

**The cotton pests in Madagascar,
with special emphasis on
the cotton aphid *Aphis gossypii* (Hom.: Aphididae)
and its natural enemies**



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Abstract

The cotton pests in Madagascar, with special emphasis on the cotton aphid *Aphis gossypii* Glover (Hom.: Aphididae) and its natural enemies

An update on the cotton pest complex and its associated natural enemies in Madagascar is presented. Field research at experimental sites in rainfed and receding flood cotton in 1997 and 1998 showed that pest pressure in Malagasy cotton is very high, which presently makes insecticide treatments indispensable. The American bollworm *Helicoverpa armigera* Hübner (Lep.: Noctuidae) is a limiting factor for cotton production in Madagascar and can be considered the key pest, whereas the Egyptian leaf worm *Spodoptera littoralis* Boisduval (Lep.: Noctuidae) and the cotton aphid *Aphis gossypii* Glover (Hom.: Aphididae) have become significant pests as a result of indiscriminate use of synthetic pyrethroids in the 1980s. Twenty arthropod natural enemy species and the aphidopathogenic fungus *Neozygites fresenii* (Nowakowski) (Entomophthorales) are reported as new records in Malagasy cotton.

Special emphasis was given to the seasonal population dynamics, spatial distribution and sampling procedures of *A. gossypii*. Aphid infestations were much more important in receding flood cotton, where outbreaks probably were related to unintentional effects of insecticide treatments. Both in 1997 and in 1998, mean aphid densities were higher in plots treated with synthetic insecticides than in the untreated control. After spayings with cypermethrin intended for bollworm control, a sharp increase of aphid densities was observed which most likely could be attributed to stimulatory effects of the pyrethroid on aphid reproduction. Furthermore, exclusion experiments revealed that destruction of aphid predator populations by insecticides may also play an important role in aphid resurgence in receding flood cotton. A model of Chambers and Aikman (1988) was used to evaluate whether the observed differences in aphid density in «free» colonies compared to colonies «protected» from predators could be attributed to predation. This was largely confirmed for the two time periods when the assumptions of the model were fulfilled, because calculated “required kill rates” were lower than values for “potential kill” derived from aphid consumption by different predator species tested in a field laboratory.

Aphid predators were highly susceptible to insecticides, and their numbers were severely suppressed in insecticide treated plots. Insecticide tests in situ confirmed that most of the currently used compounds are extremely toxic to larvae of aphid predators. However, mortalities of predators exposed to endosulfan or profenofos were significantly lower than those observed

after spraying with cypermethrin, thiodicarb or monocrotophos. Endosulfan or profenofos may therefore be considered for an improved conservation management of predators in the future.

The currently applied presence-absence sampling on terminal leaves proved to be inadequate for aphid sampling in Malagasy cotton. Infestation levels on upper plant parts showed strong fluctuations with regard to insecticide treatments and seasonal factors, such as drought or plant growth stage. The precision of mean estimates could be improved when tally thresholds for binomial counts of empty sampling units were different from $T = 0$, and only main stem leaves were considered. There was no evidence for impact of aphids on yield and the presently advocated action threshold of 15 % infested leaves is likely to be an over-estimation of the economic importance of *A. gossypii* in Malagasy cotton.

The control efficacy of neem oil extracts against *H. armigera*, *S. littoralis* and *A. gossypii* and of potassium soap against *A. gossypii* was investigated in field trials in rainfed cotton. The neem extracts failed to suppress any of the three principal pests, possibly due to insufficient uptake or the rapid decomposition of the active ingredients. The soap solution did not provide any significant control of aphid infestation, neither. Most likely, the soap treatment did not work because of incomplete coating of the pest at an application volume of 100 l/ha. Thus, considering high pest pressure, especially by *H. armigera*, and the low costs of insecticide applications, it is at present difficult to advocate biological pest control methods in Malagasy cotton. However, the drawbacks of present aphid control strategies are thoroughly discussed. If the currently used sampling method for aphids, the very low action threshold for this pest and the choice of insecticides irrespective of their effects on natural enemies were revised, significant improvements could be achieved with regard to the preservation of predator populations, especially in receding flood cotton. This may lead to a reduction of aphicide use with considerable economic and environment-related benefits for Malagasy cotton growers.

Zusammenfassung

Die Baumwollschädlinge in Madagaskar unter besonderer Berücksichtigung der Baumwollblattlaus *Aphis gossypii* Glover (Hom.: Aphididae) und ihrer natürlichen Feinde

Felddaten über das Schädlingsspektrum in der Baumwollkultur Madagaskars und der mit ihm assoziierten natürlichen Feinde werden vorgestellt und eine Aktualisierung der wirtschaftlichen Gewichtung der einzelnen Schadspezies vorgenommen. Felduntersuchungen im Regenfeldbau und in der Nachflutkultur in den Jahren 1997 und 1998 zeigten, daß der Schädlingsdruck in der madagassischen Baumwolle sehr hoch ist, was gegenwärtig Insektizidanwendungen unausweichlich macht. Der Amerikanische Kapselwurm *Helicoverpa armigera* Hübner (Lep.: Noctuidae) ist der limitierende Faktor für die Produktivität des Baumwollanbaus in Madagaskar und muß als ein Kardinalschädling betrachtet werden, wohingegen der Ägyptische Blattwurm *Spodoptera littoralis* Boisduval (Lep.: Noctuidae) und die Baumwollblattlaus *Aphis gossypii* Glover (Hom.: Aphididae) erst infolge exzessiven Einsatzes synthetischer Pyrethroide in den 80er Jahren zu wirtschaftlicher Bedeutung gelangt sind. Zwanzig Nutzarthropodenarten und der aphidopathogene Pilz *Neozygites fresenii* (Nowakowski) (Entomophthorales) werden hier erstmals für die madagassische Baumwolle beschrieben.

Ein besonderer Forschungsschwerpunkt wurde auf die Populationendynamik, das räumliche Verteilungsmuster und Stichprobenverfahren für die Erfassung von *A. gossypii* gelegt. Der Aphidenbefall war in der Nachflutkultur sehr viel höher, wo Gradationen sehr wahrscheinlich durch Insektizidanwendungen gegen *H. armigera* ausgelöst wurden. In beiden Untersuchungsjahren war der durchschnittliche Aphidenbesatz in insektizidbehandelten Parzellen höher als in der ungespritzten Kontrolle. Nach Applikationen mit Cypermethrin wurde ein markanter Anstieg der Blattlausdichten verzeichnet, der vermutlich stimulatorischen Wirkungen dieses Wirkstoffs auf die Blattlausreproduktion zuzuschreiben ist. Ausschlußexperimente ergaben, daß der insektizidbedingten Beeinträchtigung von Blattlausprädatoren gleichfalls eine wichtige Rolle im Zusammenhang mit Aphidengradationen in der Nachflutkultur zukommen dürften. Mit Hilfe eines Modell von Chambers und Aikman (1988) wurde evaluiert, ob beobachtete Dichtedifferenzen zwischen frei zugänglichen und gegen Prädatoren geschützte Blattlauskolonien dem Prädatorenkomplex zugeschrieben werden konnten. Diese Annahme konnte für die zwei Zeitperioden, wo die Prämissen des Modells erfüllt waren, bestätigt werden, weil die errechnete "erforderliche Tötungsrate" kleiner war als die "potentielle Tötungsrate". Feldlaborddaten zur "potentiellen Tötungsrate" von verschiedenen Prädatorenspezies waren zuvor in Fraßtests ermittelt worden.

Blattlausprädatoren erwiesen sich als sehr empfindlich gegenüber den verwendeten Insektiziden, und ihre Dichten waren in den insektizidbehandelten Parzellen erheblich reduziert. Wirkstofftests in situ bestätigten, daß die meisten der gegenwärtig verwendeten Mittel extrem toxisch für die Larvenstadien der Prädatoren von *A. gossypii* sind. Allerdings erwiesen sich Endosulfan und Profenofos als signifikant weniger toxisch als Cypermethrin, Thiodicarb oder Monocrotophos. Endosulfan oder Profenofos könnten deshalb zukünftig bei der Entwicklung von nützlingsschonenden Bekämpfungsverfahren eine wichtige Rolle spielen.

Die zur Zeit verwendete binomiale Stichprobenmethode an den gipfelständigen Blättern erwies sich als ungeeignet, um den Aphidenbesatz in der madagassischen Baumwolle zu schätzen. Der Blattlausbefall an den oberen Pflanzenteilen war starken Fluktuationen unterworfen, die von Insektizidapplikationen und saisonalen Faktoren wie Trockenheit oder Wuchsstadium der Baumwollpflanze abhingen. Die Präzision der Mittelwertschätzungen konnte verbessert werden, indem Zählstriche binomialer Stichproben größer als $T = 0$ gewählt und nur Hauptsproßblätter in Betracht gezogen wurden. Es gab keinen Hinweis auf den Einfluß von Aphidenbefall auf den Baumwollertrag. Die zur Zeit favorisierte Interventionsschwelle von 15 % befallenen gipfelständigen Blättern stellt wahrscheinlich eine Überschätzung der wirtschaftlichen Bedeutung von *A. gossypii* im madagassischen Baumwollanbau dar.

Die Effizienz von Neemölextrakten auf *H. armigera*, *S. littoralis* und *A. gossypii* und einer Schmierseifenlösung auf *A. gossypii* wurden in Feldexperimenten im Regenfeldbau untersucht. Die Neemölextrakte zeigten keine signifikante Wirkung auf die drei Hauptschädlinge, möglicherweise aufgrund einer unzureichenden Aufnahme oder eines zu raschen Abbaus der aktiven Wirkstoffe. Auch die Seifenlösung hatte keinen signifikanten Einfluß auf den Befall von *A. gossypii*, vermutlich wegen ungenügender Bedeckung des Schädlings bei einer Aufwandmenge von 100 l/ha. Angesichts des hohen Schädlingsdrucks, vor allem durch *H. armigera*, und der geringen Kosten von Insektizidanwendungen ist es gegenwärtig schwierig, biologische Bekämpfungsverfahren im madagassischen Baumwollanbau zu empfehlen. Nichtsdestotrotz werden die Nachteile der gegenwärtigen Bekämpfungsstrategien ausführlich diskutiert. Eine Revision der zur Zeit üblichen Stichprobentechnik, der sehr niedrigen Behandlungsschwelle und der Wahl von insektiziden Wirkstoffen ohne Rücksicht auf ihre Wirkung auf natürliche Feinde könnte zu einer erheblich verbesserten Schonung von Prädatorpopulationen führen, insbesondere in der Nachflutkultur. Dies sollte eine Reduktion der Anwendungsfrequenzen von Aphiziden ermöglichen und dem madagassischen Kleinanbau ökonomisch wie ökologisch zum Vorteil gereichen.

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1. General introduction

Madagascar, the fourth greatest island in the world, is blessed with a large variety of ecological zones which allows for an extremely diversified agricultural production (Battistini 1986). Early efforts to establish industrial cotton production in Madagascar commenced in 1903-1906 in the north-western Mahajanga region and during 1926-1933 in the Lac Alaotra region which is nowadays the biggest rice granary in the country. These experiments were not very successful, supposedly due to labour shortages and to uncontrollable insect pest pressure (Douessin 1979, Bocchino 1996). Upland cotton production in Madagascar became a profitable enterprise only in the wake of extensive agronomic and entomological field research conducted since 1952 by the French cotton research institute IRCT (Institut de Recherche du Coton et des Textiles Exotiques). The availability of synthetic organic insecticides after World War II played a key role in securing profitable yields, and subsequently the French cotton company CFDT (Compagnie Française du Développement Textile) became involved in the Malagasy cotton production (Berger 1979, Crétenet et al. 1979, Bocchino 1996).

Two different cropping systems were developed by the IRCT. In the sub-arid region of south-western Madagascar, cotton is grown as a rainfed crop from December/January to June/August. Annual rain-fall varies from a merely 300 mm near the province capital Toliara, where cotton can only be grown with supplemental irrigation, to 800-900 mm in the zones north and north-east of Toliara. However, annual fluctuations of precipitation have been increasingly erratic since the 1990s and have repeatedly compromised productivity, e.g., 1992, 1995 and 1998, when severe droughts depressed average yield far below 1,000 kg raw cotton/ha (Andriambololona et al. 1989). Cotton in south-western Madagascar is nowadays mainly grown by small peasants, who cultivate 1-2 ha on average without any means of mechanisation.

In north-western Madagascar, principally in the province Mahajanga, cotton is planted at the start of the dry season in March-April on fluvial alluvia (Malagasy *baiboho*) deposited by the river courses during the preceding high water season. This receding flood cultivation (Fr. "culture en décrue") depends crucially on an optimally timed planting date, because plant growth exclusively rely on capillary ascending water retained in the sediments. When the soil preparation and planting is optimally timed, and the ground water stock has been amply refilled by the inundation of the previous rainy season, water supply

will be favourable throughout the entire growing season, resulting in yield potentials markedly superior to average achievements in rainfed cropping, i.e., 1.5-2 t/ha compared to approximately 1t/ha, respectively. The low population density in the north-western *baiboho* areas and the high capital investments needed for mechanised land clearing favoured the establishment of large-scale farming with high fertiliser input and frequent aerial insecticide spraying (Berger 1979). However, in the 1990s many of these vast monocultures have been abandoned due to ever-increasing production costs (Rakotofiringa 1997). Contrary to the extension of the cotton cropping area in south-western Madagascar, this led to a stagnation of total surface and mean yields in receding flood cotton cultivation. In 1998, only 9,700 t of a total Malagasy raw cotton production of 32,300 t were produced in the north-west region (H. Rakotofiringa, HASYMA, pers. comm.).

According to the IRCT entomologists, insect pest pressure in Malagasy cotton was very severe, and strict control measures with synthetic organic insecticides were advocated (Delattre 1958, Caresche 1959). Rigid foliar spraying calendars, with intervention intervals ranging from eight to twelve days were applied in the 1960s and 1970s. The bollworms *Helicoverpa armigera* Hübner and *Earias* spp. (both Lep.: Noctuidae) were economically the most important pests, followed by minor pests such as the pink bollworm *Pectinophora gossypiella* (Saunders) (Lep.: Gelechiidae), the Egyptian leaf worm *Spodoptera littoralis* Boisduval (Lep.: Noctuidae), the cotton aphid *Aphis gossypii* Glover (Hom.: Aphididae), the vegetable spider mite *Tetranychus neocaledonicus* André (Acari: Tetranychidae), and the cotton stainer *Dysdercus flavidus* Signoret (Het.: Pyrrhocoridae) (Bournier and Vaissayre 1977).

Prior to the introduction of synthetic pyrethroids in 1979-1980, DDT was the most commonly used insecticide in Malagasy cotton. Insecticide resistance in pests was detected as early as 1965, when the spiny bollworm *Earias insulana* Boisduval (Lep.: Noctuidae) became increasingly insensitive to the organochlorine endrin, which was then successively replaced by carabaryl and endosulfan respectively (Bournier and Vaissayre 1977). Occasionally, resurgence of cotton stainers and aphids had to be suppressed with lindan and dimethoat, respectively (Bournier and Vaissayre 1977). From 1973 until the end of the 1970s, the mixture monocrotophos-DDT was the most commonly applied cocktail, because it not only controlled bollworms, but also aphids and mites (Peyrelongue et al. 1974).

Like in many other cotton producing countries, the availability of synthetic pyrethroids boosted the Malagasy cotton production in the beginning of the 1980s. Deltamethrin and

cypermethrin, which were applied with hand-carried, battery-operated spinning disc sprayers in ultra-low-volume (ULV), provided excellent control of the carpophagous key pests *H. armigera* and *Earias* spp. In the following years however, the monopolist cotton company HASYMA, the successor of the Malagasy branch of CFDT nationalised in 1979, faced severe infestation of the leaf worm *S. littoralis*. This leaf-feeding noctuid is particularly dangerous at higher densities, because it increasingly attacks fruiting structures once the foliage has been depleted. Laboratory tests revealed high levels of resistance in *S. littoralis* larval instars against deltamethrin and cypermethrin (Rakotofiringa 1989). Facing devastating outbreaks in the mid-80s, many large-scale growers increased dosages at higher application frequencies without success (Dove 1994b). Ironically, this crisis coincided with an unprecedented boom in cotton production in Madagascar, which had led to poorly managed expansion of the cotton area and insufficient know-how transfer to small growers by the extension service of HASYMA (Hoerner 1987). However, HASYMA ensured the survival of cotton production in Madagascar by distributing thiodicarb to farmers as early as 1987. Until today, this carbamate proved to be highly efficient against eggs and all larval instars of *S. littoralis*; moreover, it also has good efficacy against both *H. armigera* and *E. insulana* (Dove 1994a).

In the 1980s, increasing cotton aphid infestations, especially in the intensively sprayed areas of the north-western region, were recorded. During the 1990s, aphid outbreaks were regularly encountered in the cotton monocultures of the Mahajanga province. Likewise, in the south-west *A. gossypii* was considered an economically significant pest albeit not reaching densities as high as in the north-west (Andriambololona et al. 1989). Aphid resurgence was thought to be the result of various aspects of insecticide abuse, in particular of pyrethroids (H. Rakotofiringa, pers. comm.). Resistance of *A. gossypii* to the pyrethroids and also to thiodicarb and endosulfan have been observed. In rainfed cotton, the ULV-VLV (2.5-10 l/ha) spraying technique was considered inadequate for aphid control (Deguine and Leclant 1997). Ultra-low and very-low volumes provide good control of *H. armigera*, which mostly feed in the upper part of the canopy, but to a lesser degree of homopterous pests, principally located on the lower side of leaves in the median and inferior part of the foliage. Finally, the insecticide-related destruction of the albeit largely unknown natural enemy complex was suspected to have played a key role in aphid outbreaks.

At the end of the 1980s HASYMA consequently revised the spraying calendar and introduced a kind of insecticide resistance management. The principal guidelines can briefly be outlined as follows: first, alternation of active ingredients from different insecticide classes; second, combination of two active ingredients from different insecticide classes to overpower resistance build-up in *H. armigera*, *A. gossypii* and *S. littoralis*, especially during mid-season when pest infestations are highest; third, reduction of the total number of insecticide treatments, in particular of pyrethroids applications, which are moreover no longer applied at the beginning of the season in order to preserve natural enemy populations (H. Rakotofiringa, pers. comm.). These improvements have paid off, since no new cases of insecticide resistance been detected ever since. The increasing proportion of small-scale farmers in Malagasy cotton production since the 1990s (Rakotofiringa 1997) resulted in a considerable decrease of pesticide input to the crop, and undoubtedly made an important contribution to lower selection pressure on pests populations. Moreover, a profound restructuring of HASYMA's extension service in the beginning of the 1990s, which resulted in the creation of farmer co-operatives with joint liability of their members, substantially improved the technical know-how transfer to small-scale cotton growers in Madagascar (Rakotofiringa 1997). Action thresholds for bollworms, *S. littoralis*, and *A. gossypii* were developed based on observations from newly created field research stations. However, threshold guided pest management strategies have not yet been introduced on a broad scale in Madagascar cotton, and implementation of thresholds will be particularly difficult in the south-west, where a peasant community with high rates of illiteracy and poor technical expertise is predominating.

When this study started, only the polyphagous pests *H. armigera*, *S. littoralis*, and *A. gossypii* were specifically considered in the recommended spraying calendars. Since the 1980s, the oligophagous spiny bollworms (*Earias* spp.) had been reduced to a minor early-season pest of flower buds, which is thought to be due to the area-wide use of pyrethroids (Reed 1994, H. Rakotofiringa, pers. comm.). Infestations of the pink bollworm *P. gossypiella* have generally become negligible after the introduction of several new short cycle cotton varieties. The presence of some other pests, such as stainers, spider mites, or the recently introduced leaf perforator *Bucculatrix loxoptila* Meyrick (Lep.: Lyonetiidae) (Bournier 1989) have been recognised, but these species were thought to be suppressed by insecticide applications targeting at the three principal pests.

Since the departure of the French over 20 years ago, entomological research in Malagasy cotton has been episodic (Bournier 1989, Randrianandrianina-Razananaivo 1991, Delvare and Rasplus 1994). The ancient documents fell largely into oblivion, above all the scarce information on natural enemies, which had been gathered in the 1960s and 1970s (Brenière 1965, Vaissayre 1977). Thus, a systematic inventory of cotton pests and its natural enemies was needed.

In chapter 2, an update on the incidence of arthropod pests in the Malagasy cotton crop is provided as it was observed during the 1997 and 1998 cropping seasons at experimental sites in north-western and south-western Madagascar. Natural enemies associated with the pests are presented, and the susceptibility of some important aphidophagous predator species to commonly used insecticides is evaluated. *Aphis gossypii* is the most likely species to be kept in check by its natural enemies, and strategies how to preserve its predator guild are discussed. Chapter 3 describes severe cotton aphid infestations as a result of unintentional effects of insecticide treatments, i.e., destruction of predator populations and stimulatory effects of pyrethroids on aphid reproduction. In addition, the currently used sampling procedures and action thresholds are critically examined, and their role in enhancing the pest status of *A. gossypii* in Malagasy cotton is discussed. In chapter 4, the influence of predators on aphid population dynamics is investigated in detail through exclusion experiments. The model of Chambers and Aikman (1988) is used to estimate whether observed differences between aphid densities in predator exposed and protected colonies can be attributed to predation. The efficacy of alternative, environmentally less disruptive natural insecticides are investigated in the last two chapters. In chapter 5, the results of a trial comparing conventional spraying of synthetic insecticides with neem oil extracts for control of *H. armigera*, *A. gossypii* and *S. littoralis* in rainfed cotton are presented. In chapter 6 the prospects of controlling cotton aphids with potassium soap solutions are examined.

2. Cotton pests and their natural enemies in Madagascar

2.1. Abstract

An update on the cotton pest complex and its associated natural enemies in Madagascar is provided. Since the end of the 1970s, when the last reports had been published, the population dynamics of the principal pests in Malagasy cotton have undergone considerable changes. The American bollworm *Helicoverpa armigera* Hübner (Lep.: Noctuidae) is still a limiting factor for production and can be considered the key pest, whereas the Egyptian leaf worm *Spodoptera littoralis* Boisduval (Lep.: Noctuidae) and the cotton aphid *Aphis gossypii* Glover (Hom.: Aphididae) have become significant pests as a result of indiscriminate use of synthetic pyrethroids in the 1980s. New records of beneficials, in particular the discovery of the aphidopathogenic fungus *Neozygites fresenii* (Nowakowski) (Entomophthorales) in cotton aphid populations, are reported. The susceptibility of aphid predators to currently used insecticides was evaluated in field tests, and strategies to preserve predator populations in view of reducing disruptive insecticide treatments are discussed.

2.2. Introduction

Upland cotton is grown in Madagascar on an industrial scale since the 1960s, when rainfed and receding flood cropping systems had been developed by the French cotton research institute IRCT (Institut de Recherche du Coton et des Textiles Exotiques) (Berger 1979, Crétenet et al. 1979). Since the 1990s, rainfed cropping by small farmers in south-western Madagascar is considered the economically more sustainable option for the future and has bypassed the north-western region both in terms of cultivated area (22,600 ha in 1998, compared to 9,700 ha in the north-west) and profitability (H. Rakotofiringa, HASYMA, pers. comm.). In north-western Madagascar, where cotton is planted "en décrue", i.e., on fluvial alluvia at the beginning of the dry season, numerous mechanised large-scale exploitations with heavy fertiliser and insecticide inputs have been abandoned in view of the ever-increasing production costs (Rakotofiringa 1997). Usually, high costs are associated with pest control, which to date has almost exclusively been relying on insecticides. Pest pressure in Malagasy cotton has been described as very severe by pioneer entomologists (Delattre 1958, Caresche 1959), and rigid foliar spraying schedules on a calendar base, irrespective of economic thresholds, have been advocated throughout the 1960s and 1970s (Bournier and Vaissayre 1977). The American bollworm *Helicoverpa*

armigera Hübner and the spiny bollworm *Earias insulana* Boisduval (both Lep.: Noctuidae) were considered the key pests (Caresche 1959, Caresche and Brenière 1961, Appert 1968). However, the routine use of chemical therapeutics entailed heavy consequences in the 1980s, when pyrethroid-resistant strains of the Egyptian leaf worm *Spodoptera littoralis* Boisduval (Lep.: Noctuidae) caused dramatic losses and subsequently, cotton aphid outbreaks (*Aphis gossypii* Glover [Hom.: Aphididae]) were regularly observed in the north-western region (Rakotofiringa 1989, Dove 1994b). Consequently, several modifications of the spraying calendar were elaborated. The frequency of applications, in particular of pyrethroids, was reduced, new efficient active ingredients were introduced and specific schemes for alternation of the chemicals developed. However, threshold based pest management systems and biological control methods have not yet been introduced on a broad scale in Malagasy cotton, and implementation of these techniques in a grower community largely dominated by small peasants remains difficult.

Entomological research in Malagasy cotton has been sporadic for the last 20 years, and a recent inventory of pests and the natural enemy complex is lacking. In particular, the knowledge about beneficials is rudimentary and out-of-date (Vaissayre 1977). This paper provides an update on the cotton pests and their associated natural enemies in Madagascar.

2.3. Materials and methods

Field monitoring was conducted both in rainfed and in receding flood cotton during the 1997 and 1998 cropping seasons.

Rainfed site:

The experimental site in the rainfed region in south-western Madagascar was located at the PAP (Point d'Appui de la Prévulgarisation) in Ampasikibo in the community of Analamisampy, Toliara region, a field research station of the national cotton company HASYMA. In 1997, the experimental design consisted of a randomised complete block with four replications of two treatments, i.e., a "standard" insecticide spraying regime («ST») and an untreated control («NT»). The plots comprised of 38 rows of 26 m length, with an inter-row distance of approximately 73 cm, resulting in plot sizes of about 720 m². each. In order to minimise migration of insects between plots, 12 rows, corresponding to a distance of 8.5-9 m were discarded. Due to labour shortages, two plots had to be abandoned in 1998.

The Upland cotton variety D 388/8 M was sown on 12/12/1997 and 12/12/1998, respectively, at a theoretical density of 44,400 plants/ha. The fields were fertilised with 100 kg ammonium phosphate/ha, laboured and sown before the onset of the first rains which generally occur by the arrival of north-western trade winds in December. Emergence occurred on December 29 and 30, respectively. Subsequently, the fields were fertilised with 50 kg urea/ha 27 and 28 d.a.e. (days after emergence), respectively, and weeded manually three times. The cotton was harvested 119 + 147 and 120 + 148 d.a.e., respectively.

In the «ST» treatment, plots were sprayed with synthetic insecticides. In 1997, sprayings were carried out independently of pest densities, following the recommended calendar spraying schedule of HASYMA. There was a two-day interval between an insecticide treatment and the following sampling occasion. The following year, treatments were only carried out when HASYMA's thresholds for one of the principal pests, i.e., *H. armigera*, *S. littoralis* or *A. gossypii* were exceeded. Threshold densities for *H. armigera* and *S. littoralis* are 5,000 and 10,000 larvae/ha, respectively. In a stand of 44,400 plants/ha, these densities correspond to 0.113 and 0.225 larvae/plant, respectively. (The officially recommended stand for the experimental site was 88,800, which would give 0.056 and 0.113 larvae/plant, respectively. For sampling convenience, the lower density with only one plant per pocket was preferred. The HASYMA threshold for aphids is 15 % infested leaves between 40 and 100 d.a.e. and 30 % thereafter. The infestation is assessed on the five terminal leaves. Pest densities were examined on 20 randomly chosen plants per plot. When a threshold level had been exceeded, treatments were carried out the following day with an ULVA+ spinning disc hand sprayer at a rate of 10 l water solution/ha. The «NT» plots were not treated.

Receding flood site:

The receding flood site was located near Ambato-Boeni in the Mahajanga region in north-western Madagascar, where cotton is planted on alluvial deposits at the onset of the dry season.

The 1997 trial was conducted at the local PAP (Point d'Appui de la Prévulgarisation) of HASYMA. The trial was designed as a randomised complete block with two treatments, i.e., «ST» and «NT», replicated three times. The plots comprised of 44 rows of 30 m length with an inter-row distance of approximately 90 cm, resulting in plot sizes of about 1200 m². Twelve rows, corresponding to 9.5-10 m, were discarded to provide broad alleys between the plots, in order to minimise inter-plot migration of insects.

The D 388/8 M variety was sown at a theoretical density of 44,400 plants/ha on 11/04/1997. The field received 250 kg urea/ha, 150 kg potassium sulphate/ha and 8 kg boracine/ha in two doses, i.e., the day before sowing and 12 d.a.p (days after planting). Plots were weeded manually twice and harvested 149 + 165 d.a.p.

For logistic reasons, the trial in 1998 had to be conducted in a farmer's field. Because of the smaller surface area, plot size had to be limited to 18 rows of 22 m length with an inter-row distance of approximately 75 cm, resulting in plot sizes of about 300 m². In order to partly compensate for the smaller plot sizes, the two treatments were replicated six times. The cotton was planted at a density of 53,300 plants/ha on 23/04/1998 and fertilised only once with 150 kg urea/ha, 100 kg potassium sulphate/ha and 6 kg boracine/ha, according to the recommended reduced fertiliser dosages for small-scale cropping systems. The plots were weeded twice and harvested 154 + 166 d.a.p.

Similarly to the 1998 trial in the south-west, «ST» plots were treated with insecticides according to HASYMA's official calendar spraying scheme in the first year, but in compliance with HASYMA's action thresholds in 1998. In both years, a two-days interval between a treatment and the next sampling was generally respected. Thresholds for the noctuid pests are numerically the same in both regions, but may differ on a plant-to-plant basis if plant densities are different. In a stand of 53,300 plants/ha, a density of 5,000 larvae of *H. armigera* and 10,000 larvae of *S. littoralis*/ha corresponds to 0.094 and 0.188 larvae/plant, respectively. The threshold for *A. gossypii* is fixed at 15 % infested terminal leaves until 90 d.a.p. and 20 % thereafter. Aphid infestation is determined on the four terminal leaves. However, due to irregular supply of insecticides, the treatments could not be carried out in strict conformity to action thresholds. In accordance to common practice, a 15 l knapsack sprayer was used at a rate of 100 l water solution/ha. «NT» plots did not receive any insecticide treatments.

Eggs and larvae of *H. armigera*, *S. littoralis*, and *Earias* spp., as well as all stages of aphid predators were counted individually on 20 randomly chosen plants per plot, except at the north-western site in 1998, when ten plants per plot were examined.

The presence of larval and larvo-nymphal parasitoids of the noctuid pests was investigated by collecting third to fifth larval instars of *H. armigera*, *S. littoralis*, and of the cotton semi-looper *Anomis flava* (Fabricius) (Lep.: Noctuidae) during peak infestation at bloom from untreated «NT» plots. The larvae were reared individually on buds or leaves until adult emergence in a simple field laboratory without regulation of temperature (daily average temperature 27±1.5°C and 24±2°C at the rainfed and receding flood site,

respectively). Larval developmental time of *H. armigera* and *S. littoralis* was only examined at the south-western site during bloom by rearing neonate larvae from field collected eggs on buds or leaves, respectively, until emergence of the moths.

Likewise, parasitism rates of Coccinellidae larvae were determined by rearing field-collected prepupae of *Cheilomenes sulphurea* Olivier, *Cheilomenes simulans* Crotch and *Elpis dolens* Mulsant until adult emergence.

Rates of parasitism by egg parasitoids of *H. armigera* were determined at the south-western site by rearing tan coloured eggs from untreated plots until adult emergence (Lopez and Morrison 1985).

The presence of ground-dwelling predators was evaluated at the south-western site in 1997 by pitfall trapping during flowering, when caterpillar population densities were highest. Five plastic vials per plot ($\varnothing = 6$ cm), filled with 70 % alcohol, were randomly distributed in «NT» plots and examined daily.

Infestation of *A. gossypii* was in 1997 estimated by density scores, where

- 1 = 1
- 2 = 2 - 4
- 3 = 5 - 9
- 4 = 10 - 19
- 5 = 20 - 49
- 6 = 50 - 99
- 7 = 100 - 299
- 8 = 300 - 999
- 9 = 1000-3000 aphids.

Aphid densities were estimated for all sympodial fruiting branches. The medians of the above density intervals were divided by the number of leaves on the fruiting branch, providing a density estimate of *A. gossypii* per leaf for each branch. Densities per plant were calculated as average density per leaf of all fruiting branches.

In 1998, *A. gossypii* was counted individually on the following six leaves:

- the main stem leaf and another arbitrarily selected leaf of the lowest fruiting branch;
- the main stem leaf and another arbitrarily selected leaf of a randomly chosen fruiting branch in the median stratum;
- the main stem leaf and the second leaf of the terminal fruiting branch

Numbers of intact bolls and plant height were determined at the season's last sampling occasion. Simple regression of cotton yield on numbers of intact bolls and on plant height provided a simple estimation of the relative importance of boll and leaf-feeding pests, respectively, for yield. Yields per plot were compared with the mid-p point approach (Lancaster 1961) for an exact Mann-Whitney test (SAS Institute Inc. 1996):

$$P(U_{stat} \geq u_{tab}) = P(U_{stat} > u_{tab}) + \frac{1}{2} P(U_{stat} = u_{tab})$$

where U_{stat} is the test statistic and u_{tab} is the critical value $u_{0.05(2),n1+n2}$ of the U distribution.

The susceptibility of aphid predators to some commonly used insecticides in Malagasy cotton was evaluated in situ in an untreated field. Twenty-five field collected predator late-instar larvae were placed in aphid colonies on a few adjacent plants in the middle of the plot. A white plastic sheet was placed beneath the test plants to facilitate the search of individuals which had dropped off the plants. The spraying equipment and insecticide dosages were the same as in the insecticide treated «ST» plots, following HASYMA's recommendations for small growers. The treatments were carried out in the late afternoon. A control cohort did not receive any treatment. Tests at the south-western site were conducted with 3rd/4th larval instars of *Scymnus constrictus* Mulsant (Col.: Coccinellidae) and with 2nd/3rd larval instars of *Ischiodon aegyptius* (Wiedemann) (Dipt.: Syrphidae). At the north-western site, only *Cheilomenes simulans* Crotch (Col.: Coccinellidae) was tested. Surviving larvae on the plant and dead larvae found on the plastic sheet, were counted on the following morning, 14 hours after the insecticide treatment. For *C. simulans*, mortality was additionally determined 38 hours after the treatment. Moribund individuals were considered dead. The treatment efficacy was evaluated using Henderson and Tilton's formula (1955), which compares density changes in treated and untreated predator cohorts before and after the treatment:

$$\% \text{ mortality} = 100 \cdot \left(1 - \frac{T_a \cdot NT_b}{T_b \cdot NT_a} \right)$$

where T_a and NT_a are the numbers of predator larvae on treated and untreated plants after the treatment, and T_b and NT_b are the numbers of predator larvae on treated and untreated plants before the treatment, respectively. T_b and NT_b values were computed as the sum of live and dead individuals which actually were found either dead or alive 14 and 38 hours later.

Six different insecticides were tested. Predator densities were very low at the south-western site, and thus, only the tests on *C. simulans* at the north-western site could be replicated ($N = 3$ or 6). Considering the inherent conservativeness of commonly applied multiplicity adjustment procedures at higher numbers of pairwise comparisons, e.g., according to Holm (1979), the bootstrap method provided by the PROC MULTTEST procedure (SAS Institute Inc. 1996) was used to examine differences in mean mortality of *C. simulans*.

2.4. Results

The 2-year population dynamics on cotton pests provided new insights into the general pest status of herbivores in Malagasy cotton. Table 1 lists the most frequently encountered pests and gives some indications of their economic importance.

Table 1.
The principal cotton pests in Madagascar and an estimation of their economic importance

order	family	species	pest status ¹	
			north-west	south-west
Acari	Tetranychidae	<i>Tetranychus neocaledonicus</i> André	*	**
	Nitidulidae	<i>Carpophilus</i> (=Nitidula) <i>dimidiatus</i> (Fabricius)	*	*
Coleoptera	Tenebrionidae	<i>Gonocephalum simplex</i> (Fabricius)	*	—
		<i>Zophosis madagascariensis</i> Deyrolle	—	*
Heteroptera	Lygaeidae	<i>Oxycarenus hyalinipennis</i> (Costa)	*	*
	Pentatomidae	<i>Nezara viridula</i> L.	*	*
	Pyrrhocoridae	<i>Dysdercus flavidus</i> Signoret	**	***
Homoptera	Aleyrodidae	<i>Bemisia tabaci</i> Gennadius	**	**
	Aphididae	<i>Aphis gossypii</i> Glover	***	**
	Cicadellidae	<i>Igerna</i> ? <i>bimaculicollis</i> (Stål)	?	?
	Gelechiidae	<i>Pectinophora gossypiella</i> (Saunders)	*	*
	Gracillariidae	<i>Acrocercops difasciata</i> (=A. <i>bifasciata</i>) (Washington)	*	*
	Lyonetiidae	<i>Bucculatrix loxoptila</i> Meyrick	**	**
Lepidoptera	Noctuidae	<i>Anomis</i> (=Cosmophila) <i>flava</i> (Fabricius)	*	*
		<i>Earias biplaga</i> Walker	***	*
		<i>Earias insulana</i> (Boisduval)	*	***
		<i>Helicoverpa armigera</i> Hübner	****	****
		<i>Spodoptera littoralis</i> (Boisduval) (=Prodenia <i>litura</i> F.)	***	***
Thysanoptera	Thripidae	<i>Frankliniella occidentalis</i> (Pergande)	?	?
		<i>Frankliniella schultzei</i> (=F. <i>dampfi</i> Priesner) Trybom	*	?

¹ **** control measures indispensable *** control measures occasionally to be considered ** economic damage potential not well established * probably without economic impact in normal conditions ? impact unknown — presence not confirmed

Since the end of the 1970s, when the last data on cotton pest population dynamics in Madagascar had been published (Bournier and Vaissayre 1977), the economic impact of several pests has undergone considerably changes. Whereas the American bollworm *H. armigera* is still a limiting factor for cotton production in Madagascar and can be considered the key pest, the two spiny bollworms species, in particular *E. insulana* which is principally found in rainfed cotton, are nowadays reduced to a minor role as early-season pests, which are efficiently suppressed by the first insecticide treatments. Apparently, the introduction of synthetic pyrethroids in 1979-1980 has greatly contributed to attenuate pest pressure by spiny bollworms (H. Rakotofiringa, HASYMA, pers. comm.). The increased importance of the defoliator *S. littoralis*, which to some extent also feeds on buds and fruits, and of *A. gossypii* has been the two major changes in the pest management agenda. Both species played only a marginal role during the pre-pyrethroid era (Caresche and Brenière 1961, Bournier and Vaissayre 1977), but are now treated several times per season

on a calendar scheme. Although their impact on cotton yield is not well understood, some late-season pests may lead to important losses when outbreaks are not mastered, i.e., the endemic cotton stainer *Dysdercus flavidus* Signoret (Het.: Pyrrhocoridae), the sweetpotato whitefly *Bemisia tabaci* Gennadius (Hom.: Aleyrodidae), and the leaf perforator *Bucculatrix loxoptila* Meyrick (Lep.: Lyonetiidae). In the driest zones of the south-western cotton region, the polyphagous vegetable spider mite *Tetranychus neocaledonicus* André (Acari: Tetranychidae) is also of some importance at the end of the production cycle (L. Andriambololona, HASYMA, pers. comm.).

The large numbers of early-season, mostly coleopterous, herbivores which have been reported in Malagasy cotton (Caresche 1959, Brenière 1960, Delattre 1973, Couilloud 1993, Girardot 1994), rarely reach damaging densities. The tenebrionids *Gonocephalum simplex* (Fabricius) and *Zophosis madagascariensis* Deyrolle feed on plant debris and occasionally on young plant tissue, and may thus damage seedlings. Several curculionids, such as the endemic polyphagous leaf feeder *Catalalus lateritius* Fairmaire, or thrips (*Frankliniella schultzei* Trybom), the latter causing characteristic plant deformations (Delattre 1957, Kuklinski 2000), may attack young plants during the pre-squaring period, but it is unlikely that their feeding is of any economic significance.

In 1998, pest pressure depressed yields to very low levels in the untreated control. The «NT» plots only reached 10 % and 11 % of yields obtained in the insecticide treated «ST» plots at the north-western and south-western experimental site, respectively (table 2). In the preceding year, when pest pressure, especially by bollworms was considerably lower in both regions, cotton yields were much higher, and excellent results (1031 kg/ha in the north-west and 1669 kg/ha in the south-west) were recorded in the control plots.

Table 2. Raw cotton yields/ha, number of intact bolls, and plant height, determined at the season's last sampling date

«ST» = standard insecticide, and «NT» = untreated control

year	site	treatment	kg yields/ha ± SE	no. bolls ± SE	cm height ± SE
1997	Ampasikibo	«NT»	1669 ± 219 a	11.8 ± 2.2 a	112.3 ± 3.9 b
		«ST»	2689 ± 395 b	17.5 ± 2.2 b	105.6 ± 6.1 a
1998	Ampasikibo	«NT»	130 ± 20 a	1.4 ± 0.3 a	108.3 ± 5.3 b
		«ST»	1190 ± 77 b	8.1 ± 0.6 b	102.2 ± 1.8 a
1997	Ambato-Boeni	«NT»	1031 ± 230 a	9.2 ± 2.0 a	106.0 ± 7.8 b
		«ST»	1940 ± 208 b	12.1 ± 1.7 b	90.9 ± 1.3 a
1998	Ambato-Boeni	«NT»	172 ± 22 a	3.1 ± 1.4 a	104.0 ± 3.2..a
		«ST»	1657 ± 92 b	15.5 ± 1.0 b	99.9 ± 5.9 a

kg yields, number of bolls and cm plant height within the same year and site followed by the same letter are not significantly different (mid-p point approach for an exact Mann-Whitney test for yields, t-test of independent samples for bolls and plant height)

Table 3. Regression of yield on intact bolls and on plant height. 1997 and 1998 data for «ST» and «NT» pooled

regression	site	intercept \pm SE	slope \pm SE	P (slope)	r ²
bolls	Ampasikibo (N=14)	-14.38 \pm 134.32	149.54 \pm 11.01	<0.001	0.939
	Ambato-Boeni (N=18)	-86.01 \pm 144.28	122.16 \pm 12.83	<0.001	0.850
plant height	Ampasikibo (N=14)	-1193.60 \pm 3612.07	25.35 \pm 33.54	0.437	0.045
	Ambato-Boeni (N=18)	2453.57 \pm 1702.29	-13.36 \pm 16.77	0.464	0.038

Helicoverpa armigera remains the key pest in both cotton regions. Feeding on fruiting structures by bollworm larvae was of crucial importance for yields. Table 3 shows that numbers of intact bolls were a highly significant predictor for yield (adjusted $r^2 = 0.94$ for rain-grown cotton and adj. $r^2 = 0.85$ for receding flood cotton; $P = <0.001$). Boll losses through feeding by insects were largely due to *H. armigera*, because *Earias* spp. were rare, and feeding on buds and fruits by *S. littoralis* is of minor importance as long as plants have enough leaves. Among the numerous heteropterous boll feeders, which were sporadically found in the crop (Kuklinski 2000), only late season outbreaks of the cotton stainer *D. flavidus* are likely to have an impact on maturing bolls.

At the south-western site, *H. armigera* larval populations peaked during the peak-squaring/early boll stage of the host plant around 60 d.a.e. (fig. 1 and 2). At flowering, the cotton plant is highly attractive to ovipositing females (Firempong and Zalucki 1991). Late-season infestation beyond 90 d.a.e. by second or third generation caterpillars was very low in 1997. In 1998, however, the low action threshold of bollworms required interventions with cypermethrin on 14/04 and 21/04 (fig. 2). At the north-western site, infestation levels were comparatively lower. In 1997, a sharp but ephemeral peak of bollworm larvae was observed in untreated «NT» at the early boll stage, i.e., about 70 d.a.p. (fig. 3).

Endosulfan, cypermethrin, profenofos, and thiodicarb (originally introduced for control of pyrethroid-resistant *S. littoralis*) are currently the compounds used against *H. armigera* and *Earias* spp in Malagasy cotton. Although some treatments resulted in poor control (e. g., the cypermethrin application on 24/02/97, cf. fig. 1), no consistent indications for bollworm resistance against any of these insecticides were observed on the field level. By contrast, among the four mentioned compounds, only profenofos provides partial control of *A. gossypii* (Andriambololona and Rasolonjatovo 1996).

Fig. 1. Population dynamics of *H. armigera* and *S. littoralis* in Ampasikibo (south-west) in 1997

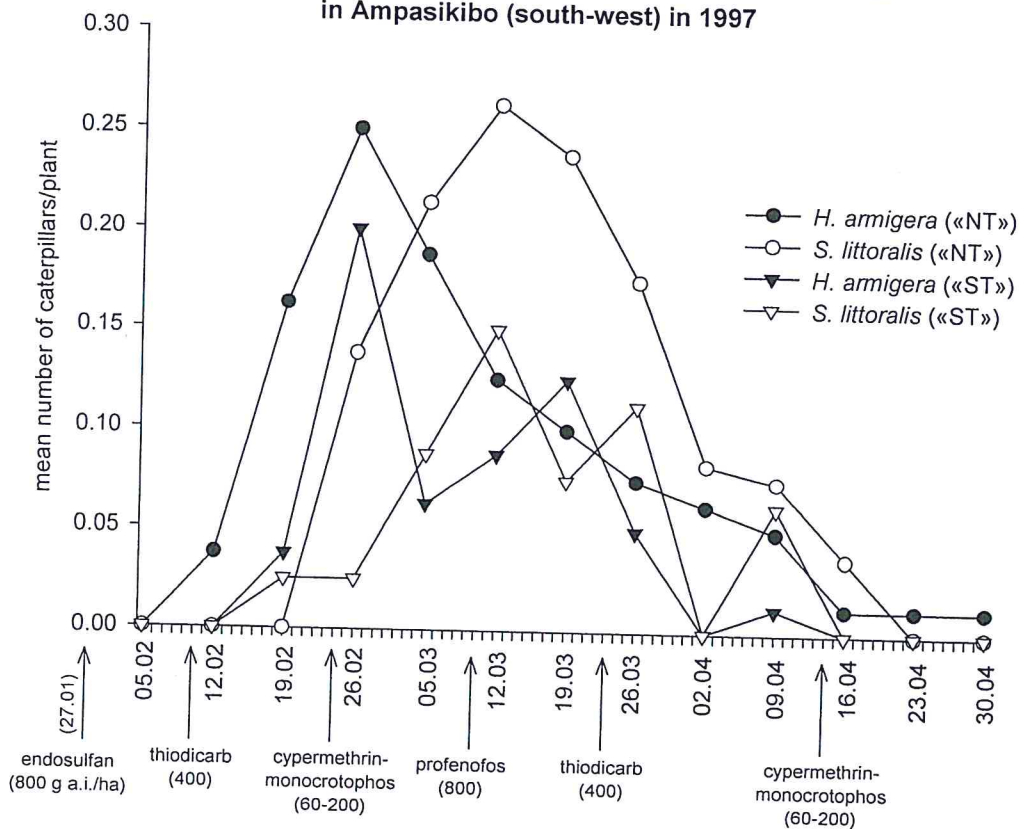


Fig. 2. Population dynamics of *H. armigera* and *S. littoralis* in Ampasikibo (south-west) in 1998

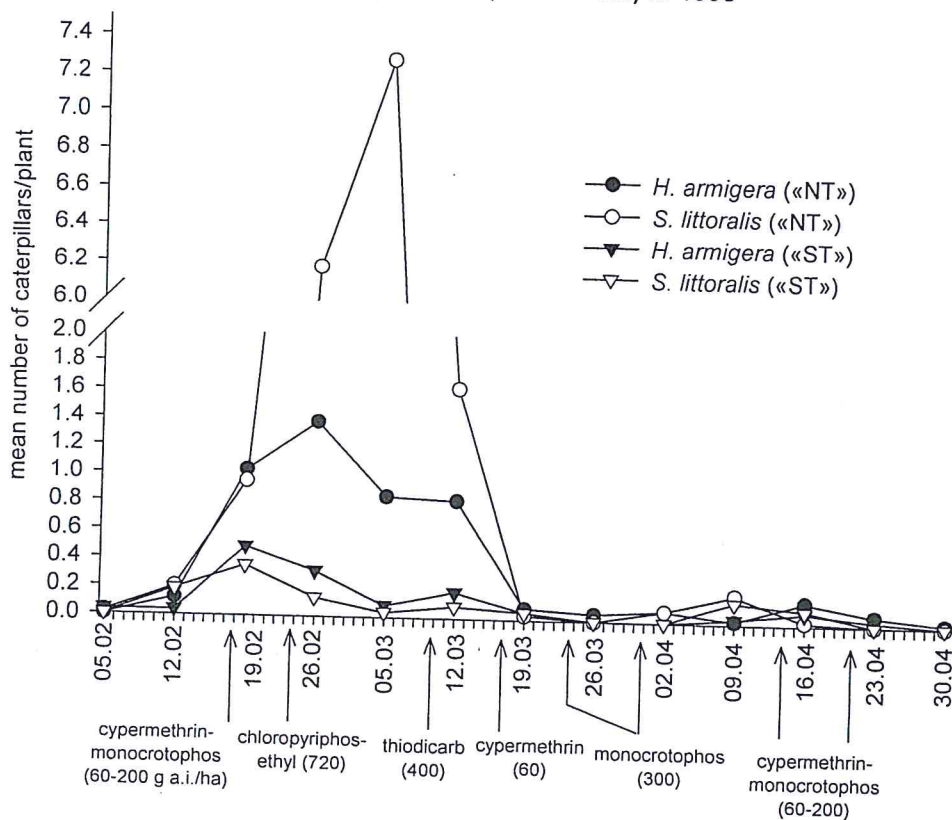
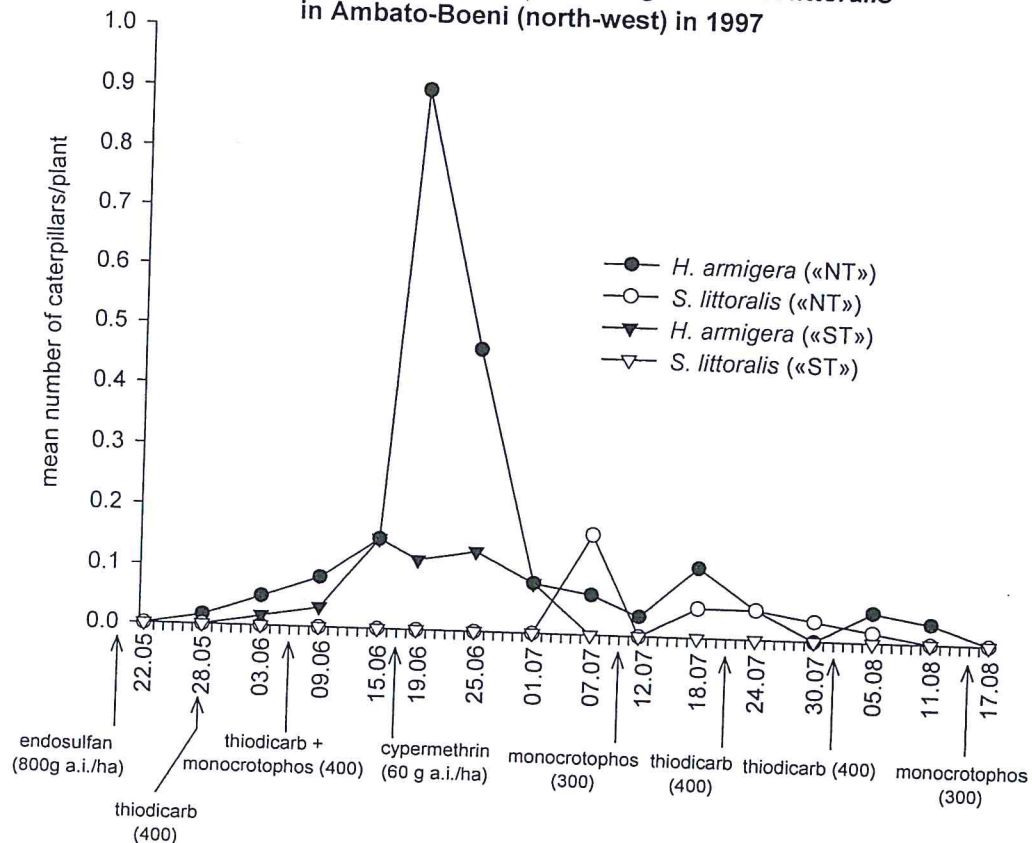


Fig. 3. Population dynamics of *H. armigera* and *S. littoralis* in Ambato-Boeni (north-west) in 1997



In rainfed cotton, *S. littoralis* peaked one to two weeks after *H. armigera* (fig. 1 and 2). This is probably due to a longer mean larval development time, since *S. littoralis* generally passes through one larval instar more. Data from the field laboratory at the south-western site showed that *S. littoralis* larvae ($n = 22$) needed $21.5 (\pm 2.3 \text{ SE})$ days to accomplish their development compared to $17.1 (\pm 1.2 \text{ SE})$ days for *H. armigera* ($n = 17$). Defoliation by caterpillars in rainfed cotton was very moderate in 1997 but not in 1998, when a major outbreak, reaching $7.3 (\pm 0.9 \text{ SE})$ larvae/plant in «NT» plots (fig. 2), was efficiently suppressed with chlorpyrifos-ethyl in the «ST» treatment. In both years, *S. littoralis* populations densities were insignificant at the north-western site (fig.3).

A large array of beneficials are associated with *H. armigera* and *S. littoralis* in Malagasy cotton. The two noctuids have most of their natural enemies in common (table 4). Parasitism rates by larval parasitoids could not be determined systematically. However, the braconids *Cotesia* (= *Apanteles*) ? *decaryi* (Granger) and *Meteorus laphygmarum* Brues were the most common species. *Helicoverpa armigera* eggs are parasitised by *Trichogramma evanescens* Westwood (Hym.: Trichogrammatidae). Egg parasitism rates

were only studied at the south-western site. No parasitoids emerged from early-season egg samples, when rainfall probably is the most important egg mortality factor. However, *T. evanescens* may have a certain regulating potential for the second and third host generation. Peak parasitism with 32 % was recorded on 11/03/1998 (n = 60), i.e., approximately three weeks after the peak in oviposition of the host.

Delvare and Rasplus (1994) described a gregarious pteromalid, *Spodophagus* (= *Oxyglypta*) *lepidopterae* (Risbec), which had been accidentally discovered in *S. littoralis* pupae from the Toliara region (south-west Madagascar) in 1987. This reclassified species parasitises the pupal or prepupal stage of various noctuids in the soil and is therefore of particular interest for IPM programmes because of its compatibility with foliar insecticide sprayings (Silvie 1995). However, in this study, *S. lepidopterae* was neither found in *S. littoralis* (n = 78) nor in *H. armigera* (n = 67) pupae reared from soil samples at the south-western site in March 1998.

The most conspicuous predator of caterpillars is *Afrius flavirostrum* Signoret (Het.: Pentatomidae). It is more commonly found to attack *S. littoralis*, possibly because the leaf worm is lacking the aggressive auto-defence behaviour of late-instar *H. armigera*. Several polyphagous Carabidae and Reduviidae (table 4), as well as spiders, also prey on the noctuid larvae. A great diversity of Araneidae, Clubionidae, Oxyopidae, Salticidae, Thomisidae, and others are present in Malagasy cotton. The pitfall trapping at the south-western site showed that nocturnal ground-dwelling carabids are common in rainfed cotton fields. In particular, the tall species *Ctenosta grandidieri* Maindron and *C. senegalense* Dejean may be important predators of last instar caterpillars which enter the soil in order to pupate.

However, considering the high densities of both noctuid pests in 1998 (*S. littoralis* only at the south-western site) and the very low yield levels in untreated plots, it seems unlikely that natural enemies are capable to prevent significant economic damage in Malagasy cotton.

Together with *H. armigera* and *S. littoralis*, the cotton aphid *A. gossypii* is believed to require specific treatments within the spraying calendar (H. Rakotofiringa, pers. comm.). Figures 4-6 show the population dynamics of cotton aphids at the north-western and the south-western site, respectively. Population dynamics took a markedly different course at the two sites. Aphid infestation in receding flood cotton was characterised by a slower early-season population increase, which is probably due to lower temperatures in dry season cotton. After the slow initial increase, however, aphid populations reached

Fig. 4. Population dynamics of *A. gossypii* and aphid predators in Ampasikibo (south-west) in 1998

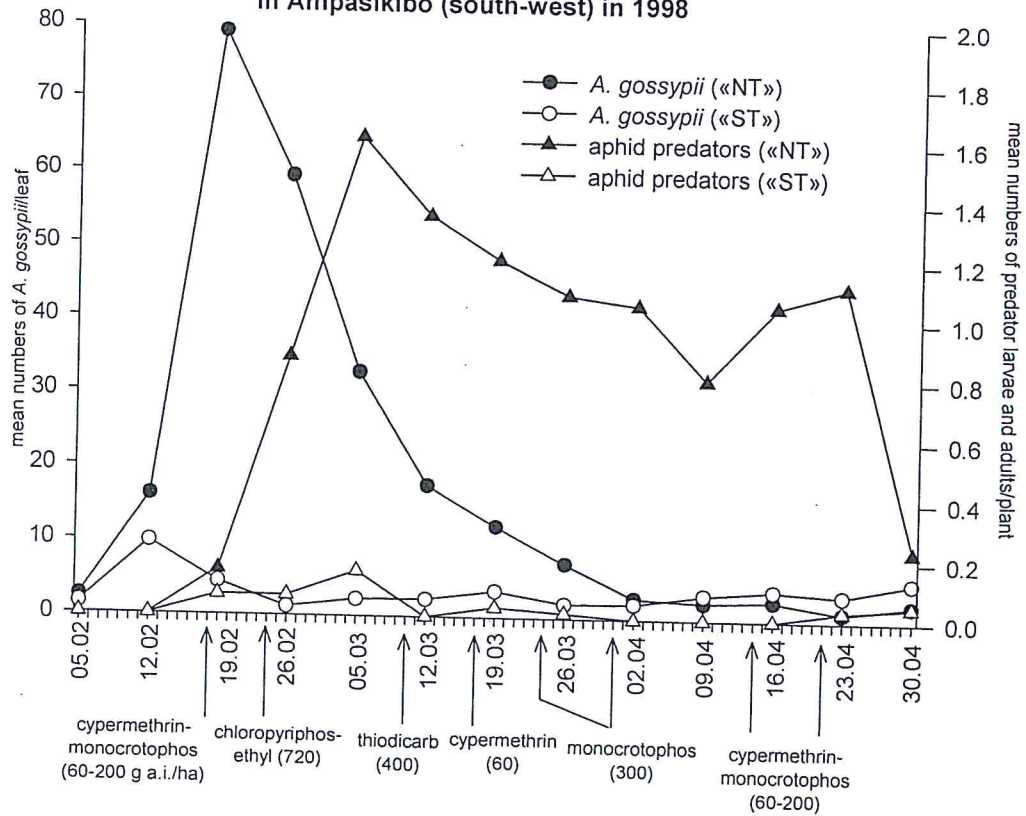
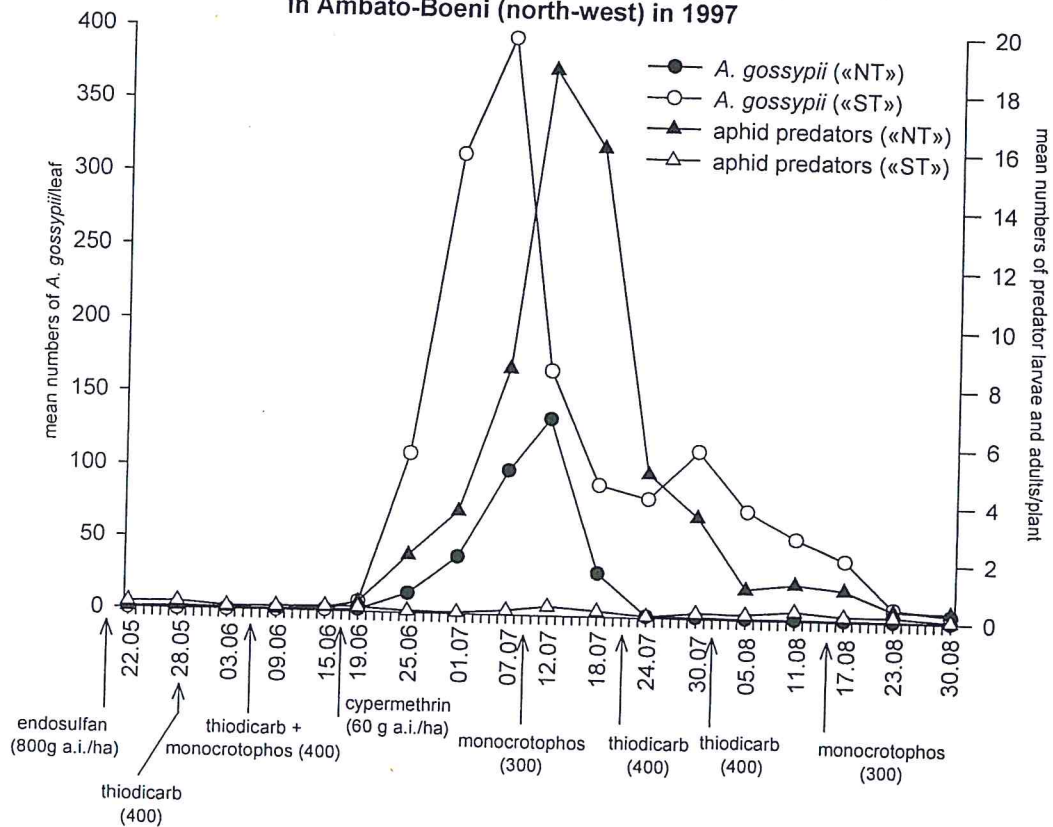
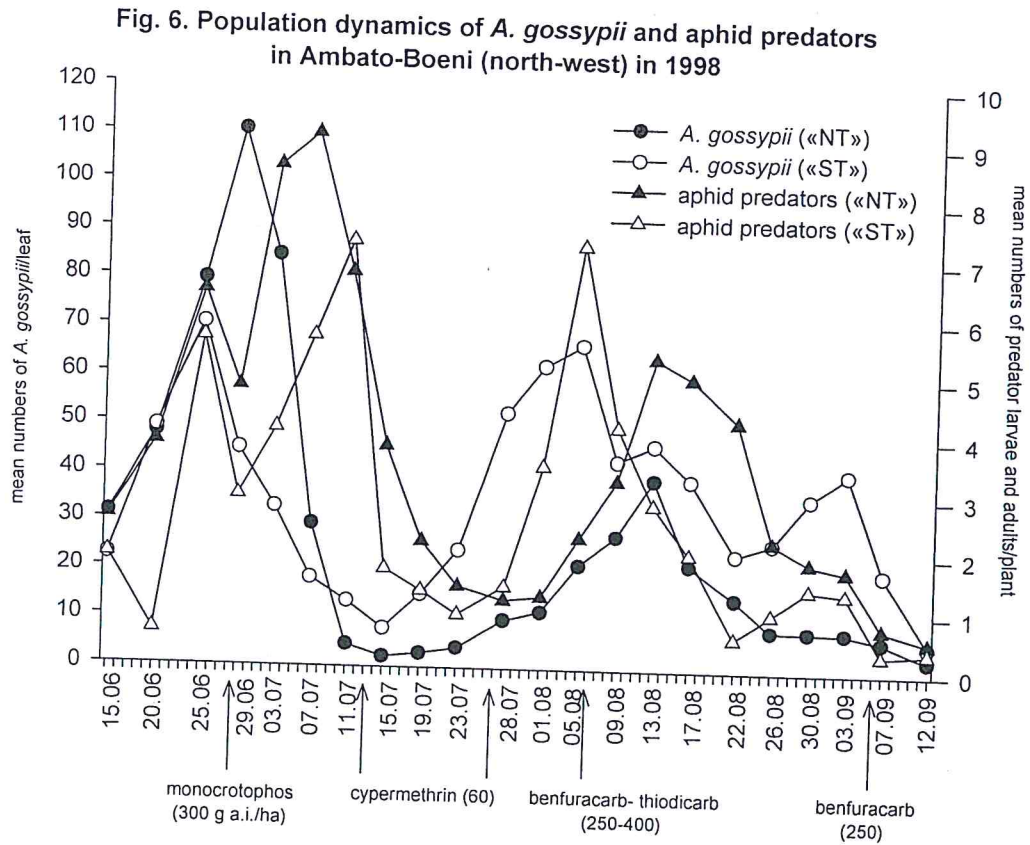


Fig. 5. Population dynamics of *A. gossypii* and aphid predators in Ambato-Boeni (north-west) in 1997





considerably higher densities at the north-western site. Heavy aphid infestation persisted during the boll maturation phase with secondary peaks observed beyond 100 d.a.p. except in untreated «NT» plots in 1997 (fig. 5). In rainfed cotton, *A. gossypii* densities increased rapidly to a moderate peak at bloom (79 individuals/leaf in «NT» in 1998, cf. fig. 4, and only 39 aphids/leaf in «NT» the year before), which was followed by a rapid decline. In «ST» plots in rainfed cotton, aphids were efficiently controlled by the first aphicidal treatment with monocrotophos, and subsequently mean densities never exceeded 10 individuals/leaf at any time of the season. By contrast, at the north-western site in both years higher aphid infestations were recorded in sprayed than in control plots. There were strong indications that cypermethrin sprayings against bollworms induced stimulatory effects on aphid reproduction. In 1997, a sharp increase in aphid infestation was observed in «ST» plots after a cypermethrin treatment on 17/06, resulting in a peak density of almost 400 individuals per leaf on July 7. This corresponded to a fourfold higher density than in «NT» plots, where aphids peaked five days later (fig. 5). In 1998, two cypermethrin applications were carried out after the first peak of *A. gossypii* (fig. 6). In both years, subsequent aphid population increase in «ST» was observed at low predator

Table 4. The principal beneficials in Malagasy cotton and an estimation of their relative abundance. Species without reference are new records

order	family	species	principal host/prey	previous records ¹	abundance ²	
					north-west	south-west
		<i>Ctenosta grandidieri</i> Maindron	Lep.?	—	?	**
		<i>Ctenosta senegalense</i> Dejean	Lep.?	—	?	**
		<i>Distichus perrieri</i> Fairmaire	Lep.?	—	?	*
	Carabidae	<i>Hyparpalus holosericeus</i> Dejean	Lep.?	—	?	*
		<i>Hyparpalus ?madecassus</i> Jeannel	Lep.?	—	?	*
		<i>Lissauchenius ?venator</i> Laferté	Lep.?	—	?	*
		<i>Scarites madagascariensis</i> Dejean	Lep.?	—	?	*
Col.		<i>Stenidia hovana</i> Fairmaire	Lep.?	—	**	*
		<i>Cheilomenes (=Cydonia) simulans</i> Crotch	<i>A. gossypii</i>	—	?	*
		<i>C. sulphurea</i> (Olivier)	<i>A. gossypii</i>	—	***	*
	Coccinellidae	<i>Elpis dolens</i> Mulsant	<i>A. gossypii</i>	C, V	**	*
		<i>Exochomus laeviusculus</i> Weise	<i>A. gossypii</i>	C, V	**	*
		<i>Pharoscyrmus (=Stethorus) madecassus</i> (Weise)	<i>A. gossypii</i>	C	**	*
		<i>Scymnus constrictus</i> Mulsant	<i>T. neocaledonicus</i>	C, V	?	?
	Calliphoridae	<i>Sarcophaga tibialis</i> Macquart	<i>A. gossypii</i>	C, V	**	**
		<i>Ischiodon (=Xanthogramma) aegyptius</i> (Wiedemann)	<i>S. littoralis</i>	R	?	?
	Syrphidae	<i>Paragus borbonicus</i> Macquart	<i>A. gossypii</i>	V?	*	**
Dipt.		<i>Carcelia evolans</i> (Wiedemann)	<i>A. gossypii</i>	V	**	*
	Tachinidae	<i>Peribaea</i> sp.	<i>H. armigera</i>	B, V	?	?
		<i>Tachina (=Exorista) fallax</i> Meigen	<i>S. littoralis</i>	—	?	*
			<i>H. armigera,</i>	B, V	?	?
			<i>S. littoralis</i>	—	?	?
	Nabidae	<i>Nabis capsiformis</i> Germar	Lep.?	—	?	*
	Pentatomidae	<i>Afrius flavirostrum</i> Signoret	Lep.	—	*	**
		<i>Coranus pallidus</i> Reuter	Lep.?	—	?	*
Het.		<i>Cosmolestes pictus</i> Klug	Lep.?	—	**	?
	Reduviidae	<i>Glymmatophora dejoncki</i> Schouteden	Lep.?	—	?	*
		<i>Pseudophonoctonus</i> sp. n.	<i>Dysdercus</i> sp.	V	?	**
		<i>Rhinocoris</i> cf. <i>saevus</i> Stål	<i>Dysdercus</i> sp.?	—	?	*
	Aphelinidae	<i>Encarsia (=Prospaltella) transvena</i> (Timberlake)	<i>B. tabaci</i>	V?	?	**
		<i>Chelonus curvimaculatus</i> (Cameron)	<i>P. gossypiella,</i>	B, V	?	?
			<i>H. armigera</i>	—	?	?
	Braconidae	<i>Cotesia (=Apanteles) ?decaryi</i> (Granger)	<i>H. armigera,</i>	B?, R?, V?	*	**
		<i>Meteorus laphygmarum</i> Brues	<i>S. littoralis</i>	—	*	**
			<i>H. armigera,</i>	B, R, V	**	**
			<i>S. littoralis</i>	—	**	**
	Chalcididae	<i>Brachymeria madecassa</i> Steffan	<i>A. flava</i>	V	?	**
		<i>B. multicolor</i> Kieffer	<i>A. flava</i>	B, S	?	?
Hym.	Eulophidae	<i>Euplectrus laphygmae</i> Ferrière	<i>H. armigera,</i>	V	?	**
			<i>S. littoralis</i>	—	?	**
	Eumenidae	<i>Eumenes maxillosus</i> (De Geer)	Lep.	B	*	*
	Ichneumonidae	<i>Charops</i> sp.	<i>H. armigera,</i>	B, R, V	*	*
		<i>Metopius</i> sp.	<i>S. littoralis</i>	—	*	*
			<i>S. littoralis</i>	R?	?	*
	Pteromalidae	<i>Spodophagus (=Oxyglypta) lepidopterae</i> (Risbec)	<i>H. armigera,</i>	D & R	?	?
			<i>S. littoralis</i>	—	?	?
	Scelionidae	<i>Trissolcus basalis</i> (Wollaston)	Pentatomidae	—	*	**
	Sphecidae	<i>Ammophila</i> sp.	Lep.	—	*	*
	Trichogrammatidae	<i>Trichogramma evanescens</i> Westwood	<i>H. armigera</i>	V	?	**
Neur.	Chrysopidae	<i>Mallada desjardinsi</i> (Navas)	Hom., Lep.	—	**	**
	Hemerobiidae	<i>Micromus plagatus</i> Navas	Hom., Lep.	—	**	*
Entomophthorales:						
	Neozygiteae	<i>Neozygites fresenii</i> (Nowakowski)	<i>A. gossypii</i>	—	**	*

¹ B = Brenière 1965, C = Couilloud 1993, D & R = Delvare and Rasplus 1994, R = Randrianandrianina-Razananaivo 1991, S = Steffan 1958, V = Vaissayre 1977 ----- ² *** abundant ** common * sporadic ? presence not confirmed

densities in «NT», i.e., <0.15/plant in 1997, and 1.33 predators/plant during the two last weeks of July 1998. Thus, it is unlikely that the stronger aphid population growth in «ST» was due to the destruction of predators populations through insecticide use.

Five species of coccinellids, two syrphids, the lacewing *Mallada desjardinsi* (Navas) and the hemerobiid *Micromus plagatus* Navas were recorded as specific aphidophagous predators (table 4). No aphid parasitoids were observed. Aphid predators were more abundant and better synchronised with their prey at the north-western site, where aphid populations increased slower and remained at higher densities for prolonged periods (fig. 5 and 6). *Cheilomenes simulans* Crotch (Col.: Coccinellidae) was the predominating species. Due to the extended duration of aphid infestation in 1998, three generations of *C. simulans* were recorded in the untreated plots. At the south-western site, peak density of predators lagged two weeks behind the peak aphid density (fig. 4). In rainfed cotton, the syrphid *Ischiodon aegyptius* (Wiedemann) was best synchronised with *A. gossypii*, but because of scarcity of prey after the aphid peak at flowering, its presence in cotton fields was only temporal, and only one syrphid generation was present in the cotton fields. *Scymnus constrictus* Mulsant was the most abundant coccinellid at the south-western site. This species was observed throughout the whole planting season. *Scymnus constrictus* seems to possess a superior searching capacity, since even small *A. gossypii* colonies on near-by alternative hosts (e.g., on different Cucurbitaceae) were frequently associated with *S. constrictus* but rarely with any other predator species. This small coccinellid is able to survive on low prey density (Kuklinski 2000), and appears to resist better than other coccinellid species to extreme maximum temperatures (>35° C) during the hot rainy season. In addition, the characteristic thick waxy layers on *S. constrictus* larvae possibly protect them to some extent against rainfall, which can be fatal to early coccinellid instars. At both sites, other Coccinellidae were only erratically present. Strikingly, *C. simulans* does not thrive under the hot and humid conditions of rain-grown cotton in south-western Madagascar. This was reflected in a total egg:adult-ratio of 1.27 at the south-western site compared to 5.56 in the receding flood crop. Similarly, in the south-west lacewings only appeared in the course of March, when rains had ceased and temperatures had decreased. Late season predators depend on alternative prey for their survival, such as *B. loxoptila* larvae.

The three species of the Coccinellinae subfamily (*C. sulphurea*, *C. simulans*, and *E. dolens*) are parasitised by the gregarious endoparasitoid *Tetrastichus cydoniae* Risbec (Hym.: Eulophidae), which attacks 3rd or 4th instar larvae and emerges from the pupa. At

the north-western site, peak parasitism rates reached 20-30 % in second generation larvae. Thus, the parasitoid may limit to some extent the predatory potential of late-season Coccinellinae populations.

Aphid predators appeared to be highly susceptible to insecticides, and their numbers were severely suppressed in the sprayed plots. The tests in situ demonstrated that most of the currently used compounds are very toxic to aphid predator larvae. Results are summarised in table 5.

Table 5. Percent mortality (\pm SE) of aphid predators 14 and 38 hours after application of an insecticide under field conditions. Values corrected according to Henderson & Tilton (1955)

insecticide (g a.i./ha)	3 rd /4 th instar <i>C. simulans</i>		3 rd /4 th instar <i>S. constrictus</i>	2 nd /3 rd instar <i>I. aegyptius</i>
	% dead \pm SE after 14h (N =)	% dead \pm SE after 38h (N =)	% dead \pm SE after 14h (N =)	% dead \pm SE after 14h (N =)
acetamiprid (12.5)	91.4 \pm 1.6 (N = 71)	100 (N = 65)	—	—
cypermethrin (60)	93.1 \pm 3.7 (N = 72)	100 (N = 67)	62.1 (N = 17)	100 (N = 18)
endosulfan (800)	37.1 \pm 7.8 (N = 137)	55.1 \pm 6.6 (N = 128)	—	—
monocrotophos (300)	82.5 \pm 8.4 (N = 141)	90.0 \pm 6.5 (N = 136)	86.7 (N = 19)	100 (N = 26)
profenofos (800)	42.2 \pm 5.0 (N = 132)	63.3 \pm 4.5 (N = 132)	—	—
thiodicarb (400)	79.5 \pm 3.7 (N = 129)	93.0 \pm 1.7 (N = 121)	80.7 (N = 17)	100 (N = 17)

Table 6. Probabilities for the equality of mean mortality of 3rd/4th instars of *C. simulans* (two-sided bootstrap at n = 10,000 and $\alpha = 0.05$)

comparison	P (after 14h)	P (after 38h)
acetamiprid - cypermethrin	0.698 (N = 3/3)	1.000 (N = 3/3)
acetamiprid - endosulfan	0.002 ** (N = 3/6)	0.004 ** (N = 3/6)
acetamiprid - monocrotophos	0.511 (N = 3/6)	0.346 (N = 3/6)
acetamiprid - profenofos	<0.001 ** (N = 3/6)	0.004 ** (N = 3/6)
acetamiprid - thiodicarb	0.063 (N = 3/6)	0.021 * (N = 3/6)
cypermethrin - endosulfan	0.002 ** (N = 3/6)	0.003 ** (N = 3/6)
cypermethrin - monocrotophos	0.437 (N = 3/6)	0.346 (N = 3/6)
cypermethrin - profenofos	0.001 ** (N = 3/6)	0.001 ** (N = 3/6)
cypermethrin - thiodicarb	0.056 (N = 3/6)	0.022 * (N = 3/6)
endosulfan - monocrotophos	0.002 (N = 6/6)	0.005 ** (N = 6/6)
endosulfan - profenofos	0.590 (N = 6/6)	0.329 (N = 6/6)
endosulfan - thiodicarb	<0.001 ** (N = 6/6)	<0.001 ** (N = 6/6)
monocrotophos - profenofos	0.003 ** (N = 6/6)	0.005 ** (N = 6/6)
monocrotophos - thiodicarb	0.757 (N = 6/6)	0.704 (N = 6/6)
profenofos - thiodicarb	<0.001 ** (N = 6/6)	<0.001 ** (N = 6/6)

* significant at $\alpha = 0.05$ ** significant at $\alpha = 0.01$

At the south-western site, the slow density of predators in the field made it impossible to replicate the tests. However, the extreme susceptibility of the syrphid *I. aegyptius* to cypermethrin, monocrotophos and thiodicarb, resulting in 100 % mortality after 14 hours, should be stressed. The coccinellid *C. simulans* showed a significantly higher degree of resistance to endosulfan and profenophos (table 6). Thus, these two compounds may be interesting candidates for natural enemy conservation strategies within the framework of IPM in Malagasy cotton.

A promising discovery was the aphidopathogenic fungus *Neozygites fresenii* (Nowakowski) (Entomophthorales), which was associated with aphid populations at both experimental sites (Kuklinski 2000). Aphids with visible signs of mycosis were discovered when the aphid population had reached its peak. After the death of the aphid, the host carcasses are rapidly overgrown by a greyish mould, produced by a saprophytic fungus imperfectus of the genus *Cladosporium* sp. (G. Zimmermann, BBA-Darmstadt, pers. comm.). However, the impact of the pathogen was difficult to estimate. Neither in 1997 nor in 1998, conditions were favourable for the development of epizootics. At the south-western site, aphid numbers were very low and in the following year, heavy rain-fall during aphid peak density ironically appeared to curb the epizootics by washing off sporulating cadavers.

2.5. Discussion

A great diversity of arthropod pests feed on cotton in Madagascar. Pest pressure may cause dramatic yield losses (Delattre 1958, Caresche 1959, Bournier and Vaissayre 1977). Older yield data (Andriambololona et al. 1989) suggest that the results in untreated plots in 1997, when yields in the «NT» plots in Ampasikibo even exceeded 1998 yields in insecticide treated «ST» plots (table 2), are exceptional. Moreover, the significant yield gain obtained in «ST» compared to «NT» plots in 1997 (909 and 1020 kg/ha at the north-western and south-western sites, respectively) still exceeded the costs of the officially recommended calendar spraying by the factor three and four, respectively.

However, since pest population dynamics vary greatly from one season to another, well-timed insecticide applications against the key pests based on reliable action thresholds are likely to improve yields further and diminish risks of pest resistance build-up and environmental disruption. Unfortunately, in a peasant community with high rates of illiteracy and low professionalism like in south-western Madagascar, a large-scale

implementation of economic thresholds in pest management does not seem realistic for the time being.

Only few herbivore species listed in table 1 are likely to be responsible for the heavy economic damage observed in untreated cotton plots in 1998. The main targets in pest management are the noctuids *H. armigera* and *S. littoralis* and the cotton aphid *A. gossypii*, which all essentially are mid-season pests in Malagasy cotton.

The temporal overlap of high densities of these pests during the peak-squaring/early boll stage of the crop makes it a challenge to develop strategies for natural enemy conservation, in particular of aphid predators. Conservation of aphidophagous predators is of foremost importance because of their role as key natural enemies of aphids, especially in north-western Madagascar, where the systematic elimination of predators by synthetic insecticides probably is a major reason for pest resurgence of *A. gossypii*. Conventionally, bollworm sprayings in Malagasy cotton commence 30-35 d.a.e., followed by five (south-west) or seven to nine further applications (north-west). However, in this study, critical densities of *H. armigera* were not observed before 45-50 d.a.e. In rainfed cotton, early egg populations may partly be destroyed by heavy rains in January. Additionally, the cotton plant possesses a higher potential for compensation of injury during early squaring than later during the peak squaring/early boll stage, when metabolic stress increases (Wilson 1994). When treatments are to be initiated slightly before or during flowering, they are likely to coincide with the increase of aphid and aphid predator populations. Thus, it is highly recommendable to refer to endosulfan or profenofos for mid-season applications, which were the least toxic chemicals to the coccinellid *C. simulans* in field tests (table 5 and 6). Because of its lower toxicity to beneficial arthropods, in particular to coccinellids (Sigrist et al. 1994, Vaissayre et al. 1995), endosulfan is usually placed at the top of the spraying calendar. However, colonisation of the cotton crop by natural enemies depends on the density of aphid prey, which is usually very low during early squaring. The conservation aspect becomes more critical during flowering. Specifically, the use of cypermethrin should be discouraged not only because of its detrimental effects on the key aphid predator *C. simulans*, but also because of the possible induction of growth stimuli on cotton aphid populations observed at the north-western site. (Some pyrethroids are suspected to trigger aphid outbreaks, though the precise physiological mechanism is unknown (Kidd and Rummel 1997). Moreover, the indiscriminate use of thiodicarb should be avoided, because it proved to be highly toxic to the aphidophagous predators tested (table 5 and 6). This carbamate is highly efficient against *S. littoralis* and the bollworms,

and is therefore commonly alternated with cypermethrin. During this two years study, infestations by *S. littoralis* were very moderate at the south-western site in 1997, and insignificant at the north-western site in both years. Thus, routine mid-season applications seem questionable. In normal conditions of food supply, *S. littoralis* is a conspicuous leaf feeder, characterised by readily predictable population increases. Risks of outbreaks, which rarely occur in Malagasy cotton since the introduction of thiodicarb in 1987, can be suppressed with high level of reliability with thiodicarb or chlorpyrifos-ethyl (Rakotofiringa 1989). However, threshold based systems do not offer any advantage over a fixed spraying calendar, if extremely low action thresholds inevitably would impose even an increase in pesticide applications. A critical density level of 10,000 *S. littoralis* caterpillars/ha is easily exceeded during short-term population fluctuations, which in part must be attributed to the very large intrinsic sampling error when scouting pests at low densities, i.e., 0.1-0.2 individuals/sampling unit or lower (Kuklinski 2000). The maximum feeding capacity of *S. littoralis* larvae recorded in our field laboratory was below the mean total consumption of 264 cm² cotton leaf surface reported from Egypt by Afifi (1990). By consequence, the weekly per-head defoliation obtained in our study corresponds only to a few percent of the total leaf surface of a cotton plant at flowering. As demonstrated by artificial defoliation experiments, cotton plants may tolerate a 20-25 % weekly loss of assimilatory surface without any impact on yield (Bishop et al. 1978, Russell et al. 1993). Thus, it is unlikely that a rise of the currently applied threshold for *S. littoralis* would present an economic risk for Malagasy cotton growers.

Equally, our results challenge the currently very rigid aphid control recommendations in Malagasy cotton. In receding flood cotton, the spraying scheme for the 1998 cropping season comprised of six to eight aphicidal treatments, according to the intensification level. In the south-west, where aphid infestations are less critical, two applications were scheduled in the official scheme. However, respecting the action threshold fixed at 15 % infested terminal leaves resulted in five aphicide treatments. Research on the relationship between binomial counts and the mean revealed that 15 % infested terminal leaves correspond to only 4-6 aphids/leaf (Kuklinski, unpubl. data). Additionally, presence-absence sampling on the terminal leaves provided little accuracy, especially when sampling units were considered infested at any density different from 0.

Outbreaks of *A. gossypii* in early-/mid-season cotton may not have any impact on yield if populations crash rapidly thereafter (Godfrey et al. 1997, Rosenheim et al. 1997). Long term infestation on moderate to high levels are more likely to be dangerous for the crop,

and aphid thresholds may therefore more adequately be expressed in terms of cumulative aphid indices (Wratten et al. 1979, Godfrey et al. 1997). In our study, we investigated only the effects on plant height and contamination of fibres. Reduced plant height may be a result of aphid feeding and honeydew production, the latter reducing photosynthesis through secondary fungal infections (Deguine and Leclant 1997). Though considerably different aphid densities were observed in treated «ST» and untreated «NT» plots in the two years, only the long lasting infestation in «ST» plots at the north-western site in 1997 significantly depressed plant growth. In rainfed cotton, average plant height was even significantly higher in «NT» plots which sustained higher aphid densities (table 2).

Late season aphid infestations, commonly observed in receding flood cotton, may be more critical because of the risk of honeydew contamination of open bolls. In receding flood cultivation, there is normally no abrupt disruption of water supply (Douessin 1979), and the host plants remain more attractive for leaf feeders during the boll maturation phase. However, only a small part (3-5 %) of Malagasy cotton fibre production is downgraded because of stickiness or sooty mould, and this proportion is economically far less important than quality losses due to dust, plant debris or untimely rainfall (H. Rakotofiringa, pers. comm.). The apparent economic profitability of late-season aphid control may be due to the suppression of whiteflies (*B. tabaci*), leaf-perforating caterpillars (*B. loxoptila*) or cotton stainers (*D. flavidus*). No thresholds have been developed for this pest complex, which is normally controlled by the last calendar spraying. Still, a late season insecticide treatment (100 d.a.e. or later) can be of economic benefit, particularly at times of a late bollworm infestation. During the boll maturation period, the cotton plant has a reduced ability to compensate for damage on fruiting structures (Sterling et al. 1989, Wilson 1994). Attempts of implementing biological control methods have not been successful in Malagasy cotton. These include inundative releases of *Trichogramma brasiliensis* Ashmead against *H. armigera* (Crétenet et al. 1976, Bournier and Vaissayre 1977), foliar applications of polyedric virus against *S. littoralis* (Rakotofiringa 1989), sprayings of neem oil extracts against *H. armigera*, *S. littoralis* and *A. gossypii* (Kuklinski, unpubl. data), and treatments with potassium soap solutions against *A. gossypii* (Kuklinski, unpubl. data). For the time being, integrated control will principally have to rely on conservation of the natural enemy guild present in Malagasy cotton fields. The key pest *H. armigera* is insufficiently controlled by its natural enemies, but can be combated with chemicals which are relatively less disruptive to aphidophagous predators. Calendar treatments against cotton aphids and *S. littoralis* do not always appear to be economically justified. In

particular, the newly discovered fungus *N. fresenii* may in the future play an important role in aphid management decisions, especially in rain-grown cotton where high degrees of relative humidity favour the entomopathogen (Latgé and Papierok 1987). This microbial agent is particularly interesting because of its compatibility with insecticide applications (Steinkraus et al. 1995). When high aphid densities coincide with cool nights, *N. fresenii* may also contribute to the decline of aphid populations in the north-western region of Madagascar.

3 Seasonal population dynamics, spatial distribution and sampling of the cotton aphid *Aphis gossypii* Glover (Hom.: Aphididae) in Madagascar

3.1. Abstract

The seasonal population dynamics, spatial distribution and sampling procedures of the cotton aphid *Aphis gossypii* Glover (Hom.: Aphididae) were evaluated during two years in rainfed and receding flood cotton in Madagascar. Aphid infestations in the rain-grown crop did not exceed 39 and 79 individuals per leaf in 1997 and 1998, respectively, and were efficiently controlled with monocrotophos in treated plots. Aphids grew to much higher densities in receding flood cotton, where their pest status, among other factors, is enhanced by unintentional effects of insecticide treatments. A mid-season outbreak in 1997 reaching a peak density of 395 aphids/leaf in treated plots was likely to be caused by a cypermethrin spraying against *Helicoverpa armigera* Hübner (Lep.: Noctuidae). When predators were not eliminated by insecticides, the beneficials seemed to be able to suppress aphid outbreaks. Analysis of within-plant distribution of aphids showed that untreated mid-season populations were concentrated in the lower and middle strata of the plant. The currently used presence-absence sampling on terminal leaves appeared to be inadequate because of fluctuating infestation levels on upper plant parts with regard to insecticide treatments and season. The precision of mean estimates could be improved when tally thresholds for binomial counts were different from $T=0$ and only main stem leaves were taken into account. There was no evidence for impact of aphids on yield and the presently advocated action threshold of 15 % infested leaves is likely to be an over-estimation of the economic importance of *A. gossypii* in Malagasy cotton.

3.2. Introduction

Since the late 1980s, the cotton aphid *Aphis gossypii* Glover (Hom.: Aphididae) is considered an important cotton pest in Madagascar (H. Rakotofiringa, HASYMA, pers. comm.). If infestation is substantial, early and mid-season populations may cause leaf curl and reduce plant productivity through feeding and production of honeydew. The honeydew is a nutrient source for contaminating fungi which block sunlight and impede the photosynthesis of the leaves. End of season aphids are, together with infestations of *Bemisia tabaci* Gennadius (Hom.: Aleyrodidae), responsible for the "stickiness" of fibres which cause serious problems during the

milling process (Slosser et al. 1989). The increasing importance of *A. gossypii*, especially in the intensive receding flood cropping system in north-western Madagascar, has been linked to the routine use of synthetic pyrethroids, introduced in 1979-80 against the economically important carphagous caterpillars *Helicoverpa armigera* Hübner and *Earias* spp. (both Lep.: Noctuidae). Outbreaks of the pyrethroid-resistant Egyptian cotton leaf worm *Spodoptera littoralis* Boisduval (Lep.: Noctuidae) in the mid-80s prompted many growers to resort to even more frequent and overdosed insecticide treatments, hereby suppressing the aphids' predator populations (Dove 1994b). There are many reports on resistance of *A. gossypii* against pyrethroids and other classes of insecticides (Kerns and Gaylor 1992, Gubran et al. 1993, Hollingsworth et al. 1994). Some products were even reported to favour the reproduction of the pest and to set off outbreaks in cotton (Kerns and Gaylor 1991, Kidd and Rummel 1997). In Madagascar, cotton aphids cannot be controlled with pyrethroids, thiodicarb or endosulfan, which are the commonly used insecticides to control bollworms (Andriambololona et al. 1989).

No detailed study has yet been carried out on the seasonal dynamics of cotton aphid populations in Madagascar. Likewise, no reliable sampling procedure has been developed for *A. gossypii* in Malagasy cotton. A presence-absence sampling scheme on the terminal leaves has been adopted from francophone Africa (Denechère 1981), but the applicability of this method for the local conditions in Madagascar has never been evaluated.

The objectives of this study were to assess seasonal population dynamics and the within-plant distribution of *A. gossypii* and to deduce an appropriate sampling procedure for this pest in Malagasy cotton.

3.3. Materials and methods

Field works were conducted at two different sites during the 1996-97 and 1997-98 cropping seasons.

Ampasikibo:

The site in the rainfed region in south-western Madagascar was located at the PAP (Point d'Appui de la Prévulgarisation) in Ampasikibo in the community of Analamisampy, Toliara region, a field research station of the national cotton company HASYMA.

In 1997, the experimental design was a randomised complete block consisting of two treatments («ST» and «NT») and four replications. The plots comprised of 38 rows of 26 m length with an inter-row distance of approximately 73 cm, resulting in plot sizes of about 720 m². In order to minimise migration of insects between plots, 12 rows corresponding to 8.5-9 m were discarded to make alleys sufficiently broad.

In 1998, two plots had to be suppressed due to labour shortages.

Table 1 resumes the main agronomic practices during these two years.

Table 1. Cultural techniques at the Ampasikibo experimental site

	1996-97	1997-98
fertilisation with 150 kg/ha ammonium phosphate (27 kg N + 67.5 kg P ₂ O ₅)	11.12.96	11.12.97
dry labour with tractor	11.12	11.12
ridging (mechanised)	12.12	12.12
sowing (Upland variety D 388/8 M)	12.12	13.12
pre-emergence herbicide application with COTOGARD (1000 g a.i./ha fluometuron and 1000 g a.i./ha prometryn)	24.12	26.12
emergence	29.12	30.12
first manual weeding	14.01.97	13.01.98
thinning to one plant per pocket (theoretical density 44,400 plants/ha)	14.01	14.01
fertilisation with 100 kg/ha urea (46 kg N)	25.01	25.01
second manual weeding	04.02	27.01
third manual weeding	23.02	04.03
first harvest	02.05	02.05
second harvest	28.05	28.05

In the «ST» treatment, plots were sprayed with synthetic insecticides. In 1997, this was carried out in accordance to HASYMA's locally recommended calendar spraying schedule independently of pest densities ("standard"). There was a two-day interval between an insecticide treatment and the following sampling date. The following year, the plots were only sprayed when HASYMA's thresholds for one of the main pests *H. armigera*, *S. littoralis* or *A. gossypii* were exceeded. The threshold densities for *H. armigera* and *S. littoralis* are 5,000 and 10,000 larvae per ha, respectively. With a theoretical planting density of 44,400 plants/ha, this corresponds to 0.113 and 0.225 larvae pro plant. The threshold for *A. gossypii* is 15 % infested leaves between 40 and 100 d.a.e. (days after emergence) and 30 % beyond this period. The infestation is assessed on the five terminal leaves. Three days prior to sampling, pest densities were checked independently for management decisions on 20 randomly chosen plants per plot. When a threshold level had been exceeded, treatments were carried out the following day with an ULVA+ spinning disc hand sprayer at a rate of 10 l water solution per ha.

The «NT» plots were not treated. Table 2 resumes the insecticide applications in «ST» which were carried out during the two seasons in Ampasikibo.

Table 2. Insecticide treatments (g a.i./ha), Ampasikibo

1997	27.01	endosulfan (800)
	10.02	thiodicarb (400)
	24.02	cypermethrin (60) + monocrotophos (200)
	10.03	profenofos (800)
	24.03	thiodicarb (400)
	14.04	cypermethrin (60) + monocrotophos (200)
1998	18.02	cypermethrin (60) + monocrotophos (200)
	24.02	chlorpyriphos-ethyl (720)
	10.03	thiodicarb (400)
	17.03	cypermethrin (60)
	24.03	monocrotophos (300)
	31.03	monocrotophos (300)
	14.04	cypermethrin (60) + monocrotophos (200)
	21.04	cypermethrin (60) + monocrotophos (200)

Ambato-Boeni:

Ambato-Boeni is situated in the north-west of Madagascar in the Mahajanga region where cotton is planted on alluvial deposits at the start of the dry season.

The 1997 trial was conducted at the local Point d'Appui de la Prévulgarisation (PAP) of HASYMA. The trial was laid out as a randomised complete block with two treatments, «ST» and «NT», and three replications. The plots comprised of 44 rows of 30 m length with an inter-row distance of approximately 90 cm, resulting in plot sizes of about 1,200 m². Twelve rows corresponding to 9.5-10 m were discarded to create broad alleys between the plots.

In 1998, the experimental site had to be moved to a private farmer's field for logistic reasons. Because of the smaller space available, plot size had to be limited to 18 rows of 22 m length with an inter-row distance of approximately 75 cm, resulting in plot sizes of about 300 m². In order to partly compensate for smaller plot sizes, the two treatments were replicated six times.

Table 3 lists the agronomic interventions during the two seasons.

Similarly to the trial in the south-west, «ST» plots were treated with insecticides according to the official calendar scheme in the first year, but in compliance with HASYMA's thresholds in 1998. A two-days interval between a treatment and the next sampling was generally respected in both years. Thresholds of the noctuid pests are numerically the same in both regions, but may diverge on a plant-to-plant level if plant densities are different. Supposing a stand of 53,300 plants/ha, a density of 5,000

Table 3. Cultural techniques at the Ambato-Boeni experimental site

	1997	1998
labour	10.04 (mechanised)	23.-27.04 (animal traction)
pulverisation of soil	10.04 (mechanised)	—
harrowing	10.04 (mechanised)	23.-27.04 (animal traction)
fertilisation with 167.5 kg/ha urea + 100 kg/ha potassium sulfate + 5.3 kg/ha boracine (77 kg N + 50 kg K ₂ O + 18 kg S + 2.4 kg B ₂ O ₃)	11.04 (mechanised)	—
fertilisation with 150 kg/ha urea + 100 kg/ha potassium sulfate + 6 kg/ha boracine (69 kg N + 50 kg K ₂ O + 18 kg S + 2.8 kg B ₂ O ₃)	—	25.04-02.05
sowing (emergence 4-5 days later)	11.04 (mechanised)	25.04-02.05
thinning to one plant per pocket (theoretical density 44,400 and 53,300 plants/ha, respectively)	27.04	20.-26.05
fertilisation with 82.5 kg/ha urea + 50 kg/ha potassium sulfate + 2.7 kg/ha boracine (38 kg N + 25 kg K ₂ O + 9 kg S + 1.2 kg B ₂ O ₃)	22.-23.04 (mechanised)	—
first manual weeding	23.04	12.-14.06
second manual weeding	21.07	14.07.
first harvest	09.-10.09	28.09
second harvest	25.-27.09	10.10.

larvae of *H. armigera* and 10,000 larvae of *S. littoralis*/ha corresponds to 0.094 and 0.188 larvae/plant, respectively. The threshold for *A. gossypii* is 15 % infested terminal leaves until 90 d.a.p. (days after planting) and 20 % during the remaining period. Aphid infestation is determined on the four terminal leaves. Since the sampling interval for research purposes in most cases did not exceed four days, the results were also used for spraying decisions and no separate sampling was carried out for pest management. In accordance to common practice, a 15 l knapsack sprayer was used at a rate of 100 l water solution per ha.

Table 4. Insecticide treatments (g a.i./ha), Ambato-Boeni

1997	20.05	endosulfan (800)
	28.05	thiodicarb (400)
	06.06	thiodicarb (400) + monocrotophos (200)
	17.06	cypermethrin (60)
	10.07	monocrotophos (300)
	22.07	thiodicarb (400)
	01.08	thiodicarb (400)
	15.08	monocrotophos (300)
1998	28.06	monocrotophos (300)
	13.07	cypermethrin (60)
	26.07	cypermethrin (60)
	06.08	benfuracarb (250) + thiodicarb (400)
	05.09	benfuracarb (250)

No insecticide treatments were carried out in «NT» plots. Table 4 resumes the insecticide applications during the two seasons in Ambato-Boeni.

In 1997, sampling started in Ampasikibo on January 22 and continued weekly until April 30. In Ambato-Boeni, samples were generally taken every six days from May 22 to August 30. Since the spatial distribution of the aphids on the cotton plants was not known, it was necessary to take whole plant samples during the first year.

Infestation of *A. gossypii* was estimated by density scores, where

- 1 = 1
- 2 = 2 - 4
- 3 = 5 - 9
- 4 = 10 - 19
- 5 = 20 - 49
- 6 = 50 - 99
- 7 = 100 - 299
- 8 = 300 - 999
- 9 = 1000-3000 aphids.

Aphid densities were estimated for all sympodial fruiting branches of 20 randomly selected plants per plot. Colonisation of the fields by aphids only started in the course of the squaring period. Hence, infestations of the basal vegetative branches were of no importance and omitted from analysis. The medians of the density intervals were divided by the number of leaves on the fruiting branches which provided a density estimation of *A. gossypii* per leaf for each branch. Considering the horizontal and vertical plant growth in the course of the season and the natural variability within the samples, the most meaningful pooling of sampling units for statistical analysis was to divide the plants vertically in an inferior, a median and a superior stratum. For treated («ST») and untreated plots («NT») independently, ranked strata means were submitted to analysis of variance and separated by means of Bonferroni's adjustment for multiple comparisons. Differences of whole-plant means between «ST» and «NT» plots were examined with a two-sided t-test for independent samples.

In order to evaluate possible heterogeneities within the strata, the mean of the lowest fruiting branch, the mean of a randomly chosen branch in the middle stratum and the mean of the two terminal branches were compared with the mean of the remainder of their stratum. The infestation on the two terminal branches were of special interest, because these roughly correspond to the sampling unit for binomial counts currently used in Malagasy cotton. Differences of means were tested against zero with a two-sided one sample t-test.

All other relevant species, i.e., pests, aphid predators and other beneficial arthropods were counted individually on the whole plant at both sites in both years.

In order to evaluate the relationship between binomial counts of aphids on terminal leaves and the mean density per plant, the model of Gerrard and Chiang (1970) was used to relate the proportion of empty sampling units (pT) to the mean (\bar{X}):

$$[1] \ln \bar{X} = a + b \ln\{-\ln(pT)\}$$

where a and b are constants.

The anti-logarithmic form of [1] yields (Nachmann 1984, Binns and Bostonian 1990):

$$[2] \bar{X} = e^a \cdot \{-\ln(pT)\}^b$$

Proportions of empty sampling units were obtained by simple presence-absence sampling of aphids on the five terminal leaves. For each sampling date, means per plant and proportions were calculated separately for «ST» and «NT».

Analysis of the 1997 data set showed that it would not be necessary to examine more than a single sample unit per stratum to obtain a sufficiently precise estimate of the global mean. However, it had previously been noticed that main stem leaves are consistently heavier infested than any other leaves on the branch and that density counts may be biased if only one of these two categories of leaves is considered. Thus, during the 1998 growing season, *A. gossypii* was counted individually on the following six leaves:

- the main stem leaf and another arbitrarily selected leaf of the lowest fruiting branch;
- the main stem leaf and another arbitrarily selected leaf of a randomly chosen fruiting branch in the median stratum;
- the main stem leaf and the second leaf of the terminal fruiting branch.

In Ampasikibo, sampling started on February 5 and continued in weekly intervals on 20 randomly selected plants until April 30. Ten plants per plot were selected in Ambato-Boeni, and sampling continued every four (or five) days from June 15 to September 12.

Cumulative aphid indices which consider both the intensity and the duration of aphid infestation, were expressed in “aphid-days” according to the formula of Wratten et al. (1979):

$$[3] I = \sum_{n=1}^{n=k-1} \frac{t_n (X_n + X_{n+1})}{2}$$

where k is the number of sampling occasions, t_n is the number of days between two sampling occasions, X_n is the aphid density on sampling occasion n , and X_{n+1} is the aphid density on sampling occasion X_{n+1} .

For the 1998 data sets, the relationships between aphid densities as dependent variable and predator numbers, number of aphids killed by entomopathogenic fungus and rainfall as independent variables, were evaluated by using the following multiple regression model:

$$[4] Y = a + b_1 X_1 + b_2 X_2 + b_3 X_3$$

where Y is the mean density of aphids per six leaves, X_1 is the number of aphid predators per plant, X_2 is the mean density of dead aphids with visible mycosis per six leaves and X_3 is the average rainfall in mm during the three days preceding each sampling date. Regression equations were developed separately for «ST» and «NT» plots ($N = 13$ for Ampasikibo data, $N = 22$ for Ambato-Boeni data). Since there is almost no rainfall in dry season cotton in north-western Madagascar, the third independent variable, i.e., X_3 , was omitted from the regression model for Ambato-Boeni.

The relationship between the mean and the proportion of empty sampling units was evaluated by plotting the mean of complete counts on six leaves against proportions of empty sampling units on the terminal leaves. Moreover, pT in equation [1] was extended to represent different tally thresholds T , which are defined as the maximal number of individuals which may appear in a sample to be considered empty (Zhang et al. 1998). Complete counts were transformed to binomial values with tally thresholds of $T = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 15$ and 20 for each of the six leaves, respectively. The correlation of the mean with pT was examined for the six leaves individually, for the pooled main stem leaves, and for the global mean. Mean-proportion pairs were calculated separately for «ST» and «NT» for each sampling date and pooled for the curve fitting.

The empirical relationship between the variance and the mean described by Taylor (1961) was used to study the spatial distribution of *A. gossypii*:

$$[5] \log(s^2) = \log a + b \cdot \log(\bar{X})$$

where the intercept a is a parameter which depends on the sample method and the slope b is the “index of aggregation” which varies continuously from $b < 1$ for a regular distribution, to random for $b = 1$, to clumped for $b > 1$ (Taylor 1961).

Taylor’s parameters were also used to calculate the optimum sample size for complete counts. Wilson and Room (1983) incorporated Taylor’s power law into Karandino’s (1976) general sample size equation:

$$[6] n = (Z_{\alpha/2} / D)^2 \cdot a \cdot \bar{x}^{b-2}$$

where $Z_{\alpha/2}$ is the standard normal deviate for a two-tailed confidence interval at a given α level (0.05), D is the precision as a fixed proportion of the mean (set at 0.25), and a and b are the parameters of Taylor’s power law.

Numbers of intact bolls and plant height were determined at the season’s last sampling occasion. Simple regression of cotton yield on numbers of intact bolls and on plant height provided a simple estimation of the relative importance of boll and leaf-feeding pests, respectively, for yield. Yields per plot were compared with the mid-p point approach (Lancaster 1961) for an exact Mann-Whitney test (SAS Institute Inc. 1996):

$$P(U_{stat} \geq u_{tab}) = P(U_{stat} > u_{tab}) + \frac{1}{2} P(U_{stat} = u_{tab})$$

where U_{stat} is the test statistic and u_{tab} is the critical value $u_{0.05(2),n1+n2}$ of the U distribution.

3.4. Results

Seasonal population dynamics

Seasonal population dynamics of *A. gossypii* were markedly different with regard to treatments and regions. In Ampasikibo (referred to in the following as the southwestern site), the aphids in «ST» plots were efficiently kept in check by the first aphicidal treatment with monocrotophos, and the mean density never exceeded 10 individuals per leaf at any time of the season (table 5 and 6, fig. 2 and 6). In «NT» plots, the aphid populations grew exponentially during the two weeks preceding their peak, which were observed during bloom at 60 (1997) and 52 (1998) d.a.e., respectively. In both years, peaks were succeeded by an equally rapid decline. In 1997, the infestation did not reach high levels (39 aphids per leaf on February 26), and the peak was ephemeral (fig. 1). The following year, peak numbers were twice as high (79 individuals per leaf), but densities were again very low during the boll maturation phase in April (fig 5).

In Ambato-Boeni (referred to in the following as the north-western site), population growth after the initial colonisation was slower than in the south-west (table 5 and 6). This was probably due to lower average temperatures in the austral winter (2-3°C lower in June in the north-west than in February in the south-west). In untreated plots, maximum densities exceeded 100 aphids/leaf in both years (fig. 3 and 7). Only during the second year of the study, a second albeit smaller peak was recorded in the «NT» plots.

**Table 5. Ampasikibo and Ambato-Boeni 1997:
means and aphid-days of *A. gossypii* populations per plant
(based on estimations of number of individuals per fruiting branch, adjusted per leaf)**

date	means in untreated plots (NT)	aphid-days in untreated plots (NT)	means in insecticide treated plots (ST)	aphid-days in treated plots (ST)	significance of the t-test $\bar{X}_{(NT)} = \bar{X}_{(ST)}$
Ampasikibo:					
22.01.1997	0.0	0.0	0.0	0.0	-
29.01.	0.0	0.0	0.0	0.0	-
05.02.	0.0	0.0	0.0	0.0	-
12.02.	0.0	0.0	0.1	0.4	0.284
19.02.	0.8	2.8	3.4	12.6	0.089
26.02.	39.3	143.2	2.3	32.6	<0.001**
05.03.	26.5	373.5	7.0	65.1	<0.001**
12.03.	4.9	483.4	0.8	92.4	<0.001**
19.03.	2.1	507.9	0.7	97.7	<0.001**
26.03.	1.9	521.9	2.7	109.6	0.107
02.04.	3.6	541.1	3.2	130.2	0.423
09.04.	3.7	566.7	2.6	150.5	0.024*
16.04.	3.5	591.9	0.9	162.8	0.002**
23.04.	1.9	610.8	0.9	169.1	0.020*
30.04.	0.8	620.2	1.5	177.5	0.059
Ambato-Boeni:					
22.05.1997	0.0	0.0	0.0	0.0	0.067
28.05.	0.1	0.3	0.0	0.0	0.078
03.06.	0.2	1.2	0.0	0.0	0.001**
09.06.	0.3	2.7	0.1	0.3	0.001**
15.06.	0.9	6.3	0.9	3.3	0.736
19.06.	1.5	11.1	6.9	18.9	0.001**
25.06.	13.3	55.5	110.6	371.4	<0.001**
01.07.	39.3	213.3	314.3	1646.1	<0.001**
07.07.	100.0	631.2	394.7	3773.1	<0.001**
12.07.	135.8	1220.7	168.4	5180.9	0.075
18.07.	29.9	1717.8	91.2	5959.7	<0.001**
24.07.	1.0	1810.5	82.3	6480.2	<0.001**
30.07.	1.0	1816.5	115.7	7074.2	<0.001**
05.08.	0.8	1821.9	75.0	7646.3	<0.001**
11.08.	0.8	1826.7	56.2	8039.9	<0.001**
17.08.	0.7	1831.2	41.5	8333.0	<0.001**
23.08.	0.6	1835.1	8.7	8483.6	<0.001**
30.08.	0.4	1838.6	4.8	8530.8	<0.001**

* significant at $\alpha = 0.05$ ** significant at $\alpha = 0.01$

The seasonal development of *A. gossypii* populations in the insecticide treated plots in Ambato-Boeni was dramatically different from the dynamics of those in the south-

west. Both in 1997 and 1998, the infestation was more severe in sprayed plots than in the control (fig. 4 and 8). In the first year, densities began to increase rapidly after a cypermethrin treatment on June 17 and rose to almost 400 individuals per leaf on July 7, a fourfold higher number as in «NT» where aphids peaked five days later. After the peak, average numbers remained above 50 aphids per leaf during more than six weeks and provoked considerable contamination with sticky honeydew and sooty mould which also affected fibres when on average 4-6 bolls had opened by mid-August.

**Table 6. Ampasikibo and Ambato-Boeni 1998:
means and aphid-days of *A. gossypii* populations per plant
(based on means of complete counts on six leaves)**

date	means in untreated plots (NT)	aphid-days in untreated plots (NT)	means in insecticide treated plots (ST)	aphid-days in treated plots (ST)	significance of the t-test $\bar{X}_{(NT)} = \bar{X}_{(ST)}$
(Ampasikibo)					
05.02.1998	2.4	0.0	1.4	0.0	0.126
12.02.	16.1	64.8	9.8	39.2	0.074
19.02.	79.0	397.6	4.4	88.9	<0.001**
26.02.	59.3	881.7	1.1	108.2	<0.001**
05.03.	32.6	1203.3	2.2	119.7	<0.001**
12.03.	17.6	1379.0	2.3	135.5	<0.001**
19.03.	12.2	1483.3	3.5	155.8	<0.001**
26.03.	7.3	1551.6	1.9	174.7	<0.001**
02.04.	2.8	1586.9	2.0	188.3	0.829
09.04.	2.3	1604.8	3.3	206.9	0.003**
16.04.	2.6	1621.9	4.0	232.4	0.003**
23.04.	1.1	1634.9	3.4	258.3	0.002**
30.04.	2.2	1646.4	5.2	288.4	0.047*
(Ambato-Boeni)					
15.06.1998	31.1	31.1	22.4	22.4	0.135
20.06.	47.9	197.5	49.0	178.5	0.887
25.06.	79.4	515.8	70.4	477.0	0.425
29.06.	110.4	895.4	44.7	707.2	<0.001**
03.07.	84.4	1285.0	32.8	862.2	0.001**
07.07.	29.3	1512.4	18.1	964.0	0.071
11.07.	4.5	1580.0	13.4	1027.0	0.001**
15.07.	2.1	1593.2	7.9	1069.6	0.004**
19.07.	2.9	1603.2	15.0	1115.4	<0.001**
23.07.	4.1	1617.2	24.2	1193.8	<0.001**
28.07.	9.9	1652.2	52.5	1385.6	<0.001**
01.08.	11.7	1695.4	62.2	1615.0	<0.001**
05.08.	21.4	1761.6	66.6	1872.6	<0.001**
09.08.	27.5	1859.4	43.0	2091.8	0.003**
13.08.	39.3	1993.0	46.3	2270.4	0.371
17.08.	21.7	2115.0	39.3	2441.6	0.004**
22.08.	14.9	2206.5	24.0	2599.8	0.018*
26.08.	8.5	2253.3	26.4	2700.6	<0.001**
30.08.	8.4	2287.1	35.8	2825.0	<0.001**
03.09.	8.3	2320.5	41.1	2978.8	<0.001**
07.09.	6.7	2350.5	20.5	3102.0	<0.001**
12.09.	3.0	2374.7	6.0	3168.3	0.004**

* significant at $\alpha = 0.05$ ** significant at $\alpha = 0.01$

The trophic injury was reflected by the stunting of the cotton plants, whose growth was inhibited from early July onwards. At the last sampling date, «ST» plants were 15.9 (\pm 3.5 SE) cm smaller than «NT» plants (table 19).

In 1998, the first peak at flowering in «ST» plots was below densities in «NT», but as in the year before, the population recovered quickly from an intermediate depression in mid-July and re-established on a plateau beyond 40 individuals per leaf (i.e., the mean density from July 28 to September 7), which was significantly higher than in

Table 7. Ampasikibo 1997: within-plant distribution of *A. gossypii* populations in untreated «NT» plots (estimations of number of individuals per fruiting branch, adjusted per leaf)

date	inferior stratum	median stratum	superior stratum
22.01	0.0 a	0.0 a	0.0 a
29.02	0.0 a	0.0 a	0.0 a
05.02	0.0 a	0.0 a	0.0 a
12.02	0.0 a	0.1 a	0.0 a
19.02	1.1 b	1.0 b	0.1 a
26.02	41.5 b	45.4 b	31.0 a
05.03	27.9 a	28.2 a	23.4 a
12.03	5.7 a	4.8 a	4.3 a
19.03	2.0 a	2.0 a	2.3 a
26.03	0.9 a	1.9 a	2.9 b
02.04	3.2 ab	3.1 a	4.6 b
09.04	2.0 a	3.4 b	5.8 c
16.04	2.1 a	3.7 b	4.7 b
23.04	1.2 a	1.6 a	2.9 a
30.04	1.0 a	0.8 a	0.5 a

Treatments within rows followed by the same letter are not significantly different ($P>0.05$, Bonferromi's adjustment of ranked values)

Table 8. Ampasikibo 1997: within-plant distribution of *A. gossypii* populations in insecticide treated «ST» plots (estimations of number of individuals per fruiting branch, adjusted per leaf)

date	inferior stratum	median stratum	superior stratum
22.01	0.0 a	0.0 a	0.0 a
29.02	0.0 a	0.0 a	0.0 a
05.02	0.0 a	0.0 a	0.0 a
12.02	0.2 a	0.1 a	0.0 a
19.02	3.0 a	3.3 a	3.8 a
26.02	2.8 b	2.3 ab	1.9 a
05.03	6.9 a	6.5 a	7.8 a
12.03	0.8 a	0.7 a	0.9 a
19.03	0.3 a	0.5 b	1.4 c
26.03	1.3 a	1.8 a	4.9 b
02.04	1.3 a	2.2 b	6.0 c
09.04	1.6 a	2.1 b	4.1 c
16.04	0.5 a	0.8 ab	1.3 b
23.04	1.0 a	0.6 a	1.2 b
30.04	1.0 a	1.3 ab	2.3 b

Treatments within rows followed by the same letter are not significantly different ($P>0.05$, Bonferromi's adjustment of ranked values)

Table 9. Ambato-Boeni 1997: within-plant distribution of *A. gossypii* populations in untreated «NT» plots (estimations of number of individuals per fruiting branch, adjusted per leaf)

date	inferior stratum	median stratum	superior stratum
22.05	0.0 a	0.0 a	0.0 a
28.05	0.1 a	0.1 a	0.1 a
03.06	0.2 a	0.3 a	0.1 a
09.06	0.4 b	0.3 b	0.1 a
15.06	1.3 b	1.0 b	0.4 a
19.06	2.1 b	1.7 b	0.7 a
25.06	19.8 b	14.3 b	5.8 a
01.07	36.8 a	50.1 b	31.0 a
07.07	97.5 b	116.6 c	86.0 a
12.07	136.3 b	154.3 b	116.7 a
18.07	20.6 a	28.2 a	40.9 b
24.07	0.8 a	1.2 a	0.9 a
30.07	0.7 a	1.1 ab	1.3 b
05.08	0.8 a	0.7 a	0.9 a
11.08	0.7 a	1.0 a	0.9 a
17.08	0.6 a	0.8 a	0.8 a
23.08	0.6 a	0.6 a	0.7 a
30.08	0.4 a	0.4 a	0.3 a

Treatments within rows followed by the same letter are not significantly different ($P>0.05$, Bonferromi's adjustment of ranked values)

Table 10. Ambato-Boeni 1997: within-plant distribution of *A. gossypii* populations in insecticide treated «ST» plots (estimations of number of individuals per fruiting branch, adjusted per leaf)

date	inferior stratum	median stratum	superior stratum
22.05	0.0 a	0.1 a	0.0 a
28.05	0.0 a	0.1 a	0.0 a
03.06	0.0 a	0.0 a	0.0 a
09.06	0.0 a	0.1 a	0.1 a
15.06	0.8 a	0.7 a	1.2 a
19.06	7.0 a	5.6 a	8.1 a
25.06	77.6 a	129.1 a	125.2 a
01.07	260.2 a	358.2 b	324.4 ab
07.07	344.9 a	428.2 a	410.8 a
12.07	182.6 b	204.6 b	117.9 a
18.07	118.2 b	103.7 b	51.8 a
24.07	113.5 b	115.3 b	18.1 a
30.07	121.2 a	133.0 a	92.9 a
05.08	73.9 a	87.3 a	63.9 a
11.08	55.8 a	64.8 a	48.1 a
17.08	54.2 a	32.2 a	37.9 a
23.08	8.5 a	8.6 a	9.2 a
30.08	4.5 a	3.8 a	6.1 a

Treatments within rows followed by the same letter are not significantly different ($P>0.05$, Bonferromi's adjustment of ranked values)

untreated plots (table 6).

Strikingly, this new increase coincided with two cypermethrin treatments on July 13 and 26 (table 2). When season-pooled numbers are compared with the aphid indices I of equation [3], overall infestation was again higher in «ST» than in «NT» (3168 to 2375 aphid-days).

Table 11. Ampasikibo 1998: within-plant distribution of *A. gossypii* populations in untreated «NT» plots (complete counts on two pooled leaves)

date	inferior stratum	median stratum	superior stratum
05.02	3.2 b	2.4 ab	1.7 a
12.02	25.0 c	14.5 b	8.7 a
19.02	106.0 b	82.9 b	48.2 a
26.02	82.1 b	68.7 b	27.2 a
05.03	35.3 b	41.2 b	21.4 a
12.03	16.8 a	22.0 b	14.1 a
19.03	9.3 a	10.7 a	16.5 b
26.03	4.6 a	8.0 ab	9.3 b
02.04	1.4 a	3.5 ab	3.6 b
09.04	1.0 a	2.5 b	3.3 b
16.04	2.2 a	3.4 a	2.1 a
23.04	1.0 a	0.7 a	1.8 a
30.04	1.7 a	2.5 a	2.5 a

Treatments within rows followed by the same letter are not significantly different ($P>0.05$, Bonferromi's adjustment of ranked values)

Table 12. Ampasikibo 1998: within-plant distribution of *A. gossypii* populations in insecticide treated «ST» plots (complete counts on two pooled leaves)

date	inferior stratum	median stratum	superior stratum
05.02	1.8 a	1.1 a	1.1 a
12.02	12.2 b	9.2 ab	8.1 a
19.02	3.9 a	4.7 a	4.7 a
26.02	0.9 a	1.1 a	1.3 a
05.03	1.5 a	2.6 a	2.5 a
12.03	1.7 a	2.5 a	2.7 a
19.03	2.8 a	2.9 a	4.8 a
26.03	1.7 a	1.7 a	2.2 a
02.04	2.6 b	2.0 ab	1.2 a
09.04	2.3 a	3.6 a	3.9 a
16.04	2.0 a	4.3 ab	5.6 b
23.04	2.6 a	3.1 ab	4.4 b
30.04	3.4 a	3.8 a	8.3 a

Treatments within rows followed by the same letter are not significantly different ($P>0.05$, Bonferromi's adjustment of ranked values)

Table 13. Ampasikibo 1998: within-plant distribution of *A. gossypii* populations in untreated «NT» plots

date	inferior mean stem leaf	other inferior leaf	median main stem leaf	other median leaf	superior main stem leaf	other superior leaf
05.02	1.3 a	5.2 b	2.0 ab	2.8 b	2.4 b	1.1 ab
12.02	29.1 b	21.0 b	21.8 b	7.3 a	9.7 a	7.8 a
19.02	139.8 e	72.1 c	119.8 d	45.9 a	46.2 ab	50.2 b
26.02	116.0 d	48.2 c	107.3 d	30.1 b	32.2 b	22.3 a
05.03	42.8 c	27.9 b	55.7 d	26.6 b	33.3 bc	9.5 a
12.03	14.2 a	19.3 b	22.1 b	22.0 b	13.5 a	14.8 a
19.03	10.5 a	8.0 a	10.8 a	10.7 a	27.3 b	5.7 a
26.03	4.7 a	4.4 a	7.8 a	8.2 ab	5.0 a	13.5 b
02.04	1.4 a	1.4 a	4.7 a	2.3 a	3.7 a	3.5 a
09.04	1.1 a	0.9 a	2.2 ab	2.9 ab	3.3 b	3.3 ab
16.04	2.8 a	1.6 a	3.2 a	3.6 a	1.7 a	2.5 a
23.04	0.6 a	1.4 a	1.0 a	0.3 a	2.0 a	1.5 a
30.04	1.7 a	1.8 a	3.3 a	1.7 a	2.0 a	2.9 a

Treatments within rows followed by the same letter are not significantly different ($P>0.05$, Tukey's test of ranked values)

Table 14. Ampasikibo 1998:
within-plant distribution of *A. gossypii* populations in insecticide treated «ST» plots

date	inferior mean stem leaf	other inferior leaf	median main stem leaf	other median leaf	superior main stem leaf	other superior leaf
05.02	2.3 b	1.3 ab	1.1 ab	1.2 ab	1.5 b	0.7 a
12.02	13.5 b	10.9 b	11.0 ab	7.3 a	10.1 ab	6.2 a
19.02	4.7 a	3.1 a	5.4 a	4.0 a	5.1 a	4.4 a
26.02	0.7 a	1.1 a	1.3 a	0.9 a	1.4 a	1.3 a
05.03	2.0 ab	1.0 a	3.1 b	2.3 ab	2.3 a	2.8 ab
12.03	2.6 b	0.9 a	2.5 ab	2.4 b	3.8 b	1.6 ab
19.03	1.9 a	3.6 a	2.8 a	2.9 a	6.9 b	2.8 a
26.03	1.3 a	2.1 a	1.5 a	1.9 a	2.2 a	2.2 a
02.04	1.9 a	3.3 a	2.1 a	2.0 a	1.2 a	1.2 a
09.04	2.0 a	2.7 a	3.5 a	3.8 a	3.6 a	4.1 a
16.04	2.1 a	1.9 a	4.7 ab	4.0 a	8.4 b	2.8 a
23.04	2.6 a	2.6 a	2.2 a	4.1 a	5.2 a	3.6 a
30.04	2.9 a	3.9 a	4.5 a	3.0 a	8.9 b	7.8 b

Treatments within rows followed by the same letter are not significantly different ($P>0.05$, Tukey's test of ranked values)

Table 15. Ambato-Boeni 1998: within-plant distribution of *A. gossypii* populations in untreated «NT» plots (complete counts on two pooled leaves)

date	inferior stratum	median stratum	superior stratum
15.06	41.0 a	26.9 a	25.5 a
20.06	59.1 b	51.3 ab	33.2 a
25.06	93.5 b	84.4 b	59.8 a
29.06	106.1 ab	140.2 b	84.9 a
03.07	81.4 a	84.6 a	87.2 a
07.07	27.3 a	28.8 a	33.2 a
11.07	4.2 a	4.1 a	5.1 a
15.07	2.0 a	2.2 a	2.1 a
19.07	2.6 a	3.5 a	2.6 a
23.07	4.2 a	4.2 a	3.9 a
28.07	13.1 b	10.2 ab	6.5 a
01.08	13.8 a	11.1 a	10.2 a
05.08	24.5 a	22.3 a	17.5 a
09.08	33.3 a	26.8 a	22.5 a
13.08	54.1 b	34.4 a	29.3 a
17.08	22.3 a	23.6 a	19.2 a
22.08	17.7 b	15.7 ab	11.3 a
26.08	9.6 a	8.3 a	7.4 a
30.08	8.7 a	9.3 a	7.1 a
03.09	8.1 a	10.0 a	6.9 a
07.09	9.3 a	5.6 a	5.2 a
12.09	3.8 a	2.4 a	2.8 a

Treatments within rows followed by the same letter are not significantly different ($P>0.05$, Bonferromi's adjustment of ranked values)

Table 16. Ambato-Boeni 1998: within-plant distribution of *A. gossypii* populations in insecticide treated «ST» plots (complete counts on two pooled leaves)

date	inferior stratum	median stratum	superior stratum
15.06	31.4 b	21.7 b	14.2 a
20.06	63.3 b	53.5 b	30.1 a
25.06	82.7 b	88.6 b	40.0 a
29.06	63.0 b	44.0 b	27.0 a
03.07	32.6 ab	44.6 b	21.1 a
07.07	19.6 a	19.6 a	15.2 a
11.07	11.9 a	12.8 a	15.6 a
15.07	4.4 a	10.6 b	8.7 b
19.07	8.9 a	18.2 b	18.1 b
23.07	18.6 a	23.4 b	30.8 b
28.07	47.4 a	60.2 b	49.9 ab
01.08	57.7 a	69.3 a	59.4 a
05.08	72.5 a	66.9 a	60.3 a
09.08	59.2 a	45.5 a	24.3 a
13.08	76.7 c	43.7 b	18.5 a
17.08	62.9 c	36.1 b	19.0 a
22.08	42.5 c	20.3 b	9.3 a
26.08	47.7 c	21.6 b	10.0 a
30.08	51.5 b	39.6 b	16.4 a
03.09	51.3 b	44.5 b	27.6 a
07.09	29.8 b	18.3 a	13.4 a
12.09	6.2 a	5.4 a	6.4 a

Treatments within rows followed by the same letter are not significantly different ($P>0.05$, Bonferromi's adjustment of ranked values)

Table 17. Ambato-Boeni 1998: within-plant distribution of *A. gossypii* populations in untreated «NT» plots

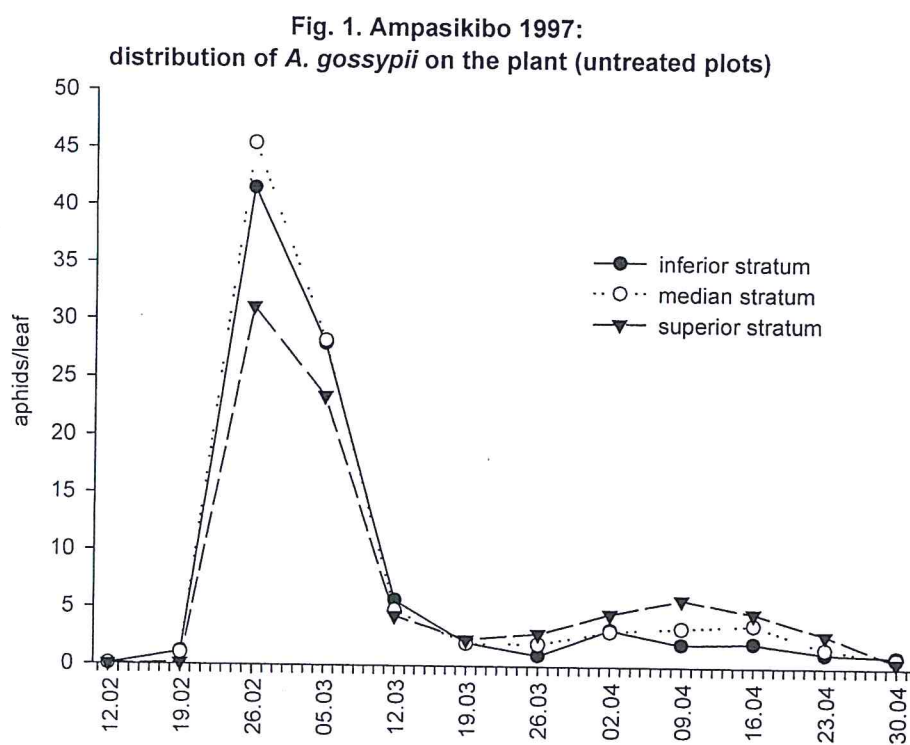
date	inferior mean stem leaf	other inferior leaf	median main stem leaf	other median leaf	superior main stem leaf	other superior leaf
15.06	75.4 c	6.5 a	43.6 b	10.3 a	29.3 b	21.6 ab
20.06	99.2 c	19.1 a	88.5 c	14.2 a	46.9 b	19.5 a
25.06	156.1 c	30.9 a	136.7 c	32.1 a	98.9 b	20.8 a
29.06	164.3 c	47.9 b	232.9 c	47.5 ab	138.8 c	31.0 a
03.07	110.3 b	52.5 a	121.8 b	47.4 a	146.9 b	27.4 a
07.07	40.6 b	13.9 a	40.0 b	17.5 a	51.6 b	14.8 a
11.07	5.9 a	2.5 a	4.6 a	3.6 a	7.2 a	2.9 a
15.07	2.2 a	1.7 a	2.6 a	1.8 a	3.0 a	1.3 a
19.07	2.7 ab	2.5 ab	4.1 b	2.8 ab	3.6 ab	1.6 ab
23.07	5.6 a	2.8 a	4.9 a	3.5 a	5.4 a	2.4 a
28.07	21.5 b	4.8 a	14.0 ab	6.5 a	9.3 a	3.7 a
01.08	19.5 c	8.0 ab	15.5 bc	6.7 a	13.7 b	6.7 a
05.08	38.4 b	10.6 a	27.5 b	17.1 ab	25.1 ab	10.0 a
09.08	52.1 c	14.5 a	33.3 c	20.3 bc	32.2 c	12.9 ab
13.08	84.1 d	24.2 b	48.7 c	20.1 a	39.9 c	18.8 a
17.08	29.9 ab	14.8 a	29.0 b	18.1 a	26.4 ab	12.1 a
22.08	20.8 b	14.5 b	17.5 b	14.0 ab	13.0 a	9.7 a
26.08	12.0 b	7.3 ab	9.7 ab	7.0 ab	9.5 ab	5.4 a
30.08	9.3 ab	8.1 ab	12.6 b	6.0 ab	9.4 b	4.8 a
03.09	9.2 ab	7.0 ab	14.6 b	5.4 ab	9.7 ab	4.2 a
07.09	12.9 a	5.7 a	6.3 a	4.8 a	7.1 a	3.3 a
12.09	4.1 a	3.5 a	2.7 a	2.0 a	3.2 a	2.5 a

Treatments within rows followed by the same letter are not significantly different ($P>0.05$, Tukey's test of ranked values)

Table 18. Ambato-Boeni 1998:
within-plant distribution of *A. gossypii* populations in insecticide treated «ST» plots

date	inferior mean		other inferior		median main		other median		superior main		other superior	
	stem	leaf	leaf	leaf	stem	leaf	leaf	leaf	stem	leaf	leaf	leaf
15.06	56.9	c	6.0	a	38.7	bc	4.7	a	22.7	b	5.8	a
20.06	106.0	c	20.6	a	89.4	c	17.7	a	44.2	b	16.0	a
25.06	136.3	c	29.1	a	147.6	c	29.6	a	59.8	b	20.1	a
29.06	92.7	c	33.3	b	73.3	c	14.8	a	41.2	b	12.7	a
03.07	49.3	b	15.8	a	72.3	c	17.0	a	28.5	ab	13.7	a
07.07	30.6	c	8.6	a	30.1	b	9.2	a	20.8	abc	9.7	a
11.07	16.5	ab	7.2	a	18.5	b	7.1	a	24.4	b	6.8	a
15.07	5.6	a	3.1	a	16.2	b	5.1	a	13.2	b	4.3	a
19.07	11.4	abc	6.3	a	22.4	d	14.0	c	27.3	d	8.9	b
23.07	26.6	b	10.6	a	26.4	bc	20.4	b	48.3	c	13.2	a
28.07	69.1	c	25.7	a	83.6	d	36.9	b	78.6	d	21.2	a
01.08	90.2	b	25.3	a	97.2	b	41.5	a	86.8	b	32.1	a
05.08	107.2	b	37.8	a	87.5	b	46.4	a	87.8	b	32.8	a
09.08	82.7	d	35.7	c	62.5	d	28.5	b	38.0	c	10.6	a
13.08	98.9	d	54.5	c	57.6	c	29.9	b	28.1	b	8.9	a
17.08	81.2	f	44.6	d	55.1	e	17.2	b	28.7	c	9.3	a
22.08	55.3	d	29.8	c	32.4	c	8.3	a	14.8	b	3.7	a
26.08	63.5	d	31.9	c	31.7	c	11.5	ab	15.3	b	4.7	a
30.08	67.4	e	35.7	cd	51.7	d	27.6	bc	26.4	b	6.3	a
03.09	69.9	e	32.8	c	57.4	de	31.6	b	38.3	cd	16.8	a
07.09	39.9	c	19.6	ab	26.1	b	10.4	a	18.1	ab	8.7	a
12.09	6.1	a	6.4	a	5.6	a	5.1	a	7.0	a	5.8	a

Treatments within rows followed by the same letter are not significantly different ($P>0.05$, Tukey's test of ranked values)



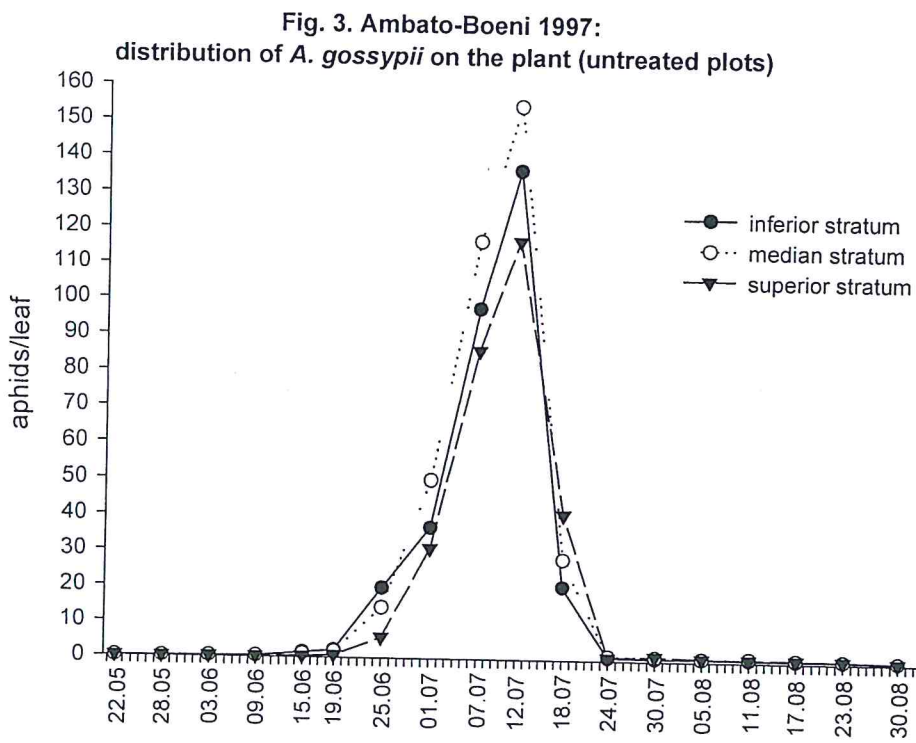
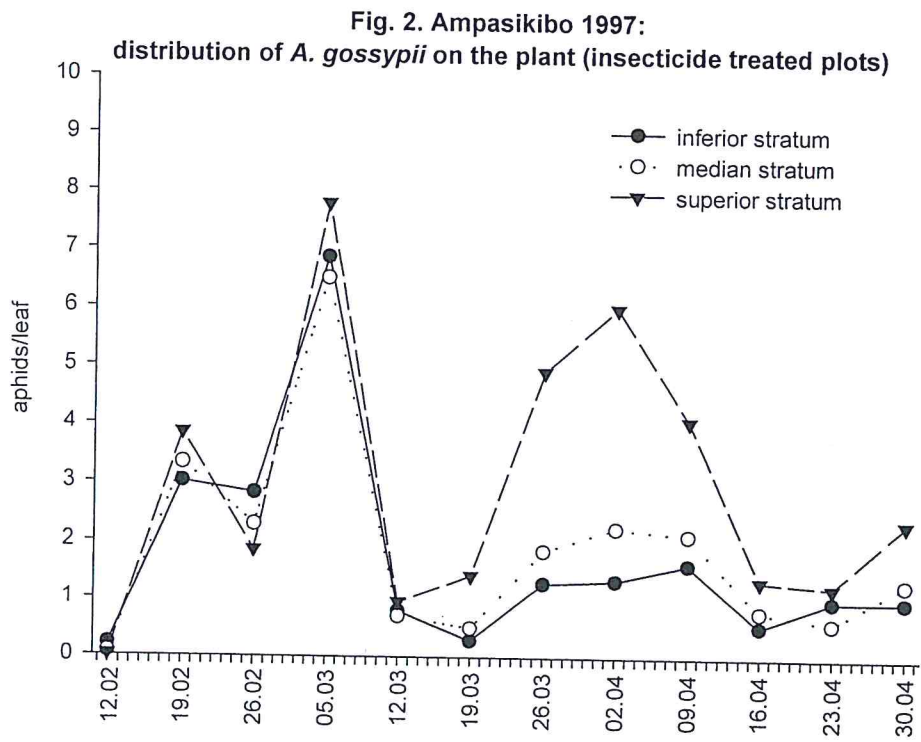


Fig. 4. Ambato-Boeni 1997:
distribution of *A. gossypii* on the plant (insecticide treated plots)

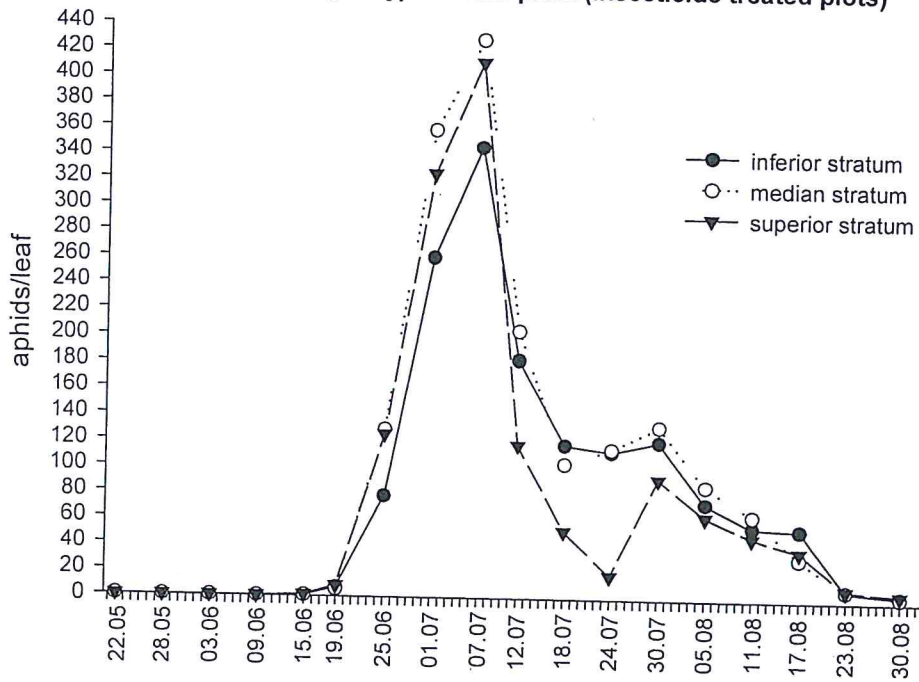


Fig. 5. Ampasikibo 1998:
distribution of *A. gossypii* on the plant (untreated plots)

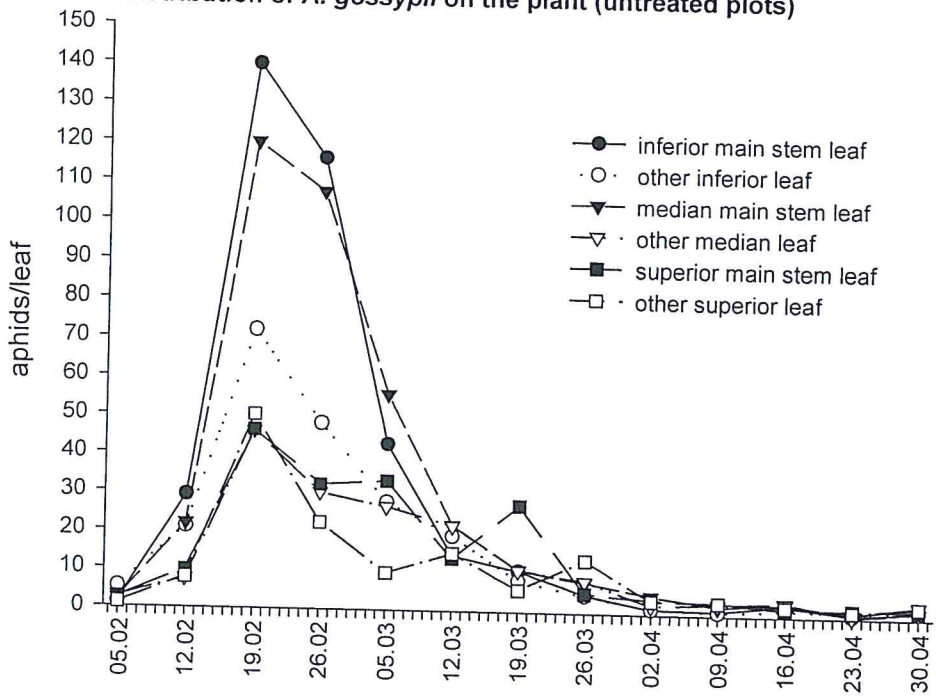


Fig. 6. Ampasikibo 1998:
distribution of *A. gossypii* on the plant (insecticide treated plots)

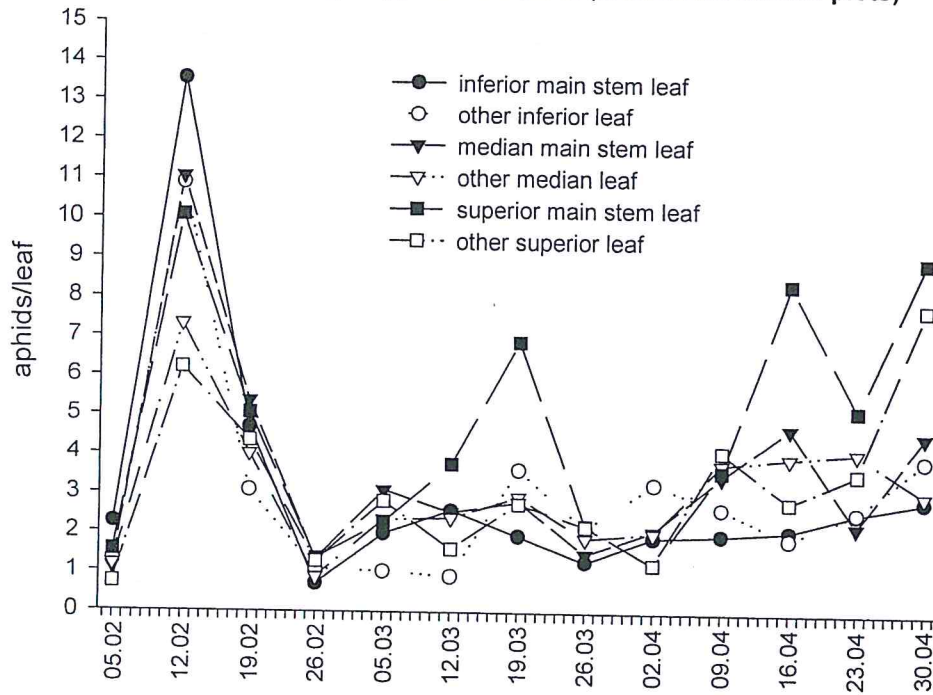
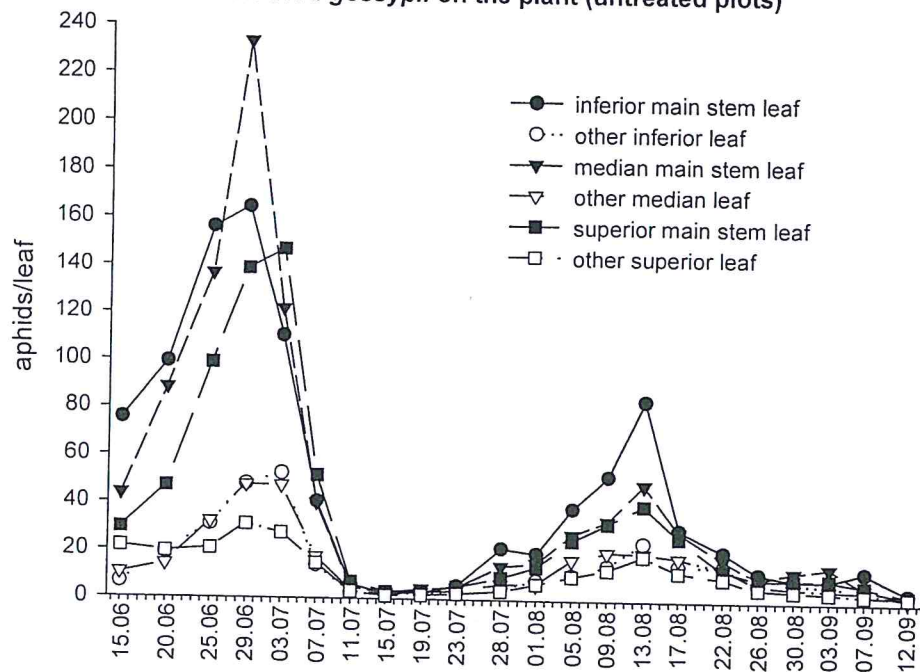
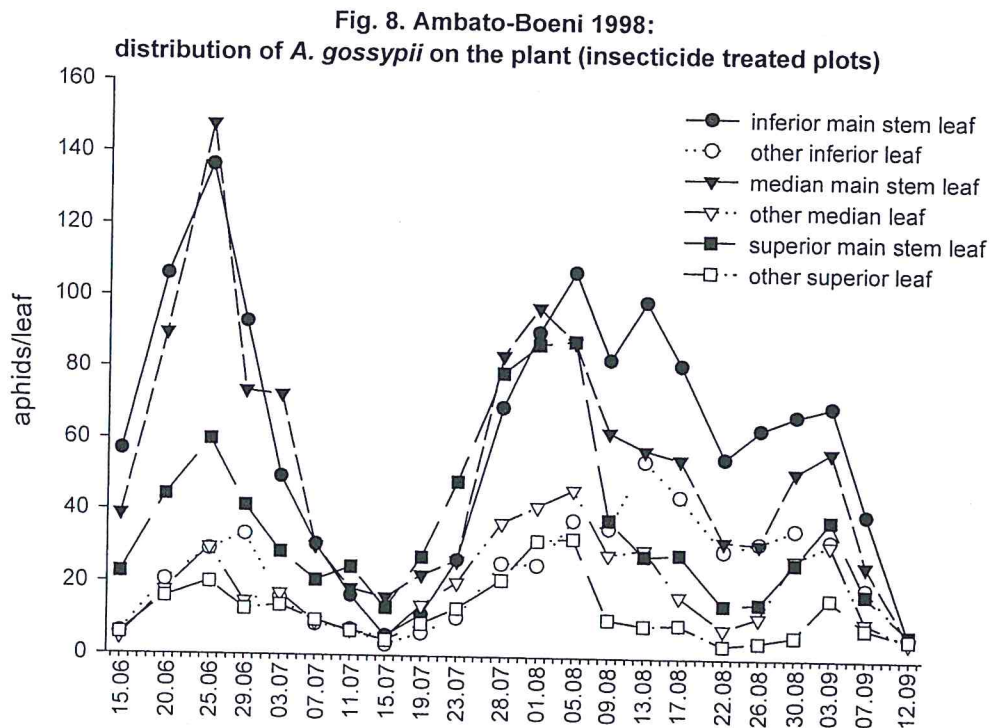


Fig. 7. Ambato-Boeni 1998:
distribution of *A. gossypii* on the plant (untreated plots)





The following species were recorded as aphidophagous predators of *A. gossypii* at both locations.

Coccinellidae:

- *Cheilomenes simulans* Crotch
- *C. sulphurea* Olivier (Vaissayre 1977, Couilloud 1993)
- *Elpis dolens* Mulsant (Vaissayre 1977, Couilloud 1993)
- *Exochomus laeviusculus* Weise (Couilloud 1993)
- *Scymnus constrictus* Mulsant (Vaissayre 1977, Couilloud 1993)

Syrphidae:

- *Ischiodon aegyptius* (Wiedemann) (Vaissayre 1977?)
- *Paragus borbonicus* Macquart (Vaissayre 1977)

Chrysopidae:

- *Mallada desjardinsi* (Navas)

Hemerobiidae:

- *Micromus plagatus* Navas

Predators were far more abundant and better synchronised with their prey in the north-west (fig. 9-12), where *C. simulans* was the dominant species. In the south-west, *S. constrictus* and *I. aegyptius* were the most important beneficials. Peak density of predators lagged two weeks behind the peak density of the prey. In insecticide treated

plots, predators were almost completely absent except in the second year in the beginning of August in the north-west, where *C. simulans* populations in the «ST» even outnumbered densities in «NT». Given the constraint to design smaller plots and narrow alleys at the north-western site in 1998, this phenomenon was possibly due to inter-plot migrations of adult coccinellids which were attracted by abundant prey in «ST» plots after the cypermethrin application on July 26.

Fig. 9. Ampasikibo 1997: population dynamics of aphid predators

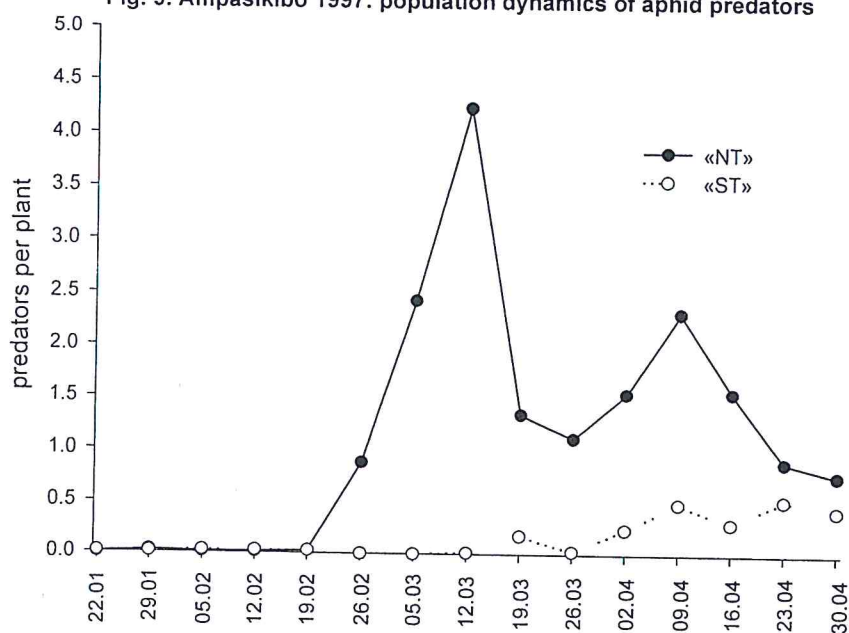


Fig. 10. Ampasikibo 1998: population dynamics of aphid predators

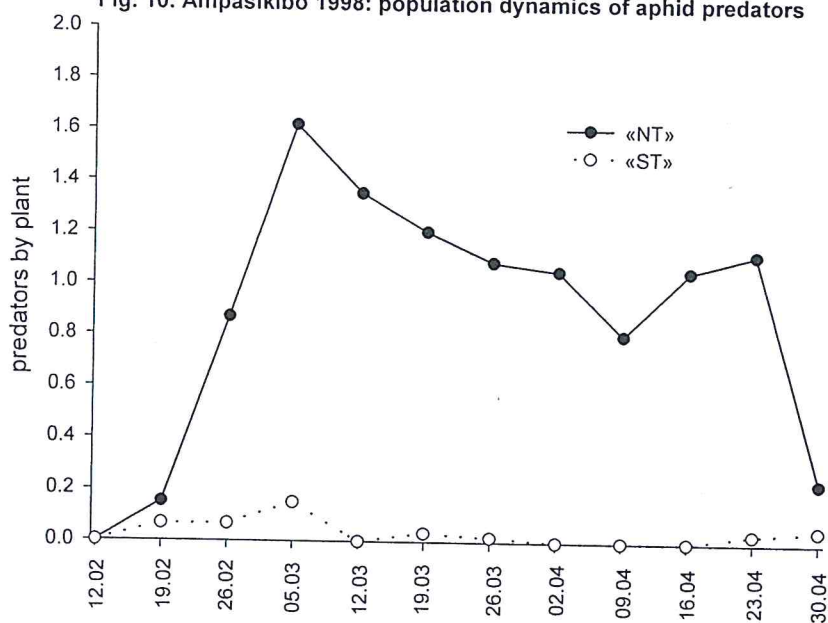


Fig. 11. Ambato-Boeni 1997: population dynamics of aphid predators

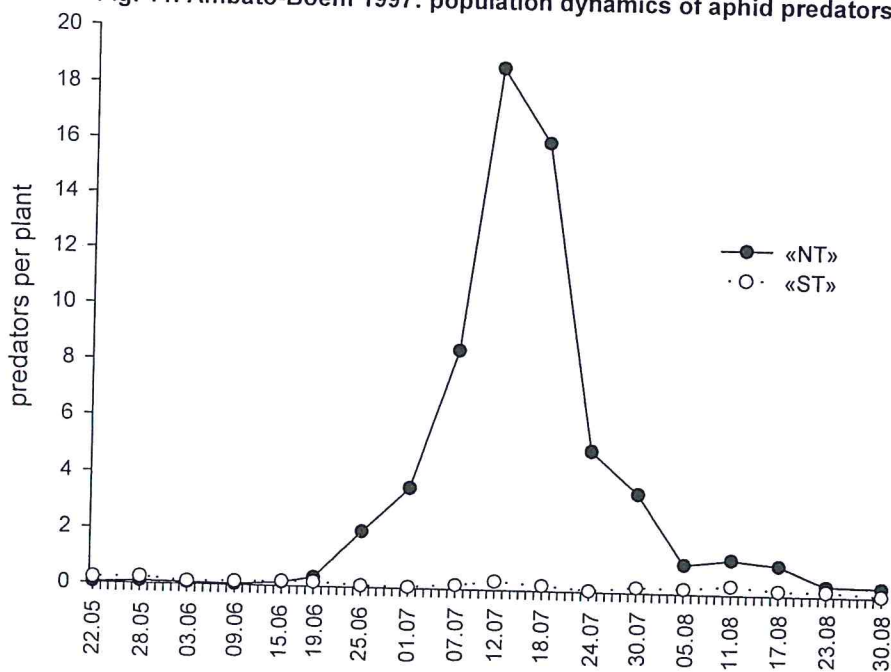
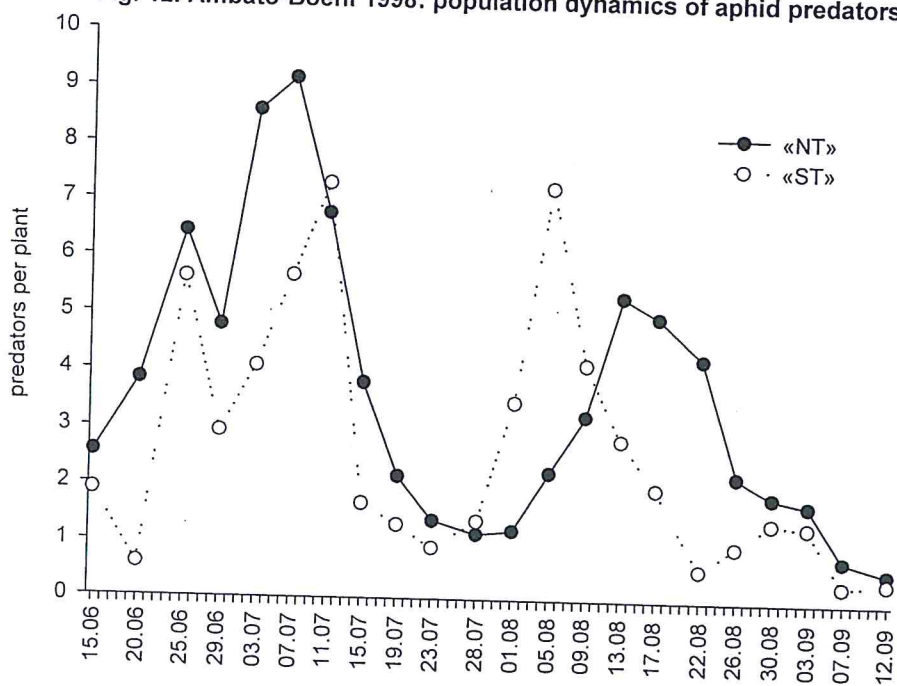
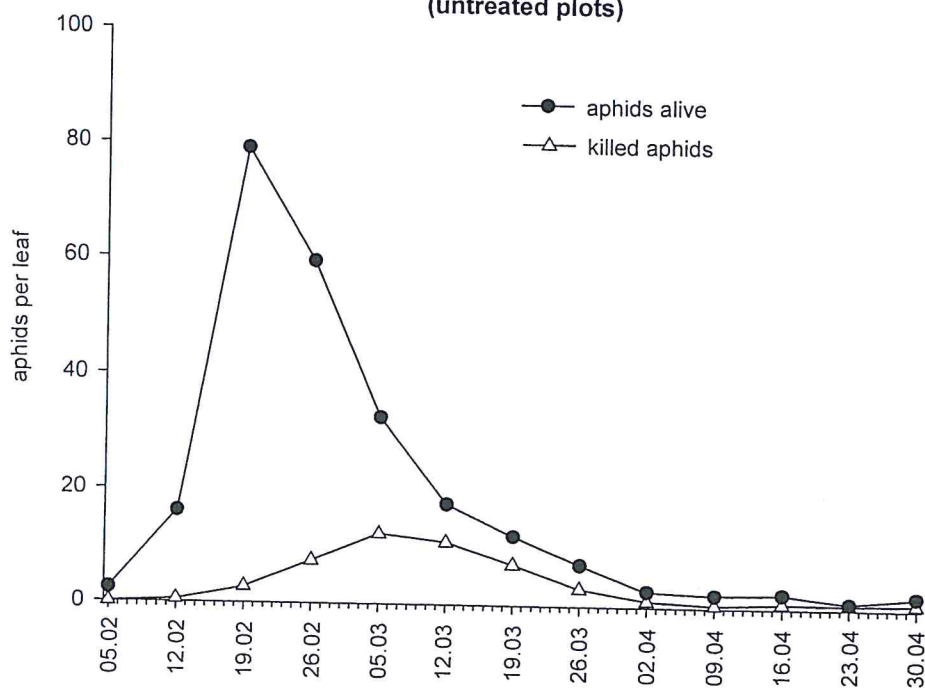


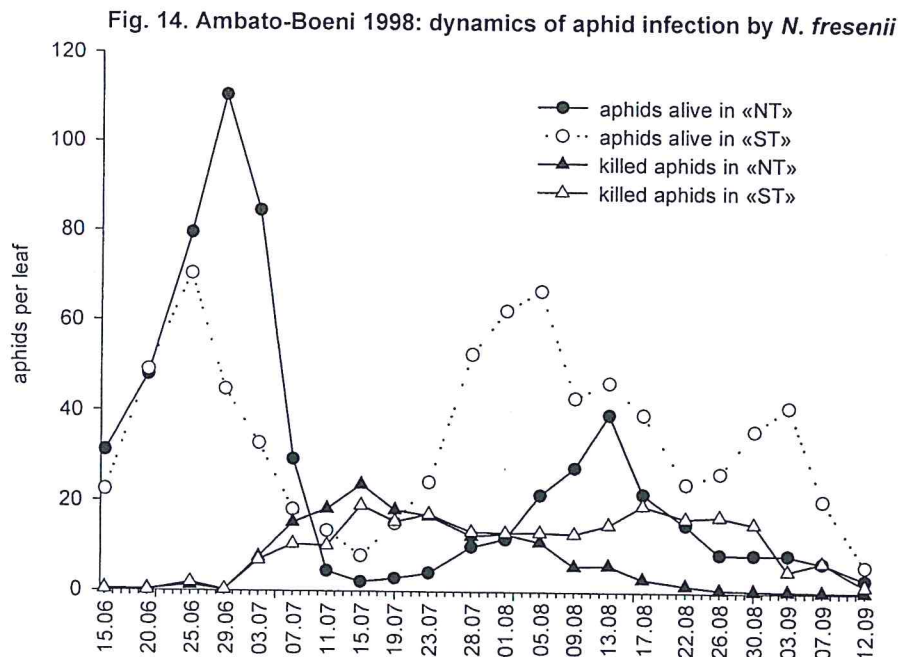
Fig. 12. Ambato-Boeni 1998: population dynamics of aphid predators



No aphid parasitoids were recorded, but the aphidopathogenic fungus *Neozygites fresenii* (Nowakowski) (Entomophthorales) was found to be associated with aphid populations at both sites. After the death of the host, the carcasses are rapidly overgrown by a greyish mould produced by a saprophytic fungus imperfectus of the genus *Cladosporium* sp. (G. Zimmermann, BBA-Darmstadt, Germany, pers. comm). In 1997, the fungus only appeared sporadically at the south-western site and was not observed in the north-west. The following year, the percentage of killed aphids with visible signs of mycosis rose to comparable levels in «NT» plots at both sites (fig. 13, 14). After the host's peak, numbers of killed aphids declined slowly and continually. However, new infections may have occurred in «ST» plots in Ambato-Boeni during the second aphid peak, indicating both a density-dependence and a compatibility of the fungus with insecticide treatments (fig 14). However, it must be considered that carcasses remain on the host plant with their stylet inserted in the plant tissue (Steinkraus et al. 1995). If they are not removed from the leaves by rain or wind, their numbers accumulate causing a "graveyard effect" which may lead to an overestimation of the proportion of infected individuals.

Fig. 13. Ampasikibo 1998: dynamics of aphid infection by *N. fresenii* (untreated plots)





In 1997, pest incidence in cotton was exceptionally low in both regions, but in the following year, yield losses in untreated plots were dramatic with 89 % and 90 % yield reduction in «NT» plots in Ampasikibo and in Ambato-Boeni, respectively (table 19). However, when yields per ha were regressed on numbers of intact bolls and on plant height, only boll numbers were significantly correlated with yields (table 20). This is a clear indication that yield reductions were largely imputable to the losses of bolls, as inflicted by the American bollworm *H. armigera*.

Table 19. Raw cotton yields/ha, number of intact bolls, and plant height, determined at the season's last sampling date

year	site	treatment	kg yields/ha \pm SE	bolls \pm SE	cm height \pm SE
1997	Ampasikibo	«NT»	1669 \pm 219 a	11.8 \pm 2.2 a	112.3 \pm 3.9 b
		«ST»	2689 \pm 395 b	17.5 \pm 2.2 b	105.6 \pm 6.1 a
1998	Ampasikibo	«NT»	130 \pm 20 a	1.4 \pm 0.3 a	108.3 \pm 5.3 b
		«ST»	1190 \pm 77 b	8.1 \pm 0.6 b	102.2 \pm 1.8 a
1997	Ambato-Boeni	«NT»	1031 \pm 230 a	9.2 \pm 2.0 a	106.0 \pm 7.8 b
		«ST»	1940 \pm 208 b	12.1 \pm 1.7 b	99.9 \pm 1.3 a
1998	Ambato-Boeni	«NT»	172 \pm 22 a	3.1 \pm 1.4 a	104.0 \pm 3.2..a
		«ST»	1657 \pm 92 b	15.5 \pm 1.0 b	99.9 \pm 5.9 a

kg yields, number of bolls and cm plant height within the same year and site followed by the same letter are not significantly different (mid-p point approach for an exact Mann-Whitney test for yields, t-test of independent samples for bolls and plant height)

**Table 20. Regression of yield on intact bolls and on plant height.
1997 and 1998 data pooled**

regression	site	intercept \pm SE	slope \pm SE	P (slope)	r^2
bolls	Ampasikibo (N=14)	-14.38 \pm 134.32	149.54 \pm 11.01	<0.001	0.939
	Ambato-Boeni (N=18)	-86.01 \pm 144.28	122.16 \pm 12.83	<0.001	0.850
plant height	Ampasikibo (N=14)	-1193.60 \pm 3612.07	25.35 \pm 33.54	0.437	0.045
	Ambato-Boeni (N=18)	2453.57 \pm 1702.29	-13.36 \pm 16.77	0.464	0.038

Multiple regression analysis

Multiple regression of “aphid densities per leaf” on “numbers of predators”, “numbers of aphids killed by entomopathogenic fungus” and “rainfall” did not yield any significant relationships in insecticide treated plots. However, multiple regression of aphid densities in untreated plots in Ampasikibo revealed a significant dependence on average rainfall during three days prior to sampling (table 21). The significance of the variable “fungus-killed aphids per plant” was inconclusive ($P = 0.092$). When “fungus-killed aphids” were retained in the model, 73 % of the variation could be explained by these two variables ($P = 0.001$). Varying the variable “rainfall” (average mm rain during three or two days or during one day before sampling) did not affect the estimate.

Data from untreated plots in Ambato-Boeni yielded a significant relationship between aphid densities and both “numbers of predators” and “numbers of killed aphids”. The correlation was positive with predators and negative with dead aphids. The coefficient of determination was lower than for the Ampasikibo data set ($r^2 = 0.45$, $P = 0.001$).

**Table 21. Multiple regression for number of aphids per leaf
on different variables («NT» plots)**

	estimate \pm SE	t value	P
Ampasikibo 1998:			
<u>dependent variable:</u> aphids/leaf			
intercept	-4.085 \pm 5.464	-0.748	0.472
<u>independent variables:</u>			
fungus-killed aphids/leaf	3.185 \pm 0.876	3.605	0.005
mean of three days rainfall	3.058 \pm 0.581	5.262	<0.001
$r^2 = 0.732$ (N=13)			
Ambato-Boeni 1998:			
<u>dependent variable:</u> aphids/leaf			
intercept	11.004 \pm 9.099	1.209	0.241
<u>independent variable:</u>			
fungus-killed aphids/leaf	-2.060 \pm 0.769	-2.680	0.015
predators/plant	7.614 \pm 1.969	3.866	0.001
$r^2 = 0.453$ (N=22)			

Within-plant distribution

Analysis of infestation by strata showed that the aphids were not evenly distributed on the cotton plant. Despite the low precision which could be expected from density estimations by scores at higher infestation levels, the 1997 data sets from both locations revealed a significant preference of «NT» populations for the lower and middle stratum of the plant (table 6 and 8, fig. 1 and 3). In the south-west, the superior stratum tended to have more aphids per leaf when the population had decreased to low densities. This may be due to the fact that younger leaves in the top of the plant become more attractive for the aphids in the course of the season. At the north-western site, *A. gossypii* was quasi absent from end of July 1997 onwards and no spatial heterogeneity was detectable.

In «ST» plots, the aphids were more uniformly distributed at peak, and in the rain-grown crop, the upper third was the significantly most infested stratum from March 19 to April 9 (table 8 and 10, fig. 2 and 4).

Table 22. Regression of mean aphid density per plant on proportions of empty sampling units, assessed on terminal leaves («NT» and «ST» pooled)

site	proportions calculated per leaves				proportions calculated per plant			
	intercept ± SE	slope ± SE	P (slope)	r ²	intercept ± SE	slope ± SE	P(slope)	r ²
N=24/24 Ampasikibo 1997	1.62 ± 0.19	0.96 ± 0.11	<0.001	0.765	0.50 ± 0.19	0.79 ± 0.15	<0.001	0.622
N=35/29 Ambato-Boeni 1997	3.13 ± 0.24	1.50 ± 0.11	<0.001	0.837	1.45 ± 0.26	1.64 ± 0.18	<0.001	0.746
N=26/21 Ampasikibo 1998	1.71 ± 0.14	1.30 ± 0.17	<0.001	0.693	0.48 ± 0.17	0.75 ± 0.19	0.001	0.424
N=44/20 Ambato-Boeni 1998	2.61 ± 0.10	1.55 ± 0.17	<0.001	0.671	-0.50 ± 0.82	2.41 ± 0.68	0.002	0.376

A further subdivision of the plant did not result in any statistically significant differences between densities on the first fruiting branch, on a randomly chosen fruiting branch in the middle of the plant, or on the two terminal branches, when compared to the remainder of the respective stratum. Plotting the proportions of empty sampling units to the mean per plant according to equation [1], assessed on the terminal four (receding flood cotton) or five (rainfed cotton) leaves (table 22), yielded a coefficient of determination of $r^2 = 0.842$ for Ambato-Boeni ($P = <0.001$). The relationship was less distinct for Ampasikibo ($r^2 = 0.725$, $P = <0.001$), especially when the proportions were calculated on a per-plant basis ($r^2 = 0.622$; $P = <0.001$). Solving equation [2] for the parameters a and b provides an estimation of the mean for the threshold infestation: 15 % infestation on the terminal leaves corresponded to 1.5

and 0.9 individuals/leaf at the north-western site in Ambato-Boeni and at the south-western site in Ampasikibo, respectively.

The within-plant distribution data obtained in 1997 were largely confirmed by results from enumerative samplings in 1998. When the two leaves of the first, the middle and the terminal branch were pooled to represent a stratum, numbers on the first and on the middle branch did generally not differ significantly from each other in the two treatments (table 11, 12, 15 and 16). Similarly to 1997, infestation was less important on the superior leaves during the phase of exponential growth of *A. gossypii*. During the second half of the sampling period, at lower densities, this tendency was levelled or in the case of Ampasikibo even reversed (table 11 and 12). A notable exception was «ST» in Ambato-Boeni, after the aphids had peaked a second time (table 16).

It became also evident that main stem leaves consistently harbour more aphids than other leaves on the fruiting branch (table 13-14, 17-18; fig. 5-8), which is probably due to a more active metabolism in axillary leaves.

Relationship of the mean to the proportion of empty sampling units

Analysis of the relationship between the overall mean and empty sampling units for different sampling units and tally thresholds from $T = 0$ to $T = 20$ showed that the fit can be improved by modifying the value for T (table 23 and 24). For the six individual leaves considered, $T = 0$ yielded the lowest fits except for the pooled main stem leaves. Main stem leaf infestations were consistently closer related to the mean than infestation on other leaves of the branch. From the Ampasikibo data, the best fit was obtained when the overall mean was regressed on pT , calculated as the mean of six leaves, with $T = 7$ ($r^2 = 0.979$). In the case of Ambato-Boeni, the overall mean was best fitted to proportions of empty sampling units when $T = 10$, with $r^2 = 0.956$ (fig. 16). When a single main stem leaf was considered, the terminal was the least appropriate, but there was no clear tendency for the optimum tally threshold for the first or middle main stem leaf.

Fitting the mean of six leaves to proportions counted on the four or five terminal leaves with $T = 0$ for the 1998 data set resulted in poorer fits than for the 1997 data, considering that the sampling units only partly overlap (tab. 22). The prediction of the mean for aphid thresholds yielded even lower densities, i.e., 0.8 and 0.5 *A. gossypii*/leaf in Ampasikibo and Ambato-Boeni, respectively. If the mean is plotted against the two upper leaves (table 23 and 24), the estimation is 0.2 aphids in the

north-west ($a = 1.65$, $b = 1.89$, $r^2 = 0.664$) and 0.5 aphids in the south-west ($a = 1.59$, $b = 1.26$, $r^2 = 0.828$).

Table 23. Ampasikibo 1998: Regression of mean density per plant on proportions of empty sampling units at different tally thresholds («NT» and «ST» pooled)

tally threshold T		inferior mean stem leaf	other inferior leaf	median main stem leaf	other median leaf	superior main stem leaf	other superior leaf	main stem leaves pooled	all leaves pooled
0	a	1.684	1.503	1.308	1.452	1.453	1.682	1.511	1.565
	b	1.399	1.082	1.073	1.249	1.201	1.156	1.379	1.461
	r ²	0.887	0.770	0.822	0.704	0.824	0.755	0.928	0.947
	N	24	24	23	24	25	25	20	19
1	a	2.003	1.899	1.670	1.951	1.946	2.107	1.978	2.079
	b	0.979	0.924	0.714	1.048	1.038	0.960	1.063	1.213
	r ²	0.856	0.810	0.817	0.825	0.836	0.768	0.918	0.963
	N	25	24	23	25	26	26	23	22
2	a	2.230	2.236	2.106	2.307	2.268	2.398	2.243	2.392
	b	0.853	0.947	0.980	1.005	0.958	0.982	0.947	1.118
	r ²	0.864	0.863	0.871	0.854	0.849	0.781	0.903	0.958
	N	25	24	23	26	26	26	24	23
3	a	2.477	2.430	2.318	2.490	2.451	2.794	2.429	2.619
	b	0.885	0.865	0.924	0.873	0.906	1.188	0.890	1.052
	r ²	0.914	0.863	0.885	0.827	0.845	0.833	0.918	0.970
	N	24	24	23	26	26	25	24	23
4	a	2.607	2.600	2.452	2.668	2.601	2.911	2.608	2.820
	b	0.805	0.863	0.882	0.827	0.899	1.031	0.893	1.039
	r ²	0.896	0.868	0.894	0.813	0.832	0.776	0.930	0.975
	N	24	25	24	26	26	25	23	23
5	a	2.720	2.681	2.604	2.802	2.711	3.013	2.679	2.935
	b	0.765	0.777	0.857	0.845	0.858	0.967	0.818	0.986
	r ²	0.895	0.838	0.899	0.828	0.856	0.751	0.913	0.971
	N	24	26	25	25	26	25	24	23
6	a	2.769	2.800	2.706	2.914	2.881	3.156	2.798	3.074
	b	0.739	0.791	0.838	0.837	0.888	0.952	0.824	0.990
	r ²	0.893	0.831	0.914	0.837	0.863	0.743	0.926	0.977
	N	24	26	25	25	26	25	24	23
7	a	2.786	2.825	2.748	3.002	2.973	3.261	2.892	3.166
	b	0.648	0.723	0.766	0.827	0.893	0.936	0.809	0.961
	r ²	0.831	0.787	0.901	0.849	0.878	0.747	0.934	0.979
	N	24	26	25	24	26	25	25	22
8	a	2.876	2.902	2.848	3.131	3.111	3.229	2.980	3.251
	b	0.655	0.715	0.782	0.832	0.907	0.834	0.792	0.934
	r ²	0.854	0.786	0.905	0.858	0.877	0.709	0.936	0.975
	N	22	26	24	24	26	25	25	23
9	a	2.886	3.002	2.814	3.158	3.114	3.356	3.020	3.300
	b	0.633	0.708	0.727	0.797	0.843	0.858	0.780	0.911
	r ²	0.847	0.817	0.877	0.822	0.830	0.711	0.935	0.968
	N	22	26	24	24	26	25	24	23
10	a	2.934	3.068	2.911	3.250	3.193	3.679	3.107	3.335
	b	0.617	0.714	0.724	0.770	0.840	0.978	0.770	0.857
	r ²	0.839	0.812	0.900	0.870	0.832	0.786	0.950	0.967
	N	19	24	24	24	26	23	23	23
15	a	3.255	3.324	3.183	3.679	3.543	4.085	3.320	3.537
	b	0.605	0.681	0.659	0.752	0.876	0.894	0.678	0.737
	r ²	0.850	0.776	0.931	0.854	0.806	0.797	0.925	0.935
	N	16	21	24	22	21	22	19	20
20	a	3.518	3.741	3.347	3.963	3.722	4.283	3.565	3.700
	b	0.672	0.737	0.629	0.759	0.811	0.863	0.682	0.671
	r ²	0.929	0.896	0.925	0.881	0.754	0.773	0.954	0.941
	N	13	17	17	17	19	20	17	12

Table 24. Ambato-Boeni 1998: Regression of mean density per plant on proportions of empty sampling units at different tally thresholds («NT» and «ST» pooled)

tally threshold T		inferior mean stem leaf	other inferior leaf	median main stem leaf	other median leaf	superior main stem leaf	other superior leaf	main stem leaves pooled	all leaves pooled
0	a	1.576	2.018	1.170	1.698	1.258	2.238	1.153	1.490
	b	1.718	1.494	1.843	1.827	1.639	1.535	1.950	1.972
	r ²	0.828	0.659	0.813	0.651	0.544	0.551	0.882	0.814
	N	36	38	37	36	34	38	36	34
1	a	2.170	2.539	1.801	2.372	1.802	2.776	1.851	2.176
	b	1.374	1.318	1.501	1.504	1.581	1.293	1.582	1.667
	r ²	0.847	0.755	0.818	0.752	0.676	0.689	0.869	0.867
	N	40	43	38	43	40	43	40	39
2	a	2.513	2.934	2.224	2.863	2.280	3.165	2.289	2.637
	b	1.192	1.260	1.337	1.403	1.362	1.190	1.393	1.514
	r ²	0.850	0.816	0.852	0.820	0.747	0.683	0.892	0.900
	N	41	43	41	43	43	44	43	42
3	a	2.657	3.143	2.484	3.125	2.599	3.445	2.551	2.920
	b	1.111	1.129	1.241	1.241	1.249	1.190	1.300	1.433
	r ²	0.862	0.812	0.894	0.839	0.784	0.700	0.915	0.929
	N	43	44	43	44	43	43	43	43
4	a	2.813	3.308	2.694	3.336	2.833	3.655	2.769	3.136
	b	1.036	1.088	1.138	1.172	1.144	1.153	1.225	1.342
	r ²	0.853	0.807	0.883	0.851	0.799	0.743	0.924	0.939
	N	44	44	43	44	43	44	44	44
5	a	2.939	3.448	2.870	3.482	2.978	3.837	2.926	3.298
	b	1.005	1.089	1.070	1.087	1.051	1.094	1.147	1.265
	r ²	0.871	0.829	0.880	0.871	0.788	0.768	0.923	0.946
	N	44	44	44	43	44	43	44	44
6	a	3.051	3.570	2.980	3.599	3.085	3.949	3.043	3.418
	b	0.984	1.011	0.995	1.025	0.997	1.060	1.096	1.196
	r ²	0.863	0.830	0.881	0.871	0.793	0.788	0.925	0.948
	N	44	44	44	44	43	44	44	43
7	a	3.115	3.690	3.064	3.715	3.190	4.003	3.131	3.521
	b	0.939	0.983	0.962	0.982	0.968	0.941	1.049	1.141
	r ²	0.856	0.853	0.892	0.850	0.801	0.777	0.923	0.949
	N	44	42	44	44	44	44	44	44
8	a	3.174	3.735	3.147	3.798	3.282	4.071	3.211	3.596
	b	0.900	0.908	0.945	0.965	0.929	0.896	1.001	1.086
	r ²	0.864	0.845	0.899	0.853	0.831	0.791	0.930	0.953
	N	44	44	44	44	43	44	44	44
9	a	3.220	3.788	3.217	3.854	3.343	4.156	3.276	3.654
	b	0.904	0.875	0.883	0.942	0.901	0.904	0.977	1.050
	r ²	0.863	0.842	0.887	0.861	0.839	0.809	0.932	0.952
	N	44	44	43	44	43	44	44	44
10	a	3.283	3.879	3.296	3.897	3.407	4.226	3.344	3.731
	b	0.887	0.870	0.813	0.848	0.901	0.848	0.933	1.008
	r ²	0.874	0.833	0.902	0.838	0.857	0.821	0.938	0.956
	N	44	44	43	44	43	44	43	44
15	a	3.481	4.075	3.511	4.181	3.626	4.511	3.559	3.925
	b	0.727	0.738	0.712	0.795	0.745	0.795	0.774	0.842
	r ²	0.867	0.791	0.921	0.827	0.877	0.815	0.930	0.949
	N	43	43	42	41	43	41	40	35
20	a	3.660	4.229	3.663	4.270	3.782	4.696	3.694	4.010
	b	0.706	0.693	0.745	0.676	0.690	0.718	0.686	0.712
	r ²	0.891	0.775	0.925	0.794	0.868	0.793	0.931	0.927
	N	43	43	42	41	43	41	40	35

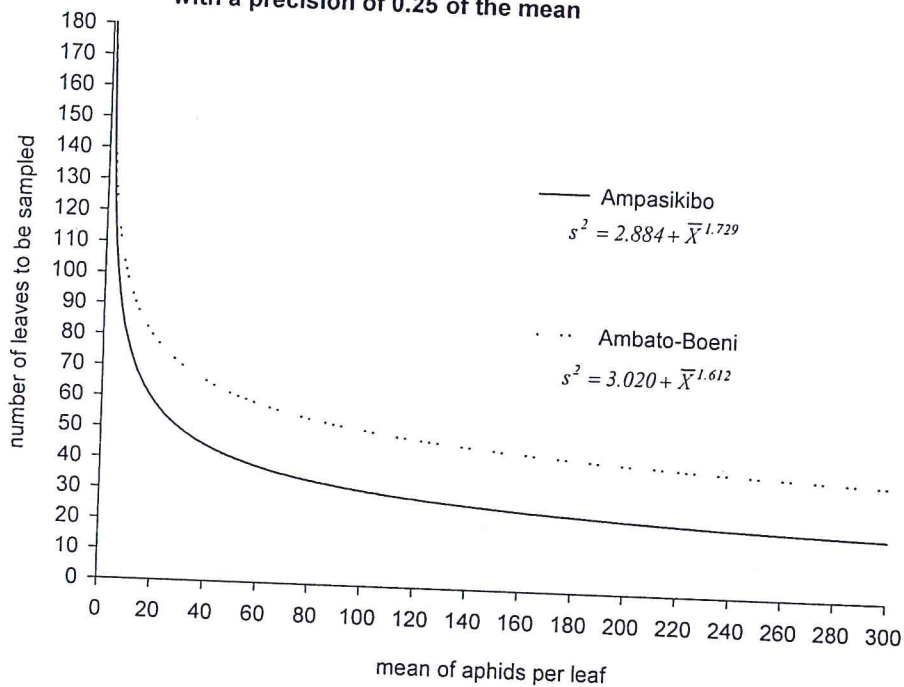
Relationship of the variance to the mean

The fit of Taylor's model to the 1998 data was very good, as indicated by the high coefficients of determination ($r^2 = 0.99$ for both locations). Aphids showed a clumped distribution (table 25). The parameters of the two regressions values were significantly different ($P = 0.001$). Figure 15 presents the optimum number of leaves to be sampled for complete counts when the precision is fixed at 0.25 of the mean.

Table 25. Regression of the variance $\log(s^2)$ on the mean $\log(\bar{X})$

site	$\log a \pm SE$	$b \pm SE$	P(slope)	r^2	N
Ampasikibo 1998	3.020 ± 0.024	1.612 ± 0.032	<0.001	0.990	26
Ambato-Boeni 1998	2.884 ± 0.035	1.729 ± 0.028	<0.001	0.989	44

Fig 15. Optimum sample size for *A. gossypii* with a precision of 0.25 of the mean



3.5. Discussion

The present study of the cotton aphid's seasonal population dynamics in Malagasy cotton provided strong indications that the pest status of *A. gossypii* has to be considered separately for the two cropping regions. In north-western Madagascar, *A. gossypii* is of much greater importance. This confirms more recent investigations (Andriambololona et al. 1989) just like statements from the 1960s, when cotton was introduced to this area (Bournier and Vaissayre 1977). In contrast to the extensive

production system in south-western Madagascar, dry season cotton has until very recently been dominated by intensive large-scale exploitations with heavy fertiliser and insecticide inputs (Berger 1979, Rakotofiringa 1997). When devastating invasions of pyrethroid-resistant *S. littoralis* occurred in the mid-eighties, many growers multiplied insecticide sprayings, resulting in up to 15 treatments per season (H. Rakotofiringa, pers. comm.). Severe outbreaks of *A. gossypii* in the following years have been attributed to the elimination of its natural enemies and to cross-resistance against DDT and pyrethroids (Dove 1994b). However, there has yet not been any reports on insecticide-induced aphid outbreaks in Malagasy cotton. Results from this study strongly indicate that the reproduction of pyrethroid-resistant *A. gossypii* was stimulated by the cypermethrin sprayings against *H. armigera* on 17/6/97, on 13/7 and on 26/7/98. The higher aphid numbers in «ST» plots cannot be explained by comparatively higher predation rates in «NT». When the explosive population growth started just after the treatment on June 17, there were yet hardly any predators present in the field (fig. 11).

The existence of stimulating effects of some insecticides on *A. gossypii* reproduction has been reported in different zones of the US cotton belt, where outbreaks after treatment with cypermethrin, cyhalothrin or sulfopros have been observed (Kerns and Gaylor 1991, 1993; Kidd and Rummel 1997). The underlying mechanisms has been described as trophobiosis, i.e., indirect stimulation of reproduction through conditioning of the nutritional status of the host plant (Kerns and Gaylor 1993). If trophobiosis in cotton particularly affects the terminal meristem, this could explain why aphid densities in «ST» tendend to increase on the upper plant plots following a cypermethrin treatment (fig. 4 and 8).

Thus, the *A. gossypii* biotype in north-west Madagascar may be considered a secondary or "man-made" pest in the way it has been described since the 1980s for many cotton areas around the world (Deguine and Leclant 1997).

The situation in rain-grown cotton in the south-west is entirely different. Neither failures of chemical control nor any late-season recurrence of *A. gossypii* were recorded in Ampasikibo. However, cypermethrin was sprayed alone only once, but combined with aphicidal monocrotophos five times (table 2). Though the necessity to treat *A. gossypii* in rain-grown cotton is highly debatable, the mixture is appreciated by HASYMA for several reasons: both components are not only the cheapest available (costs for farmers for one application are below an equivalent of 15 kg raw cotton/ha), but their combination is supposed to produce a synergistic effect which

allows for reduction of doses and suppresses resistance development in pest populations with greater assurance (Denholm and Rowland 1992, Cauquil and Vaissayre 1994). Besides, as long as sprayings are conducted on a calendar scheme regardless of economic injury levels, binary products are also simply used for convenience purposes, because it saves the effort to identify the pests actually present in the field. Monocrotophos is an effective aphicide which is used in Malagasy cotton since 1973 (Peyrelongue et al. 1974). However, it was only during the field trials at the south-west site that its performance was totally convincing. There was no indication that the survival rate of the aphids was greater in lower strata of the plant, as often assumed in connection with the ULV/VLV spraying technique which is very efficient for control of key pests on upper plant parts like young instars of *H. armigera* (Deguine and Leclant 1997). In the north-west, where spraying volumes are tenfold higher, the monocrotophos treatments on 10/7/97 and 28/6/98 stopped further aphid population growth, but were not able to reduce infestations to low levels. The described divergence between the two cropping systems may be explained by the different level of intensification in the two regions. The insecticide spraying calendar for the rain-grown crop in south-western Madagascar was reduced from ten to six treatments between 1986 and 1996. The de facto average number of treatments in the region is even lower (Andriambololona et al. 1989). Also, new active ingredients were introduced and alternated with the pyrethroids, which are now confined to two mid-season sprayings. This may have helped to avoid the selection of aphid strains which react to trophobiotic effects suspected to play a key role in the north-west, where eight interventions on small-scale fields and eleven for the intensive system were officially recommended in 1998. Furthermore, the management of soil fertility presents a major difference between the two regions. Aphids are well-known to respond to the level of soluble nitrogen available in the sap of their host plants (Klingauf 1987, Ekukole 1992, Slosser et al. 1997). Intensively cultivated areas in the north-west receive 115 kg N/ha in two supplies, whereas small growers only apply a single dose of 69 kg (table 3). Approximately the same quantity is recommended and supplied for by HASYMA in the south-west (table 1). However, contrary to the north-west, about two-thirds of the rain-grown cotton fields do not receive any fertiliser at all, because these are resold on the black market by farmers in financial difficulties during the economic "tide-over" period (period of distress between the depletion of last year's supplies and the next harvest), which covers almost the entire cotton cropping season (L. Andriambololona, HASYMA, pers. comm.).

Data on the population dynamics of aphid predators suggest that suppression of natural enemies by insecticides may also play an important role in auto-induced aphid pest problems in the north-west. The demographic explosion of *A. gossypii* in the «ST» plots of Ambato-Boeni in 1997 took place during a period of almost complete absence of aphidophagous predators (fig. 4, 11). Interpretation of the 1998 data is more difficult because of unexpected high densities of predators in sprayed plots. Field trials on the effect of currently used insecticides on *C. simulans* and *S. constrictus* populations have demonstrated the high toxicity of monocrotophos, thiodicarb, and cypermethrin for these predators (see chapter 2). Moreover, the large differences in cotton yields between the «ST» and «NT» plots prove the efficacy of the insecticide sprayings. Thus, the high numbers of beneficials in «ST» were probably due to migration of adult predators from untreated plots. Apparently, the interaction between the treatments was enhanced by the attractiveness of high aphid numbers for reproductive females, especially for the very fecund coccinellid *C. simulans*. In these conditions, plot sizes for insecticide trials should, if possible, be large to minimise interference between control and treated plots (Reed 1976, Munro 1987).

In the south-west, predators are less likely to have an impact on aphid populations. Excessive temperatures in austral summer with maxima beyond 35°C and heavy precipitations may have detrimental effects on fecundity and longevity and on survival of early larval instars, respectively (Xia 1997). *Cheilomenes simulans*, the by far most important coccinellid in the north-west, was hardly observed before the end of the rainy season in late March, when temperatures decrease considerably. But then, scarcity of aphid prey forced late-season coccinellids to rely on cannibalism and less appropriate prey like *B. tabaci* or *Bucculatrix loxoptila* Meyrick (Lep.: Lyonetiidae) larvae. When numbers of coccinellid eggs and adults were pooled for both years, the egg:adult-ratio was 1.27 and 5.56 in Ampasikibo and Ambato-Boeni, respectively.

The potential of the aphidopathogenic fungus *N. fresenii* must also be considered separately by regions. A priori, fungal infections are supposed to be favoured by high degrees of relative humidity (Hagen and Van den Bosch 1968, Latgé and Papierok 1987) which occur in the rainy season. On days with rain-falls, average RH can exceed 90 % (Grouzis and Rocheteau 1998). In 1997, however, host densities seemed to be too low for secondary infection cycles, necessary to trigger spectacular epizootics (Steinkraus et al. 1991). In 1998, heavy rainfall at peak densities of *A. gossypii* seemed ironically to curb the development of potential epizootics, possibly

by washing off sporulating cadavers from the plants (see chapter 3). No meteorological data was available for the Ambato-Boeni site, but the impact of the fungus seemed to be fostered by a coincidence of high host density with cool nights in the beginning of July 1998 when abundant dew was present on leaves.

The evaluation of the impact of the natural antagonists on aphid densities by means of multiple regression suggested that the disease co-evolved closely with host density only at the rain-grown south-western site in Ampasikibo. In the north-west, fungus-killed aphids were negatively correlated with living aphids, possibly because of the accumulation of dead individuals in samples during the period of aphid population decline (fig. 14). On the other hand, predators had probably a regulating effect on aphid infestation in Ambato-Boeni, but were not significantly correlated to aphid densities in Ampasikibo (table 21). This would confirm the presumption that the hot rainy season in the south-west favours fungal infections but affect predators' activity and survival. Inversely, cooler temperatures and the absence of rainfall in the north-west provide better conditions for the arthropod natural enemies but lessen the impact of the pathogen. The positive correlation of aphid numbers to rainfall in Ampasikibo may seem surprising. It is likely that this is the result of the confounding effects of rainfall and crop stage. Considering that the aphid peaks occurred during flowering when rains were still abundant, the attractiveness of this host plant stage is probably an important factor in cotton aphid population dynamics.

Results from this study indicate that aphid management problems may be exacerbated by inadequate sampling procedures, leading to inconsistencies in management decisions. The analysis of the spatial distribution of *A. gossypii* revealed that during the period of rapid population increase at flowering, aphids preferably colonise the lower and middle portions of the cotton plant. However, this may be modified and partly even reversed by insecticide treatments, late-season change of meteorological conditions, and by the host plant's nutritional status. When data from all sampling dates and both treatments were pooled for each season, proportions of empty sampling units calculated on the terminal parts of the plant did not provide a sufficiently precise estimate of the global mean per plant. Also, the 1998 data suggested that only main stem leaves should be sampled, because proportions calculated from all other leaves yield poor correlations to the overall mean. The variability of aphid distribution patterns with regard to treatments and time may have contributed to the difficulty to choose an appropriate tally threshold for the binomial sampling of main stem leaves.

When the lowest, middle and terminal main stem leaf were pooled, the simple presence-absence method ($T = 0$) gave acceptable results. However, if only one leaf is to be considered, the tally threshold should be at least $T = 3$ and not higher than $T = 10$, and the coefficient of determination is only close to 90% (table 23, 24).

The relationship between the variance and the mean showed significant variability between the north-west and south-west data sets. The index of aggregation is supposed to hold over a wide range of ecological conditions for the same species, as long as the sampling procedure is the same (Taylor 1961). This categorical affirmation has been criticised, because age-specific dispersal and mortality are frequently observed in insect populations (Wilson et al. 1989, Kuno 1991, Davis 1994). However, if a precision of 0.25 of the mean is considered sufficient for pest management purposes, required sample sizes are perfectly feasible for both calculated equations as long as aphid densities are not were low. N exceeds 100 if the mean is below nine (Ambato-Boeni) or five aphids per leaf (Ampasikibo), respectively.

The at present applied mid-season action threshold of 15 % infested leaves seems very low and inevitably advocates an increase of sprayings which may appear economic in the short term but in reality is due to the elimination of other important pests of the crop. Devastating yield reductions in the order of 90 %, recorded in the control plots in 1998, are common in Malagasy cotton and seem to justify a very strict protection regime (Caresche 1959, Bournier and Vaissayre 1977, Andriambololona et al. 1989). However, in this study, no statistical proof for an impact of *A. gossypii* on yield could be found. The stunting of growing cotton plants during high and prolonged aphid infestation at the Ambato-Boeni site did not significantly affect yields. In addition, Malagasy strains of *A. gossypii* do not transmit the blue disease virus which is common in central Africa (Cauquil and Vaissayre 1971). Yield proved to depend on retention of bolls and thus principally on the management of carpophagous pests, i.e., *H. armigera*, and to a lesser extent *Earias insulana* Boisduval (Lep.: Noctuidae), the cotton stainer *Dysdercus flavidus* Signoret (Het.: Pyrrhocoridae) and other heteropterous boll feeding insects (Couilloud 1989). Late-season control of whiteflies (*B. tabaci*), which outnumber aphids beyond 100 d.a.e., and of leaf-feeding caterpillars *B. loxoptila* may also contribute to delude growers into economic justification of aphicide use at the end of the production cycle.

Malagasy cotton aphids are essentially mid-season pests which appear to be particularly attracted to the flowering stage of the host plant (O'Brian et al. 1991).

During this period, *A. gossypii* colonises all plant parts including young stems, petioles, buds, and flowers. Big, dark, vigorous morphs prevail. In rain-grown cotton, however, the honeydew produced at peak infestation is washed off by the last precipitations of the rainy season, and residual late-season populations, which mostly consist of "yellow dwarfs" (Wool et al. 1995), do not seem to have the potential for a second increase on senescent plants which have shed most of their leaves by 100-120 d.a.e. In dry season cotton, the absence of rainfall enhances the importance of mid-season honeydew, and the possibility of population peaks beyond 100 d.a.p. creates problems with stickiness of fibres in open bolls. However, only a small part (3-5 %) of Malagasy cotton production is de facto downgraded to second or third quality because of honeydew contamination. This is economically far less important than quality losses due to dust, plant debris or untimely rainfall (H. Rakotofiringa, pers. comm.).

Information about physiological yield responses to *A. gossypii* infestation are scarce and controversial, and there are no generally recommendable sampling procedures to determine densities. Results from studies in irrigated Californian cotton indicate that even very early and very high densities (>1,000 aphids/leaf) do not affect yield if populations collapse rapidly (Godfrey et al. 1997, Rosenheim et al. 1997). Godfrey et al. (1997) calculated a negative relationship of 0.36 lbs (= 0.16 kg) raw cotton yield per aphid-day (i.e., aphids per leaf and day) for longer-lasting mid-season infestations. Fuson et al. (1995) reported that 20 aphid-days were necessary to cause a yield reduction of one pound (i.e., 0.454 kg). In Texas dryland cotton, recommended action thresholds for late-season aphid infestations are at least 50-100 individuals/leaf during 10-14 days (Godfrey et al. 1997).

Yet, thresholds for aphids in Malagasy cotton are still far below these large ranges of economic impact. A treatment with monocrotophos costs approximately the equivalent of 10 kg raw cotton (which is the value of the chemistry only). This amount raises to 31 kg for the alternative use of benfuracarb and to 35 kg for carbosulfan. Applied to the relationship of Godfrey et al. (1997), this would imply damage thresholds of 63, 194 and 219 aphid-days, respectively, and thresholds of 441, 1366 and 1402 aphid-days for the regression presented by Fuson et al. (1995). Considering the observed early-season population dynamics of *A. gossypii* in Malagasy cotton, it may take the aphids several weeks during the squaring period to reach even the lowest of these thresholds (table 5 and 6).

Hence, there are strong indications that an action threshold of 15 % infested terminal leaves, characterised by a poor correlation to the population's mean, and possibly not presenting more than one individual per leaf, is a gross over-estimation of the economic impact of the aphids. When spraying calendars in the next years are to be substituted by a threshold-based pest management scheme, as advocated by local decision-makers, this may lead to frequent use of chemicals and is likely to have implications for potential recurrence of pest pressure.

4. Effect of predator exclusion on the population dynamics of the cotton aphid, *Aphis gossypii* Glover (Hom.: Aphididae), in Malagasy cotton

4.1. Abstract

The influence of the predator complex on the population dynamics of the cotton aphid, *Aphis gossypii* Glover (Hom.: Aphididae), in rainfed and receding flood cotton in Madagascar was investigated in exclusion experiments. Crawling predators were excluded from aphid colonies on «protected» leaves by an insect glue barrier on the petioles, whereas predators had full access to «free» leaves. This simple design succeeded in creating predatory free environments on «protected» leaves where pooled densities were 7.3-17 fold lower than on «free» leaves. The insecticide spraying regime had a predominating impact on the population dynamics. Aphid numbers were markedly higher in receding flood cotton, where several cypermethrin treatments probably induced growth effects on the pest populations. The model of Chambers and Aikman (1988) was used to evaluate whether the observed differences in aphid densities in «free» compared to «protected» colonies could be attributed to predation. This was largely confirmed for two time periods analysed, because calculated “required kill rates” were lower than values for “potential kill” obtained from aphid consumption tests in captivity. The large error in the parameter estimation of the model is examined. It is concluded that predators may have an important impact on *A. gossypii* populations in receding flood cotton, and the prospects for integrating natural enemies in crop protection management systems are discussed.

4.2. Introduction

The aphid *Aphis gossypii* Glover is considered an economically important cotton pest in Madagascar (H. Rakotofiringa, HASYMA, pers. comm.). Aphid infestations are believed to be responsible for yield reductions (Andriambololona et al. 1989), but the extent of economic damage inflicted to the crop at observed pest densities is unknown. However, problems with stickiness of fibres from the cotton production areas in the north-western region of Madagascar have been repeatedly reported by national textile companies (H. Rakotofiringa, pers. comm.). In north-western Madagascar, where cotton is grown on alluvial deposits during the dry season,

A. gossypii infestations are of far greater importance than in the rainfed crop in the south-west. The lack of rainfall is commonly used to explain differences in the population dynamics between the two regions (L. Andriambololona, HASYMA, pers. comm.). Heavy rains are supposed to curb cotton aphids' population growth (Deguine and Leclant 1997) and to wash off honeydew and sooty mould from leaves. However, *A. gossypii* population development has never been studied in relationship to the destruction of its natural enemy complex as a consequence of insecticide treatments targeting at the lepidopterous pests *Helicoverpa armigera* Hübner, *Earias* spp. and *Spodoptera littoralis* Boisduval (all Lep.: Noctuidae) (Dove 1994b). Cotton fields in north-western Madagascar receive approximately twice as many often insecticide treatments as rain-grown cotton in the south-west of the island. The recommended calendar spraying scheme comprised of eight to eleven treatments in 1997 and 1998 with six applications of compounds which have been demonstrated to cause mortality beyond 90 % among the larvae of the most important aphid predator *Cheilomenes simulans* Crotch (Col.: Coccinellidae) (cf. chapter 2). Aphids are known to be preyed on by a large array of oligophagous predators, and resurgence of cotton aphids have frequently been described as a result of elimination of predators (Dixon 1998, Hagen and Van den Bosch 1968, Rosenheim et al. 1997, Zhang 1992). In Madagascar, five species of Coccinellidae, two Syrphidae, one Chrysopidae and one Hemerobiidae have been recorded as aphidophagous predators (cf. chapter 3). Therefore, the impact of the aphidophagous predator complex on the population dynamics of *A. gossypii* was studied in an exclusion field experiment.

4.3. Materials and methods

Predator exclusion trials were conducted in Ambato-Boeni (in receding flood cotton on alluvial deposits in north-western Madagascar) in 1997 and 1998, and in Ampasikibo (in rainfed cotton in the south-west) in 1998. In 1997, aphid densities in Ampasikibo were too low to allow for any exclusion effect, and therefore the trial was not completed. The three experiments were all carried out in the experimental plots, which also were used for additional population dynamics studies (cf. chapter 2 and 3). Details of plot design and agronomic techniques are listed in chapter 3. The sprayings which were conducted in «ST» plots are presented in table 1.

Table 1. Treatments in insecticide sprayed «ST» plots

site	year	date	intervention
Ambato-Boeni	1997	20.05	endosulfan (800 g a.i./ha)
		28.05	thiodicarb (400)
		06.06	thiodicarb (400) + monocrotophos (200)
		17.06	cypermethrin (60)
		10.07	monocrotophos (300)
		22.07	thiodicarb (400)
		01.08	thiodicarb (400)
		15.08	monocrotophos (300)
Ampasikibo	1998	18.02	cypermethrin (60) + monocrotophos (200)
		24.02	chlorpyrifos-ethyl (720)
		10.03	thiodicarb (400)
		17.03	cypermethrin (60)
		24.03	monocrotophos (300)
		31.03	monocrotophos (300)
		14.04	cypermethrin (60) + monocrotophos (200)
		21.04	cypermethrin (60) + monocrotophos (200)
Ambato-Boeni	1998	28.06	monocrotophos (300)
		13.07	cypermethrin (60)
		26.07	cypermethrin (60)
		06.08	benfuracarb (250) + thiodicarb (400)
		05.09	benfuracarb (250)

The exclusion experiment consisted of two main treatments, i.e., «protected» leaves, where predators had no access, and «free» leaves where predators had unlimited access to aphid colonies. In the «protected» leaves an insect glue barrier on the leaf petioles prevented an attack by crawling predators, i.e., mainly coccinellid, syrphid and chrysopid larvae. The control consisted of leaves where predators had free access to the aphid colonies. Twenty pairs of «protected» and «free» leaves were selected randomly in each insecticide treated «ST» and untreated «NT» plot, except in 1998 in Ambato-Boeni when ten pairs per plot were selected. Similar pairs of leaves with regard to plant stratum and position on the branch (main stem leaf or leaf of higher order) were chosen in order to minimise bias when comparing the two groups. Results from previous experiments had shown that aphid population growth is affected by these two factors (cf. chapter 3). The number of aphids and of aphidophagous predators (only the active predatory stages) were counted on the same leaves throughout the season. Accidentally present predators on «protected» leaves, mostly flying adults, were removed and for the respective sampling date, these leaves were excluded from data analysis. Also, when leaves had dropped and had to be replaced, these data were recorded as missing values for the respective sampling occasion.

In 1997, counts started in Ambato-Boeni on June 30 and continued every two or three days until August 30. The following year, the colonies were generally examined daily from June 23 until September 15. In Ampasikibo, the aphids were counted every two or three days from February 20 until April 25.

Mean number differences in aphid densities between «protected» and «free» colonies were tested separately for «ST» and «NT» treatments with a two sided t-test for each sampling occasion (Zar 1974).

A precise estimation of the predators' impact on aphid population dynamics in «free» colonies proved to be more difficult. No generally applicable method exists to account for predation as mortality factor under field conditions (Luck et al. 1988, Jarvis and Kidd 1996).

Chambers and Aikman (1988), referring to an older model by Bombosch (1963), presented a formula which describes aphid density as a function of the initial density, the rate of increase of the aphid population in the absence of predators and the rate of kill of the predators:

$$[1] N_t = N_0 e^{at} \left(\frac{1 - kP}{aN_0} + \frac{kP}{a} \right),$$

where N_t is the number of aphids after t days, N_0 is the initial aphid number and at is the rate of increase of the aphid population in the absence of predation after t days; the product of P , number of predators, and k , numbers of consumed aphids per predator during the time interval t , is the "rate of kill".

Thus, the "rate of kill" is supposed to be constant within the time unit t . If predator density changes within a sampling interval, Chambers and Aikman (1988) suggested to assume that this change is linear. The formula then becomes:

$$[2] N_t = N_0 e^{at} + k/a \left\{ \left(P_0 + \frac{b}{a} \right) (1 - e^{at}) + bt \right\},$$

where P_0 is the predator density at the beginning of the time interval and b is the proportional rate of density change calculated by $(P_t - P_0)/t$.

The parameter a is derived from density data of «protected» colonies at the start and at the end of the respective time interval by:

$$[3] a = \frac{\ln N_t - \ln N_0}{t}.$$

When [2] is solved for k , an estimate of the kill per predator which would have been necessary to cause the observed change in «free» colonies during the time unit t is obtained:

$$[4] k = a(N_t - N_0 e^{at}) / \left\{ P_0 + \frac{b}{a} + bt - e^{at} \left(P_0 + \frac{b}{a} \right) \right\} \text{ (Chambers and Aikman 1988).}$$

This “required kill per predator” can then be compared to data on “potential kill per predator” from tests in the laboratory.

In order to evaluate potential kill rates, aphid predator eggs were collected in the field and larvae reared in plastic vials until adult emergence in a simple field laboratory without regulation of temperature. Predator larvae were daily offered field collected *A. gossypii* ad libitum (with no distinction of instars). Ten control colonies without predators were held to calculate the baseline mortality of the aphids, which were subtracted from the feeding capacity of each instar per day. The voracity of coccinellid adults was not determined but assumed to be 75% of the feeding capacity of 4th instar larvae (Hodek and Honěk 1996). The tests were conducted in March 1998 in Ampasikibo, when daily average temperatures were around 27°C, and in July/August 1998 in Ambato-Boeni. No meteorological data could be recorded in Ambato-Boeni, but average temperatures during this period are usually around 24-25°C (Berger 1979).

4.4. Results

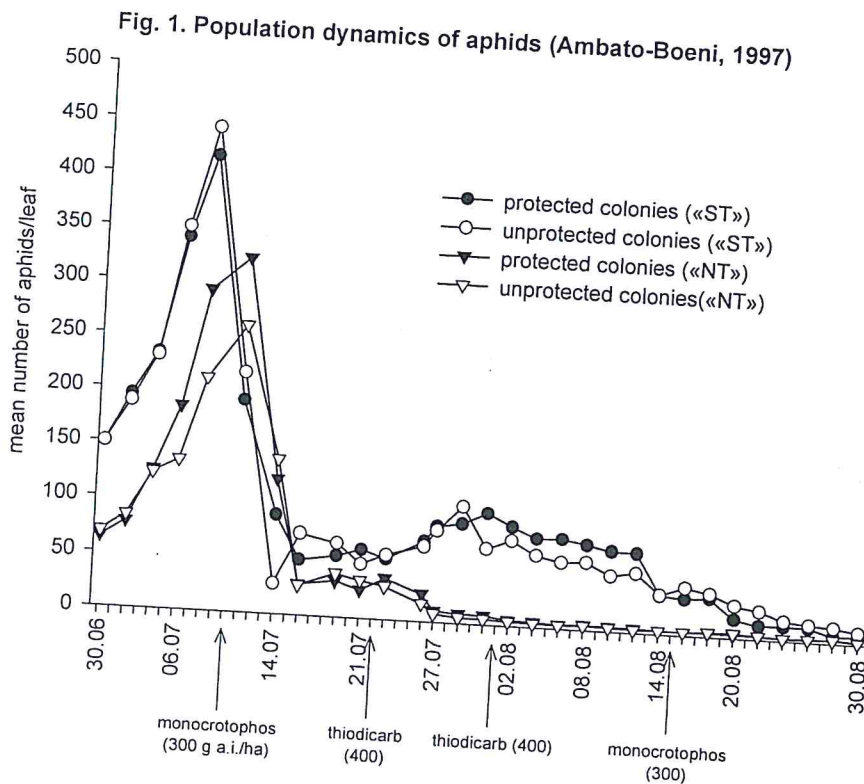
Considerable aphid infestations were encountered in both years in Ambato-Boeni, the north-western site. Population dynamics were characterised by a first sharp peak during flowering (1998) or during the early boll period (1997) and a second broader and longer peak, during boll maturation late July/August (fig. 1 and 3). In 1997, however, no second peak was observed in the NT» plots.

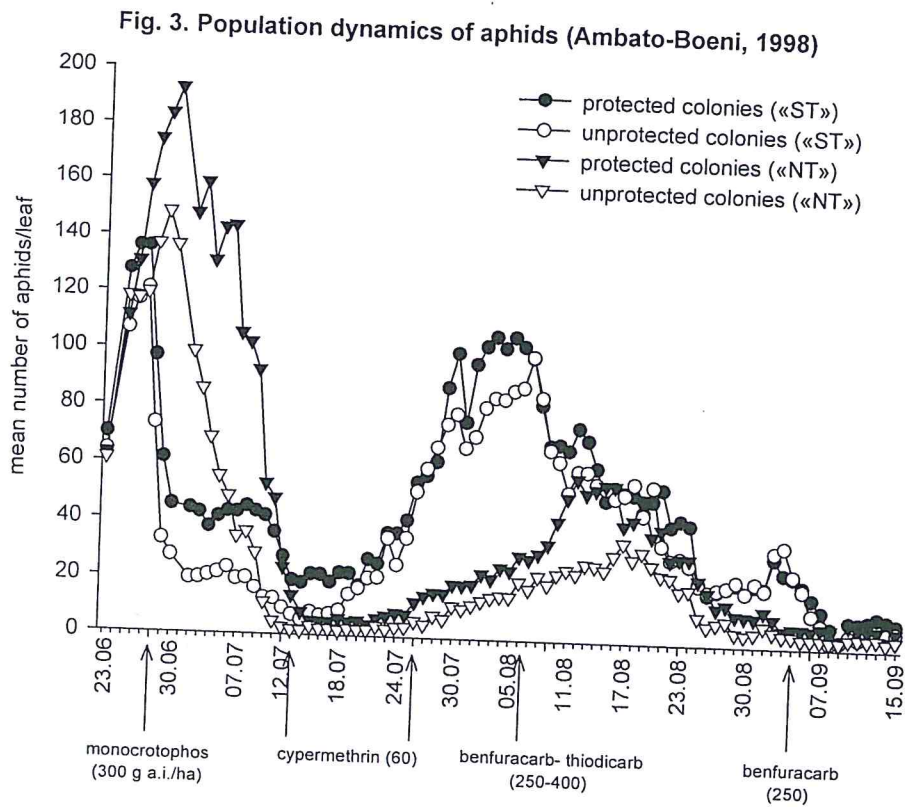
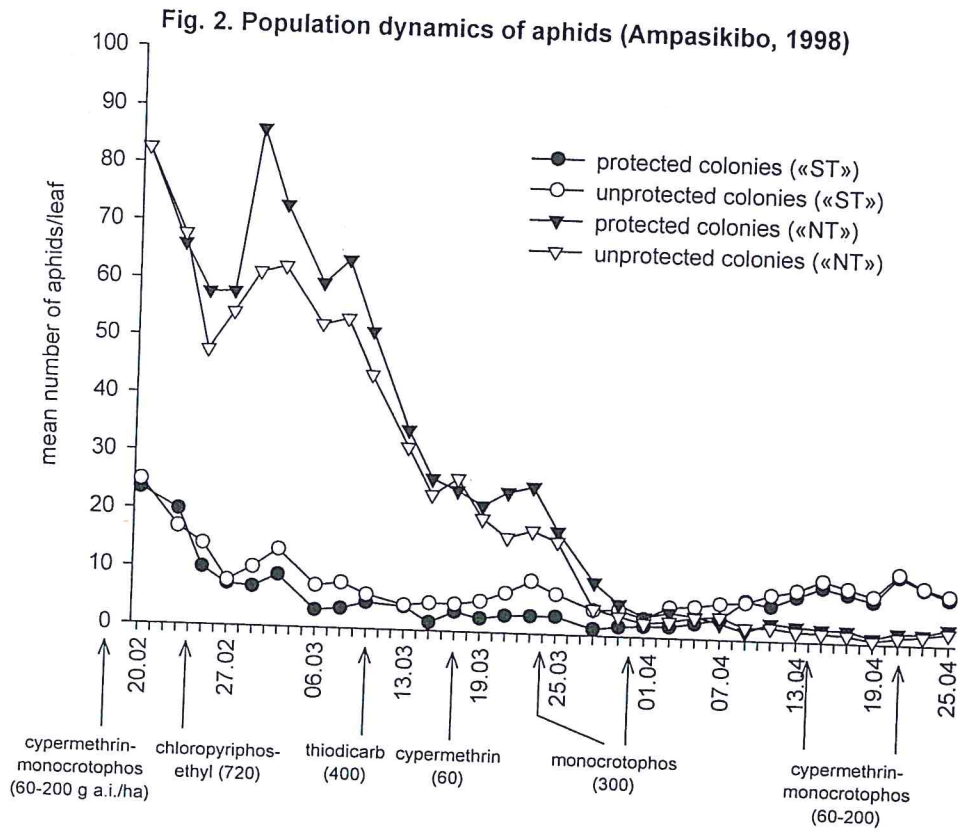
For logistic reasons, the trial at the south-western site in Ampasikibo site could not commence before the peak of the aphid population. By then, an aphicidal monocrotophos treatment had already been carried out in «ST» plots on 18/02. From the beginning of March onwards, many leaves had to be replaced due to of intensive drought. New leaves may then not have been selected completely at random by the observers but biased towards higher aphid densities, especially in the «ST» plots.

Nevertheless, untreated populations increased to much higher densities, and this tendency was only reversed in the course of April (fig. 2).

In all three experiments, the treatment effect "insecticide applications" («ST»-«NT») dominated over the treatment effect "predator exclusion" («protected»-«free» colonies). However, the basic similarity of infestation patterns in all four treatments, characterised by a sharp population increase during the flowering period and a rapid subsequent decline, indicated that factors other than insecticides and predators, such as the nutritional suitability of the cotton host plant at bloom, had an important impact on the aphids' population dynamics.

Apparently, some insecticide sprayings which had been carried out before the start of the trials, influenced the subsequent development of the aphid populations. However, the effects of the chemicals were contradictory: whereas in Ampasikibo, an aphicidal spraying on 18/02 with cypermethrin-monocrotopfos considerably reduced subsequent aphid densities (fig. 2), the cypermethrin treatments in Ambato-Boeni on 17/06/1997 (before the start of the experiment) and on 13/07 and 26/07/98 lead to higher aphid infestations in the «ST» than in the «NT» plots (cf. chapter 2).





In all three experiments, the aphid predator guild was likely to have influenced aphid numbers in «free» colonies. For instance in «NT» plots in Ambato-Boeni 1997, aphid densities in «protected» colonies were significantly higher than in «free» colonies during the five days before the peak in July (table 2). Moreover, periods where aphid densities between «free» and «protected» did not differ significantly coincided with low predator abundance.

Table 2. Population dynamics of *A. gossypii* in Ambato-Boeni 1997 and significance test ($\alpha = 0.05$) of difference between «protected» and «free» colonies

date	protected colonies (ST)	free colonies (ST)	protected colonies (NT)	free colonies (NT)	P of t-test $\bar{X}_{(prot)} = \bar{X}_{(free)}$ (ST)	P of t-test $\bar{X}_{(prot)} = \bar{X}_{(free)}$ (NT)
30.06	150.0	150.0	64.0	68.8	0.998	
02.07	194.1	188.1	78.0	84.2	0.762	0.474
04.07	233.6	231.0	126.1	123.9	0.915	0.450
06.07	340.7	350.7	184.9	135.8	0.786	0.881
08.07	416.6	443.0	292.6	211.6	0.553	0.009
11.07	192.3	217.9	323.1	261.1	0.491	0.040
14.07	89.7	27.8	121.7	140.1	0.020	0.031
16.07	50.1	74.0	28.3	27.4	0.092	0.514
19.07	55.4	66.9	33.0	39.7	0.263	0.944
21.07	62.2	49.2	25.8	34.6	0.239	0.555
23.07	55.1	58.8	37.3	30.3	0.725	0.268
26.07	72.3	68.0	25.3	16.3	0.702	0.327
27.07	86.7	82.9	10.4	7.6	0.793	0.347
29.07	90.2	105.7	8.6	5.2	0.444	0.259
31.07	100.7	69.0	8.4	5.0	0.020	0.035
02.08	89.9	77.5	5.3	4.1	0.386	0.044
04.08	80.3	65.4	4.9	3.4	0.275	0.208
06.08	81.4	60.6	3.9	3.3	0.151	0.164
08.08	77.4	61.7	4.9	4.2	0.146	0.492
10.08	72.6	50.8	4.3	3.6	0.079	0.548
12.08	72.1	54.4	4.2	2.9	0.104	0.464
14.08	35.5	36.0	3.4	3.3	0.965	0.202
16.08	33.5	43.7	3.4	3.4	0.419	0.924
18.08	35.1	39.3	3.8	4.4	0.664	0.974
20.08	17.3	30.0	3.2	4.6	0.073	0.586
22.08	12.7	25.9	3.0	3.4	0.049	0.101
24.08	13.2	17.9	2.3	2.4	0.199	0.532
26.08	12.8	15.7	2.5	2.8	0.454	0.836
28.08	6.6	14.2	3.2	3.2	0.001	0.699
30.08	6.8	10.6	2.1	1.6	0.103	1.000
						0.368

Figure 4 shows that in 1997, predators were basically absent in «free» colonies in the insecticide treated «ST» plots. Significantly higher aphid densities in «protected» compared to «free» colonies were recorded only twice in the «ST» treatment (table 2). In 1998, significant lower densities on «free» compared to «protected» leaves were observed from end of June until mid-July in «ST» and throughout July until mid-August in «NT» plots (table 4). This coincided with a strong presence of aphidophagous predators, except for the second half of July in «NT» when aphid

densities remained stable on a very low level (fig. 6 and table 4). The high predator numbers in «ST» were probably due to more inter-plot migration of adult predators as a result of smaller plot size and narrower alleys at the Ambato-Boeni site in 1998. This was also reflected by smaller ratios of predator densities on «free» and on «protected» leaves (table 5). Nevertheless, the experimental design generally succeeded in excluding predators from «protected» aphids. The average predator density per leaf in «protected» colonies was only 0.011 in both treated and in untreated plots, which was 7.3 fold and 11.1 fold less, respectively, than on «free» leaves.

Table 3. Population dynamics of *A. gossypii* in Ampasikibo 1998 and significance test ($\alpha = 0.05$) of difference between «protected» and «free» colonies

date	protected colonies (ST)	free colonies (ST)	protected colonies (NT)	free colonies (NT)	P of t-test	
					$\bar{X}_{(prot)} = \bar{X}_{(free)}$ (ST)	$\bar{X}_{(prot)} = \bar{X}_{(free)}$ (NT)
20.02	23.5	24.9	82.4	82.5	0.997	0.678
23.02	19.9	17.0	65.9	67.7	0.857	0.358
25.02	10.0	14.1	57.7	47.5	0.285	0.270
27.02	7.2	7.9	57.7	54.2	0.696	0.248
01.03	6.9	10.2	86.1	61.3	0.191	0.050
03.03	8.9	13.3	72.8	62.3	0.347	0.097
06.03	3.0	7.3	59.6	52.4	0.472	0.050
08.03	3.4	7.9	63.7	53.4	0.276	0.217
10.03	4.6	5.9	51.3	43.8	0.431	0.631
13.03	4.1	4.3	34.5	31.4	0.657	0.915
15.03	1.4	4.8	26.2	23.4	0.622	0.072
17.03	3.3	4.7	24.2	26.3	0.687	0.515
19.03	2.3	5.3	21.8	19.6	0.624	0.172
21.03	3.0	6.9	24.2	16.5	0.121	0.161
23.03	3.0	9.1	25.3	17.7	0.200	0.018
25.03	3.0	6.9	17.8	16.0	0.742	0.088
28.03	1.1	4.4	9.2	4.6	0.129	0.029
30.03	1.7	4.6	5.6	3.4	0.180	0.063
01.04	1.9	3.2	3.5	2.4	0.281	0.129
03.04	1.9	5.3	4.4	2.8	0.149	0.008
05.04	2.7	5.5	3.8	3.7	0.883	0.126
07.04	3.4	6.2	2.7	3.9	0.467	0.092
09.04	6.8	6.5	1.5	2.2	0.497	0.906
11.04	5.9	7.9	3.0	2.3	0.615	0.378
13.04	7.7	8.8	2.6	1.7	0.495	0.671
15.04	9.4	10.6	2.3	1.5	0.402	0.683
17.04	8.4	9.4	2.2	1.3	0.369	0.704
19.04	7.3	8.1	1.0	0.5	0.186	0.711
21.04	11.6	12.1	2.0	1.2	0.394	0.888
23.04	9.7	9.8	1.9	1.5	0.723	0.961
25.04	8.0	8.5	2.9	2.2	0.574	0.831

In Ampasikibo in 1998, no apparent exclusion effect was observed in the «ST» plots, most likely due to extremely low predator numbers (pooled over the season only 0.044 individuals/leaf). In the untreated «NT» plots, average predator densities were

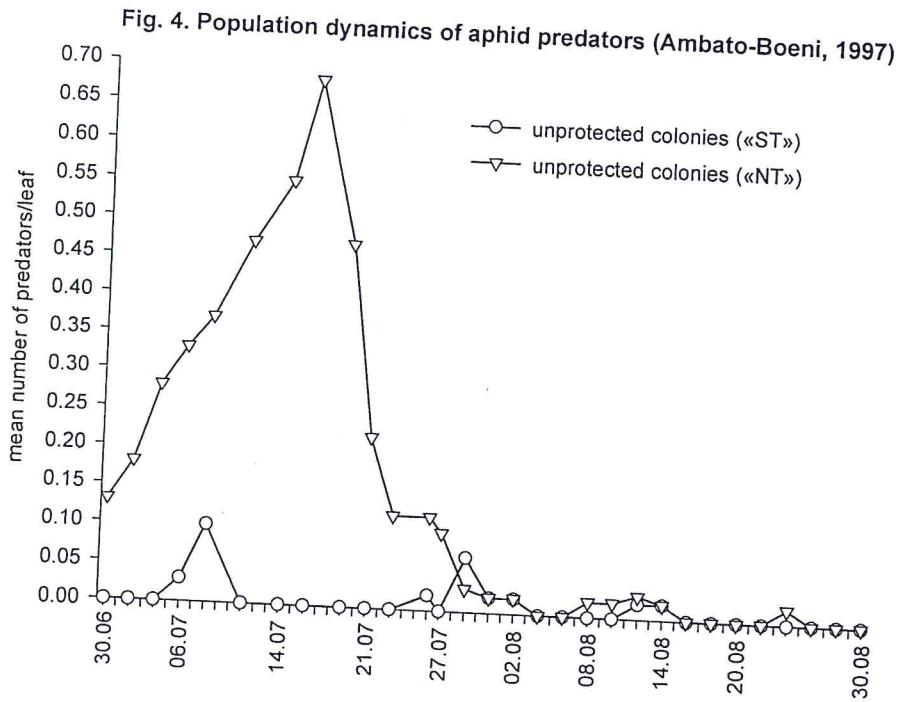
much lower than in both years in Ambato-Boeni (fig. 5). Shortly after the peak, numbers of «protected» aphids were higher than those on «free» leaves, but the significance tests were very close to the critical $\alpha = 0.05$ value (table 3).

Table 4. Population dynamics of *A. gossypii* in Ambato-Boeni 1998 and significance test ($\alpha = 0.05$) of difference between «protected» and «free» colonies

date	protected	free	protected	free	P of t-test	
	colonies (ST)	colonies (ST)	colonies (NT)	colonies (NT)	$\bar{X}_{(prot)} = \bar{X}_{(free)}$ (ST)	$\bar{X}_{(prot)} = \bar{X}_{(free)}$ (NT)
23.06.	70.0	63.9	62.7	61.0	0.466	0.832
25.06.	127.6	106.9	111.3	118.1	0.228	0.713
26.06.	136.0	117.0	130.6	117.4	0.305	0.469
27.06.	135.8	121.0	157.8	119.5	0.470	0.082
28.06.	97.2	73.6	174.2	137.0	0.076	0.099
29.06.	61.5	33.1	183.5	148.4	0.007	0.177
30.06.	45.1	27.3	192.6	136.5	0.057	0.040
02.07.	43.8	19.4	148.0	99.1	0.013	0.007
03.07.	42.6	19.6	159.0	86.1	0.020	<0.001
04.07.	37.5	20.5	131.0	68.9	0.068	0.001
05.07.	41.2	21.5	143.1	55.5	0.107	<0.001
06.07.	43.1	23.4	143.9	48.5	0.139	<0.001
07.07.	43.0	19.4	105.8	34.3	0.069	<0.001
08.07.	44.9	19.9	102.6	36.0	0.059	0.004
09.07.	43.3	16.4	92.9	28.7	0.041	0.004
10.07.	41.8	12.8	53.1	11.3	0.024	0.010
11.07.	36.0	12.7	47.9	4.6	0.040	0.005
12.07.	27.5	9.4	23.6	2.5	0.037	0.002
13.07.	19.3	7.0	13.9	1.7	0.126	0.007
14.07.	18.4	5.4	8.0	1.5	0.070	0.013
15.07.	21.6	8.2	4.9	3.0	0.106	0.191
16.07.	21.4	7.0	4.8	2.1	0.082	0.033
17.07.	18.8	7.6	4.8	2.1	0.103	0.037
18.07.	22.3	9.0	5.9	1.8	0.093	0.003
19.07.	22.1	14.7	4.9	2.3	0.273	0.029
20.07.	17.9	17.0	5.3	2.1	0.879	0.010
21.07.	27.2	20.7	4.1	2.2	0.437	0.092
22.07.	25.8	21.0	6.2	3.6	0.609	0.033
23.07.	36.6	34.8	7.2	2.7	0.873	0.003
24.07.	36.7	25.5	8.4	3.5	0.320	0.009
25.07.	41.3	35.1	8.0	3.6	0.635	0.007
26.07.	54.6	51.5	12.4	5.8	0.827	0.023
27.07.	57.2	59.7	14.8	4.7	0.870	0.007
28.07.	62.2	67.2	16.0	8.0	0.762	0.033
29.07.	88.3	75.4	15.9	6.8	0.613	0.022
30.07.	100.5	79.1	19.2	11.5	0.269	0.092
31.07.	76.2	67.2	18.9	10.6	0.541	0.111
01.08.	96.9	71.3	19.3	12.0	0.117	0.115
02.08.	103.1	81.6	23.2	13.6	0.197	0.176
03.08.	106.7	85.2	21.6	14.8	0.211	0.170
04.08.	102.7	84.7	25.6	15.6	0.311	0.137
05.08.	106.7	87.8	24.6	15.3	0.278	0.073
06.08.	103.4	89.0	29.9	20.7	0.365	0.071
07.08.	99.5	99.9	28.8	18.3	0.985	0.070
08.08.	82.9	85.6	30.8	22.9	0.867	0.288
09.08.	68.6	67.1	34.3	20.1	0.910	0.046
10.08.	69.1	63.1	42.3	23.7	0.651	0.045
11.08.	67.2	52.6	50.6	25.5	0.203	0.058
12.08.	75.2	59.9	57.5	24.1	0.290	0.018
13.08.	70.9	59.9	52.4	27.6	0.408	0.074
14.08.	61.2	55.6	53.9	27.1	0.610	0.126
15.08.	50.0	54.3	55.4	25.6	0.661	0.051
16.08.	54.6	51.0	55.3	30.9	0.718	0.171

Table 4
(cont.)

17.08.	52.9	52.2	41.5	35.5	0.946	0.634
18.08.	52.2	56.2	43.4	29.7	0.719	0.317
19.08.	46.2	45.1	51.3	32.4	0.890	0.282
20.08.	50.3	55.2	38.0	27.7	0.686	0.432
21.08.	54.4	34.9	40.3	24.3	0.071	0.319
22.08.	41.5	29.7	29.9	23.7	0.187	0.664
23.08.	43.6	30.5	30.5	19.0	0.159	0.316
24.08.	42.0	28.0	30.5	19.5	0.098	0.336
25.08.	22.1	21.2	23.0	10.1	0.896	0.023
26.08.	17.9	18.9	18.8	6.9	0.875	0.005
27.08.	19.4	19.9	13.3	7.9	0.943	0.128
28.08.	20.8	20.6	14.7	8.9	0.980	0.093
29.08.	22.0	22.8	11.0	4.9	0.909	0.012
30.08.	19.0	18.9	10.7	4.3	0.980	0.007
01.09.	21.7	22.5	10.3	5.0	0.889	0.052
02.09.	20.6	20.1	12.6	7.5	0.909	0.055
03.09.	31.3	33.5	10.2	5.6	0.661	0.076
04.09.	25.8	35.4	6.1	4.4	0.238	0.362
05.09.	24.7	25.4	6.9	4.3	0.892	0.111
06.09.	21.5	20.3	6.9	3.3	0.790	0.062
07.09.	17.4	11.8	6.4	3.3	0.085	0.085
08.09.	12.9	8.3	7.3	3.2	0.021	0.042
09.09.	7.4	2.4	7.1	2.8	0.017	0.081
10.09.	2.8	2.6	3.3	2.6	0.856	0.264
11.09.	9.7	4.8	8.9	3.8	0.056	0.046
12.09.	9.3	4.0	7.5	4.0	0.049	0.062
13.09.	10.0	5.8	6.9	3.6	0.227	0.079
14.09.	11.3	5.8	6.9	4.0	0.122	0.181
15.09.	10.4	5.8	3.7	2.7	0.180	0.179
	9.1	6.4	6.5	3.6	0.408	0.223



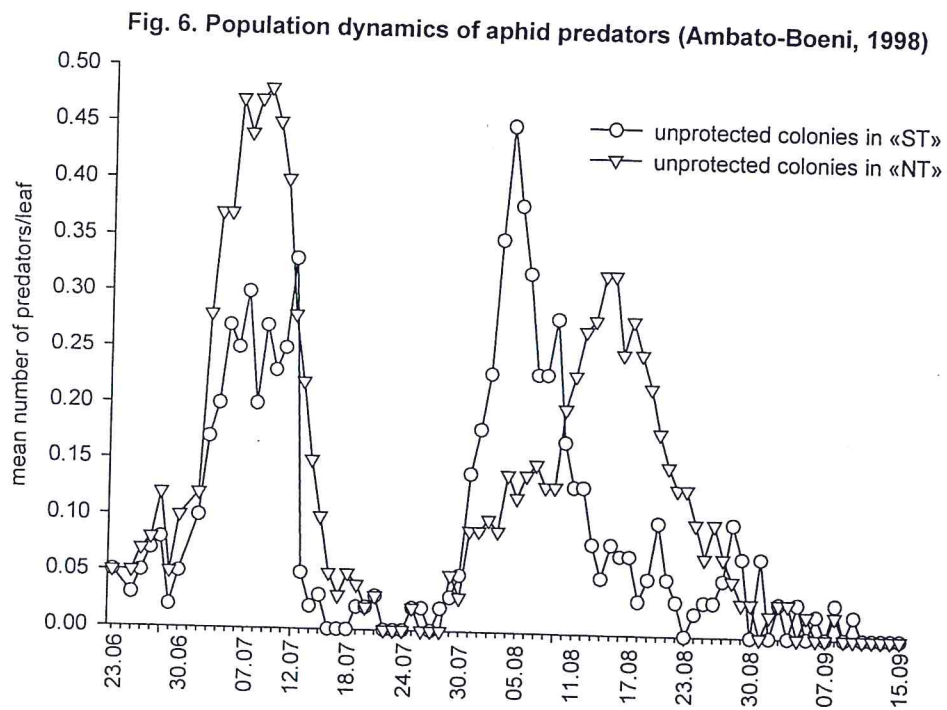
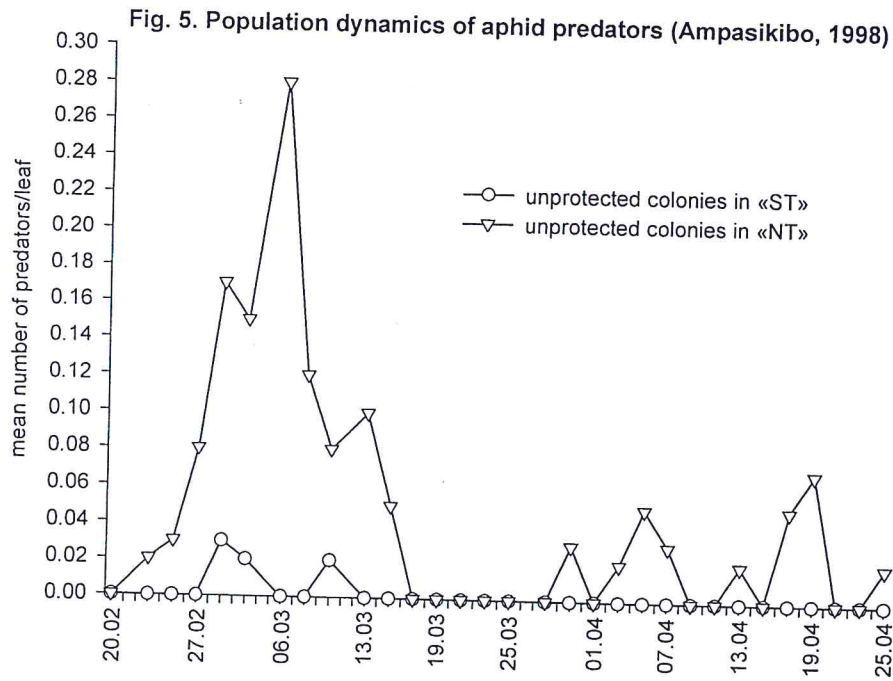


Table 5. Ratio of predator densities on «free» and «protected» leaves (pooled data across one season)

Ambato-Boeni 1997		Ampasikibo 1998		Ambato-Boeni 1998	
«ST»	«NT»	«ST»	«NT»	«ST»	«NT»
17.0	15.7	-	13.7	11.1	7.3

The predator complex was composed of five species of Coccinellidae (*Cheilomenes simulans* Crotch, *C. sulphurea* Olivier, *Elpis dolens* Mulsant, *Exochomus laeviusculus* Weise, *Scymnus constrictus* Mulsant), two Syrphidae (*Ischiodon aegyptius* (Wiedemann), *Paragus borbonicus* Macquart), one Chrysopidae (*Mallada desjardinsi* Navas) and one Hemerobiidae (*Micromus plagatus* Navas).

Other predators, some of which are essentially nocturnal, such as polyphagous Carabidae (*Ctenosta grandidieri* Maindron, *C. senegalense* Dejean, and others) and spiders (Oxyopidae, Salticidae, Thomisidae, and others), heteropterous predators (Pentatomidae and Reduviidae) which mainly feed on caterpillars, and larvae of mantids (Empusidae) may also play a role as aphid enemies when more suitable prey such as caterpillars becomes scarce, but their impact on cotton aphid populations is probably more erratic. They were rarely encountered in samples and not quantified. No aphid parasitoids were recorded. Aphid cadavers with visible signs of mycosis, killed by the entomophthoral fungus *Neozygites fresenii* (Nowakowski), were noticed both in Ampasikibo and in Ambato-Boeni in 1998, but the impact of the pathogen could not be quantified.

All mentioned aphid predator species occurred at both sites, but their proportions were quite different. *Cheilomenes simulans* was the most important aphid natural enemy in the north-west, representing 52 % of the total number of all active predatory individuals found on free leaves during the two year study in Ambato-Boeni. In 1998, this coccinellid was able to accomplish three generations due to the extended duration of aphid infestation. *Scymnus constrictus* and *I. aegyptius* were the predominating beneficials at bloom in Ampasikibo. In rainfed cotton, Neuroptera only appeared during the cool season, i.e., from March onwards, and thus, did not have any influence on mid-season aphid infestation.

Table 6 summarises the data on daily consumption rates of the different predator species. In Ampasikibo, the extremely low densities of predators in the field limited the number of replications in the consumption experiments. Moreover, the scarcity of

prey, which had to be collected in the field, may have led to an under-estimation of the potential feeding capacity of predators in Ampasikibo. It was impossible to rear first instars of *S. constrictus*, *P. borbonicus* and *I. aegyptius* (and also the second instar of the latter species), because (i) eggs were difficult to find in the field and (ii) neonate larvae turned out to be very susceptible to succumb to stress. The voracity of young Neuroptera larvae was assumed to be 15 % (1st instar) and 30 % (2nd instar), respectively, of the consumption of the 3rd instar (Tawfik et al. 1974). The daily consumption of 1st instar *S. constrictus* was estimated to 10.1 aphids/day. This is approximately 15 % of the total consumption of L2-L4, which was derived from the values for the four other coccinellids.

Table 6. Average daily consumption of aphids by predator species
*Ambato-Boeni **Ampasikibo

predator species	number of <i>A. gossypii</i> consumed per day \pm SE				total consumption during larval development Σ L1-4 \pm SE (n)
	L1	L2	L3	L4	
<u>Coccinellidae</u>					
<i>C. simulans</i> *	13.2 \pm 1.2	23.7 \pm 1.3	31.3 \pm 2.2	39.6 \pm 2.3	241.0 \pm 8.8 (44)
<i>C. simulans</i> **	20.9 \pm 5.4	22.9 \pm 1.8	39.6 \pm 3.7	67.1 \pm 22.8	254.8 \pm 27.0 (5)
<i>C. sulphurea</i> *	16.8 \pm 1.3	29.3 \pm 1.9	39.9 \pm 1.9	50.2 \pm 1.7	435.5 \pm 13.0 (56)
<i>C. sulphurea</i> **	22.8 \pm 7.8	25.4 \pm 2.5	29.7 \pm 5.9	66.7 \pm 4.0	363.3 \pm 17.3 (3)
<i>E. dolens</i> *	10.7 \pm 1.4	21.1 \pm 2.1	28.1 \pm 2.7	37.5 \pm 5.4	238.7 \pm 16.4 (24)
<i>E. laeviusculus</i> *	8.3 \pm 1.3	12.1 \pm 2.3	18.6 \pm 2.1	27.3 \pm 1.8	297.3 \pm 21.8 (15)
<i>S. constrictus</i> **	10.1	13.2 \pm 1.6	16.7 \pm 1.2	37.1 \pm 2.8	123.7 \pm 6.5 (33) ¹
<u>Chrysopidae</u>					
<i>M. desjardinsi</i> *	9.5 \pm 0.8	13.6 \pm 0.9	23.1 \pm 1.8	—	197.6 \pm 8.3 (46)
<i>M. desjardinsi</i> **	13.9 \pm 2.4	29.1 \pm 1.4	30.2 \pm 0.6	—	208.1 \pm 17.3 (13)
<u>Hemerobiidae</u>					
<i>M. plagatus</i> *	6.7 \pm 1.0	15.3 \pm 1.2	24.4 \pm 2.1	—	95.5 \pm 6.2 (20)
<u>Syrphidae</u>					
<i>I. aegyptius</i> **	12.1	24.2	80.6 \pm 7.3	—	116.9
<i>P. borbonicus</i> **	6.2	22.8 \pm 2.0	41.1 \pm 4.7	—	70.1

values in italic are estimates (see text) ¹ sum of L2-L4 only

“Required kill” values could only be calculated for short periods at the Ambato-Boeni site (04/07-11/07/1997 and 08/08-12/08/1998), because the model of Chambers and Aikman (1988) requires that the aphids’ “background increase rate” is only calculated for the exponential growth phase in non-limiting conditions. This can only be

assumed for the period before the peak of the aphid population. In 1998, the densities on «protected» and «free» leaves were not significantly different, neither in «ST» nor in «NT» plots during the period prior to peak at the end of June (table 4). However, the growth phase before the second peak in the «NT» plots (08/08-12/08) was considered to be consistent with the prerequisites of the model. For the above mentioned reasons, the Ampasikibo data could not be analysed with the model.

During the period between 04/07 and 11/07/1997 in «NT» plots, the increase rate of *A. gossypii* in the absence of predators was $a = 0.134$, the initial aphid density on «free» leaves was $N_0 = 123.9$, the density after seven days was $N_t = 261.1$ and the initial predator density was $P_0 = 0.280$ with a positive linear increase of $b = 0.027$ per day. This results in

$$0.134 \cdot (261.1 - 123.9e^{0.134 \cdot 7}) / \left\{ 0.28 + \frac{0.027}{0.134} + 0.027 \cdot 7 - e^{0.134 \cdot 7} \left(0.28 + \frac{0.027}{0.134} \right) \right\} = 13.3,$$

which is the number of aphids which must have been killed daily per predator in order to relate the observed differences in aphid densities between «free» and «protected» colonies to predation only. The potential daily kill per predator for the different predator instars and species present in the field samples were calculated to be 26.5 [19.9; 33.1].

For the period 08/08-12/08/1998 in Ambato-Boeni, the model yielded the following result:

$$0.156 \cdot (24.1 - 22.9e^{0.156 \cdot 4}) / \left\{ 0.13 + \frac{0.025}{0.156} + 0.025 \cdot 4 - e^{0.156 \cdot 4} \left(0.13 + \frac{0.025}{0.156} \right) \right\} = 19.2,$$

which is to be compared to a potential kill of 24.9 [21.5; 28.3].

These simple comparisons would suggest that the predator guild may easily have caused the observed aphid density differences between «protected» and «free» colonies.

4.5. Discussion

The destruction of predator populations may be an important factor for pest resurgence of *A. gossypii* in Malagasy cotton. Comparison of density data of protected with predator exposed aphid colonies in untreated plots suggests that natural enemies have a significant effect on the population dynamics of the pest. However, the control potential is more promising in receding flood cotton than in the rainfed crop. The

1997 exclusion trial in Ambato-Boeni clearly demonstrated that aphid outbreaks in the north-west are related to chemical control of boll feeding pests, in particular of *H. armigera*. Apart from the quite expensive carbamates benfuracarb and carbosulfan, which are preferably sprayed against late-season aphid infestations, monocrotophos is the only true aphicide currently used in Malagasy cotton. Cypermethrin and thiodicarb, the two main assets for bollworm control, are inefficient against aphids, and at least cypermethrin is strongly suspected to favour reproduction of *A. gossypii* populations (cf. chapter 3). Cypermethrin, thiodicarb and monocrotophos, have been shown to be extremely detrimental for *C. simulans* larvae (cf. chapter 2). Thus, the combined effects of insecticide-induced reproduction stimuli and exclusion of predator most likely caused the aphid outbreak in the 1997 «ST» plots in Ambato-Boeni, with densities exceeding 400 aphids/leaf (fig. 1).

However, no straightforward relationship between predator numbers and aphid population density changes could be established. The peak density of predators lagged behind that of their aphid prey, and the influence of the natural enemies on the population decline of *A. gossypii* cannot not be clearly distinguished from other effects like intra-specific competition or deteriorating host plant quality (Van Emden 1966, Frazer 1987). The applicability of the model of Chambers and Aikman (1988) is restricted to periods of “unlimited growth”. This assumption was only fulfilled for the periods from 04/07-11/07/97 and 08/08-12/08/98 in Ambato-Boeni, and required daily kill rates of 13.3 and 19.2 aphids per predator individual, were calculated for these two time intervals. Potential kill estimates derived from field laboratory data were superior to these values, but kill rates in captivity are likely to over-estimate field kill rates, because predators were fed ad libitum with prey, and no search capacity limits or prey switching behaviour were considered. For example, Neuroptera larvae are likely to be diverted from aphids when small lepidopteran larvae are present (Kabissa et al. 1995, 1996).

However, calculated values for “required kill” must be interpreted with precaution. Stewart and Dixon (1988) criticised the approach of Chambers and Aikman (1988) for lacking procedures to determine the variability of the estimates. Formula [4] contains five parameters, each of which is not free from error. The largest variability is connected to the aphids’ “background increase rate” a , calculated from «protected» colonies. When a is determined with the upper and the lower 95 % confidence limits of the density estimates to yield the smallest and highest increase rate for the time

period t , e.g., for the period 04/07-11/07/97, $a = 0.07$ and 0.215 , respectively, the required kill for t would be $k_{\min} = -17.8$, which cannot be interpreted, and $k_{\max} = 51.8$, respectively. When the other parameters are varied in the same way, the gap widens even further. Thus, with this method, the possibility that predators contributed to a negative population change in exposed aphid colonies should only be rejected if k values are very large.

Several factors may favour predators in the north-western receding flood cotton compared to rainfed cotton in south-western Madagascar. Firstly, the natural enemies benefit from the absence of a close season in the receding flood cropping system. Alternative aphid prey in crops such as maize (infested by *Rhopalosiphum maidis* (Fitch)) or legumes (hosts of *Aphis craccivora* Koch) are cultivated on the surrounding hillsides during the inundation period. Secondly, the rate of increase of *A. gossypii* is slower in the dry season than in the hot rainy season in south-western Madagascar, probably due to lower temperatures (cf. chapter 3). Both factors allow for a better temporal overlap of predator and prey populations.

The great differences in predator numbers which were observed between the two experimental sites are mainly due to the coccinellid *C. simulans*. In Ambato-Boeni, this species was abundant right from the beginning of the exponential growth phase of the aphid population. By contrast, in Ampasikibo *C. simulans* was only occasionally recorded during the hot, rainy season and appeared more regularly only in the course of April, when the aphid infestation had already collapsed. A similar trend was observed for the lacewing *M. desjardinsi*, with densities peaking in April, when aphid predators rely on alternative prey. These two species may have a relatively low optimum development temperature with implications for their efficacy at very high maximum temperatures ($>35^{\circ}\text{C}$) regularly occurring in Ampasikibo until April (Grouzis and Rocheteau 1998). This would explain the differences in the observed total egg:adult-ratio for *C. simulans* of 1.27 and 5.56 in Ampasikibo and Ambato-Boeni, respectively. Heavy rainfall and strong winds may also have disastrous effects on young predator larvae, as shown by the results of a previous experiment (cf. chapter 2).

So far, the economic and ecological benefits of integrating natural enemies in crop protection management decisions remain to be demonstrated in Malagasy cotton. All predator species are recorded for the first time from receding flood cotton in Madagascar. More detailed studies are needed to elucidate the effect of currently

recommended insecticides on the population dynamics of *A. gossypii*. In particular, the potential growth stimulus of cypermethrin on the aphids merits further investigations. However, it can be recommended to use the pyrethroid only in combination with the aphicide monocrotophos. Moreover, as long as pre-established calendar sprayings, regardless of pest densities in the field, prevail, no additional interventions against aphids should be scheduled at all. The economic impact of light to modest aphid infestations is probably over-rated (cf. chapter 3) and confounded with damage caused by other herbivores. When treatments against the American bollworm *H. armigera* are indispensable, they can be carried out efficiently with other products, such as endosulfan or profenofos, which are less toxic to *C. simulans* (cf. chapter 2). This option would be particularly interesting during flowering, when the coincidence of pest pressure by bollworms, the foliage-boll feeder *Spodoptera littoralis* Boisduval (Lep.: Noctuidae) and *A. gossypii* makes it difficult to integrate natural enemies into pest management decisions.

5. Field tests of control efficacy of neem oil extracts and synthetic insecticides against key pests of rainfed cotton in Madagascar

5.1. Abstract

The pest control efficacy of foliar applications of two neem oil extracts and of a synthetic insecticide regime were compared in a field trial in rainfed cotton in southwestern Madagascar. The neem extracts failed to control any of the major pests, i.e., *Helicoverpa armigera* Hübner, *Spodoptera littoralis* (Boisduval) (both Lep.: Noctuidae) and *Aphis gossypii* Glover (Hom.: Aphididae). Seasonal population dynamics of these species in neem treated plots did generally not differ significantly from those in the untreated control. Plots treated with cypermethrin and thiodicarb were significantly less infested when pest pressure was high during bloom and resulted in almost three to four fold higher raw cotton yields. However, the performance of a total of six insecticide treatments based on very low thresholds was expected to turn out even more superior to the control. Detailed analysis of efficacy against the two noctuids revealed somewhat arbitrary results referring to fundamental sampling problems at very low densities. Taylor's power law were used to estimate optimum sample sizes and to obtain an estimation of precision which is reached at pre-established conventional sample sizes. The low level of reliability at conventional sample sizes may explain inconsistencies in management decisions and subsequent control success.

5.2. Introduction

Pest pressure is generally very high in Madagascar's cotton cropping systems, often reducing yields in untreated fields to only 10-15% of their potential (Andriambololona et al. 1989). Most of the damage is attributed to the American bollworm *Helicoverpa armigera* Hübner (Lep.: Noctuidae), but the foliage feeder *Spodoptera littoralis* (Boisduval) (Lep.: Noctuidae) and the cotton aphid *Aphis gossypii* Glover (Hom.: Aphididae) may also play a major role in certain circumstances. Ever since Malagasy cotton production started on an industrial scale in the 1960s, pest management has been heavily relying on conventional chemical control with a calendar spraying schedule of six to twelve treatments according to season and cropping system (Bournier and Vaissayre 1977). Resistance of *Earias*

insulana Boisduval (Lep.: Noctuidae) against endrin and outbreaks of *S. littoralis* and *A. gossypii* after introduction of synthetic pyrethroids in the beginning of the 1980s have been associated with routine use of chemical therapeutics regardless of economic thresholds (Bournier and Vaissayre 1977, Rakotofiringa 1987, Dove 1994b).

The deterioration of the economic conditions in Madagascar in the 1990s has forced many large-scale growers to withdraw from cotton cultivation, leaving the space to small peasants who cultivate 1-2 ha on average without means of mechanisation (Rakotofiringa 1997). Insecticide sprayings are carried out on a calendar basis. Synthetic insecticides are economically the most important input factors in Malagasy cotton production and present serious health hazards to users because of insufficient protection equipment. These considerations have raised the interest in non-chemical alternatives in plant protection. The neem tree *Azadirachta indica* A. Juss (Meliaceae) is abundant in the semi-arid south-western region of Madagascar where rainfed cotton is produced. Neem oil extracts have been efficiently used against the larval instars of many lepidopterous pests and some aphid species (Schmutterer 1990). Neem components are considered environmentally safe and much more specific than conventional chemicals, thus allowing a better conservation of the non-target beneficial arthropod fauna (Schmutterer 1995). Yet, neem components have never been tested for control of cotton pests in Madagascar. In a field trial, the performance of two different oil extracts and of a synthetic insecticide regime was evaluated against *H. armigera*, *S. littoralis* and *A. gossypii*.

5.3. Materials and methods

The experimental site was located on a farmer's field near Ampasikibo in the community of Analamisampy in the Toliara region in south-western Madagascar.

The Upland cotton variety D 388/8 M was sown on 10/12/1997 at a theoretical density of 88,800 plants/ha. The field was fertilised with 100 kg ammonium phosphate, laboured and sown before the onset of the first rains, which generally commence with the arrival of north-western trade winds in December. Emergence took place on 30 December. The field was fertilised with 50 kg urea 23 days after emergence (d.a.e.) and weeded manually three times. The cotton was harvested 119 and 147 d.a.e.

The experimental design consisted of a randomised complete block with four treatments and four replications. Since the soil partly contained alluvial deposits and the direction of the fertility gradient was known, plots were made long and narrow (45 x 4,5 m) and arranged perpendicular to the gradient. Plots were separated from each other by three row alley-ways (approx. 2,5 m broad). The experiment consisted of four treatments: in treatment «ST», plots were sprayed with cypermethrin or thiodicarb, the two most commonly used insecticides in Malagasy cotton production. In the «AZAL» treatment, plots were sprayed with a commercial neem oil formulation produced by TRIFOLIO-M GmbH, Lahnau, Germany («Neem AZAL 1 % Azadirachtin A»). «INDOSUMA» plots were treated with a local neem oil extract from the INDOSUMA oil mill in Toliara. «NT» is referred to as the untreated control. For details of sprayings see table 1.

Table 1. Insecticide treatments

date	«ST»	«AZAL»	«INDOSUMA»
15.02	cypermethrin 60 g a. i./ha	neem 2.50 l/ha	neem 3.71 l/ha
23.02	thiodicarb 400 g a. i./ha	neem 2.33 l/ha	neem 2.50 l/ha
04.03	thiodicarb 400 g a. i./ha	neem 2.81 l/ha	neem 2.77 l/ha
12.03		neem 2.17 l/ha	neem 3.55 l/ha
17.03	cypermethrin 60 g a. i./ha		
20.03			neem 2.50 l/ha
24.03	thiodicarb 400 g a. i./ha	neem 2.08 l/ha	
28.03			neem 2.67 l/ha
31.03		neem 2.50 l/ha	
06.04			neem 3.16 l/ha
12.04	cypermethrin 60 g a. i./ha	neem 1.67 l/ha	neem 2.88 l/ha

The sprayings were carried out with a hand-held battery-operated ULV spinning disc sprayer. The scheduled application rate of the neem oils was 2,5 l/ha, whereas emulsifiable concentrates diluted in 10 litres of water were used in the «ST» treatments. These two techniques are considered equivalent for pest control in rain-grown Malagasy cotton (H. Rakotofiringa, HASYMA, pers. comm.).

When pest threshold levels had been exceeded, treatments were carried out the same evening or the following day, depending on weather conditions. The national cotton company HASYMA has developed action thresholds for the major cotton pests, though they still await their official implementation. For *H. armigera*, the threshold is 5,000 larvae/hectare (0.0625 larvae/plant in a stand of 80,000 plants/ha) and for

S. littoralis 10,000 larvae/ha (or 0.125/plant). Sixty g of cypermethrin/ha were used for control of *H. armigera* only, whereas applications of 400 g/ha thiodicarb were used either against *H. armigera* alone or in case of mixed infestations against both noctuid pests. Two principles were respected throughout the season: First, no plot received more than one treatment per week, because this would have been both ecologically and economically questionable and in any case impracticable for small grower systems in south-western Madagascar. Second, the aphid threshold was not incorporated in the spraying decisions because aphids cannot be considered key pests in rain-grown cotton (cf. chapter 3). In addition, the threshold for *A. gossypii* in Malagasy cotton is very low, and its application would inevitably have resulted in frequent interventions, interfering with the management of the more important lepidopterous pests, in particular of *H. armigera*.

Sampling began on February 14 and continued generally every four days until April 15. *Helicoverpa armigera* and *S. littoralis* larvae were counted on 20 randomly selected plants per plot, omitting the two border rows. Aphid density and presence of aphid predators were assessed on six leaves per plant:

- on the main stem leaf and another arbitrarily selected leaf of the lowest fruiting branch;
- on the main stem leaf and another arbitrarily selected leaf of a randomly chosen fruiting branch in the median stratum;
- on the main stem leaf and the second leaf of the terminal fruiting branch.

Larval instars and adults of aphid predators were counted individually, whereas *A. gossypii* number was estimated by scores, where 1 = 1 to 10 individuals, 2 = 11-100 and 3 = more than 100 individuals.

Insect density data, i.e., the numbers of *H. armigera* and *S. littoralis* caterpillars/plant, means of predator larvae and adults on six leaves, and means of *A. gossypii* scores on six leaves were submitted to rank transformation and subsequently analysed with one-way ANOVA. Means were separated by Tukey's test for multiple comparisons (Horn and Vollandt 1995).

Treatment efficiencies were also evaluated by means of the Henderson and Tilton equation (1955), which compares the density proportions in treated and untreated plots before and after a treatment:

$$[1] \% \text{ efficacy} = 100 \cdot \left(1 - \frac{T_a \cdot NT_b}{T_b \cdot NT_a} \right)$$

where T_a and NT_a are mean densities in treated and untreated plots after the treatment and T_b , and NT_b are mean densities in treated and untreated plots before the treatment, respectively.

In order to avoid the problem to divide by 0, empty sampling units were replaced by the insignificant small value 10^{-5} .

Yields per plot were compared with an exact Mann-Whitney test and submitted to the Bonferroni-Holm adjustment for multiple comparisons (Holm 1979).

For evaluating the distribution of the noctuid larval instars in the cotton field, mean densities and variance of *H. armigera* and *S. littoralis* in each plot were pooled for each sampling date. Plotting of $\log(\text{variance})$ against $\log(\text{mean})$ results in a linear function with a slope b , which is supposed to represent a species-specific index of aggregation (Taylor 1961, Taylor et al. 1978):

$$[2] \log(s^2) = \log(a) + b \cdot \log(\bar{x})$$

where the intercept a is a parameter which depends on the sample method and the slope b is the “index of aggregation” which varies continuously from $b < 1$ for a regular distribution, to random for $b = 1$, to clumped for $b > 1$ (Taylor 1961).

The optimum sample size was determined by means of the general formula of Wilson and Room (1983) who incorporated Taylor’s power law into the Karandinos (1976) sample size equation set:

$$[3] n = (Z_{\alpha/2} / D)^2 \cdot a \cdot \bar{x}^{b-2}$$

where $Z_{\alpha/2}$ is the standard normal deviate for a two-tailed confidence interval at a given α level (0.05), D is the precision as a fixed proportion of the mean (set at 0.25), \bar{x} is the estimate of the mean, and a and b are the parameters of Taylor’s power law.

[3] can be solved for D , which is the precision de facto obtained at a given sample size:

$$[4] D = \frac{Z_{\alpha/2}}{\sqrt{\frac{n}{a \cdot \bar{x}^{b-2}}}}$$

The optimum sample size for a Poisson distribution is (Wilson and Room, 1983):

$$[5] n = \frac{(Z_{\alpha/2} / D)^2}{\bar{x}}$$

Solved for D , [5] comes to

$$[6] D = \frac{Z_{\alpha/2}}{\sqrt{n \cdot \bar{x}}}$$

which is the de facto precision at a given sample size for a Poisson distribution.

5.4. Results

Figures 1, 2 and 3 show the seasonal population dynamics of *H. armigera*, *S. littoralis* and *A. gossypii*, respectively. Pest pressure by *H. armigera* and *S. littoralis* was relatively severe. In accordance with observations on the population dynamics in previous years, *H. armigera* larval populations peaked at bloom (63 d.a.e.). *Spodoptera littoralis* usually infests cotton fields one to two weeks later, but in this trial, its appearance was precocious and peaked simultaneously with the bollworms. Being principally mid-season pests in Malagasy cotton, the presence of both species at levels repeatedly beyond the threshold until the end of the sampling period in mid-April, was quite unusual. Serious damage occurred to immature bolls in neem treated and in «NT» plots, resulting in heavy yield losses (table 2).

Table 2. Raw cotton yields (kg/ha) \pm SE

«ST»	«INDOSUMA»	«AZAL»	«NT»
1047 \pm 211.1 b	269 \pm 153.5 a	390 \pm 87.7 a	396 \pm 99.7 a

Treatments within rows followed by the same letter are not significantly different ($P > 0.05$, Bonferromi-Holm's adjustment of ranked values)

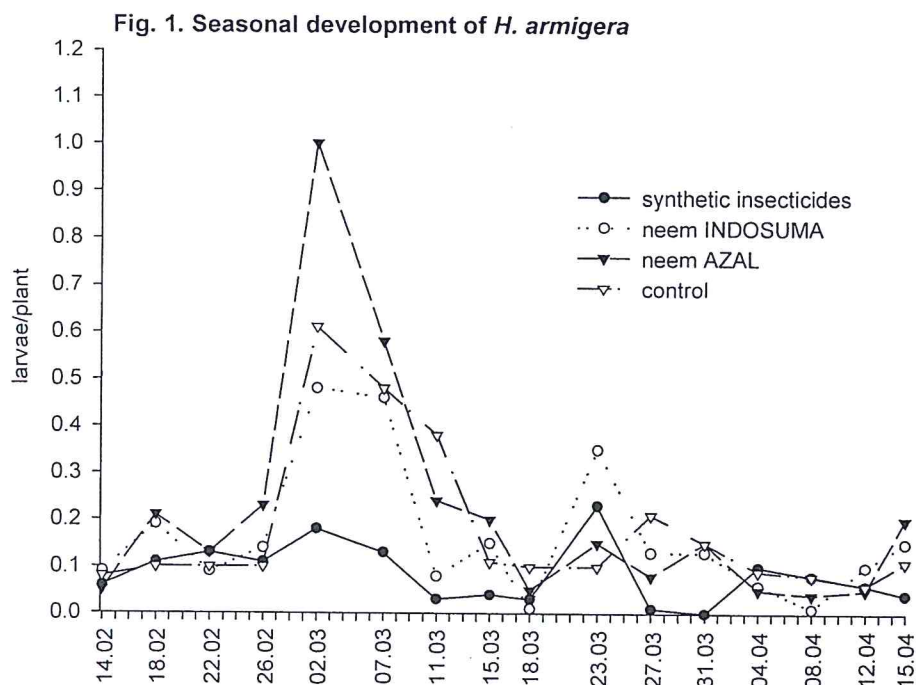


Fig. 2. Seasonal population dynamics of *S. littoralis*

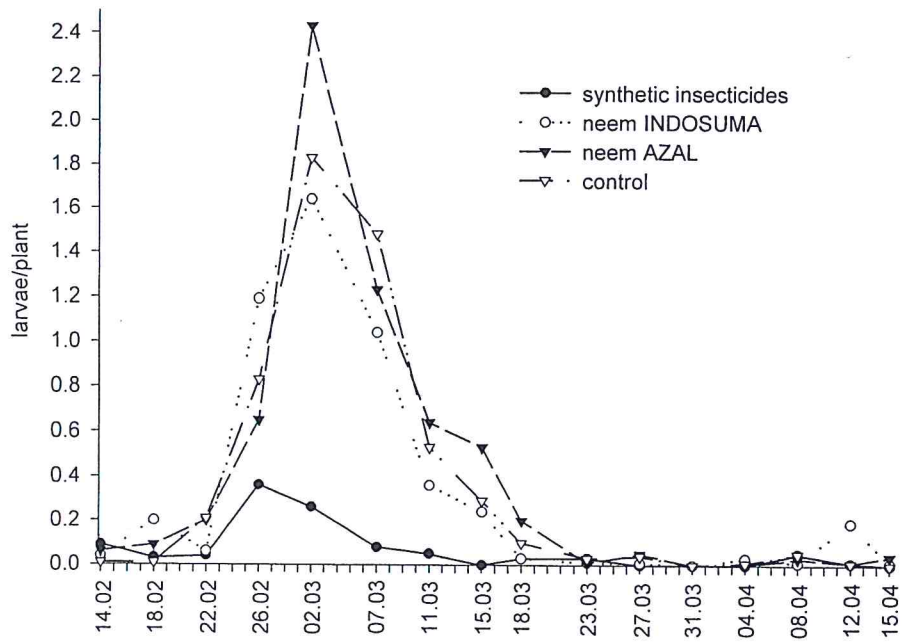
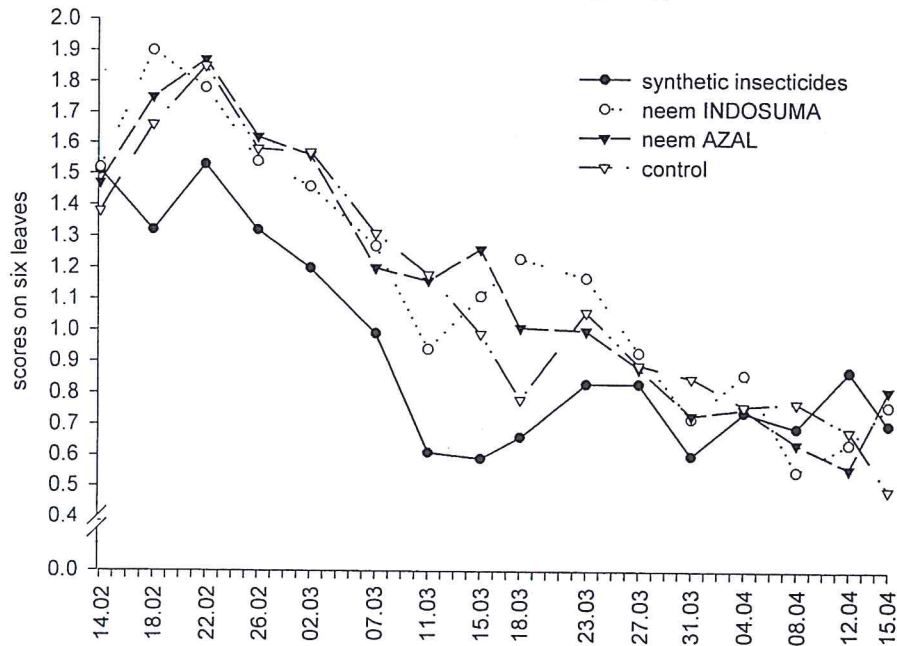
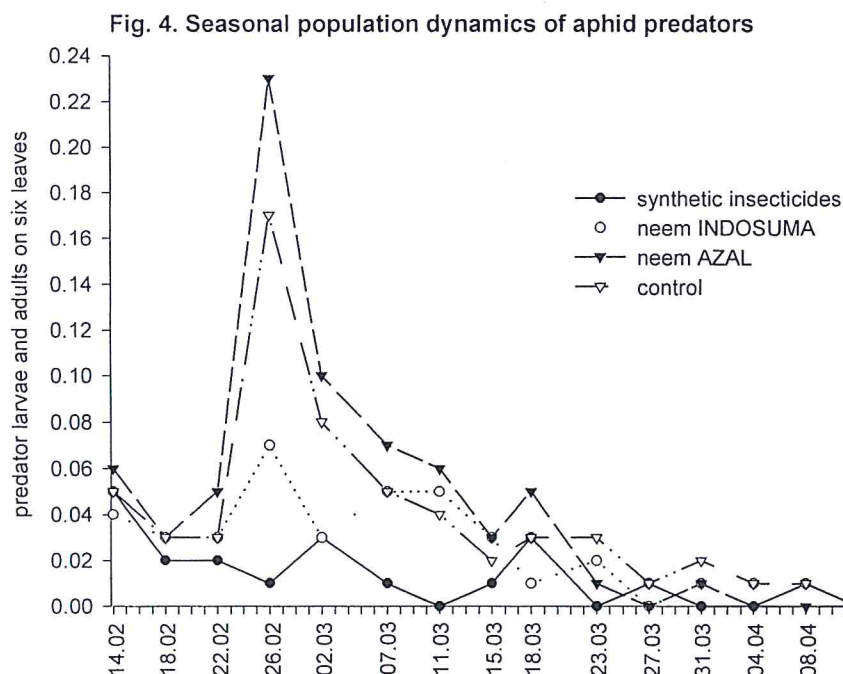


Fig. 3. Seasonal population dynamics of *A. gossypii*





None of the two neem treatments efficiently suppressed the densities of any one of the three cotton pests. Both for control of *H. armigera* and of *S. littoralis*, conventional insecticides were significantly superior to the neem extracts during the crucial phase of the cotton plants' boll production in the beginning of March, i.e., 60-70 d.a.e. when larval populations peaked (table 3 and 4).

Table 3. Seasonal population dynamics of *H. armigera* (larvae/plant)

date	«ST»	«INDOSUMA»	«AZAL»	«NT»
14.02	0.06 a	0.09 a	0.05 a	0.08 a
18.02	0.11 a	0.19 a	0.21 a	0.10 a
22.02	0.13 a	0.09 a	0.13 a	0.10 a
26.02	0.11 a	0.14 a	0.23 a	0.10 a
02.03	0.18 a	0.48 b	1.00 b	0.61 b
07.03	0.13 a	0.46 b	0.58 b	0.48 b
11.03	0.03 a	0.08 a	0.24 b	0.38 b
15.03	0.06 a	0.15 a	0.20 a	0.11 a
18.03	0.03 a	0.08 a	0.05 a	0.10 a
23.03	0.23 ab	0.35 b	0.15 ab	0.10 a
27.03	0.01 a	0.13 ab	0.08	0.21 b
31.03	0.00 a	0.13 ab	0.15 ab	0.15 b
04.04	0.10 a	0.06 a	0.05 a	0.09 a
08.04	0.04 a	0.01 a	0.04 a	0.08 a
12.04	0.06 a	0.10 a	0.05 a	0.06 a
15.04	0.04 a	0.15 ab	0.20 b	0.11 ab

Means within rows followed by the same letter are not significantly different ($P > 0.05$, Tukey's test)

Table 4. Seasonal population dynamics of *S. littoralis* (larvae/plant)

date	«ST»	«INDOSUMA»	«AZAL»	«NT»
14.02	0.09 a	0.04 a	0.06 a	0.01 a
18.02	0.03 a	0.20 a	0.09 a	0.01 a
22.02	0.04 a	0.06 ab	0.20 b	0.21 b
26.02	0.36 a	1.19 b	0.65 a	0.83 a
02.03	0.26 a	1.64 b	2.43 c	1.83 bc
07.03	0.08 a	1.04 b	1.23 b	1.48 b
11.03	0.05 a	0.36 b	0.64 b	0.53 b
15.03	0.00 a	0.24 ab	0.53 c	0.29 bc
18.03	0.03 a	0.03 a	0.20 a	0.10 a
23.03	0.03 a	0.01 a	0.01 a	0.03 a
27.03	0.00 a	0.01 a	0.05 a	0.04 a
31.03	0.00 a	0.00 a	0.00 a	0.00 a
04.04	0.00 a	0.03 a	0.00 a	0.01 a
08.04	0.05 a	0.01 a	0.03 a	0.05 a
12.04	0.01 a	0.19 a	0.01 a	0.01 a
15.04	0.00 a	0.01 a	0.04 a	0.00 a

Means within rows followed by the same letter are not significantly different ($P>0.05$, Tukey's test)

During this period, densities of *H. armigera* and *S. littoralis* in «INDOSUMA» and «AZAL» plots did not differ significantly from the untreated control. From end of March onwards, densities were low in absolute numbers and no significant differences between treatments were observed. However, the very low threshold level made further insecticide interventions in all three treatments necessary.

Treatments started directly after the first sampling date on February 15 when for the first time *H. armigera* exceeded the threshold. Respecting the one week minimum delay between two treatments, a total of six treatments with cypermethrin and thiodicarb were carried out for control of *H. armigera* in «ST» plots. In «AZAL» and «INDOSUMA» plots, seven and eight sprayings, respectively, were carried out for suppression of bollworms. The threshold for *S. littoralis* Egyptian was exceeded once in «ST» and three times in «INDOSUMA» and «AZAL», though no individual treatment had to be carried out for control of this pest.

The data on degrees of treatment efficacy investigated with the Henderson and Tilton formula [1] did not reflect very well the superior performance of the synthetic insecticides. Though the cypermethrin and thiodicarb applications in the «ST» plots resulted in a significantly better pest control and higher cotton yields compared to the two neem treatments, the proportions of insecticide-induced mortality were surprisingly poor especially for the mid-season sprayings (table 7).

The neem treatments had little effect on the population dynamics of *A. gossypii* (table 5 and 8). Aphid densities were rather similar in the «INDOSUMA», «AZAL» and «NT» plots.

Table 5. Seasonal population dynamics of *A. gossypii* (means of scores on six leaves)

date	«ST»	«INDOSUMA»	«AZAL»	«NT»
14.02	1.51 a	1.52 a	1.47 a	1.38 a
18.02	1.32 a	1.90 c	1.75 bc	1.66 b
22.02	1.53 a	1.78 b	1.87 b	1.85 b
26.02	1.32 a	1.54 b	1.62 b	1.58 b
02.03	1.20 a	1.46 b	1.56 b	1.57 b
07.03	0.99 a	1.27 b	1.20 b	1.31 b
11.03	0.61 a	0.94 b	1.16 c	1.18 c
15.03	0.59 a	1.11 b	1.26 b	0.99 b
18.03	0.66 a	1.23 c	1.01 b	0.78 a
23.03	0.83 a	1.17 c	1.00 b	1.06 bc
27.03	0.83 a	0.93 a	0.88 a	0.89 a
31.03	0.60 a	0.72 a	0.73 a	0.85 b
04.04	0.74 a	0.86 a	0.75 a	0.76 a
08.04	0.69 ab	0.55 a	0.64 ab	0.77 b
12.04	0.87 a	0.64 b	0.56 b	0.68 b
15.04	0.70 b	0.76 b	0.81 b	0.49 a

Means within rows followed by the same letter are not significantly different ($P>0.05$, Tukey's test)

Table 6. Seasonal population dynamics of aphid predators (means of larvae and adults on six leaves)

date	«ST»	«INDOSUMA»	«AZAL»	«NT»
14.02	0.05 a	0.04 a	0.06 a	0.05 a
18.02	0.02 a	0.03 a	0.03 a	0.03 a
22.02	0.02 a	0.03 a	0.05 a	0.03 a
26.02	0.01 a	0.07 b	0.23 c	0.17 b
02.03	0.03 a	0.03 a	0.10 b	0.08 b
07.03	0.01 a	0.05 b	0.07 b	0.05 ab
11.03	0.00 a	0.05 b	0.06 b	0.04 b
15.03	0.01 a	0.03 a	0.03 a	0.02 a
18.03	0.03 a	0.01 a	0.05 b	0.03 ab
23.03	0.00 a	0.02 ab	0.01 ab	0.03 b
27.03	0.01 a	0.00 a	0.00 a	0.01 a
31.03	0.00 a	0.01 a	0.01 a	0.02 a
04.04	0.00 a	0.01 b	0.00 a	0.01 a
08.04	0.01 a	0.01 a	0.00 a	0.01 a
12.04	0.00 a	0.00 a	0.00 a	0.00 a
15.04	0.00 a	0.01 a	0.00 a	0.01 a

Means within rows followed by the same letter are not significantly different ($P>0.05$, Tukey's test)

During the period of exponential growth (47-55 d.a.e.), *A. gossypii* populations increased even significantly faster in «INDOSUMA» than in untreated plots. Surprisingly, cypermethrin and thiodicarb consistently suppressed aphid infestation

from the very beginning of the sprayings until mid-March when densities decreased to low levels in all plots. Yet, both thiodicarb and pyrethroids are reputedly devoid of any aphicidal effect in Malagasy cotton (L. Andriambololona, HASYMA, pers.comm.). On the contrary, cypermethrin is suspected to cause outbreaks of *A. gossypii* in counter-season cotton (cf. chapter 3).

Table 7. Percent efficacy of insecticide applications against *H. armigera* and *S. littoralis*

date	<i>H. armigera</i>			<i>S. littoralis</i>		
	«ST»	«INDOSUMA»	«AZAL»	«ST»	«INDOSUMA»	«AZAL»
18.02	-35.0	-60.7	-218.8		<-100.0	-40.0
26.02	10.0	-57.1	-84.0	<-100.0	<-100.0	16.3
07.03	7.9	-25.6	24.9	64.7	21.6	37.4
15.03		<-100.0	-180.7		-19.9	-50.5
18.03	20.0					
23.03		<-100.0			-100.0	
27.03	99.7		76.5	100.0		<-100.0
31.03		-41.7			<-100.0	
04.04			42.9			100.0
08.04		76.7			87.5	
15.04	66.7	16.7	-122.2		16.7	<-100.0

Table 8. Percent efficacy of insecticide applications against *A. gossypii* and its predators

date	<i>A. gossypii</i>		aphid predators		
	«INDOSUMA»	«AZAL»	«ST»	«INDOSUMA»	«AZAL»
18.02	-3.9	1.0	42.5	-15.4	25.5
26.02	-1.7	-1.8	89.2	53.0	9.1
07.03	-4.0	8.1	40.6	<-100.0	-5.8
15.03	-41.7	-28.9		-8.0	3.6
18.03			<-100.0		
23.03	29.8			-2.9	
27.03		-4.6	<-100.0		-42.9
31.03	19.6			0.0	
04.04		-14.9			50.0
08.04	36.6			-71.4	
15.04	-63.1	-99.3	83.3	0.0	83.3

In «NT» plots, aphid predators peaked only four days after its prey (table 6, fig. 4). The beneficial fauna consisted of coccinellids, syrphid larvae and lacewings. *Scymnus constrictus* Mulsant (Col.: Coccinellidae) and *Ischiodon aegyptius* Wiedemann (Dipt.: Syrphidae) were the most frequently encountered species. Syrphids showed the best temporal synchronisation with their prey. No aphid parasitoids were recorded. Incidence of the aphidopathogenic fungus *Neozygites fresenii* (Nowakowski) (Entomophthorales) was weak. The synthetic insecticides proved to be very harmful to aphidophagous predators, as reflected by the high degrees of “negative” efficacy of the first three treatments, when predators were most abundant (table 8). The

thiodicarb treatment on February 23 disrupted the predators' development and reduced their numbers to such an extent that the subsequent decline of *A. gossypii* hardly can be attributed to predation. In «INDOSUMA» plots, predator density reached only 40 % of the peak numbers in control plots. On the other hand, predator densities in «AZAL» were higher than in the control. However, the general tendency was that the neem extracts did not seem to influence predator populations.

Table 9. Optimum sample size (*n*) estimation for *H. armigera* and *S. littoralis*, according to Wilson and Room (1983) and to the Poisson distribution, and attainable precision *D* when *n* = 80

density per plant	plant density per ha (stand=80,000)	<i>n</i> for <i>H. armigera</i> (Wilson and Room 1983)	<i>n</i> for <i>H. armigera</i> (Poisson distribution)	<i>D</i> for <i>H. armigera</i> at <i>n</i> =80 (Wilson and Room 1983)	<i>D</i> for <i>H. armigera</i> at <i>n</i> =80 (Poisson distribution)	<i>n</i> for <i>S. littoralis</i> (Wilson and Room 1983)	<i>D</i> for <i>S. littoralis</i> at <i>n</i> =80 (Wilson and Room 1983)
0.01	800	4,807	6,147	1.94	2.19	4,298	1.83
0.02	1,600	2,537	3,073	1.41	1.55	2,430	1.38
0.03	2,400	1,746	2,049	1.17	1.27	1,740	1.17
0.04	3,200	1,339	1,537	1.02	1.10	1,373	1.04
0.05	4,000	1,090	1,229	0.92	0.98	1,143	0.94
0.06	4,800	921	1,024	0.85	0.89	984	0.88
0.0625	5,000	887	983	0.83	0.88	951	0.86
0.07	5,600	799	878	0.79	0.83	867	0.82
0.08	6,400	707	768	0.74	0.77	776	0.78
0.09	7,200	634	683	0.70	0.73	705	0.74
0.10	8,000	575	615	0.67	0.69	646	0.71
0.125	10,000	468	492	0.60	0.62	538	0.65
0.15	12,000	396	410	0.56	0.57	463	0.60
0.20	16,000	304	307	0.49	0.49	365	0.53
0.25	20,000	247	246	0.44	0.44	304	0.49
0.30	24,000	209	205	0.40	0.40	262	0.45
0.40	32,000	160	154	0.35	0.35	206	0.40
0.50	40,000	130	123	0.32	0.31	172	0.37
0.60	48,000	110	102	0.29	0.28	148	0.34
0.70	56,000	96	88	0.27	0.26	130	0.32
0.80	64,000	85	77	0.26	0.25	117	0.30
0.90	72,000	76	68	0.24	0.23	106	0.29
1.00	80,000	69	61	0.23	0.22	97	0.28

The linear regression of log(variance) on log(mean) yielded the following relationships:

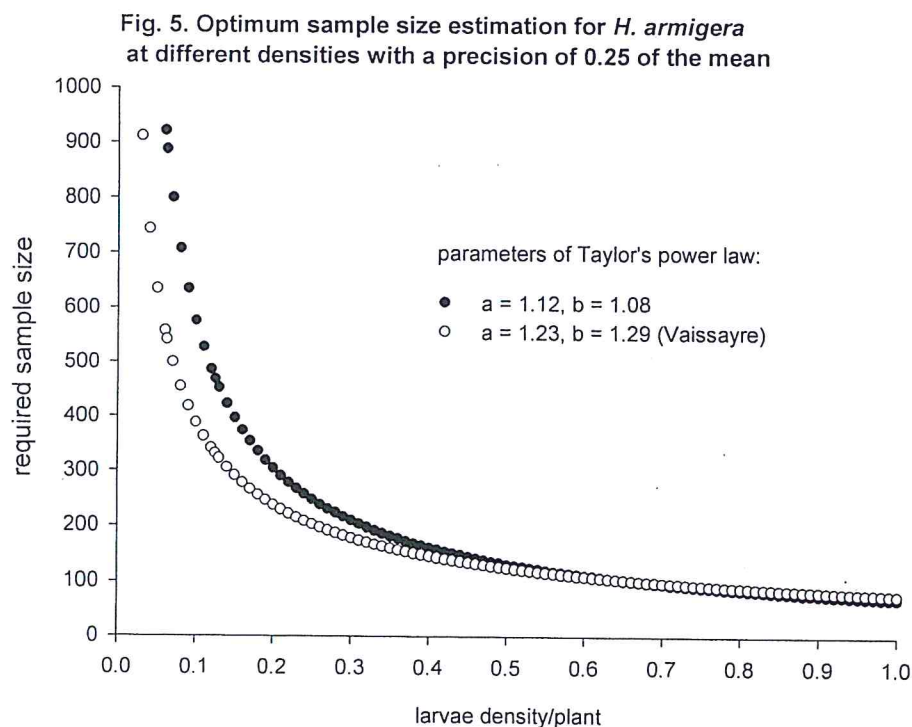
$$s^2 = 1.12 \cdot \bar{x}^{1.08} \quad (n = 16, r^2 = 0.976) \text{ for } H. \textit{armigera}$$

and

$$s^2 = 1.58 \cdot \bar{x}^{1.18} \quad (n = 15, r^2 = 0.937) \text{ for } S. \textit{littoralis}.$$

The slope for *H. armigera* was not significantly different from 1 ($P = 0.096$), indicating a random distribution. By contrast, the distribution of *S. littoralis* larvae appeared to be clumped ($P = 0.046$). Table 9 shows that after incorporating Taylor's parameters in equation [3], the optimum sample sizes for *H. armigera* and *S. littoralis*

populations at their threshold density are as high as 887 and 538 plants, respectively. Assuming a random distribution, a sample size of 983 would be required at a density of 0.0625 larvae/plant. Figure 5 visualises the function for *H. armigera* over a large range of densities.



5.5. Discussion

There are numerous reports on successful control of noctuid caterpillars by neem extracts (Schmutterer 1990, Sinha 1990, Sombatsiri et al. 1995). The effect may be based on acute toxicity or on antifeedant properties (Blaney et al. 1990, Mohapatra et al. 1995, Murugan et al. 1998). Saxena and Rembold (1984) reported that neem seed oil volatiles had a repellent effect on *H. armigera* female imago, and that the oil acted as oviposition deterrent at contact. There are also some reports on susceptibility of aphids to neem extracts (Ostermann and Dreyer 1995, Upadhyay and Mishra 1999), though it seems generally acknowledged that foliar applications of neem products are less likely to affect homopterous pests (Saxena 1995).

However, reported results are difficult to compare to each other because often local, non standardised neem preparations are used. The local oil extract used in the present trial stemmed from the 1997 stock of the local oil mill INDOSUMA in Toliara.

Subsequent analysis of its azadirachtin-A content at the Trifolio-M GmbH laboratory in Germany revealed a rather low value of 675 ppm, which is almost 15 times less than that of the commercial "Azal" extract, supposed to contain 1 % azadirachtin-A (W. Zehrer, GTZ, pers. comm.). This low azadirachtin-A concentration could have been due to inappropriate storage conditions in the mill or to naturally low contents in locally harvested neem kernels. Nevertheless, deleterious effects on insects do not exclusively rely on azadirachtin-A, and the "Azal" extract tended to be even less efficient against *H. armigera* and *S. littoralis* (fig. 1 and 2).

The conditions for the application of the neem oils were not ideal, and this may partly explain the rather poor results in both neem treatments. Though the larger nozzle, normally intended for 10 l VLV treatments of emulsifiable concentrates, was used and temperatures usually were high (25-30°C), the oils appeared to be too viscid to be applied in conventional ULV technique, resulting in doubling of spraying time and irregular flows within a range of 1.67 to 3.71 litres/ha (table 1). Dilution with 50 % cotton seed oil did not substantially improve the quality of the treatment and would, if not at the cost of increasing volume and time, have reduced the insecticidal power of the neem extract.

The half-life of neem components is known to be quite low in the alkaline environment of cotton leaves (H. Schmutterer, pers. comm.). When the substances are not ingested within 24 h, about half of the insecticidal power of the extract is lost. Moreover, though the 1998 vegetation period on the whole was too dry, rains were abundant in February and impaired planning for treatments in the afternoon. Thus, in this month plots were sprayed in the morning to assure that thresholds and sampling intervals could be respected. The intense heat and insolation at that time of the year may have contributed to an accelerated degradation of the neem ingredients.

Additionally, the partly cryptic feeding behaviour of *H. armigera* may explain the poor control in the neem treatments. The first larval instar of the bollworm feeds on leaves, but older larvae gnaw at or penetrate into squares and bolls, where they are partly or entirely concealed and well protected against natural enemies and insecticide sprays (King 1994). *Helicoverpa armigera* caterpillars are affected by poisons mainly by contact once they move to other buds or fruits. *Spodoptera littoralis* however, is essentially a conspicuous leaf feeder, and is much more likely to ingest a significant amount of the neem oils.

The Henderson and Tilton (1955) data on treatment efficacy revealed fundamental difficulties in managing low infestation levels of the noctuid pests. This is especially true for *H. armigera*, which is extremely dangerous for the cotton crop even at low densities. The efficacy values indicate which proportion of a negative density change can be attributed to an insecticidal effect (table 7). Though cypermethrin and thiodicarb permitted an economically valid control of the bollworms, the calculated percent insecticide-induced mortality of *H. armigera* was surprisingly poor and seem somewhat arbitrary.

Four days sampling intervals are possibly too long for evaluating before and after density proportions, especially at very low densities. Short-term density fluctuations can occur by recruitment of or emigration from the sampled development stage, i.e., by hatching of eggs or by pupation. This bias is more important in the beginning of the season when only one generation is present in the field. Also, heavy rainfalls and winds are known to cause considerable mortality rates in *H. armigera* eggs and young larvae (Kyi et al. 1991). For example, abundant rains from 16 to 20/02 (132 mm) probably had a detrimental effect on eggs and young larvae of both noctuid pests since their populations started to increase only from February 26 onwards. However, differences in impact of natural enemies could be imagined to account for differences in short-term mortalities in «NT» and «ST» plots. Both noctuids are preyed on by several Reduviidae, Carabidae and Pentatomidae Asopinae, and parasitised by braconids, eulophids, ichneumonids and others. Aphid predators are largely eliminated by synthetic insecticides (table 6 and 8, see also chapter 2), and there are strong indications that most of the currently used chemicals in Malagasy cotton also have detrimental effects on natural enemies of bollworms.

The somewhat arbitrary fluctuations of very small populations of *H. armigera* refer also to an elementary sampling problem of this pest. According to Taylor's power law and the sample size equations which have been derived from the mean-variance relationship by Wilson and Room (1983), in a cotton stand of 80,000 plants/ha, the recommended threshold of 5,000 larvae/ha corresponds to only one individual per 16 plants. At these low densities, an impracticably big theoretical sample size is needed either if the underlying distribution is assumed to be random or to be slightly clumped (table 9).

If, for obvious logistic reasons, the sample size for *H. armigera* has to be restricted to as low as 80 sample units, the de facto precision level is only 83 % of the mean or 2,925-7,075 larvae/ha at the threshold density. A sample size of $n = 80$ would be perfectly appropriate only at a density of about 68,000 larvae/ha.

The distribution of *S. littoralis* was clumped. Contrary to *H. armigera*, females of *S. littoralis* lay their eggs in groups and only second instar larvae begin to disperse from the oviposition site. This behaviour results in a lower optimum sample size at densities until 6.000 larvae/hectare (0.075 larvae/plant), whereupon n decreases slower than in the Poisson distribution (table 9).

Considering the solitary habits of *H. armigera* with its single egg deposits and a pronounced cannibalistic behaviour, and the low densities at which the pest is present in the cotton crop (except a short period during the peak squaring-early boll stage), randomness does not seem an improbable spatial pattern for this species. Vaissayre (1973) stated that the distribution of *H. armigera* and *E. insulana* in irrigated cotton in Madagascar did not depart significantly from the Poisson distribution as long as counts were made on a plant-to-plant basis and densities were low. When he sampled on 5 m² units, *H. armigera* larvae appeared to be aggregated and the following parameters were obtained: $s^2 = 1,23 \cdot \bar{x}^{1,29}$ ($n = 14$, $r^2 = 0,98$). Then, optimum sample size would be lower as long as density is inferior to 0.65 larvae/plant (fig. 5).

Whatever a random or a slightly contagious spatial distribution is assumed, realistic sample sizes may result in considerably biased density estimates and sprayings are at risk to be badly timed. Actually, several additional threshold-induced treatments against *H. armigera* would had to be carried out in both «ST», «INDOSUMA» and «AZAL» plots if not a one-week minimum delay between two consecutive sprayings had been imposed in advance (table 1 and fig. 1).

Though significantly superior to the neem treatments, the synthetic insecticide regime gave unsatisfactory results, because yields in «NT» plots reached 27 % of the yield in «ST». When carpophagous pressure by *H. armigera* is high as was the case, untreated plots normally achieve only 10-15 % or less of yields in plots protected by weekly calendar treatments (Andriambololona et al. 1989). If integrated pest management principles are to be implemented in Malagasy cotton in the future, six well-targeted threshold based insecticide sprayings should be economically equivalent to a calendar schedule with ten ore more interventions. If non quantifiable costs like long-term

resistance development, drinking water pollution or user health risks are not taken into account, it can be argued that management of *H. armigera* based on a threshold of 5,000 larvae/ha does not present an economically valid alternative to routine spraying. This threshold is lower than even in the most intensive high-yielding cotton cropping systems in the world (Brook et al. 1992, Wilson 1994). Considering the virulent pest complex in Malagasy cotton and the limited impact of indirect injury caused by leaf feeders, it cannot be stated that this precaution is unfounded. However, the impossibility to manage very small *H. armigera* populations seems evident. In the course of our spraying programme, it is likely that poor treatment efficacy was in part due to bad timing as a consequence of intrinsic sampling problems, resulting in large errors. During the immigration peak at bloom, the one-week minimum interval rule prevented a hardly needed intervention against both *H. armigera* and *S. littoralis* on February 26. During the boll maturation phase, when the cotton plant is at least capable of compensation, sampling errors can have dramatic effects on yield. During this period, even the younger larvae will be directed towards bolls, because physiological stress make the plant shed most of newly produced squares (Wilson 1994), and all carpophagous feeding will have direct repercussions on yield.

6. Efficacy of soap solution and synthetic insecticides against the cotton aphid *Aphis gossypii* Glover (Hom.: Aphididae) in rainfed cotton in Madagascar

6.1. Abstract

The efficacy of a 2.5-3 % aqueous potassium soap solution against *Aphis gossypii* Glover (Hom.: Aphididae) was compared to a chemical insecticide regime in rain-grown cotton in south-western Madagascar. The soap treatments did not provide any significant protection for the crop against aphid infestation, possibly due to insufficient coverage of the pest using an application volume of 100 l/ha. Aphid infestation was significantly lower in plots treated with synthetic insecticides from the beginning of the sprayings until end of March, when aphid densities levelled down in all experimental plots. However, the low action threshold for aphids applied in Malagasy cotton made eight treatments with conventional insecticides necessary. The conventional protection resulted in a modest yield increase of 268 and 309 kg raw cotton/ha compared to the soap treatment and the untreated control, respectively. The failure of the aphicides to assure higher yield levels is discussed with regard to other pests in Malagasy cotton which may have a greater impact on the crop than *A. gossypii*.

6.2. Introduction

Since the end of the 1980s, an increasing infestation by *Aphis gossypii* Glover (Hom.: Aphididae) has been recorded in rainfed cotton in south-western Madagascar (Andriambololona et al. 1989). During the same period, pest resurgence of cotton aphids have been reported world-wide (Deguine and Leclant 1997). Outbreaks of *A. gossypii* have been attributed to resistance against different active ingredients, elimination of natural enemies, and to the inadequacy of oil-based ultra low volume (ULV) spraying techniques against homopterous cotton pests in general (Chen et al. 1991, Gubran et al. 1993, Deguine et al. 1994).

These three factors may also be responsible for increasing aphid attack in rain-grown cotton in Madagascar. Aphids are largely insensitive to endosulfan, thiodicarb and cypermethrin, commonly used to combat the carpophagous pests *Helicoverpa armigera* Hübner and *Earias insulana* Boiduval, or the foliage feeder *Spodoptera littoralis* (all Lep.: Noctuidae). However, these active ingredients are all toxic to predators of *A. gossypii*, albeit to differing degrees (cf. chapter 2). The poor coverage of lower plant parts by

ULV-VLV applications during windy weather may in part also explain control inefficiencies against cotton aphids. At present, two specific aphicidal calendar sprayings per growing season are intended to control aphids in Malagasy rain-grown cotton. A mid-season application of monocrotophos aims at the population peak during flowering, when *A. gossypii* causes direct trophic injury to the plant, whereas a late season treatment, mostly with carbosulfan or benfuracarb, is supposed to minimise production of honeydew which entails stickiness and the growth of sooty mould on fibres.

However, there are strong indications that the economic importance of *A. gossypii* in Madagascar is over-estimated. Down-grading of fibres because of stickiness or mould is of minor importance for rain-grown cotton production (H. Rakotofiringa, HASYMA, pers. comm.), and quantitative yield losses, which are commonly attributed to direct damage by aphids, are possibly due to other pests than *A. gossypii* (cf. chapter 3). Insecticide interventions on a calendar basis may be superfluous when aphid population levels are low and by contrast most likely contribute to build-up of pest resistance. Moreover, badly timed sprayings are harmful to the natural enemy fauna of cotton pests, and insecticide treatments in general pose serious health hazards to the poorly trained and equipped small cotton growers in Madagascar.

Thus, less toxic and environmentally more friendly aphicidal products are of great interest to cotton growers. Soap solutions have been successfully introduced for control of *A. gossypii* in some organic cotton farming systems, for example in Egyptian barbadense cotton (El-Araby and Merckens 1999). The insecticidal effect of soap solutions on soft-bodied arthropods are based on the lysogenic properties of fatty acids on the insects' cuticula (Kuklinski, in press). Detergents are cheap, readily available and of little environmental concern. This paper discusses the efficacy of a potassium soap solution against *A. gossypii* as compared to conventional chemical aphicides.

6.3. Materials and methods

The trial was carried out at the PAP (Point d'Appui de la Prévulgarisation) in Ampasikibo, an experimental station of the national cotton company HASYMA located in the community of Analamisampy in the Toliara province, south-western Madagascar.

Because of the very small surface area available, plot size had to be restricted to 13,5 x 7,5 m. Inter-plot alleys were four rows (approx. 3 m) wide. The field was fertilised with 100 kg ammonium phosphate, laboured and sown (Upland variety D 388/8 M) on 13/12/1997. Emergence took place on December 30. Seedlings were thinned to one plant

15 days after emergence (d.a.e), resulting in a theoretical density of 44,400 plants/ha. The field was fertilised with 100 kg urea 26 d.a.e. and weeded manually three times. The cotton was hand-picked 123 and 146 d.a.e.

The randomised complete block design consisted of three treatments with four replicates. The «soap» plots were treated with a 2,5-3,0 % potassium soap solution («KALISOL», Bio-Protect, Roisdorf, Germany). Two percent of pure alcohol were added to the solution. The alcohol dissolves the waxy layers on the aphids' cuticula and diminishes the surface tension of the water (U. Helberg, BIOHERB, pers. comm.). Soap sprayings were carried out in the evening with a CP 15 knapsack sprayer at a rate of 100 l water/ha. In «ST» plots («standard» treatment), synthetic aphicides, i.e., monocrotofos, carbosulfan and benfuracarb, were applied with a ULVA+ spinning disc sprayer at a volume of 10 l water/ha (table 1). For logistic reasons, applications in «ST» were mostly carried out in the morning.

Aphids in the «ST» and «soap» plots were treated according to the local threshold, i.e., when more than 15 % of the five fully developed terminal leaves were infested. However, plots were never sprayed more than once a week.

Table 1. Insecticide treatments

	«ST» (g a.i./ha)	«soap» (l/ha)
10.02	monocrotofos (300)	soap 2.82 l/ha
19.02		soap 2.82 l/ha
20.02	monocrotofos (300)	
25.02		soap 2.90 l/ha
26.02	carbosulfan (300)	
03.03		soap 2.52 l/ha
10.03	benfuracarb (250)	soap 2.88 l/ha
17.03	benfuracarb (250)	soap 2.85 l/ha
26.03		soap 2.58 l/ha
27.03	monocrotofos (300)	
03.04	monocrotofos (300)	soap 2.95 l/ha
11.04		soap 2.96 l/ha
12.04	benfuracarb (250)	

Control plots («NT») did not receive any treatment.

Sampling began on February 9 and continued generally every four days until April 13. However, after a treatment, sampling recommenced two days later.

Aphis gossypii and its predators were examined randomly on 20 plants per plots on the following leaves:

- on the main stem leaf and another arbitrarily selected leaf of the lowest fruiting branch;

- on the main stem leaf and another arbitrarily selected leaf of a randomly chosen fruiting branch in the median stratum;
- on the main stem leaf and the second leaf of the terminal fruiting branch.

Larval instars and adults of aphid predators were counted individually, whereas *A. gossypii* numbers were estimated by density scores, where 1 = 1-10 aphids, 2 = 11-100 and 3 = > 100 aphids.

Treatment efficacy was evaluated using the equation of Henderson and Tilton (1955) which compares the density proportions in treated and untreated plots before and after the intervention:

$$\% \text{ efficacy} = 100 \cdot \left(1 - \frac{T_a \cdot NT_b}{T_b \cdot NT_a} \right)$$

where T_a and NT_a are mean densities in treated and untreated plots after the treatment, and T_b and NT_b are mean densities in treated and untreated plots before the treatment, respectively.

In order to avoid the problem to divide by 0, empty sampling units were replaced by the insignificant small value 10^{-5} .

Means of aphid scores and of predator numbers were rank transformed prior to analysis of variance (ANOVA) and compared by means of Bonferroni's adjustment for multiple comparisons (Horn and Vollandt 1995).

Yields per plot were compared with an exact Mann-Whitney test and submitted to the Bonferroni-Holm adjustment for multiple comparisons (Holm 1979).

6.4. Results

The soap treatment did not provide a sufficient suppression of aphid infestation. Figure 1 shows that the soap solution "Kalisol" was not a viable alternative to chemical control. From the beginning of the sprayings until end of March, when aphid densities levelled down in all plots, aphid densities were significantly lower in the «ST» plots compared to the two other treatments (table 2). The superiority of the synthetic insecticide treatment was also reflected in considerably higher efficacy values. With one exception, chemicals reached a percent efficacy of 33-53 %, whereas the «soap» treatment reached positive values only three times and the average efficacy of nine sprayings was negative (table 3).

The yield level was very poor in all treatments, ranging from 76 to 669 kg/ha. However, mean raw cotton yield in the «ST» treatment was significantly higher than in the «soap» and «NT» plots. (table 4).

Table 2. Population dynamics of *A. gossypii* (average density score on six leaves) and aphid predators (average number on six leaves)

«ST» = standard insecticide, «soap» = soap treatment, «NT» = untreated control

date	<i>A. gossypii</i>			predators		
	«ST»	«soap»	«NT»	«ST»	«soap»	«NT»
09. 02	0.81 a	0.89 a	0.78 a	0.00 a	0.00 a	0.00 a
13. 02	0.53 a	1.18 b	1.05 b	0.01 a	0.01 a	0.01 a
17. 02	1.30 a	1.78 c	1.45 b	0.03 a	0.03 a	0.03 a
21. 02	0.83 a	1.95 b	1.97 b	0.00 a	0.03 b	0.02 ab
24. 02	0.59 a	1.42 b	1.69 c	0.01 a	0.03 a	0.03 a
27. 02	0.27 a	1.61 c	1.44 b	0.01 a	0.05 b	0.04 ab
03. 03 ¹	0.13 a	1.40 c	1.39 b	0 a	0.03 b	0.03 b
05. 03	0.16 a	1.06 b	1.30 c	0 a	0.04 b	0.02 ab
09. 03	0.37 a	1.00 b	1.15 c	0.00 a	0.02 b	0.03 b
12. 03	0.16 a	1.12 c	0.96 b	0 a	0.03 b	0.01 a
16. 03	0.46 a	1.06 b	1.12 c	0 a	0.02 b	0.01 ab
19. 03	0.29 a	0.90 b	1.06 c	0 a	0.01 ab	0.02 b
22. 03	0.35 a	0.94 b	0.95 b	0 a	0.01 ab	0.03 b
25. 03	0.65 a	0.86 b	0.78 ab	0.00 a	0.02 a	0.03 a
28. 03	0.45 ab	0.61 b	0.34 a	0 a	0.01 a	0.00 a
01. 04	0.52 b	0.57 b	0.35 a	0 a	0.01 ab	0.02 b
03. 04 ¹	0.45 a	0.62 b	0.69 b	0.01 a	0.02 a	0.02 a
06. 04	0.26 a	0.64 b	0.69 b	0.00 a	0.01 a	0.02 a
10. 04	0.34 a	0.50 b	0.49 b	0 a	0.02 b	0.03 b
13. 04	0.18 a	0.45 b	0.41 b	0.00 a	0.02 a	0.01 a

Treatments within rows followed by the same letter are not significantly different ($P > 0.05$, Bonferromi's adjustment of ranked values)

¹ Sampling was carried out before sprayings

Following the official aphid thresholds, «ST» plots had to be treated eight times and «soap» plots even nine times. Percent infested leaves remained beyond 15 % in all plots throughout the season (table 5), but plots were only treated once a week. Synthetic insecticides led to a significant reduction in predator densities, particularly between end of February until mid of March (table 2). Moreover, insecticides were more "efficient" in reducing predator than pest numbers (table 3).

The population dynamics in «soap» and «NT» plots followed a similar pattern. Significantly lower mean density scores in the soap treatment were observed after the sprayings on March 3 and 17. However, significantly higher densities compared to the control were recorded on February 25 and on March 10 and 26. Thus, density differences appeared to fluctuate rather arbitrarily in one or another direction and seemed not to be related to any aphicidal effect in the «soap» plots. In particular, the soap treatment failed to control aphids at their peak infestation level during the flowering period at the end of

February (fig. 1, table 2). However, the detergent did not affect the density of aphid predators (table 2 and 3). Predator numbers generally remained on a very low level (fig. 2). Maximum density reached only 0.05 predators per leaf on February 27. This was approximately five fold less than what was observed in adjacent experimental plots (cf. chapter 2 and 4). At these low levels, predation can hardly be expected to have a great impact on the aphid population.

Table 3. Impact of insecticides and soap solutions on *A. gossypii* and aphidophagous predators, expressed in percent efficacy (Henderson & Tilton 1955)¹

sampling date after the treatment	efficacy against <i>A. gossypii</i>		efficacy against predators	
	«ST»	«soap»	«ST»	«soap»
13. 02	51.8	20.4	33.3	50.6
21. 02	53.2	19.2	77.8	-80.6
27. 02	46.8	-33.4	34.1	-39.4
05. 03	-	18.8	-	-41.7
12. 03	48.0	-33.6	99.0	<-100.0
19. 03	32.6	9.5	30.0	65.0
28. 03	-58.3	-62.6	97.1	-100.0
06. 04	42.6	-2.7	82.0	43.8
13. 04	40.0	-5.0	<-100.0	<-100.0

¹ 0 values were replaced by 10^{-5}

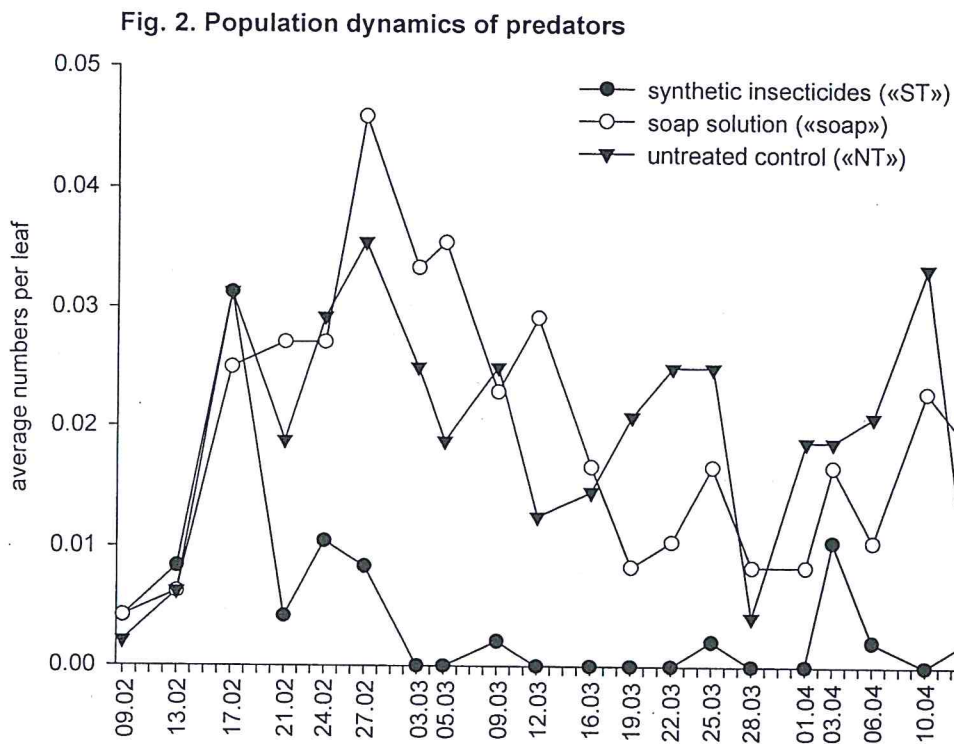
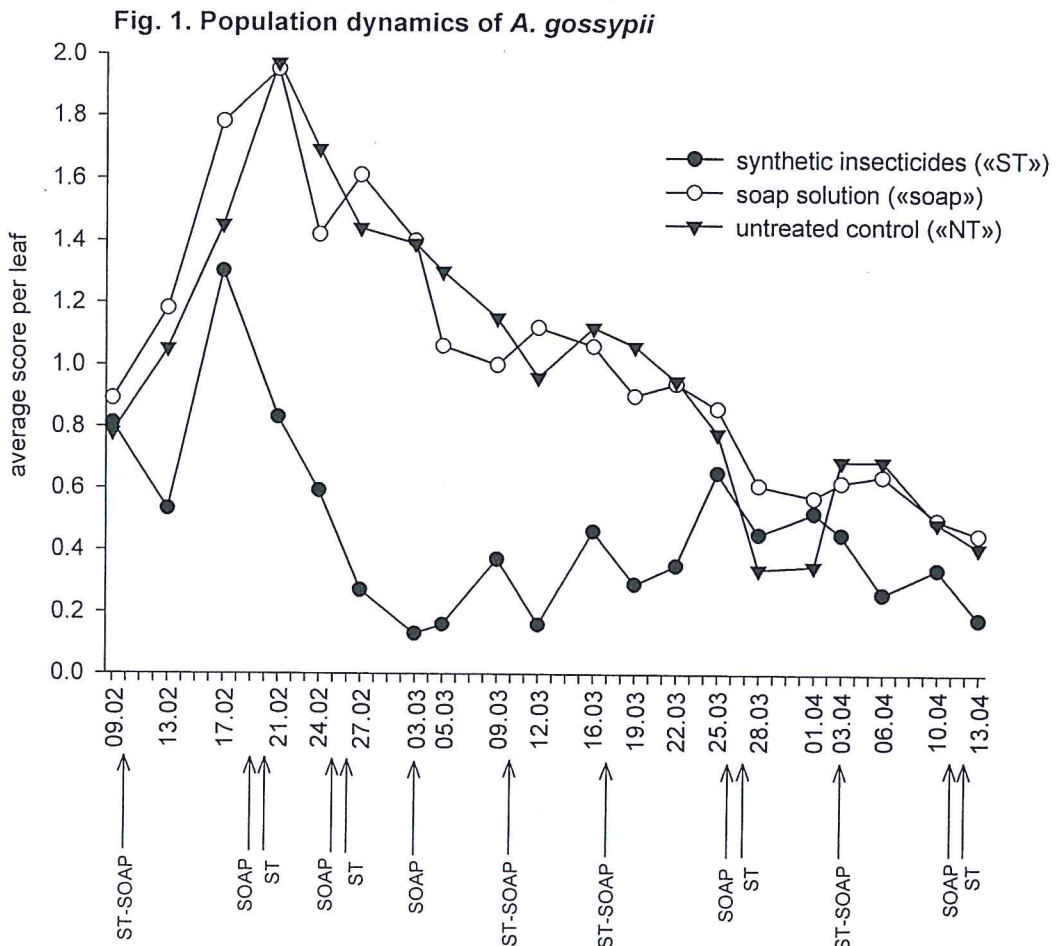
Table 4. Raw cotton yields (mean \pm SE; kg/ha)

«ST»	«soap»	«NT»
474.3 \pm 78.1 b	217.5 \pm 42.5 a	165.1 \pm 30.3 a

Treatments within rows followed by the same letter are not significantly different ($P > 0.05$, Bonferromi-Holm's adjustment of ranked values)

Table 5. Infestation by *A. gossypii* (percent infested terminal leaves)

date	«ST»	«soap»	«NT»
09. 02	44.2	48.3	45.1
13. 02	36.5	63.5	56.8
17. 02	75.8	82.0	76.5
21. 02	54.3	92.5	95.3
24. 02	43.3	82.5	93.8
27. 02	23.3	91.0	86.3
03. 03	17.8	77.0	77.8
05. 03	25.3	77.3	72.0
09. 03	43.8	71.8	67.3
12. 03	17.3	77.5	66.8
16. 03	38.0	73.5	84.8
19. 03	25.8	78.5	77.5
22. 03	45.3	75.0	77.3
25. 03	70.8	81.5	86.3
28. 03	44.3	67.8	59.8
01. 04	58.8	54.3	52.5
03. 04	55.3	60.3	62.5
06. 04	33.5	59.3	73.5
10. 04	40.5	68.0	54.8
13. 04	23.3	45.0	35.8



6.5. Discussion

Little information about control of cotton aphids with soap solutions is available. Most experiences with detergents have been gained in organic farming systems, and no data on efficacy against *A. gossypii* have been published. The insecticidal power of detergents rely on a good coverage for a maximum amount of time (Gilrein 1992). This is why fields should be sprayed in the evening in order to slow down the drying up of the solution. High application volumes are also required to reach aphids in the lower strata of the plants. In Egypt, five litres soap diluted in 600 litres water per ha are successfully applied against early-season infestations of *A. gossypii* (C. Boecker, SEKEM, Egypt, pers. comm.). However, such a high application rate is completely unrealistic under the dry conditions of south-western Madagascar, where water is the major constraint for agriculture (Hoerner 1986). Insecticide applications in this region are generally carried out with ULV/VLV battery-operated spinning disc sprayers, and the prospects of any additional expenditure in terms of work or time is met with outspoken reluctance by growers.

Apparently, 100 litres of a 2.5-3.0 % solution do not assure a sufficient coating of the pest when the plants have developed a dense canopy and the greater part of the aphid population feeds on the lower side of the leaves in the lower and middle strata of the plants (cf. chapter 3). These constraints specific to the cotton crop may not apply to those cases where detergents are successfully used against aphid pests, such as in orchards or in the greenhouse (U. Helberg, pers. comm.).

However, the yield data revealed that the conventional chemical control in the «ST» plots did not provide satisfactory results, either. Eight applications of synthetic organic aphicides only secured 474 kg of raw cotton/ha, 256 kg more than in the «soap» plots, which is below the break-even point of profitability in small farmer systems in rain-grown Malagasy cotton (L. Andriambololona, HASYMA, pers. comm.). The yield level in the «ST» treatment was only 40 % of yields obtained in adjacent plots where an insecticide trial was conducted with a total of eight sprayings, six of which were directed against bollworms (cf. chapter 2, 3).

Aphis gossypii cannot be considered a key cotton pest in south-western Madagascar (cf. chapter 3). Injury due to feeding of plant sap is not critical at low to modest infestation levels, and quality losses of fibres as a consequence of honeydew secretion are negligible in comparison to other sources of degradation like dust, plant debris or inadequate storing conditions (H. Rakotofiringa., pers. comm.). The large gap between yields in «ST» plots obtained in the two trials is probably due to insufficient control of bollworms by

monocrotophos and the carbamates benfuracarb and carbosulfan (Dove 1994a, Peyrelongue et al. 1974). The significantly higher yield in the «ST» compared to the «soap» and «NT» plots may not be attributable to aphid control but to an unknown extent to the suppression of pests other than aphids, i.e., boll feeders, whiteflies (*Bemisia tabaci* Gennadius [Hom.: Aleyrodidae]), cotton stainers (*Dysdercus flavidus* Signoret [Het.: Pyrrhocoridae]) and cotton leaf perforators (*Bucculatrix loxoptila* Meyrick [Lep.: Lyonetiidae]). The non-boll feeders, usually considered as minor pests, commonly reach outbreak-like population densities in untreated late-season cotton, but are all highly susceptible to all insecticides applied at the end of the cycle (cf. chapter 2).

The HASYMA threshold for *A. gossypii* has been deducted from trials where damage by pests other than aphids was deliberately ignored (Andriambololona et al. 1989). Low thresholds may seem justified, as long as insecticide sprayings concomitantly keep other pests in check, and economic benefits are not compromised by long-term build-up of pest resistance. In this trial, however, following the action threshold of 15 % infested terminal would have meant even higher frequencies of insecticide applications with little economic benefit for the farmers. The costs of the eight aphid interventions in this trial amounted to the equivalent of 166 kg raw cotton (value of insecticides only). High proportions of infested leaves can correspond to small aphid numbers per leaf, which are unlikely to cause damage to the crop, especially during the period before the opening of the first boll (cf. chapter 2). In addition, the recommended binomial sampling technique used for spraying decisions provides little accuracy when applied to terminal leaves and when sampling units are considered infested at any density different from 0 (cf. chapter 3). For example, density estimates of scores on six leaves resulted in significantly higher aphid densities in control than in «soap» plots on 05/03, 09/03 and 19/03, whereas percentage infested leaves indicated higher infestation in the soap treatment.

Pest management decisions should rely on more precisely defined economic thresholds. In Madagascar, cotton aphids are more reliably controlled by natural enemies than most other cotton pests (cf. chap. 3, 4). Parasitic fungi and predators, in particular syrphids and the coccinellid *Scymnus constrictus* Mulsant, are likely to contribute to aphid population decline at the flowering/early boll stage. The low predator numbers in the untreated control plots of this experiment were possibly due to repellent effects of neighbouring insecticide treated «ST» plots, considering that the plot size used in this experiment was comparatively small for this kind of insecticide trials (Petersen 1994). Thus, big plots should be used in insecticide regime experiments whenever possible.

7. General discussion

The objective of this study was to provide a general update on arthropod cotton pests and their natural enemies in Madagascar. Special emphasis was given to the seasonal population dynamics, spatial distribution, sampling procedures, and predators of *A. gossypii*. Cotton aphids hold a special position in Malagasy cotton, because they are considered to be an important pest only since the late 1980s, and outbreaks have been linked up with unintentional effects of insecticide treatments, i.e., destruction of natural enemy populations and stimulatory effects of synthetic pyrethroids on aphid reproduction (Dove 1994b).

Monitoring of the seasonal population dynamics of *A. gossypii* in rainfed and in receding flood cotton during the 1997 and 1998 cropping seasons revealed marked differences in infestation patterns depending on the insecticide regime and the region (cf. chapter 3).

In rainfed cotton in south-western Madagascar, aphids are efficiently kept in check by aphicidal treatments with monocrotophos. In this study, mean densities in treated plots were negligible in rainfed cotton. Only 178 and 288 aphid-days were accumulated during 98 and 85 days in 1997 and 1998, respectively. Infestation in untreated plots were characterised by exponential growth during the two weeks preceding the aphid peak at flowering/early boll, followed by a rapid decline. However, peak densities reached only moderate levels. According to regressions of physiological yield responses on aphid densities developed by Fuson et al. (1995) and Godfrey et al. (1997), the observed cumulative aphid indices for mid-season infestations did not reach levels which would have warranted interventions with aphicides. The apparent economic success in repeated aphicidal sprayings in rainfed cotton are most likely due to the elimination of pests other than aphids. Monocrotophos not only provides partly control of the American bollworm *H. armigera*, but also suppresses species generally considered minor pests in Malagasy cotton, such as cotton stainers (*D. flavidus*), whiteflies (*B. tabaci*) or leaf-perforators (*B. loxoptila*). Late season infestations of stainers can lead to incomplete boll opening and secondary degradation of fibres by saprophytic fungi (Kuklinski 2000). Late-season infestations of whiteflies, which occupy the same

ecological niche as *A. gossypii* and cause similar injury, exceeded aphid densities in both years of this study.

It is generally acknowledged that aphid infestations in receding flood cotton in north-western Madagascar are considerably more severe than in rainfed cotton (Dove 1994b; H. Rakotofiringa, pers. comm.). Aphids are thought to be secondary pests, resulting from the abuse of synthetic pyrethroids since the early 1980s. However, the underlying mechanisms of this development were not well understood. The economic status of *A. gossypii* in receding flood cotton, where it is nowadays considered the principal pest after *H. armigera*, was confirmed in this study (cf. chapter 3). Though aphid densities increase slower during the dry, cool season in the north-western region, higher and more persisting infestation levels are observed than in the south-west. Infestations in receding flood cotton were characterised by a second, late-season peak except in untreated plots in 1997. Ironically, accumulated aphid-days were higher in insecticide sprayed than in untreated plots despite of three specific treatments with monocrotophos or benfuracarb which were carried out in both years. Both in the 1997 and 1998 study, sharp aphid population increases were observed after cypermethrin treatments for control of bollworms. There was strong evidence that the aphid outbreaks were induced by a reproduction stimulus conveyed by the pyrethroid, possibly by manipulating the metabolism of the host plant (Kerns and Gaylor 1993). The absence of this initial rapid population growth phase in the untreated plots could not be explained by higher predation rates through conservation of predator populations, because predator densities were very low during these periods.

The inventory of natural enemies carried out during this study revealed a large array of natural enemies feeding on cotton pests in Madagascar (cf. chapter 2). In this study, 20 arthropod natural enemy species and an entomophthoralean aphid pathogen are presented as new records. However, *A. gossypii* appears to be the only pest which may be consistently controlled in check by beneficials. Five species of Coccinellidae, two Syrphidae, one Chrysopidae and one Hemerobiidae were recorded as aphidophagous predators at both experimental sites. Predators are far more abundant and better synchronised with their prey in receding flood cotton, where the coccinellid *C. simulans* is the most abundant species. Aphid predator populations in rainfed cotton are at a disadvantage not only because of poor early-season supply of prey, but

also due to excessively high temperatures and rainfall which have detrimental effects on fecundity, adult longevity, and on survival of young larval instars, respectively.

An important discovery was the occurrence of the aphidopathogenic fungus *N. fresenii* in Malagasy cotton aphid populations. During this study, conditions were not very favourable for the activity of the fungus. However, the pathogen seems to have the potential to cause spectacular epizootics, providing that high degrees of relative humidity coincide with high host densities. Further research is needed to elucidate whether the presence of killed aphids in the field can help to reduce the frequency of mid-season aphicide applications. An interesting aspect of the control potential of *N. fresenii* is the compatibility of the fungus with insecticide treatments intended to suppress other pests, such as bollworms (Steinkraus et al. 1995). In contrast, the extreme susceptibility of aphid predators to most of the commonly used insecticides in Malagasy cotton was demonstrated in situ tests in the field. Cypermethrin, thiodicarb, and monocrotophos were highly toxic to the late instar larvae of the syrphid *I. aegyptius* and the two most important coccinellids *C. simulans* and *S. constrictus* (cf. chapter 2).

The impact of aphid predators on the aphid population dynamics was investigated in exclusion experiments (cf. chapter 4). A neat tendency of increased aphid densities in colonies protected from predators compared to colonies where predators had free access was observed. However, the influence of predation on the observed differences was not readily quantifiable. The model of Chambers and Aikman (1988) used in this study has the disadvantage of being applicable only to the aphids' exponential growth phase in non-limiting conditions. Moreover, the estimates of "required kill" are flawed by a large and undefined error. Nevertheless, for the two time periods at the receding flood site, when the assumptions of the model were fulfilled, the calculated required daily kill rates were inferior to potential kill values obtained from field laboratory data, indicating that the observed density differences between free and protected colonies may have been caused solely by predation.

This study concludes that outbreaks of cotton aphids must be considered the result of a pest management strategy which until today has been relying uniquely on chemical therapeutics (Bournier and Vaissayre 1977, Berger 1979). Consistently, pest resurgence of *A. gossypii* has been more serious in receding flood cotton. During the 1980s, insecticide input had been particularly heavy in the north-western region, because the routine use of pyrethroids for bollworm control had entailed outbreaks of

a new pest, *S. littoralis*, which turned out to be almost completely resistant to deltamethrin and cypermethrin (Dove 1994b). Contrary to rainfed cotton, where aphids are efficiently suppressed with monocrotophos, aphid problems in receding flood cotton are not only caused by resistance of *A. gossypii* to insecticides currently applied for control of *H. armigera* and *S. littoralis* or *Earias* spp. (cypermethrin, thiodicarb, endosulfan). In the north-western cotton region, the suppression of predator populations and probably even more important, the stimulatory effects of cypermethrin on aphid reproduction, repeatedly impose remedial aphicidal treatments as long as cypermethrin and other toxic compounds are not replaced by less disruptive products.

This study also demonstrated that inadequate sampling procedures and unjustifiably low action thresholds may enhance inconsistencies in aphid management (cf. chapter 3) The statistical assessment of the currently applied binomial sampling method on four or five terminal leaves revealed several sources of error in aphid management decisions. Mid-season aphid populations are concentrated in the lower and middle strata of the cotton plant. The proportional infestation levels on the upper leaves was strongly fluctuating, apparently influenced by insecticide treatments and seasonal factors, such as drought or plant growth stage. The model of Gerrard and Chiang (1970), which relates the proportion of empty sampling units to the mean, was a useful tool to evaluate the precision of the mean estimate for different sampling units and different tally thresholds T (i.e., the maximal number of individuals which may appear in a sample to be considered empty) (Zhang et al. 1998). The reliability of the mean estimate could be considerably improved when tally thresholds for binomial counts of empty sampling units were different from $T = 0$ and only main stem leaves were taken into account (cf. chapter 3).

There was no direct evidence for any impact of aphids on raw-cotton yields. Regression analysis of yield on number of intact bolls and on plant height revealed that boll retention, but not plant stunting as caused by leaf-feeding pests, significantly determined yield levels (cf. chapter 2). The economic impact of *H. armigera* can be dramatic if not controlled. At both sites and in both years, yield losses in untreated fields exceeded the equivalent of management costs with insecticides by a factor of three or more. The temporal overlap of economically significant bollworm infestation with peak densities of both *A. gossypii*, *S. littoralis* and their natural enemies during

the host plant's flowering stage leaves growers in a dilemma: They are obliged to control mid-season infestations by boll feeders with chemicals, which by consequence disrupt the build-up of aphid-suppressing predator populations. However, it is possible to refer to more selective insecticides, such as endosulfan or profenofos which proved to be less toxic to the coccinellid *C. simulans* in field tests (cf. chapter 2). In the future, it will pay off to evaluate new active ingredients not only with regard to their efficacy against the target pests, but also to examine their potential to preserve the beneficial entomofauna.

The presently advocated action threshold of 15 % aphid infested leaves is likely to be an over-estimation of the economic importance of *A. gossypii* in Malagasy cotton. The value of 15 % infested terminal leaves is poorly correlated to the overall population mean and corresponds to only a few aphids per leaf (cf. chapter 3). The direct trophic injury inflicted to the plant by the aphids' sap feeding was not reliably reflected in reduced plant growth, and plant height was not significantly correlated to yields. Also, quality losses due to honeydew contamination of fibres play de facto only a minor role in Malagasy cotton when compared to the proportion of fibres downgraded due to dust, plant debris or untimely rainfall.

Neither the field tests of neem oil extracts against *H. armigera*, *S. littoralis* and *A. gossypii* (cf. chapter 5), nor the trial with potassium soap solution sprayings against *A. gossypii* (cf. chapter 6) yielded promising results. The high pest pressure in Malagasy cotton, in particular of *H. armigera*, and the low costs of chemical control make it at present difficult to advocate alternative pesticides and biological control methods. However, the recent history of Malagasy cotton production has repeatedly exemplified the risks of indiscriminate use of synthetic insecticides. For the time being, good IPM practise will essentially have to rely on the conservation of the natural enemy complex naturally present in Malagasy cotton fields.

8. References

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Identifications were made by the following taxonomists:

H.-P. Aberlenc: Syrphidae; J.-P. Bournier: *Frankliniella occidentalis* (Pergande); G. Delvare: hymenopterous parasitoids; C. Duverger: Coccinellidae; J.-M. Males: *Afrius flavirostrum* Signoret (all CIRAD-CA, Montpellier); J. Bonfils (Aiguefonde, France): *Igerna ?bimaculicollis* (Stål); G. Goergen (IITA-PHMD, Cotonou, Benin): Carabidae, Reduviidae; V. J. Montserrat (Madrid): *Micromus plagatus* Navas; P. Ohm (Kiel): *Mallada desjardinsi* (Navas); G. Zimmermann (BBA, Darmstadt): *Neozygites fresenii* (Nowakowski), *Cladosporium* spp..

Curriculum vitae

I was born in Tondern (Tønder), Denmark, on 30 June 1965. In 1982, I graduated from the German secondary school "Ludwig-Andresen-Schule" in Tondern and continued studies at the grammar school "Deutsches Gymnasium für Nordschleswig" in Apenrade (Åbenrå), Denmark. I passed the "Abitur" (A-level) examination in 1985. The same year, I was recognised as a conscientious objector and was dispensed from serving in the armed forces. For twenty months, I worked in a nursing home for elderly and disabled people in Kiel and in a hospital in Niebüll, both Germany.

In 1987, I started to study philosophy at the University of Göttingen, Germany. The following year, I took up my studies in biology at the same university. After the preliminary exam in biology in 1990, I began to specialise in botany, phytopathology, applied entomology and pedology. I passed the oral examination in April 1993. Later that year, I joined the Plant Health Management Division of the International Institute of Tropical Agriculture (IITA-PHMD) in Cotonou, Republic of Benin, to carry out experimental work for my Diploma thesis, dealing with the potential of entomopathogenic fungi for control of lepidopteran stem borers. In 1995, I graduated in Biology at the University in Göttingen as a "Diplom-Biologe", an academic degree comparable to a Master of Science.

The same year, I was admitted to the faculty of Horticulture at the University of Hannover as a PhD student. I had been proposed to work on cotton pests in Madagascar by W. Zehrer of the German Technical Cooperation (GTZ). During three years, I was engaged in field experiments in two cotton regions in Madagascar. My studies were supported by the local GTZ project «Promotion de la Protection Intégrée des Cultures et des Denrées Stockées à Madagascar» and by the Malagasy cotton company HASYMA. However, as was also the case during my stay in Benin, I financed my private life costs on my own.

Late 1998, I returned to Hannover for the writing-up of the thesis. Additionally, I wrote a monograph on cotton pests in Madagascar entitled "Les ravageurs de la culture cotonnière malagasy avec une attention particulière à *Aphis gossypii* et ses ennemis naturels".

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