995 and 1996 in the area known as Igalaland (part of Kogi State, Nigeria) that lies to the south-east of the confluence of the rivers Niger and Benue. It has an area of approximately 14,000 km^2 (1.5% of the total land area of Nigeria), and a population of more than one million (McNamara and Morse, 1998). Igalaland is located in the Southern Guinea savannah ecological zone with an average annual rainfall of 1400–1600 mm. The rainy season continues from April to September, allowing farmers to utilise both an early (April–July) and a late (July–September) cropping season. Agriculture in Igalaland is predominantly arable, and cowpea is widely grown for both home consumption and sale. Pest infestation on cowpea is virtually guaranteed every season, but some areas are more prone to pest attack than others.

2.2. Site management

The experiments took place 'on farm', and were in areas farmers described as pest 'hot-spots' for the appropriate season. The experiments contained five treatments replicated five times in a Latin Square (total size approximately 33 m × 48 m). Individual plot size within all the experiments was approximately 5 m×8 m (8 ridges by 5 m long, 40 m^2). Between each plot a border of approximately 2 m was cleared to prevent insect movement across adjacent blocks (Ezueh and Taylor, 1983). Stands of cowpea (2–3 seeds per hole) were planted approximately 25 cm apart (Dina, 1977; Oladrin and Oso, 1985; Atiri et al., 1986), and thinned to two plants per stand as the first trifoliate leaves were expanding (Koehler and Mehta, 1972). Healthy seedlings that were thinned were transplanted to areas where germination had failed (Oladrin and Oso, 1985). This gave a population of 4000 stands per experiment, 160 stands per plot (320 plants per plot) and an average plant density of 80,000 plants per hectare.

2.3. Experiments and treatments

A summary of the six experiments is presented in Table 1. The cowpea variety for all the experiments was IT82D-889 (upright and determinate). Four experiments utilised carbofuran granules applied as Furadan 3G to pre-determined plants. Carbofuran is known to be effective against cowpea aphid, foliage thrips, leafhopper, striped foliage beetle and cowpea foliage beetle (Singh, 1987). Carbofuran was added to the plants approximately 1 week after planting, with 3 g of Furadan 3G applied to the ground around each plant stand (0.09 g a.i. per stand). Previous experience suggested that carbofuran could be expected to provide protection against insect pests for up to 50 days. Furathiocarb as Promet 400 CS (400 g a.i. per litre), was utilised in Experiments 5 and 6 in place of carbofuran. Promet was applied as a seed dressing (application rate of 2.5 kg of Promet per 100 kg seed), and is known to be effective against soil, sucking and chewing pests in cotton, maize, rape and pea (Wyss, Novartis, personal communication, June 1999). It was hypothesised that

Table 1
1995–1996 cowpea partial insecticide experiments

Season (date planted)	Experiment no.	Insecticide	Number of plants observed per treatment per sample
Late 1995 (26 August)	1	Carbofuran	50
Late 1995 (28 August)	2	Carbofuran	50
Early 1996 (27 May)	3	Carbofuran	100
Early 1996 (30 May)	4	Carbofuran	100
Early 1996 (13 June)	5	Furathiocarb	100
Early 1996 (12 July)	6	Furathiocarb	100

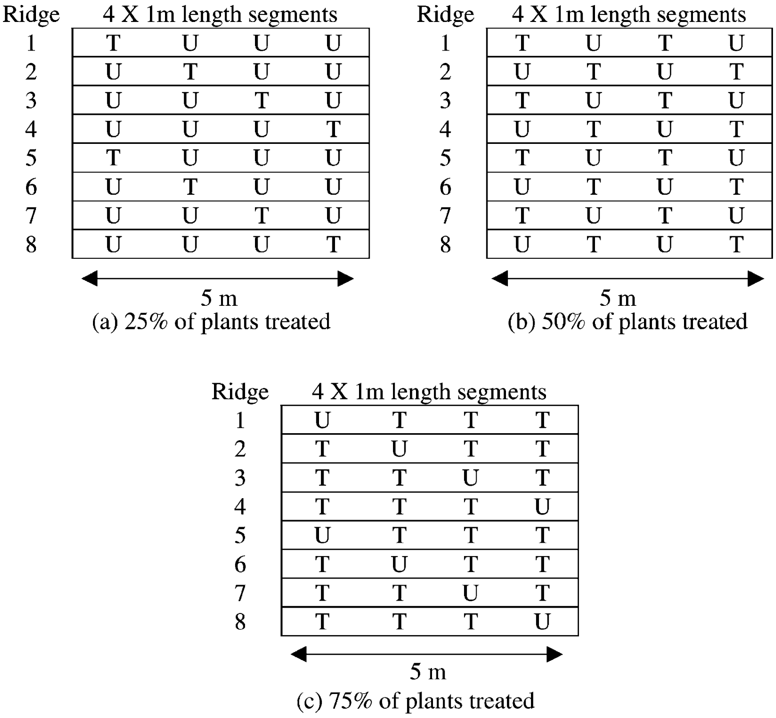
insecticide drift would be unlikely when a seed dressing formulation was utilised.

Partial insecticide application treatments, in which 25, 50 or 75% of the plants in a plot were treated with insecticide (the R component), were utilised, the remaining component comprised untreated and therefore susceptible (S) plants. Two controls were included: one with no plants treated (entirely susceptible; 0% treatment) and one with all the plants treated (entirely resistant; 100% treatment).

The treatments were applied in a similar manner to that described by Ward and Morse (1995). In each plot the eight ridges were divided by physical cutting into four sections called segments and these represented the basic unit of treatment. Dividing ridges into segments took place in all plots whatever the treatment. The result was 32 segments per plot with approximately four cowpea stands (eight plants) in each segment. The insecticide treatment was applied to all of the plants in the pre-determined segments so that the percentage of treated segments equalled the percentage of treated plants for that treatment. Plant populations were monitored the week after germination (a variation of up to 5% from the intended percentage of treated stands per plot was allowed before intervention occurred). The application of treatments was arranged in a pattern that would give the maximum interface between segments of differing treatment. This entailed a structured mosaic design showing identical patterns for the 25 and 75% mixtures and an alternating design for the 50% mixture (Fig. 1).

2.4. Sampling and assessments

Data for *Ootheca mutabilis* leaf damage (counts and scores), *Aphis craccivora* scores and flower count data was collected. Except for the 100% treatment, only untreated plants were sampled and assessed. All sampling was done visually with minimal disruption to the



Ridge	4 X 1m length segments			
1	T	U	U	U
2	U	T	U	U
3	U	U	T	U
4	U	U	U	T
5	T	U	U	U
6	U	T	U	U
7	U	U	T	U
8	U	U	U	T

5 m

(a) 25% of plants treated

Ridge	4 X 1m length segments			
1	T	U	T	U
2	U	T	U	T
3	T	U	T	U
4	U	T	U	T
5	T	U	T	U
6	U	T	U	T
7	T	U	T	U
8	U	T	U	T

5 m

(b) 50% of plants treated

Ridge	4 X 1m length segments			
1	U	T	T	T
2	T	U	T	T
3	T	T	U	T
4	T	T	T	U
5	U	T	T	T
6	T	U	T	T
7	T	T	U	T
8	T	T	T	U

5 m

(c) 75% of plants treated

Fig. 1. Arrangement of treated segments of ridge in each mixture plot (ridges are represented horizontally). T: treated segment (1 m length of ridge). All the plant stands on this segment receive the treatment. The treatment was insecticide (carbofuran or furathiocarb). U: untreated segment (1 m length of ridge). All of the cowpea plant stands on this segment received no insecticide treatment—(a) 25% of plants treated; (b) 50% of plants treated; (c) 75% of plants treated.

plants. There was some variation in the number of plants sampled as is shown in Table 1.

For Experiments 1 and 2, the damage caused by *O. mutabilis* beetles on each sampled plant was quantified by counting the number of leaves exhibiting *O. mutabilis* damage. As long as the damage appeared to be a result of *O. mutabilis* feeding, any quantity of leaf damage was sufficient for the leaf to be counted as damaged. In the other experiments, a scoring system was employed for *O. mutabilis* leaf damage. The system employed was adapted from Alghali (1991), with a scale of 0–10; 0 represented 0% of the leaf surface eaten, through to 10 representing 91–100% of the leaf surface eaten. Since leaf damage was almost totally due to *O. mutabilis*, distortion of data by other foliar insects was minimal. Measurement of leaf damage continued until flowers were observed on most plants.

Due to the size of *A. craccivora* colonies it was more appropriate to record aphid scores rather than aphid numbers. The (0–10) score that was utilised was based on that used by Morse (1989) in the same region. The number of flowers was assessed through the counting of the number of flowers on each plant sampled. Cowpea flowers are attacked by thrips and pod borers, which will influence the number of flowers and will influence the number of pods to a greater extent. The number of abscission scars on the peduncle were also monitored (Ward, 2000) and this suggested that flower per pod loss was in proportion to flower per pod production. Therefore, flower production was used as an indication of potential yield.

The number of untreated plants in the 75% insecticide-treated plots constrained the number of plants that could be sampled. In Experiments 1 and 2 only 10 plants per plot were sampled. This was increased to 20 in Experiments 3–6. To avoid bias, the selection of plants for sampling was semi-structured, similar numbers of plants were chosen from segments close to the edge and close to the centre of each plot.

2.5. Data analysis

Data from the 100% treated plots were excluded from the analyses in order to avoid skewing the data. Analyses were conducted using data from each plant sampled rather than plot means as this would lose a great deal of information regarding the possible causes of variation (R. Thompson, Rothamsted, personal communication, November 1999). The data from each sample time were analysed separately using analysis of variance (ANOVA), and all data were transformed to logarithms $z = \ln(x + 1)$. To determine whether a significant relationship existed across the treatments (0–75%), the treatment structure was converted to a polynomial. This allowed the treatment sum of squares to be separated into orthogonal components, representing linear, quadratic and deviations from a quadratic fit. Table 2 shows the skeleton ANOVA table.

Table 2
ANOVA frameworks employed in the experiments

Main effects	DF
Cowpea (percentage of insecticide-treated plants)	3
Linear	1
Quadratic	1
Deviation from linear and quadratic	1
Row	4
Column	4
Error	188
Total	199

3. Results

The back-transformed treatment means from each experiment and an indication of the level of significance is presented in Figs. 2–4. This information is summarised in Table 3. In Table 3, the experiments are grouped; by year (1–2 from late season 1995) and the early season 1996 experiments further grouped by insecticide used: carbofuran (5–6) or furathiocarb (3–4) was used as an insecticide. All of the 1995 experiments utilised carbofuran.

A large proportion of the samples in both the 1995 and the 1996 experiments had significant trends across the treatments for both the number of damaged leaves and leaf damage. For both variables, the greater the proportion of insecticide-treated plants the lower the pest damage on the untreated plants in the same treatment. The same trends were observed for both carbofuran and furathiocarb, although generally more pronounced with carbofuran than

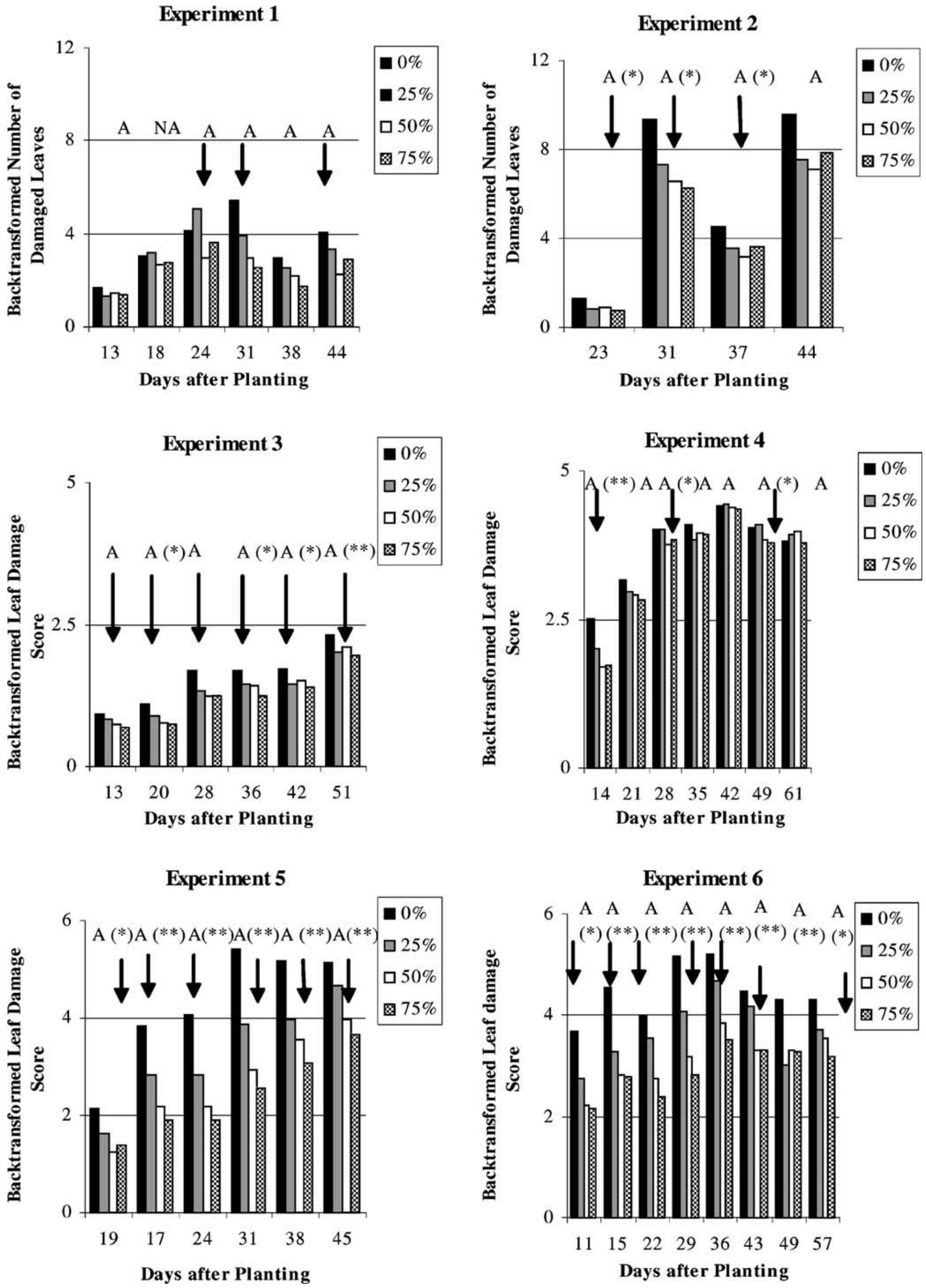


Fig. 2. Back-transformed mean number of damaged leaves per leaf damage score on susceptible plants. Treatment means (in the order 0, 25, 50 and 75% of the plants treated) are presented from left to right. Samples from the same experiment are located on the same graph with the earliest sample on the left. This is labelled through the sampling date (days after planting). A: data suitable for an ANOVA; NA: data not analysed as unsuitable for an ANOVA; (*): ANOVA demonstrated a significant difference (5% level of confidence); and (**): ANOVA demonstrated a significant difference (1% or less level of confidence). An arrow indicates that there was a significant (at least 5%) relationship across the treatments. The direction of the arrow suggests the nature of the relationship.

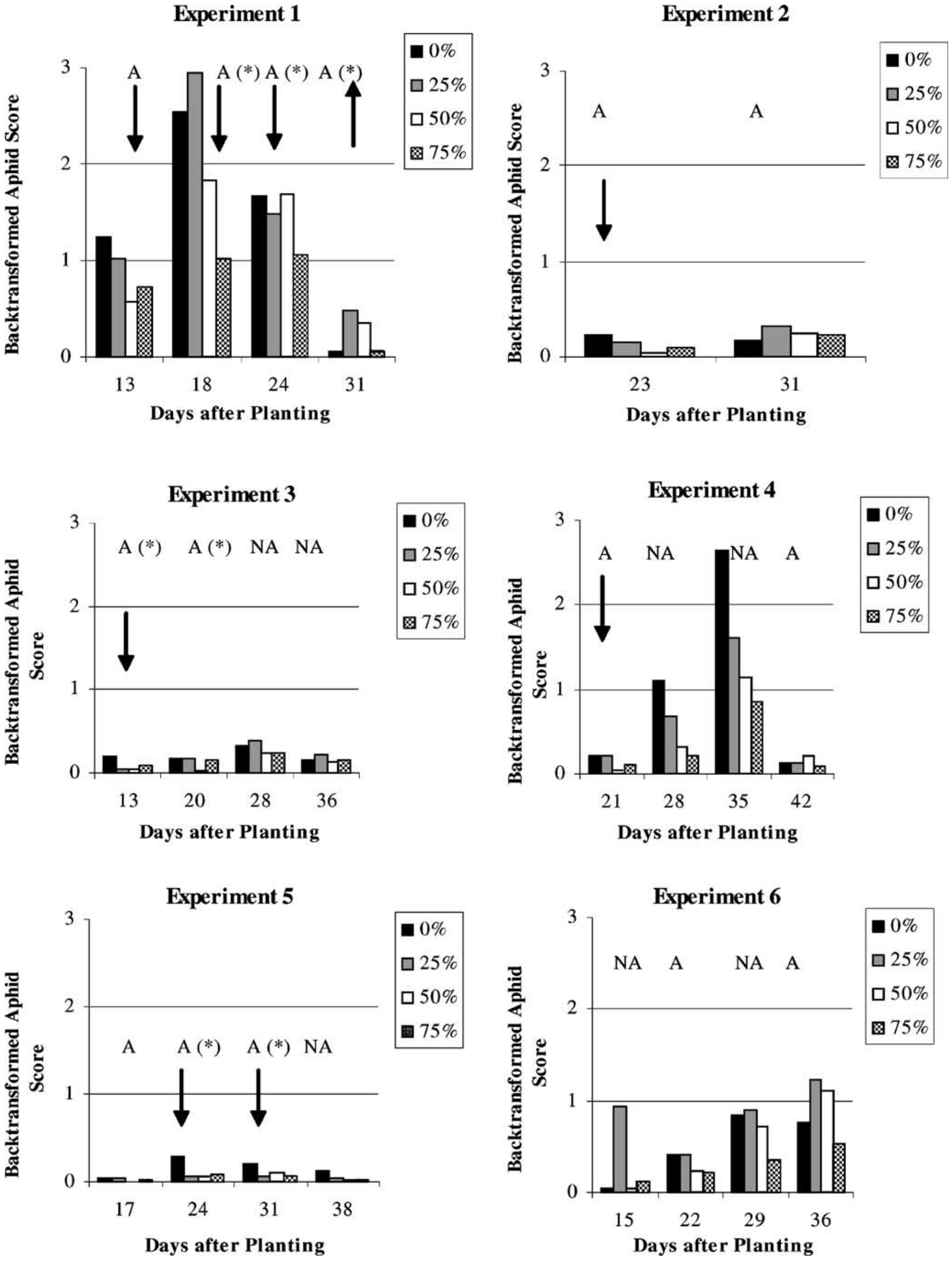


Fig. 3. Back-transformed mean aphid score on susceptible plants. Treatment means (in the order 0, 25, 50 and 75% of the plants treated) are presented from left to right. Samples from the same experiment are located on the same graph with the earliest sample on the left. This is labelled through the sampling date (days after planting). A: data suitable for an ANOVA; NA: data not analysed as unsuitable for an ANOVA; (*): ANOVA demonstrated a significant difference (5% level of confidence); and (**): ANOVA demonstrated a significant difference (1% or less level of confidence). An arrow indicates that there was a significant (at least 5%) relationship across the treatments. The direction of the arrow suggests the nature of the relationship.

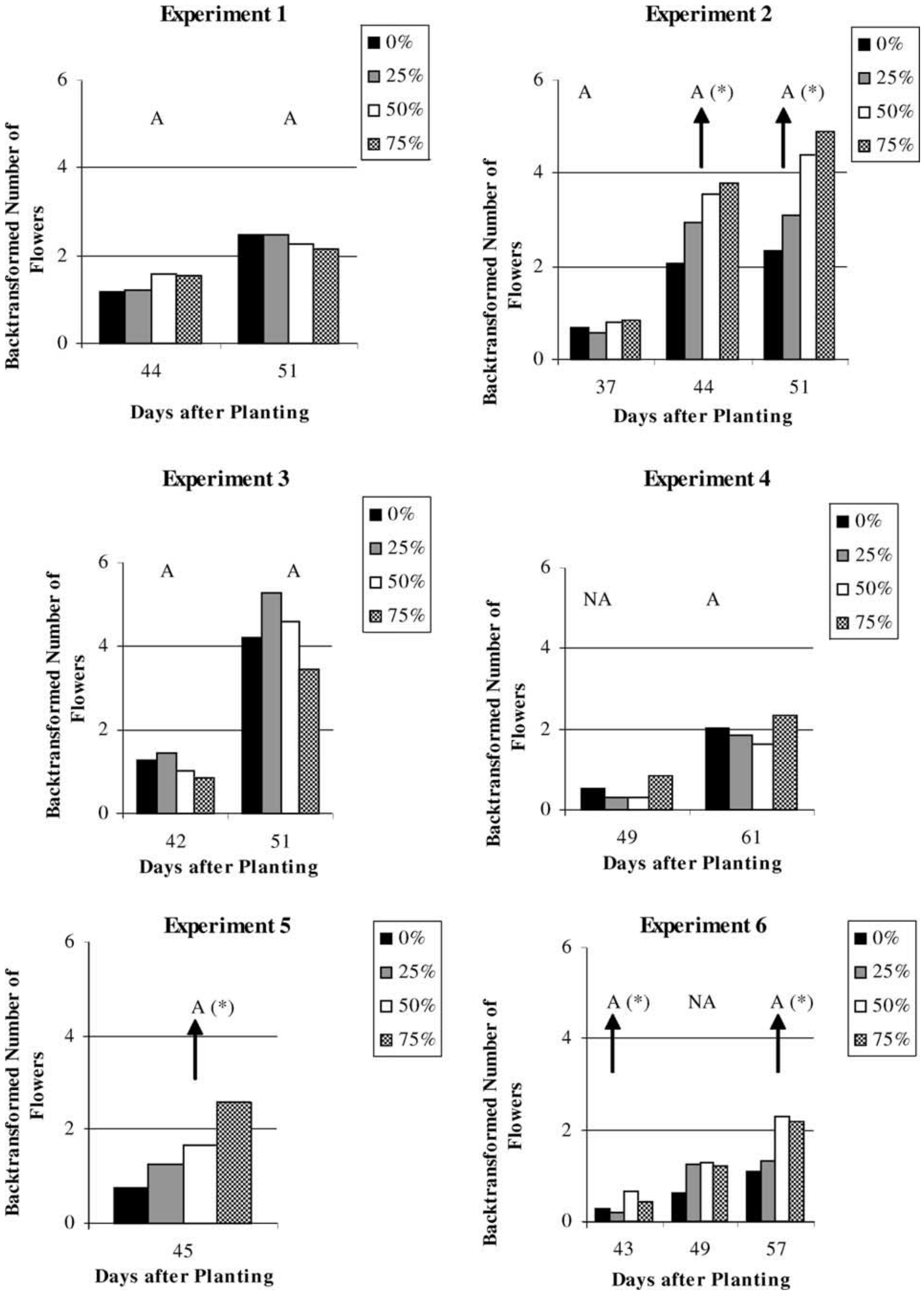


Fig. 4. Back-transformed mean number of flowers on susceptible plants. Treatment means (in the order 0, 25, 50 and 75% of the plants treated) are presented from left to right. Samples from the same experiment are located on the same graph with the earliest sample on the left. This is labelled through the sampling date (days after planting). A: data suitable for an ANOVA; NA: data not analysed as unsuitable for an ANOVA; (*): ANOVA demonstrated a significant difference (5% level of confidence); and (**): ANOVA demonstrated a significant difference (1% or less level of confidence). An arrow indicates that there was a significant (at least 5%) relationship across the treatments. The direction of the arrow suggests the nature of the relationship.

Table 3
Summary of ANOVA tests performed on transformed data sets for the partial insecticide application experiments

Comparison	Damaged leaves	Leaf damage		Aphid score			Flowers		
Experiment no.	1–2	3–4	5–6	1–2	3–4	5–6	1–2	3–4	5–6
Total number of samples	10	14	13	6	8	8	5	4	4
Total number of samples analysed[a]	9	14	13	6	5	5	5	3	3
No. samples with significant differences between treatment means	5	12	8	3	1	3	0	2	0
Percentage of significant samples (of those analysed) (%)	50	86	62	50	13	38	0	50	0
No. samples with significant trends across treatment means[b]	6	13	9	5	2	2	2	3	0
Percentage of significant samples (%)	60	93	69	83	25	25	40	75	0
Nature of trend[c]									
Positive	0	0	0	1	0	0	2	3	0
Negative	6	13	9	4	2	2	0	0	0

[a] Only those data sets that would legitimately fit an ANOVA were analysed. This accounts for the discrepancy between the number of times a variable was sampled and the number of times that it was analysed.

[b] The number of significant linear and quadratic regression analyses were similar, although it would appear that there were generally more significant linear than quadratic relationships. As a result, linear and quadratic trends have been grouped together in this table. As transformed data was used in the analysis, it is hard to determine the exact nature of the relationship across the treatment means. The 5% probability level has been used to determine significance either for the difference between the treatment means or the indication of a significant trend across the treatment means.

[c] The number of samples showing a significant linear or quadratic trend across the treatment means are further divided as to whether they exhibit a positive or a negative trend in relation to increasing percentages of insecticide-treated plants. A negative trend infers a decreasing mean with an increasing percentage of treatment, while a positive trend implies an increase. The direction of the trend was made from visual observations of Figs. 1–3.

furathiocarb. Leaf damage was generally higher in the early season.

There were fewer significant differences to be shown between the aphid score treatment means; although this may well have been influenced by the magnitude of aphid densities. However, the predominant significant trend was of a reduction in the aphid score with an increase in the percentage of insecticide-treated cowpea plants in a treatment. Aphid populations were generally higher in the late season of 1995 than the early season of 1996. Little difference was observed between the impact of carbofuran and furathiocarb in the early season 1996 experiments.

With carbofuran as a treatment there were significant trends across the treatment flower means. The nature of these trends was the opposite of that seen with leaf damage and aphid infestation; a greater number of flowers occurring on untreated plants as the percentage of treated plants increased. Significant differences or trends were not observed with the furathiocarb treatments.

4. Discussion

The results show that there was a benefit, in terms of crop protection, for susceptible cowpea plants to be grown in the presence of insecticide-treated cowpea plants. They further show that the greater the percentage of insecticide-treated plants the greater this crop protection benefit. The results correlate well with those of Ward and Morse (1995) for beans grown in the UK. It should be noted that the pest infestation on the susceptible components was still well above that on insecticide-treated plants. Therefore, a farmer who had access to synthetic pesticides would be unlikely to adopt such a cropping strategy unless varietal mixtures could maintain pest population thresholds below the economic threshold for spraying. Farmer adoption of cowpea varietal mixtures in Igalaland is also likely to be influenced by the fact that currently cowpea is only grown as a pure stand. ‘Purity’ of seed is a determinant of market price as different varieties of seed cook at different rates and have different tastes. Nevertheless, if a varietal mixture could be developed utilising near isogenic components this problem could be circumvented.

The carbofuran treatments demonstrated a further benefit in terms of flower production. The impact of foliage pests on yield has been widely discussed (Enyi, 1975; Huxley and Summerfield, 1976; Singh, 1980; Annan et al., 1996; Abate and Ampofo, 1996). These results would suggest that lower foliage pest infestation and damage led to an increase in flower production, and it is possible from the results reported here to suggest which pest was had the greater impact on flower production. As different methods for assessing leaf damage were utilised in the two seasons the data from the two seasons cannot be directly compared. However, the early season 1996 experiments (Experiments 3–6) were comparable as different insecticides, with a differential impact on *O. mutabilis*; carbofuran being apparently more effective against while they had a similar efficacy against *A. craccivora*. It was in the carbofuran experiments for which significant differences between the flower treatment means were observed, suggesting that leaf damage rather than the aphid infestation had a greater impact on flower production.

The mechanism of the pest management in the partial insecticide application treatments will be important for those considering pest resistance management. The results of these experiments provide some scope for the discussion of the mechanism. One possibility is that *A. craccivora* and *O. mutabilis* are able to perceive and hence avoid the insecticides; the greater the stimulus (i.e. the greater the proportion of insecticide-treated plants) the greater the avoidance of the plot and the lower the pest incidence on the untreated plants. In effect the treated plants would be operating as a sort of mechanical barrier that the insects simply avoided. However, it would appear that *O. mutabilis* could not detect the presence of carbofuran as it fed on leaves of carbofuran-treated plants, and dead *O. mutabilis* beetles were observed underneath carbofuran-treated cowpea plants. Treated plants were also observed to cause *A. craccivora* mortality following attempts at feeding. A second possibility, insecticide drift was also very unlikely. Granular insecticide was applied to physically divided ridge segments, and care was taken so as to deliver only the required amount of insecticide to each plant before covering with soil. In addition, the observed effects with seed treatment (where drift would be much less of a problem) were broadly the same as with carbofuran.

There are two further explanations based on pest mortality caused by feeding on the insecticide-treated plants. With a lateral infestation of pests, those landing and feeding on the treated plants would be killed thereby reducing the infestation pressure on susceptible plants. The greater the percentage of treated plants in a plot the greater the number of pests that would die as they spread through the crop. Such ‘flypaper’ control was described as a mechanism of plant pathogen control using multilines (Jensen, 1988). The Latin square experimental design can assist an investigation into the probability of this effect having occurred. If there were a filtering effect it would occur at both a plot and an experimental level. Therefore, it would be expected that there would be a higher pest infestation in control plots on the outside of the experimental layout than those towards the centre. This requires the pest data needs to be disaggregated by location within the experiment. In terms of experiment edge interface, there are four different possible positions for a plot:

- Position 1—The plot has two borders with the edge of the experiment.
- Position 2—The plot has one border with the edge of the experiment.
- Position 3—The plot is at one plot’s depth to the edge of the experiment.
- Position 4—The plot is at two plot’s depth to the edge of the experiment.

These locations are shown in Fig. 5. Experiment 5 was the only experiment with a 0% control plot in Position 4. Therefore, this experiment was the best experiment in which to compare the pest infestation on

1	2	2	2	1
2	3	3	3	2
2	3	4	3	2
2	3	3	3	2
1	2	2	2	1

Fig. 5. The four possible plot positions in the Latin square design.

Experiment 4

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6	Sample 7	Sample 8
Position 1	3.2	3.6	3.7	4.45	4.6	3.5	4.15	3.8
Position 2	4.9	5.5	4.925	6.9	6.425	5.85	5.65	6.075
Position 3	3.325	4.45	3.45	4.375	4.8	4.025	3.5	3.25
Position 4								

Experiment 5

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5	Sample 6
Position 1	1.2	1.3	2	1.55	1.4	2.05
Position 2	1.15	1.225	1.8	2.025	1.975	2.625
Position 3	0.85	1.1	1.7	2.05	1.8	2.3
Position 4	1.05	1.15	1.45	1.3	1.75	2.2

Fig. 6. Mean leaf damage for plants in the 0% control treatments by location.

Experiment 1

	Sample 1	Sample 2	Sample 3	Sample 4	Sample 5
Position 1	1.3	2.9	1.5	0	0.1
Position 2	1.95	2.5	1.65	0	0.15
Position 3	1.1	2.7	2.45	0.3	0
Position 4					

Experiment 5

	Sample 1	Sample 2	Sample 3	Sample 4
Position 1	0.35	0	0.1	0.4
Position 2	0.3	0.525	0.45	0.125
Position 3	0.35	0.05	0.3	0.4
Position 4	0.35	0.05	0.3	0.4

Fig. 7. Mean aphid score for plants in the 0% control treatments by location.

the 0% treatments. Additional experiments exhibiting a spread of 0% plot locations and a large number of samples showing significant differences between the treatment means were also compared.

Although not analysed for significance, the results in Figs. 6 and 7. would appear to show that the plots towards the centre of the experiment (Positions 3 and 4) do not consistently show less leaf damage and aphid infestation than those plots on the edge of the experiment (especially those plots on the corner of the experiments). It is therefore, unlikely that the reduction in pest infestation is due to a filtering out of pests as a result of their lateral movement through the crop.

The experiments showed that partial insecticide application treatments did reduce both *O. mutabilis* and *A. craccivora* on the untreated, susceptible component. This led to an increase in the average number of flowers per plant. However, this research does not explain why this effect occurred and therefore, pest resistance management implications cannot be explored.

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