Assessing the feasibility for cotton production in tropical Australia: Systems for *Helicoverpa* spp. management

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ABSTRACT

Cotton was previously grown in tropical Australia from 1963-1974 during the wet season (summer). The failure of this industry was primarily caused by inadequate insect management, which caused resistance in Helicoverpa armigera. *Since 1974 management of* H. armigera *has been the major factor limiting expansion in tropical Australia. In 1994 a feasibility study on producing cotton in tropical Australia, with a strong emphasis on sustainability was commenced. One of the cornerstones of this proposal was that the use of insecticides to control pests, particularly* Helicoverpa *spp. (*Helicoverpa armigera *and* H. punctigera*) would be kept to a minimum and transgenic cotton varieties (INGARD™) would be used to assist this. INGARD™ cotton was grown during the dry season (winter) in tropical Australia to avoid certain pests, which were problematic in the 1960-70's when cotton was previously grown in this area. The cotton was grown according to best practice integrated pest management principles – it was scouted regularly and records kept of pest and beneficial insect numbers. Control of pests occurred according to predetermined thresholds. Biological products and chemicals, which targeted specific insects, were preferred over more broad-spectrum chemicals. Companion crops such as lucerne, lablab, or pigeon pea were planted as strips within the cotton crop to attract* Helicoverpa *spp. away from the cotton. INGARD™ alone was used as a benchmark every season. After six years of trials, INGARD™ cotton grown with a companion crop consistently had less* Helicoverpa *spp. eggs and larvae on it than the INGARD™ cotton grown alone. INGARD™ cotton grown alone received more insecticide sprays for Helicoverpa spp. control and had a lower yield than INGARD™ cotton grown with companion crops.*

Introduction

Cotton was previously grown in the Ord River Irrigation Area in NW Australia (15.5°S, 128.0°E) from 1963-1974. One of the major causes of the industries demise was the development of insecticide resistance in *Helicoverpa armigera* (Wilson, 1974). Although *H. armigera* was not the major pest initially, insecticides targeted at other pests including *Spodoptera litura, Pectinophora gossypiella* and *Earias huegeliana* conferred resistance to a range of organochlorine, organophosphate and carbamate insecticides. Spray records indicate that whilst only 12 insecticide applications were required to grow the first crops, this rose to 21 sprays in 1971 and to an average of 40 sprays in the final season of 1974 (Michael and Woods, 1980).

Genetic engineering techniques have led to the development of transgenic cotton varieties containing specific insecticidal genes, initially the Cry1Ac delta-endotoxin from *Bacillus thuringiensis*. INGARD™ cotton varieties have been commercially available in Australia for the past six years and have reduced pesticide use by up to 60% (Fitt, 1998). INGARD™ cotton varieties have also facilitated the implementation of novel management strategies, which are not compatible with pesticide use (e.g. food sprays, pheromones, parasites and predators). This gene technology has greatly improved the prospect of establishing sustainable cotton production systems in high insect pressure environments where heavy pesticide usage is not desirable (Strickland *et al*., 1998). However, the technology must be supported by integrated pest management methods, pre-emptive resistance management and merged with complimentary cultural and agronomic practices. A feasibility study examining whether it would be possible to re-introduce cotton to the Ord, using new transgenic varieties was commenced.

One novel move that was investigated in the Ord was growing cotton during the winter dry season (March-October) instead of during the summer-wet season. This substantially avoided the high pest abundance of *Helicovpera armigera, Helicoverpa punctigera, Spodoptera litura, Pectinophora gossypiella* and *Anomis* spp., which characterize the wet season (Strickland *et al*., 1998). Additionally the logistics of crop management were enhanced in the dry winter months. It was found that INGARD™ varieties demonstrated excellent efficacy against a range of lepidopteran pests including *Helicoverpa armigera* but efficacy declined when plants approached full boll load and there was a requirement for additional *Helicoverpa* control (Strickland *et al*., 1998). The development of an integrated pest management system to compliment the transgenic cotton varieties and minimize pesticide use was seen as being essential for sustainable production.

This paper describes some of the management options for *Helicoverpa*, which are being assessed in the Ord with an aim to re-establishing a cotton industry in tropical NW Australia.

Experimental procedure

All the trials were planted as two rows (86 cm apart) on 1.8 m beds, which is the standard farming practice for the Ord River Irrigation Area. The target population was eight plants per meter row and this was generally achieved. Fertilizer and herbicide were applied according to the field history and the crops requirements. The cotton was flood irrigated according to weather conditions, crop growth and pan evaporation levels. Five varieties of INGARD™ cotton (Siokra L23*i*, NuCOTN 37, Sicot 189*i*, Siokra V16*i* and Sicot 289*i*) were used between 1997 and 2002 dependant on breeding developments and seed availability.

Plot size was 10-80 ha depending on field availability. Plots were separated by at least 100 m in an effort to minimize the effects of pesticide drift and the confounding effects of inter-plot insect movement. The treatments and the number of replicates, which occurred on a farm in any given year was dependent on the growers preferences and availability of fields. Treatments used were INGARD™ cotton grown alone, and INGARD™ cotton grown with a lucerne, lablab or pigeon pea companion crop.

Companion crops were planted as strips 10.8 m wide every 302.4 m within the cotton crop. The companion crop utilized approximately 0.3% of the crop area. Lucerne (12 kg/ha), pigeon pea var. Quest (35 kg/ha) and *Dolichous lablab* var. Rongoi (40 kg/ha) were planted in six rows per 1.8 m bed. Companion crops were managed with slashing and water to control flowering and pod set so that they remained lush and attractive to insects all season. INGARD™ cotton grown alone was used as the benchmark every season.

Pest abundance was measured by direct field counts. Field counts followed the standardized sampling procedure detailed in the computer based decision support system, EntomoLOGIC (Dillon and Fitt, 1995). This program was also used to determine pest thresholds but the specific treatments applied varied according to the companion crop being evaluated. INGARD™ cotton grown with any of the companion crops was sprayed with insecticides that targeted the specific pest problem, particularly early and mid-season. Chemicals were not applied according to a net formula, though IPM friendly chemicals were always preferred where available. Late in the season, more broad-spectrum insecticides may have been used if environmental conditions or pest pressure did not favor the use of pest specific chemicals. The INGARD™ cotton grown alone was sprayed with either broad-spectrum insecticides or insecticides targeting specific pests depending on circumstances.

Beneficial insect (predators and parasites) abundance was measured by suction sampling. This utilized an Echo® blower-vac machine with a flow rate of 10 l/second. Each sample was 5 m of row length and five samples were taken in each plot. Both the cotton and the companion crops were sampled. Collections were returned to the laboratory for species identification and recording.

Yield of the cotton lint for each treatment was determined from data supplied by the commercial picking and ginning contractors. Cotton yields per hectare excluded the area used for the companion crop.

Results

Statistical analysis of the results was difficult, because replication of the IPM treatments was dependent on land availability; if an inadequate amount of land was available, some treatments were replicated less. In addition, replication on multiple farms with different management practices created variability that was difficult to account for with classical statistical methods. For this reason, standard error bars have been omitted from many of the graphs and trends in results rather than statistical significance are discussed.

Figure 1 and Figure 2 show the mean number of *Helicoverpa* eggs and larvae respectively, on each IPM treatment between 1997 and 2002. Over the six years of crop scouting *Helicoverpa* pressure was relatively light with a maximum of 100 eggs/m found on any one occasion. Most *Helicoverpa* oviposition occurred early in the season and trended toward a decline 71 days after planting. This generally coincided with mid-late squaring in June (Figure 1). The abundance of larvae was low at the start of the season and increased from around 71 days after planting (Figure 2). This can be attributed to the performance of the INGARD™, which effectively controlled early-season lepidopteran pests.

The presence or absence of a companion crop did not significantly influence oviposition on the cotton and trends in oviposition were seasonal rather than specific to an IPM treatment. In 1997 and again in 2000 INGARD™ cotton grown alone had significantly higher numbers of *Helicoverpa* eggs than INGARD™ cotton grown with a companion crop ($F_{1,783}$=5.828, P=0.016 and $F_{3,284}$=4.172, P=0.007 respectively). In other years, there was no significant difference between the treatments but INGARD™ cotton grown alone trended toward higher oviposition by *Helicoverpa* than on INGARD™ cotton grown with a companion crop.

All the cotton crops grown during this trial were managed for *Helicoverpa* larvae. Chemical treatments were applied to the crops when larval pressure reached 2 larvae/m. The control of larval populations of *Helicoverpa* probably negated any significant influence the companion crops may have contributed to the level of larval populations.

The presence or absence of a companion crop did not significantly influence the number of pesticide treatments which a crop received to control *Helicoverpa* ($F_{3,64}$=1.157, P=0.333). Trends in pesticide application were related to farm locations and seasonality rather than specific IPM treatments although INGARD™ cotton grown alone usually required more pesticide applications to control *Helicoverpa* larvae than INGARD™ cotton grown with a companion crop (Table 1).

Over the six years of the IPM trial, yields between fields varied enormously from 1.78 bales/ha to 8.9 bales/ha. The yield variability has been difficult to account for in pest management terms given that all the crops were scouted in a consistent manner and the same pest thresholds were applied throughout the trial. The presence or absence of a companion crop had a significant influence on the yield of INGARD™ cotton ($F_{3,64}$=3.886, P=0.013). INGARD™ cotton grown with a lablab companion crop had a significantly lower yield than INGARD™ cotton grown alone or INGARD™ cotton grown with a lucerne or pigeon pea companion crop (Table 2).

A density dot plot showing the yield of cotton in each treatment from every field found that three fields had extremely low yield, two of which were INGARD™ cotton grown with a lablab companion crop (Figure 3). These low yields were attributed to agronomic problems such as poor nutrition, poor irrigation management or water logging. The density dot plot also showed that the yields for INGARD™ cotton grown with a lablab companion crop were clustered between five to six bales/ha while yields for the other IPM treatments appeared to be more normally distributed. The homogeneity of the variances for the different treatments was examined using the Scheffé-Box test (Sokal and Rohlf, 1981). The observed F ratio ($F_{3,11}$=0.2275) was found to be non-significant so it was concluded that the variances were homogeneous. The clustered yields for INGARD™ cotton grown with a lablab companion crop were probably caused by pests other than *Helicoverpa*.

The most common beneficial insects found in the cotton and the companion crops were generalist predators such as spiders, ants, lady-bird beetles (*Coccinella transversalis*) and carabid beetles. *Trichogramma pretiosum* was the most common parasitic wasp although *Telenomus sp*. and *Microplitis demolitor* were also abundant in some years. Predatory Hemiptera (*Oechalia schellenbergii, Geocoris lubra, Deraeocoris signatus* and *Orius spp.*) also occurred. The numbers of beneficial insects collected from the cotton was low at the start of the season and then generally increased (Figure 4). The presence or absence of the companion crop significantly influenced the number of beneficial insects found in the cotton ($F_{3,1881}$=16.723, P=0.000). Less beneficial insects were collected from INGARD™ cotton grown alone than from any other treatment. INGARD™ cotton grown with a lucerne companion crop generally had the highest number of beneficial insects but this was not consistent from year to year.

On most sampling occasions the type of companion crop did not influence the number of beneficial insects collected from the companion crop (Figure 5). Rather the presence of beneficial insects in the companion crop was influenced by seasons with more beneficial insects being collected in 1997 and 1999 than in any other years. From early August, low numbers of beneficial insects were collected from lablab but this may have been due to management of the companion crop rather than a true decline in the abundance of predators and parasites.

Discussion

A key factor of the integrated pest management system being proposed for cotton in the Ord is the use of companion crops for managing pests and encouraging naturally occurring biological control agents such as predators and parasitoids to move into the cotton. The companion crops were usually planted around the same time as the cotton. Lablab and pigeon pea established quickly but lucerne was more difficult to establish primarily due to the hot weather and often required replanting a number of times. Lablab and pigeon pea were found to be attractive to pests and beneficial insects in both the vegetative and flowering phases although attractiveness increased with flowering. Lucerne companion crops were generally attractive to insects only during flowering. Management of flowering and pod setting in the companion crops was a concern because the life of the companion crop could be shortened, and if viable seed was produced the companion crops could potentially become weeds. Flowering and pod formation were successfully managed by slashing the companion crop one or two times during the season. This maintained attractiveness to insects and also prevented the lablab from becoming invasive into the cotton. Management of lablab and pigeon pea flowering generally occurred between July and August. During this time lower numbers of beneficial insects were recorded in both the cotton and companion crops than on cotton and lucerne. Slashing, at the time it occurred in the trial, may have reduced the companion crops potential to attract beneficial insects. It has been observed that if lablab and pigeon pea are slashed in August, they can be slow to recover.

Companion crops grown in association with INGARD™ cotton decreased the abundance of *Helicoverpa* on the cotton. This probably occurred in two ways. The companion crops were more attractive to the pests than the cotton and drew pests away from the cotton (Annells and Strickland, 2002). The companion crops were also attractive to beneficial insects, which prey on *Helicoverpa* and their higher abundance in close proximity to the cotton may have encouraged dispersal into the cotton when food resources became limiting in the companion crop. Once in the cotton, the beneficial insects contributed to the control of pest species.

As early as 1961, van den Bosch and Stern recognized that "expansion of integrated control programs were limited in part by the nature of the available control materials at the time." They further postulated that the absence of effective and selective chemical materials was probably the major factor limiting greater acceptance of integrated pest management. The introduction of INGARD™ cotton in Australia and new selective chemicals such as NPV virus, spinosad and indoxacarb, which target *Helicoverpa* and other Lepidoptera only and are well tolerated by non-target organisms including many beneficial arthropods has expanded the horizons of integrated pest management in agriculture. The new "soft" insecticides available do have limitations in application and efficacy but the presence of beneficial insects can greatly enhance their efficacy in the field. Timely applications of Tracer® (480 g/l Spinosad applied at 200 ml/ha)) in concert with the presence of active beneficial arthropods will extend the effective control interval of Tracer® thus offering the potential of lower product sprays when compared to a conventional insect management program (Petersen *et al*., 1997). INGARD™ cotton grown alone generally required more insecticide applications for *Helicoverpa* control than INGARD™ cotton grown with a companion crop. It was also observed that INGARD™ cotton grown alone generally required more follow-up spraying if new generation chemicals were used. The higher abundance of beneficial insects in INGARD™ cotton associated with a companion crop increased the effectiveness of the "soft" chemicals by controlling *Helicoverpa*, which escaped the chemical application.

Yield variability and declining yields during the six years this integrated pest management trial occurred are difficult to account for in pest management terms given that crops were scouted in a consistent manner and the same *Helicoverpa* thresholds were used. Early experiments with INGARD™ cotton in the Ord raised concerns that the fixed threshold of 2 larvae/m row may not be appropriate for the unusual winter growing environment. The reverse growing season means that cotton growth is rapid during the high temperatures at the beginning and end of the season but slow during boll development in the mid-season. This is when most pest damage occurs. Also, extensive periods of sub-threshold damage by *Helicoverpa* were observed. Experiments exploring the impact different fixed thresholds for *Helicoverpa* have on yield found that significant yield was being lost by adhering to the standard threshold of 2 larvae/m (Strickland and Annells, 2002). It was perceived that the lower thresholds had the effect of early intervention in prolonged sub-threshold situations. A dynamic threshold has been developed which has the potential to increase yield without increasing overall chemical usage (Strickland and Annells, 2002).

Low yields for INGARD™ cotton grown with a lablab companion crop may have been caused by pests other than *Helicoverpa*. A complex of mirids including *Creontiades dilutus* and *Creontiades pacificus* occur on cotton in the Ord. The use of companion crops has been shown to be a valuable tool for attracting mirids away from the cotton but two problems have been observed. Firstly, mirids are highly mobile and adults will move between the companion crops and the cotton. Secondly, companion crops appear to act as nurseries, breeding up mirids, which attack the cotton (Annells and Strickland, 2002). Mirid damage to cotton grown during the winter can be severe. Under winter growing conditions in northern Australia small numbers of mirids can cause large reductions in cotton yield (Ward personal communication, 2002). It is probable that the presence if lablab and its attractiveness to mirids contributed to low yields in INGARD™ cotton grown with a lablab companion crop. Alternative forms of mirid control including a trap and kill approach with soil insecticides such as aldicarb applied to the companion crops are under investigation. Early results have indicated that this is very successful at controlling mirid numbers in companion crops with little impact on beneficial insects (Annells and Strickland, unpublished data).

Companion crops demonstrated a capacity to produce relatively large numbers of beneficial insects, both predators and parasitoids. The presence of a companion crop increased the number of beneficial insects found on the INGARD™ cotton and this should have a direct impact on the number of *Helicoverpa* present in the crop. Lablab has the most consistent number of beneficial insects throughout the season and between seasons while beneficial arthropod numbers on the other companion crops fluctuated widely depending on seasonal conditions. It is disappointing that the use of a lablab companion crop contributes to low cotton yield but if this can be overcome through better management of mirids in the companion crop, the consistency of lablab at attracting pest and beneficial insects and its easy management may be an important consideration when using companion crops in a farming system.

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References

- Annells, A.J. and Strickland, G.R. (2002). Evaluation of companion crops as part of an integrated pest management package for GM cotton in the Kimberley. Proceedings of the 11th Australian Cotton Conference August 2002, Brisbane

Queensland.
- Dillon, G.E. and Fitt, G.P. (1995). Reassessment of sampling relationships for *Helicoverpa* spp. (Lepidoptera: Noctuidae) in Australian Cotton. *Bulletin of Entomological Research*, **85**: 321-329.
- Fitt, G.P. (1998). Efficacy of INGARD™ Cotton – Patterns and consequences. *In* Proceedings of the 9th Australian Cotton Conference 12-14 August 1998, Broadbeach Queensland pp233-245.
- Michael, P.J. and Woods, W.M. (1980). An entomological review of cotton growing in the Ord River Area of Western Australia. Technical Bulletin No 48, Department of Agriculture, Western Australia 17pp.
- Sokal, R.R. and Rohlf, F.J. (1981). Biometry, The Principles and Practice of Statistics in Biological Research. Published by W.H. Freeman and Company, New York, pp. 405-407.
- Strickland, G.R. and Annells, A.J. (2002). Toward dynamic thresholds for *Helicoverpa* on transgenic cotton in the Kimberley. *In* Proceedings of the 11th Australian Cotton Conference August 2002, Brisbane Queensland.
- Strickland, G.R., Yeates, S.J., Fitt, G., Constable, G.A., and Addison, S.J. (1998). Prospects for a sustainable cotton industry in tropical Australia using novel crop and pest management. *In* Proceedings of the World Cotton Research Conference-2, Athens, Greece, September 6-12, 1998. pp. 850-857.
- Petersen, L.G., Ruberson, J.R., Sprenkel, R.K., Weeks, J.R., Danohoe, M.C., Smith, R.H., Swart, J.S., Reid, D.J. and Thompson, G.D. (1997). Tracer naturalyte insect control and IPM. *Down to Earth*, **52**: 28-34.
- Van den Bosch, R. and Stern, V.M. (1961). The integration of chemical and biological control of arthropod pests. *Annual Review of Entomology,* **7**: 367-386.
- Wilson, A.G.L. (1974). Resistance of *Heliothis armigera* to insecticides in the Ord irrigation area, north Western Australia. *Journal Economic Entomology,* **67**: 256.

Table 1. *The number of spray applications applied to INGARD™ cotton grown with different companion crops to control* Helicoverpa spp. *in each year of an integrated pest management trial in the Ord. Blank cells indicated that this treatment was not undertaken in this year.*

	Control	Lucerne	Lablab	Pigeon Pea
1997	2.25±0.453	1.50±0.65		
1998	3.75±0.75	4.00±0.33		
1999	3.50±0.89	3.67±0.33	4.50±0.65	4.00
2000	5.00±1.00	5.00	4.00±2.00	3.50±0.50
2001	2.00±0.63		0.75±0.48	0.00
2002	1.25±0.25		1.25±0.25	
Overall mean*	2.70±0.32	3.45±0.31	2.43±0.55	2.75±0.95

*Means calculated from row data from all plots and not from the annual means.

Table 2. *The yield (bales/ha) of INGARD™ cotton grown with different companion crops in each year of an integrated pest management trial in the Ord.*

	Control	Lucerne	Lablab	Pigeon Pea
1997	6.89±0.47	7.16±0.26		
1998	6.99±0.38	6.89±0.32		
1999	6.11±0.35	5.68±0.45	6.13±0.53	6.58
2000	7.69±0.21	8.27	6.98±1.75	7.87±0.52
2001	5.25±0.36		4.66±0.74	6.17
2002	5.68±0.18		4.45±0.38	
Overall mean*	6.31±0.21	6.65±0.25	5.35±0.41	7.12±0.49

* Means calculated from row data from all plots and not from the annual means.

Figure 1.
Mean number of Helicoverpa spp. eggs found on INGARD™ cotton grown with different IPM treatments for six winter seasons in the Ord River irrigation area.

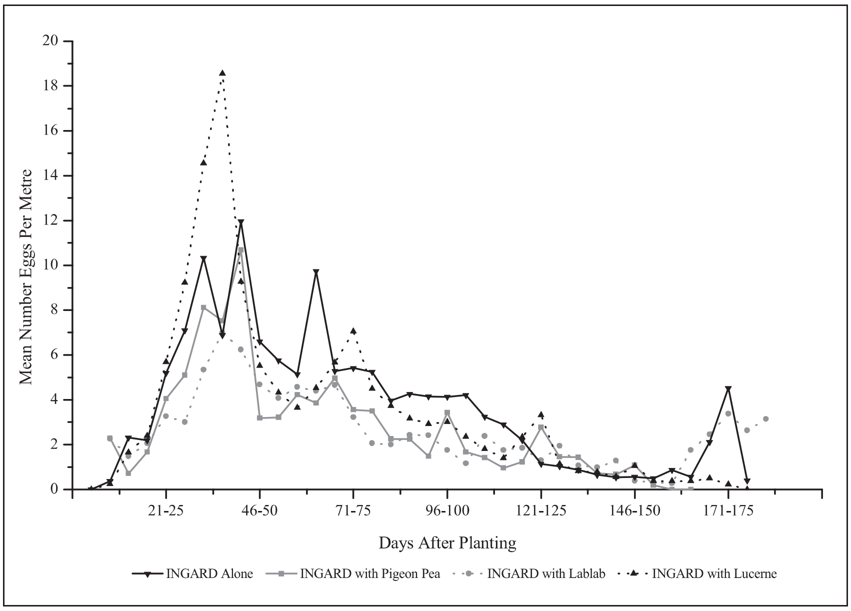

Figure 2.
Mean number of Helicoverpa spp. larvae found on INGARD™ cotton grown with different IPM treatments for six winter seasons in the Ord River irrigation area.

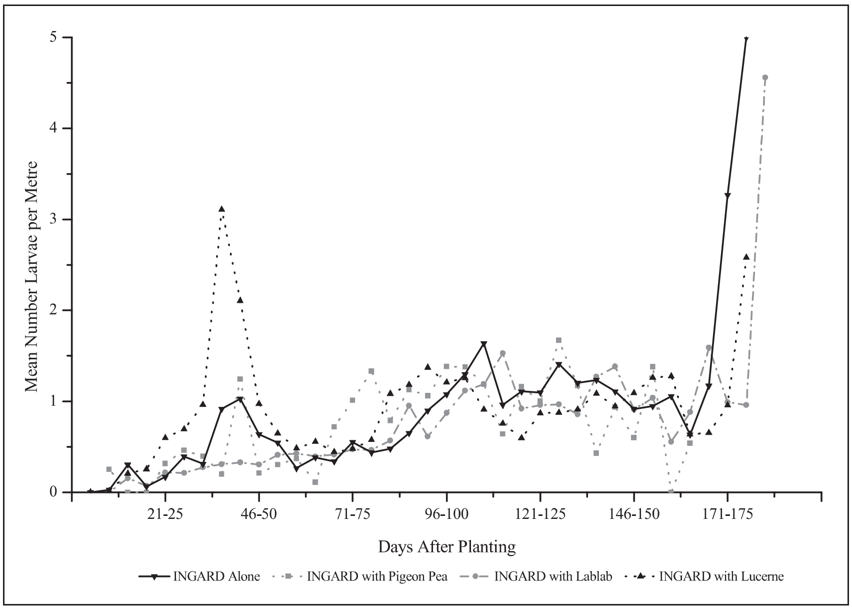

Figure 3.
Density dot plot showing the yield of INGARD™ cotton grown with different companion crops from every field in the trial. (Control = INGARD™ cotton grown alone).

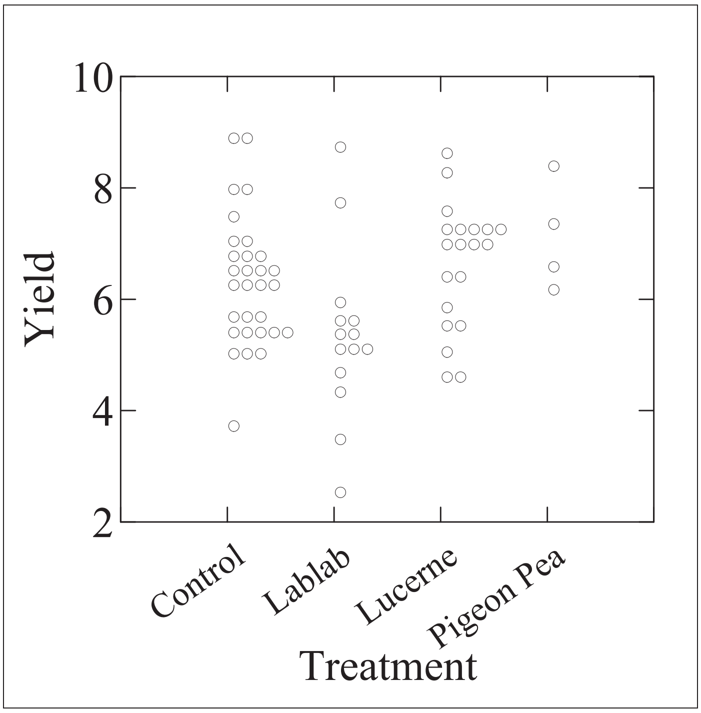

Figure 4.
Mean number of beneficial insects collected with a suction sampler from INGARD™ cotton grown with different IPM treatments in the Ord between 1997 and 2002.

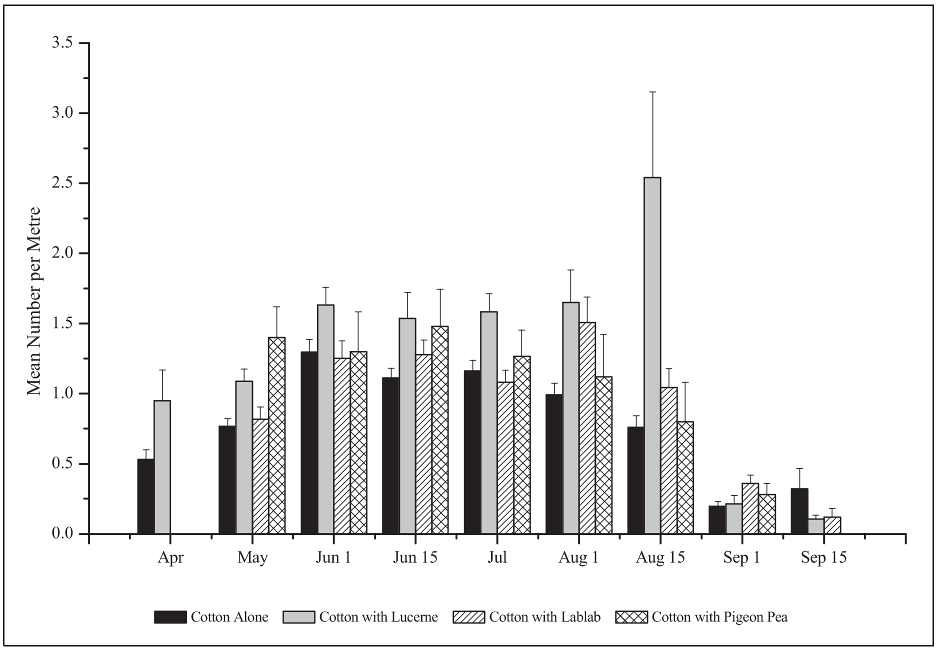

Figure 5.
Mean number of beneficial insects collected with a suction sampler from different companion crops grown next to INGARD™ cotton in the Ord between 1997 and 2002.