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The Impact of Insecticides on Beneficial Arthropods in Cotton Agro-Ecosystems in South Africa

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Abstract. The unique diversity of beneficial arthropods in South Africa can be regarded as an important natural resource in agro-ecosystems as it plays an important role in the natural control of insect pests. Insecticide applications reduce the ability of these beneficials to regulate cotton pests. In the absence of insecticides, average daily predation rates of 37% and 30% of bollworm eggs and larvae respectively were found in exclusion experiments. By minimizing the number of pesticide applications the combination of the direct negative effect of pesticide application on predator populations and secondary pesticide effects such as the stimulation of red spider mite populations as a result of predator suppression, can be avoided. This would open the option to fully utilize the full pest control potential of the natural enemy complex.

Anthropogenic stress is exerted on environments in many ways and is generally widely researched. However, the impact of man on a particular natural resource, namely, the natural enemies of our economic important insect pests is a matter of great importance which has received relatively low priority in environmental research to date. This paper aims to highlight the importance of beneficial arthropods as a natural resource using a cotton agro-ecosystem as an example.

Cotton in Africa is attacked by a complex of pests of which the African bollworm, *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae) is the key pest species throughout the Old World and subtropics (Matthews 1989; Van Hamburg and Basson 1987). This insect is probably one of the most economically important insect pests in South Africa and is highly polyphagous (Pearson 1958). It attacks besides cotton, a wide range of crops such as maize, grain-sorghum, tobacco, citrus, sunflower, various vegetables etc. Cotton is especially vulnerable to bollworm attack due to the long flowering period of cotton and the fact that *H. armigera* concentrates its attack on the flowers and fruiting parts of plants.

The other components in the cotton pest complex are the red bollworm (*Diparopsis castanea* Hampson), spiny bollworms (*Earias* spp.), cotton stainers (*Dysdercus* spp.) and a few pests of minor importance such as thrips, leafhoppers, whiteflies, and aphids. Red spider mite (*Tetranychus cinnabarinus* (Boisduval)) is also a serious pest on cotton but is induced by indiscriminate insecticide application, probably as a result of the elimination of the natural enemies of red spider mites (Van Hamburg and Basson 1987).

Cotton is extensively sprayed in South Africa, especially against the African bollworm. Before 1975 farmers sprayed mainly preventatively for up to 15 times per season which escalated production costs and increased the risk of bollworm resistance against insecticides (Whitlock 1973) and had negative environmental effects such as the negative impact on the natural enemy complex with the resulting buildup of secondary pests. In an effort to reduce the use of insecticides, research was done to establish an economic threshold as a decision criterium for spraying. Spraying according to a threshold of 0.5 bollworm egg per plant or more led to a reduction in the average number of sprays per season from 15 (preventative spraying) to 8. Further research on the spraying criterium showed that spraying, based on a larval index of 8 larvae per 12 plants led to a further reduction in the average number of sprays to 2.3 per season (Van Hamburg 1981; Van Hamburg and Kfir 1982; Kfir and Van Hamburg 1983). Results from these studies on economic thresholds during 1981–1983 showed that although the average number of sprays was substantially reduced (from 15 to 2.3 per season), no statistically significant decrease in yield could be detected in plots sprayed on average 2.3 times compared to plots sprayed 15 times. The following factors could possibly explain this:

1. the presence of biological regulating factors which could possibly regulate bollworm and red spider mite populations in the absence or minimal use of insecticides,
2. other possible negative side effects of extensive insecticide use, counteracting the advantage of better bollworm control.

Evidence for the importance of natural enemies in the regulation of pest populations is numerous (Croft 1990; Chambers *et al*. 1983; Edwards *et al*. 1979; Vickerman and Sunderland 1975). In Kenya natural enemies (mainly predators) and other ''unidentified factors'' contributed up to 96% of *Chilo partellus* generation mortality (Oloo 1989; Oloo and Ogeda 1990).

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The natural enemies of *Helicoverpa armigera* in Africa were reviewed by Van den Berg *et al*. (1988) based on published, unpublished and museum sources. A large variety of natural enemies are represented in almost 300 host records. Striking differences were found in the reported parasitoid complexes between East Africa and southern Africa (Van den Berg *et al*. 1988). Only three of 24 parasitoid species are important in both areas. Egg parasitoids seem more important in southern Africa but scarce in East Africa. Dipteran parasitoids are more common in southern Africa with relatively low incidence of Hymenopteran parasitoids, whereas in East Africa the Ichneumonid and Braconid parasitoids are much more common Studies in Kenya on smallholder crops showed that the incidence of parasitism was generally low ($<5\%$) or absent (Van den Berg *et al*. 1993), and that predators have a great impact on the survival of *H. armigera* eggs and larvae (Van den Berg 1993). Parsons and Ullyett (1934) recognized the role of *Orius* sp. in the control of *H. armigera* eggs on cotton.

This paper aims to describe the abundance and diversity of the natural enemy complex of *H. armigera* on cotton and its vulnerability to the indiscriminate use of insecticide, and to evaluate the influence of the natural enemy complex on the survival of *H. armigera* eggs and first instar larvae from exclusion experiments.

Material and Methods

During the 1985 to 1987 seasons three studies were carried out on cotton near Brits in the North West Province. The first study was aimed at the evaluation of the types and abundance of natural enemies and pests in unsprayed cotton (1986–1987 season). In the second study exclusion experiments were carried out in unsprayed cotton to determine the influence of the natural enemy complex of cotton pests on the survival of bollworm eggs and first instar larvae (1985–1987 seasons) and in the third study an experimental protocol was used to evaluate the effect of pesticide application on the predator/bollworm relationship in a cotton field at the same location (1985 season).

Natural Enemy Diversity and Abundance

The number of *H. armigera* eggs and larvae and their natural enemies were determined on weekly samples of 90 random plants by careful scouting of the plants. The predators found were collected and identified as far as possible and the *H. armigera* eggs and larvae were collected and reared through in the laboratory on a chick pea (*Cicer arientinum*) based artificial medium (Van Hamburg 1976) in order to isolate the parasitoids and to determine percentage parasitism.

Exclusion Experiments

Within a 10-hectare high potential, irrigated cotton field, an experimental plot of about 5 hectare was divided into 6 plots (35 m $\times$ 33 rows). Four plants were selected randomly in each plot and covered with a transparent plastic rain shelter, held by three poles, to eliminate the possible mortality of eggs and larvae as a result of rain and irrigation (Mabbett and Nachapong 1983; Nuessly *et al*. 1991). The four plants in each plot received one of the following treatments:

1. The plants were covered with organdy sleeves which were held open by a wire frame. The base of the plants were treated with Reverant^{R}, a sticky substance to keep all arthropods from climbing on the plants and plants were pruned to isolate them from neighboring plants. Three *H. armigera* eggs, from laboratory cultures were attached inside the squares or flower bracts with egg albumin. The plants were scouted for four consecutive days and all intact, missing or damaged eggs were noted. All the missing and damaged eggs were replaced daily to ensure that three eggs were available each day on all the treatment plants.
2. The same treatment as in 1, but without the sleeve.
3. The same treatment as in 1, but first instar larvae from laboratory cultures were placed in the squares or flower bracts instead of eggs. The plants were searched daily and their presence or absence was noted. The missing larvae were replaced to keep the infestation at three larvae per plant per day.
4. The same treatment as in 3, but without the sleeve.

The plants in the sleeved treatments were treated with a contact insecticide (dichlorvos), with a persistence of less than one day (Tomlin 1994), four days before the artificial infestation, to ensure that these plants were free of natural enemies. Predation rates were calculated from the data for all four treatments for the four treatment days.

Insecticide Application Experiments

The effect of a registered and generally used pesticide namely Deltamethrin^{R} at the registered dose of 500 ml/ha, on cotton pests and their natural enemies was determined, when applied according to two threshold levels. First, a threshold level of 0.5 *H. armigera* egg per plant and, second, a threshold level of a larval index of 8 or more. The larval index was obtained as follows: 12 randomly selected plants were searched weekly for bollworm larvae; larvae shorter than 4 mm were not counted, those from 4 to 15 mm were each counted as one and those longer than 15 mm were each counted as three (Kfir and Van Hamburg 1983). The relative abundance of the two most important cotton pests namely the African bollworm, and the red spider mite, were recorded during weekly surveys as part of this economic threshold experiment, similar to those published by Van Hamburg and Kfir (1982) and Kfir and Van Hamburg (1983). The relative abundance of the pests and the predating stages of the more prominent predator species, consisting of the mirids, anthocorids, coccinellids and chrysopids were determined by the careful manual scouting of 16 random plants per week in unsprayed control plots and in plots sprayed according to the threshold decision criteria for spraying.

Results

Natural Enemy Diversity

A large variety of predators was found on cotton. The feeding stages of the more prominent predator groups and the total number of predators in each group observed during weekly surveys of 90 cotton plants during the 1986–1987 season are summarized in Table 1. The predators listed are observed or potential predators of *H. armigera*.

The mirids were the dominant predators and were represented by a number of unidentified species feeding on bollworm eggs and a *Campylomma* sp., which also predated on red spider mites. The next most abundant predator group was the Anthocoridae (Hemiptera) which was represented by *Orius thripoborus* and an *Orius* sp. followed by a variety of spiders, coccinellids (mainly *Scymnus moreletti, Hippodamia varigata, Cheilomenes propinqua, Exochomus flavipes, Lioadalea flavomaculata*), ants,

Table 1. Total number of feeding stages of predators observed in weekly surveys of 90 plants per week in an unsprayed cotton field near Brits during the 1986/87 season

Predator group	Total number observed
Miridae	2088
Anthocoridae	475
Spiders	414
Coccinellidae	167
Formicidae	37
Chrysopidae	28
Staphilinidae	17
TOTAL	3226

Table 2. Egg parasitoids of *Helicoverpa armigera* found on cotton during the 1986/87 season

Sample size (eggs)	Number parasitized	Parasitoid	Total % parasitism	Range
315	38	*Trichogrammatoidea lutea* Trichogrammatidae	12.1	0–24.6
	17	*Telenomus* sp. Scelionidae	5.4	0–12.2
315	55	Total %	17.5	0–26.1

Table 3. Larval parasitoids of *Helicoverpa armigera* found on cotton during the 1986/87 season

Sample size (larvae)	Number parasitized	Parasitoid	Average % Parasitism
218	6	Tachinidae spp.	2.8
	4	*Apanteles diparopsidis* (Braconidae)	1.8
	7	*Pristomerus* sp. (Ichneumonidae)	3.3
	1	*Meteoris* sp. (Ichneumonidae)	0.5
	1	*Metopius* sp. (Ichneumonidae)	0.5
218	19	Total %	8.9

chrysopids, and staphilinids. Relatively few ants were found on the plants and consisted mainly of *Dorylus* and *Pheidole* spp. The Staphilinidae was represented by *Olichota fageli* (Williams). Very few predators were able to survive in sprayed cotton fields with the exception of *O. fageli*, which were found in large numbers feeding on the emerging red spider mite populations. These predators seem to have developed a resistance to the pesticides, as did the red spider mites. The egg parasitoids that were reared from *H. armigera* eggs, and rates of parasitism, are shown in Table 2.

The rate of egg parasitism was relatively low (up to 26%) compared to rates of up to 64% on cotton in South Africa (Van Hamburg 1981). *Trichogrammatoidea lutea* (Trichogrammatidae: Hymenoptera) was the dominant egg parasitoid with rates of parasitism up to 24.5% and a seasonal parasitism rate of 12%, followed by *Telenomus ullyetti* (Scelionidae: Hymenoptera) with parasitism of up to 12% and a seasonal rate of 5.4%. The larval parasitoids that were reared from *H. armigera* larvae during the 1986–1987 season, and seasonal rates of parasitism, are presented in Table 3.

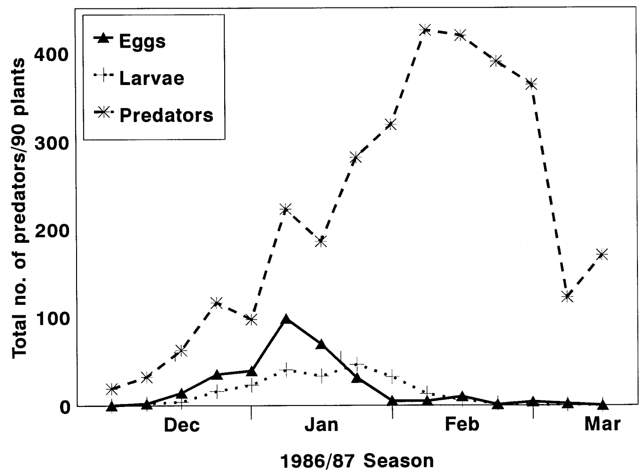

Fig. 1. Total number of eggs, and larvae of, and predators counted on 90 cotton plants during weekly surveys in a cotton field near Brits, 1986–1987 season

Table 4. Total number of predators (predating stages) found on sleeved and unsleeved cotton plants counted during surveys on four consecutive days

Predator group	Sleeved plants	Unsleeved plants
Miridae	7	145
Anthocoridae	4	45
Coccinellidae	0	2
Chrysopidae	1	6
Spiders	0	26
Total	12	224

Larval parasitism was generally low on cotton (<9%) and contributed little to bollworm mortality. Although a greater diversity of parasitoids has been reported on cotton in South Africa, few were found during these trials.

The Relative Abundance of H.armigera *and its Predators on Cotton*

The total number of *H.armigera* eggs and larvae as well as the number of predators in weekly samples of 90 plants in an unsprayed cotton field during the 1986–1987 season is shown in Figure 1.

The Predation Rate of the Natural Enemy Complex on H. armigera *Egg and First Instar Larval Populations in Cotton*

The results of the exclusion trial are summarized in Tables 4 to 8. The efficiency of the exclusion measure was tested and scouting results of four consecutive days for predators on the sleeved and unsleeved plants are given in Table 4.

A total of 224 predators were counted on the 72 unsleeved plants of which most were mirids and anthocorids. Only 12 predators were found on the 72 sleeved plants. The sleeves were

Table 5. The survival of *Helicoverpa armigera* eggs on sleeved and unsleeved cotton plants during four consecutive days

Treatment	No. eggs placed	No. eggs intact	No. eggs lost	No. eggs damaged
Sleeved	72	60 (83%)	5 (7%)	7 (10%)
Unsleeved	72	33 (46%)	4 (6%)	35 (49%)

Table 6. Daily predation rate of *Helicoverpa armigera* eggs on sleeved and unsleeved cotton plants calculated for four consecutive days

Day	Sleeved	Unsleeved	Predation rate
1	0.13	0.56	0.43
2	0.06	0.44	0.38
3	0.33	0.56	0.23
4	0.17	0.61	0.44
Mean	0.17	0.54	0.37

Table 7. The survival of *Helicoverpa armigera* larvae on sleeved and unsleeved cotton plants

Treatment	No. larvae placed	No. larvae intact	No. larvae lost	No. larvae damaged
Sleeved	72	58 (82%)	8 (11%)	6 (8%)
Unsleeved	72	37 (51%)	31 (43%)	4 (6%)

Table 8. Daily predation rate of *Helicoverpa armigera* larvae on sleeved and unsleeved cotton plants

Day	Sleeved	Unsleeved	Predation rate
1	0.23	0.72	0.49
2	0.22	0.33	0.11
3	0.11	0.50	0.39
4	0.17	0.30	0.22
Mean	0.18	0.46	0.30

therefore relatively efficient in excluding the predator complex. The percentage of eggs which survived on sleeved and unsleeved plants as well as the percentage damaged and missing eggs are given in Table 5.

Total egg mortality (presumably mainly due to predation) for the four days, on unsleeved plants was 54% compared to 17% mortality (due to unknown factors and some predation from a few undetected predators) on sleeved plants. A mean daily predation rate was calculated for each daily replication from the fraction of eggs surviving and adjusted for the mortality rates of eggs on the sleeved plants (Table 6).

The mean predation rate of eggs on unsleeved plants was statistical significantly higher than on the sleeved plants ($t = 5.4678$, $P = 0.0016$). The percentage of first instar larvae which survived on sleeved and unsleeved plants as well as the percentage lost and dead larvae are given in Table 7.

The total first instar larval mortality (presumably mainly due to predation) for the four days, on unsleeved plants was 49% compared to 18% mortality (due to unknown factors and some predation from a few undetected predators) on sleeved plants. A

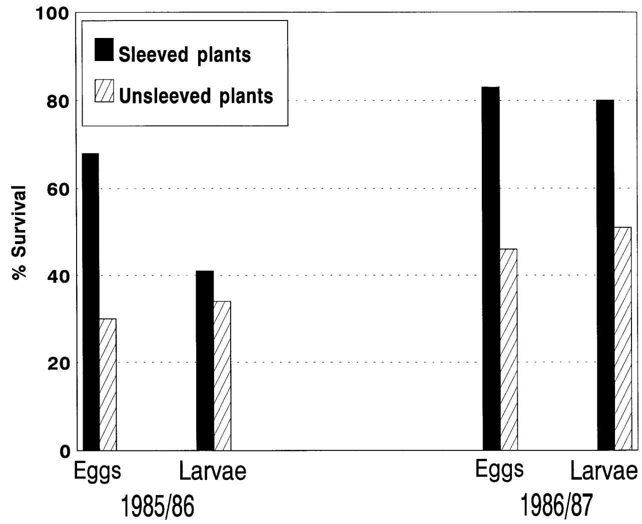

Fig. 2. The percentage survival of *Helicoverpa armigera* eggs and first instar larvae on sleeved and unsleeved cotton plants in two predator exclusion experiments

daily predation rate was calculated for each trial day in the same way as for the calculation of egg predation rates (Table 8).

The mean predation rate of first instar larvae on unsleeved plants was statistical significantly higher than on sleeved plants ($t = 2.7913$, $P = 0.0315$). A similar exclusion trial was carried out earlier during the 1985/86 season. The total survival of eggs and first instar larvae for these two exclusion trials are summarized in Figure 2.

Negative Effects of Insecticide Application Against Cotton Pests

Direct Effects: Unfortunately most predators are vulnerable to insecticides (Ehler *et al*. 1973; Eveleens *et al*. 1973; Jepson 1989; Croft and Brown 1975) and the impact of bollworm chemical control on the incidence of the predator complex in cotton was therefore investigated.

The negative effects of chemical bollworm control can be demonstrated from data that was collected as part of an economic threshold trial during the 1984/85 season. The total number of prominent predator species found in weekly surveys of 16 randomly selected cotton plants in each of the two threshold treatments (0.5 eggs per plant and a larval index of 8) were counted and compared with predator counts in unsprayed plots. The data are shown in Figure 3.

Treatments sprayed according to the 0.5 eggs per plant threshold, received three deltamethrin applications and the larval index of 8 threshold only one. These applications are indicated in Figure 3 with arrows. A significant decline in predator numbers with the commencement of insecticides is obvious from Figure 3. This reduction in predator populations coincides with the boll development stage of cotton. Predator numbers remained low in plots which received three spray applications with a slight recovery at the end of the season. The

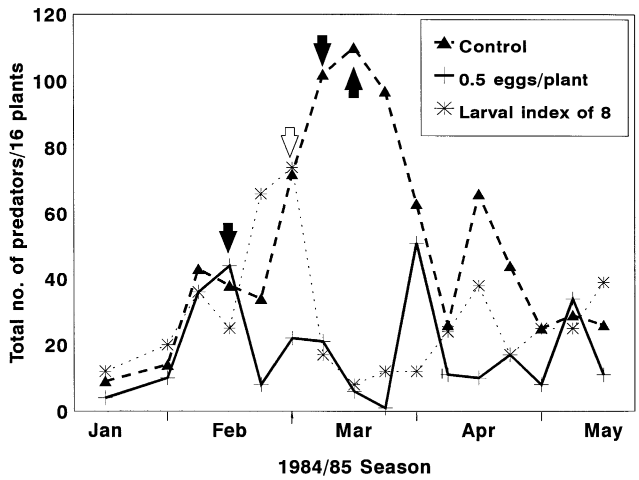

Fig. 3. Total number of predators found during weekly samples on 16 plants in unsprayed cotton plots and in cotton plots sprayed according to two threshold strategies. Solid arrows indicate insecticide applications applied on the plots sprayed according to the 0.5 egg per plant threshold; open arrows indicate applications on plots sprayed according to a larval index of 8

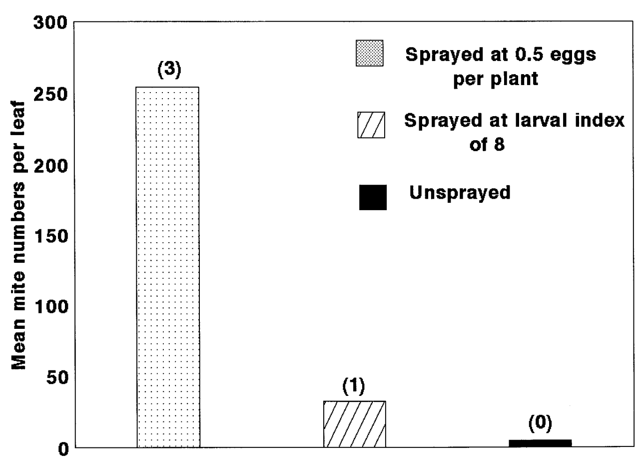

Fig. 4. Mean number of red spider mites per leaf in the top 20% of unsprayed cotton plants, plants sprayed according to the 0.5 egg per plant threshold, and plants sprayed at larval index of 8. The figures in parantheses ( ) indicate the number of insecticide applications applied

larval index of 8 threshold treatment received only one spray application and application commenced two weeks later than the 0.5 egg per plant threshold treatment. This ensured a relatively high predator population up to the beginning of March and a slightly better recovery of predator populations towards the end of the season.

Secondary Effects: With the indiscriminate use of broad spectrum insecticides, secondary phytophagous insects, normally of no or little importance, emerge as serious pests (Eveleens *et al*. 1973; Croft 1990). In cotton fields the commencement of application of synthetic pyrethrins insecticides coincides with an enormous build up of red spider mites (Van Hamburg and Basson 1987). This red spider mite population explosion is probably a direct result of the elimination of the natural enemy complex. The mean number of red spider mites per leaf in the top 20% of cotton plants in plots sprayed according to the 0.5 egg per plant and a larval index of 8 threshold, was determined at the beginning of April as part of the economic threshold trial mentioned above. The data are summarized in Figure 4. The stimulating effect of the deltamethrin applications on red spider mite populations is clearly shown in Figure 4.

Conclusions and Discussion

It is obvious that the natural enemy complex in cotton can be regarded as an important natural resource in the regulation and control of cotton phytophagous insects. A wide variety of predators were found in cotton (Tables 1 to 3) which, as a complex of mortality factors, can provide high daily predation rates of bollworm eggs and larvae if pesticides are minimized or eliminated (Tables 5 to 8). However, seasonal parasitism was generally low at less than 9% larval parasitism and less than 18% egg parasitism. This corresponds with results found in Kenya (Van den Berg *et al*. 1993). The possible augmentation of especially the larval parasitoids of *H. armigera* should therefore be investigated in future research. The composition of predators differed significantly from the composition found in Kenya (Van den Berg *et al*. 1993). Miridae species and to a lesser extend the anthocorids were the dominant predators which differs from surveys in Kenya where the ants and anthocorids were the dominant predators.

A typical predator-prey relationship is evident from Figure 1, showing a build up of *H. armigera* eggs and larvae followed by a large increase in predator numbers which coincided with a decrease in bollworm eggs and larvae. It seems therefore as if the natural enemy complex, and especially the predators constitute an important controlling factor in *H. armigera* populations although not enough to prevent spraying altogether as indicated by the insecticide applications that were necessary during the economic threshold experiments. The natural enemy complex provided a variety of controlling agents with build in redundancy to ensure a total positive controlling effect. However, the predator population build up came too late to prevent the peak of bollworm larvae during the vulnerable flowering stage of cotton in January .

It is clear from data in Tables 6 and 8 that predators had an important impact on the egg and larval survival of *H.armigera* populations during the exclusion trials and daily predation rates varied around an average of 37% (range 23–44%) for eggs and 30% (range 11–49%) for larvae.The daily predation rates varied considerably which could be expected since environmental conditions would have effected the activity of predators. The predation rates may also change over time during the season. This variability is demonstrated in Figure 2, which could have been influenced by unknown factors such as plant condition (Van den Berg 1993). However, the relative importance of these predators is still most significant and constitutes a natural resource which should be protected and augmented. The long term seasonal evaluation of predation should be further investigated.

Van Hamburg and Kfir (1982) and Kfir and Van Hamburg (1983) showed in economic threshold trials that an increase in insecticide applications did not correlate with an increase in yield. In fact there was a tendency of decreasing yield with weekly applications. The combination of the direct negative effect of pesticide application on predator populations (Figure 3) and secondary pesticide effects such as the stimulation of red spider mite populations as a result of predator suppression (Figure 4), would have a negative effect on the efficiency of the chemical control programs and on cotton production. A study by Roach and Hopkins (1981) showed that when synthetic pyrethroids (such as deltamethrin) were used against *Heliothis* in cotton fields, most predator species were eliminated. It can be assumed that with preventative spraying programs of up to 13 applications per season in South Africa, few if any of the natural enemies species will survive. The only predator population which increased with pesticide applications was the staphilinid *O. fageli*. This beetle was found to feed on red spider mites and seems to be resistant against the pesticide treatments. This predator was not included in the predator counts shown in Figure 3. The drastic reduction of natural enemies with the commencement of pesticide applications reduce the capacity of the natural enemies to regulate the resurgence of bollworm populations and the effect of population explosions of red spider mites populations would to some extend counteract the advantage of improved bollworm control.

The economic implication of these results for farmers in South Africa and especially for subsistence farmers is considerable. Some cotton farmers spray as often as 13 times per season with serious financial consequences. It has been calculated (Mumford and Van Hamburg 1986) that under marginal dry land conditions, one insecticide application could cost the farmer up to 10% of his gross margin. Preventative cotton spraying is therefore not only ecologically unwise but also very costly. In temporary agro-ecosystems the best way of reducing the use of insecticides is by developing accurate damage threshold levels and reducing the number of insecticide applications and extend their time of commencement as far as possible. The optimal use and protection of the wide diversity of natural enemies of insect pests as a natural resource is essential for profitable cotton farming in South Africa and recommendations for chemical control especially for the growing number of subsistence farmers should only be based on good scientific research.

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