Patterns of lacewing (Neuroptera: Chrysopidae) flight activity, flight height and spatial distribution of eggs on maize plants

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Lacewings (Chrysopidae) are important beneficial insects in nearly all cropping systems. However, monitoring of lacewing numbers is difficult due to the nocturnal behaviour of adults and the difficulty of finding eggs and larvae on plants. Techniques facilitating easy finding of eggs and adults will result in improved pest management decisions and monitoring of these beneficial organisms. This study was conducted to determine flight activity patterns as well as preferred oviposition sites of lacewings on maize plants to facilitate time-effective searching for eggs. The daily flight activity pattern and flight height of lacewings were recorded and sweep-net samples were taken to determine lacewing numbers in different adjacent vegetation types (maize, lucerne, natural veld). The preferred area of oviposition was determined by inspecting maize plants for lacewing eggs and recording the distribution of eggs on leaves. *Chrysoperla pudica* (Navás) was the predominant species in maize. Lacewings were most active between 16:00 and 22:00 and flew largely between 0.5 and 2.5 m above ground level. Oviposition occurred predominantly on leaves near maize ears. Data on spatial distribution of eggs facilitate monitoring of eggs numbers in maize cropping systems and is also of use in general pest management.

Key words: beneficial insects, *Chrysoperla* spp., egg scouting, monitoring, non-target insects.

INTRODUCTION

The Neuroptera are excellent indicators of environmental and habitat transformation, and also include key species for signifying areas and faunas that require priority protection (Mansell 2002). For this reason members of the family Chrysopidae (lacewings) are often used in studies on non-target effects of agrochemicals and genetically modified crops (Andow & Hilbeck 2004). Since the first deployment of genetically modified crops with insecticidal properties (Bt maize and Bt cotton), there has been concern with regard to possible non-target effects of these crops (Meeusen & Warren 1989; Gould 1998). Bt maize produces Cry 1Ab proteins that are toxic to lepidopteran stem borers but have also been reported to adversely affect lacewings (Hilbeck *et al.* 1998). However, results to the contrary have also been reported (Romeis *et al.* 2003; Lawo *et al.* 2007).

Chrysoperla spp. (Neuroptera: Chrysopidae), are some of the potential non-target species that could indirectly be affected by eating herbivorous prey that consume Bt proteins aimed at target pests (Hilbeck *et al.* 1998). Among the prey consumed are pests of economic importance such as aphids, whiteflies, mites and mealybugs (Senior & McEwen 2007) which also feed on Bt maize. Lacewing larvae are polyphagous and active predators with a highly effective searching capacity (Senior & McEwen 2007; Barnes 1975). For example *Chrysoperla zastrowi* (Esben-Petersen) consumes an average of 488 aphids or 906 potato tuber moth eggs during its larval stage (Barnes 1975).

The temporary nature of field crops necessitates avoidance or escape of insects when the crops are harvested and environmental conditions turn unfavourable. The two most important strategies utilized by lacewings are migration and diapause (Duelli 1980). Duelli (1980) studied flight patterns of *Chrysoperla carnea* (Stephens) and found that shortly after emergence the adults perform adaptive dispersal flights which are straight downwind flights. This use of wind to migrate, combined with the fact that the adults are small and that flight activity is nocturnal, make it very difficult to observe and study the migration and flight activity patterns of lacewings.

Since lacewing eggs are small and the oviposition site on maize plants is not known, searching for their eggs is labour-intensive and time-consuming. It is therefore difficult to determine the

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abundance of eggs in crop fields and to collect data that would be important in monitoring of these beneficial organisms. The need therefore exists to develop a scouting technique that enables time-effective and efficient search and detection of lacewing eggs on maize plants.

Limited and contradicting information exists on the oviposition patterns of *Chrysoperla* spp. on crops. *C. zastrowi* appears to be indiscriminate in its choice of oviposition sites in the field and it does not have preferences for specific plant parts such as leaves or stems for oviposition (Barnes 1975). While some studies reported that females prefer to lay eggs near aphid-infested areas on plants (Skaife 1979; Petersen & Hunter 2002; Kunkel & Cottrell 2007), oviposition in locations where their major food source, aphids, was absent, was also reported (Coderre *et al.* 1987; Duelli 1984).

The aims of this study were to determine if there was a pattern in the spatial distribution of *Chrysoperla* spp. eggs on maize plants, to study the daily flight activity pattern of lacewings, the height above the crop canopy they fly and movement of adults between maize fields and surrounding grasslands. Results will facilitate development of effective scouting strategies for lacewing eggs in maize fields which will contribute to monitoring for IPM purposes as well as possible non-target effects of Bt maize on these organisms.

MATERIAL AND METHODS

Field experiments on lacewing flight patterns, oviposition preferences and presence in different vegetation types were conducted at the Vaalharts irrigation scheme (27°50′S 24°50′E) located in the Northern Cape province. The Vaalharts irrigation scheme is a high input irrigation scheme where no intercropping is practised.

Species identification

Sweep-net samples were taken in a maize field at each site to identify the species present in the fields. Sweeps were made by moving the sweep-net in an up-and-down pattern over maize foliage while walking down the maize row. These samples were collected from a total row length of approximately 50 m. Individuals of the green lacewings were used for species identification and no distinction was made between sexes.

Spatial distribution of lacewing eggs

The distribution of lacewing eggs on plants was studied at both the Vaalharts irrigation scheme and the Tshiombo irrigation scheme (22°47′S 30°27′E) in the Limpopo province. In contrast to Vaalharts, the latter site is characterized by low-input resource-poor farming in which intercropping is common. All maize fields on which data were collected were surveyed approximately 2–3 weeks after flowering (pollination). Ears in the milk to soft dough stages of development were therefore present on all plants. Surveys were carried out during these plant growth stages since prey (aphids) and lacewing numbers increase during the post-flowering stages of maize.

Sixty maize plants on which *Chrysoperla* females oviposited were inspected at Vaalharts and 76 at Tshiombo. More plants were inspected at Tshiombo since the abundance of eggs per plant was lower than at Vaalharts. Leaves of each maize plant were counted and numbered from the top of the plant downwards. The number of the leaves that covered the maize ear was documented and in cases where there was more than one ear per plant, leaf numbers of both ears were recorded. Each leaf of each plant was examined for eggs, starting from the top (flag leaf), downwards to the lowest (oldest) leaf. When an egg was observed it was noted whether it was on the proximal or distal half of the leaf and whether it was situated on the adaxial or abaxial surface. All eggs that were encountered during the survey were stalked eggs. Both hatched and un-hatched eggs were counted.

Flight activity and flight height

Five 6-m-high sticky traps were placed inside a lucerne field (about 2 ha) situated adjacent to a maize field (40 ha). Each trap consisted of two 6 m-high PVC pipes between which a sticky trap was suspended. The sticky traps were constructed of thin light-weight wooden frames (6 m × 30 cm) covered with mosquito gauze. The frame was attached to ropes on a pulley system between the two PVC pipes to facilitate up and down movement when a trap had to be inspected for lacewings. Commercially available glue commonly used on insect traps was applied to the mesh which was marked at 50-cm intervals from bottom to top. The traps were erected on five occasions (May, August, September and November 2009, and March 2010) and left in the field to be monitored for two night-cycles. The nocturnal flight activity of lacewings was monitored every hour from 16:00 until 08:00 the next morning. The number of lacewings trapped at different heights was determined by lowering the mesh-covered panels and counting the number of captured lacewings on the mesh. Traps were left in place during the day but were not monitored between 08:00 and 16:00. At commencement of monitoring at 16:00, traps were checked for the presence of lacewing adults to determine if any individuals had been trapped during the day.

Seasonal abundance of lacewings in crops and grasslands

During the 2009/2010 season sweep net samples were taken at regular intervals in a lucerne (2 ha) and a Bt maize field (40 ha) as well as in the grassland (1 ha) adjacent to this field. Sweep-net samples were taken on five occasions (May, August, September and November 2009, and March 2010). Five sampling areas of about 36 m^2 were randomly selected inside each field and ten 180° sweeps made in each area. The number of lacewings in each sampling area was then determined.

Data analysis

Data on the spatial distribution of eggs were expressed as a proportion of the total number of eggs per specific leaf, as well as per abaxial or adaxial leaf surface.

Data on flight patterns were pooled for all trapping periods and means determined, followed by calculation of a 2-hour moving average over time. The numbers of lacewings captured at specific height-categories (*e.g.* 2.0–2.5 m) above ground level were calculated as a proportion of total catch and expressed as a percentage. The mean number of lacewings collected with sweep nets per vegetation type was calculated and expressed as number per hectare.

RESULTS AND DISCUSSION

Species identification

Nearly all the lacewings collected at both the Vaalharts and Tshiombo sites were *Chrysoperla pudica* (Navás). Very few (<5) lacewings other than green lacewings were collected. These were therefore considered not to be important with regard to the oviposition data that were collected.

Spatial distribution of lacewing eggs

At Vaalharts 275 eggs were found, with a mean of 4.58 eggs per plant, whereas at Tshiombo 112 eggs were found, with a mean of 1.47 eggs per plant.

Clear patterns in horizontal (proximal/distal on leaf) and vertical (in relation to maize ear position) egg distribution were observed. This spatial pattern was related to the vertical position of the ears on the plants and has to be interpreted in this context.

At both sites the majority of maize ears were located in the axil of leaf number 7 (Fig. 1). At Vaalharts 89 % of the 79 ears were located in the axils of leaf numbers 7 and 8 (Fig. 1a) while at Tshiombo, ear location was slightly more variable, with 87 % of the 132 ears occurring in the axils of leaf numbers 6 to 8 (Fig. 1b).

At both sites a clear pattern was observed in vertical distribution of eggs on the plants relative to the position of maize ears. At Vaalharts, 73 % of eggs were laid on the leaf that covered the ear (leaf no. 7) and the four leaves above that ear (Fig. 2a). At Tshiombo where 81 % of the eggs occurred on leaf numbers 5–9 (Fig. 2b), which is the area on the plant were the majority of ears occurred.

A definite pattern in the horizontal distribution of *Chrysoperla* eggs was also observed. At Vaalharts 90 % of eggs were laid on the proximal end of the leaf (Fig. 3a) with 88 % on the adaxial leaf surface (Fig. 3a). At Tshiombo, 88 % of eggs were found on the proximal end of the leaves, but eggs were more evenly distributed on the surfaces with 42 % on the adaxial and 58 % on the abaxial surfaces of the leaves (Fig. 3b).

The preferred oviposition sites for lacewings on maize were therefore on the leaves in the vicinity of the ears. Consequently, scouting for *Chrysoperla* eggs can be done more rapidly and more reliably by searching only on the leaves on and near the ears.

Aphids are the major prey for lacewing species (Coderre 1988). Maize is often infested by aphids such as *Rhopalosiphum padi* (L.) and *R. maidis* (Fitch) (Hemiptera: Aphididae), especially during the post-flowering period when aphids mostly occur underneath the bases of the leaves that cover the ears. Although the presence and abundance of aphids were not recorded during this study it was noted that the plants on which there were lacewing eggs were often also infested with aphids. Although it was not the aim of this study to determine the relationship between the presence of aphids and lacewing eggs, our observations seem to suggest a strong relationship.

Other studies, however, appear to show no clear pattern in the way lacewings choose oviposition sites. Some species lay eggs in locations without

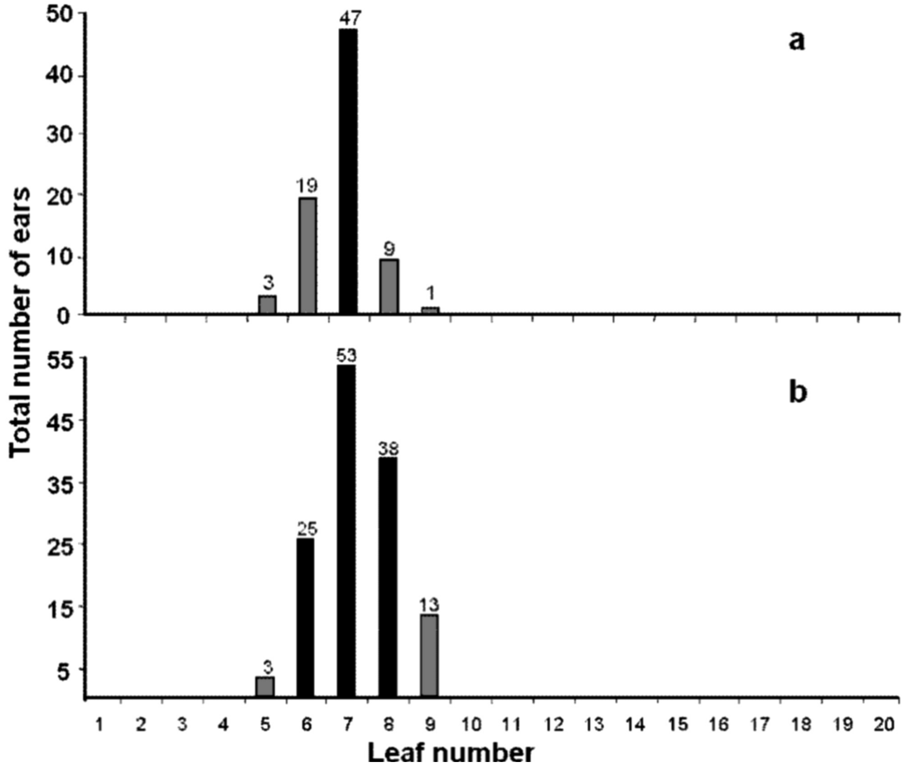

Fig. 1. Positioning of maize ears on plants at (**a**) Vaalharts and (**b**) Tshiombo. Darker bars indicate the leaf position (axil) at which most maize ears occurred.

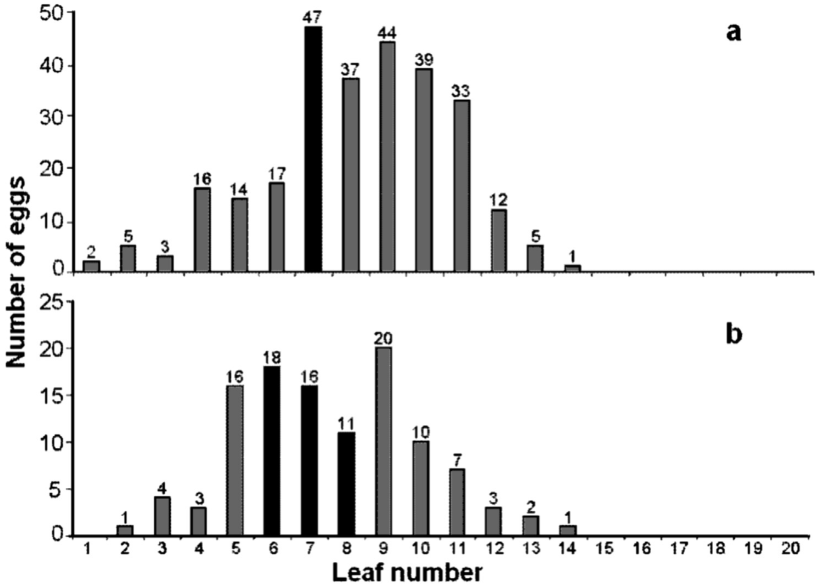

Fig. 2. Number of *Chrysoperla* spp. eggs found per maize leaf at (**a**) Vaalharts, and (**b**) Tshiombo. Darker bars indicate the leaf position (axil) at which most maize ears occurred.

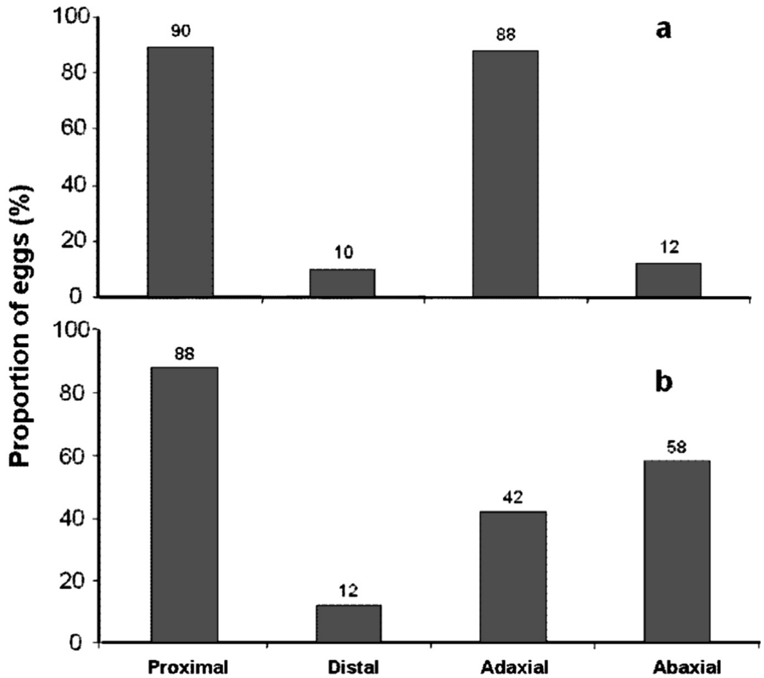

Fig. 3. Horizontal distribution of *Chrysoperla* spp. eggs on maize leaves at (**a**) Vaalharts irrigation scheme, and (**b**) Tshiombo irrigation scheme.

aphid colonies while some lay eggs near aphid colonies. Skaife (1979) observed that lacewing females generally choose the underside of leaves which are infested with aphids. Patel & Vyas (1985, cited by Szentkiralyi 2007) reported that the overwhelming majority of eggs of *C. carnea* on cotton were located on the leaves, with only a few deposited on fruits and branches. They also observed that more eggs were laid on the abaxial surface of leaves. On maize in Canada, *C. oculata* (Say) females deposited their eggs on the six leaf-levels below the ear, with no consideration for the availability of the aphids on the plants (Coderre *et al.* 1987). On the other hand Liao *et al.* (1984) found that in pecan orchards *C. rufilabris* (Burmeister) oviposition increased as aphid density increased. Females of *C. carnea* are attracted to the smell of honeydew (Hagen *et al.* 1976) while *C. cognata* (McLachlan) females are attracted by aphid sex pheromones (Boo *et al.* 1998). The abovementioned studies indicate that different species react differently to different stimuli. This may suggest that the distribution pattern of eggs may also differ between species, as observed in this study with *C. pudica* in South Africa and *C. oculata* in Canada (Coderre *et al.* 1987).

Although the presence of aphids seems to influence lacewing oviposition behaviour, it is most likely not critical to the survival of lacewings since their larvae are polyphagous and active predators with a highly effective searching capacity (Barnes 1975; Senior & McEwen 2007). These larval characteristics make the importance of ovipositing near aphid colonies less critical for subsequent survival (Coderre *et al.* 1987). When the offspring of a species have generalized feeding habits and are mobile enough to move to other plants, or there are different requirements for juvenile and adult feeding, ovipositing females may show little discrimination among host plants (Thompson 1988).

Flight activity and flight height

Since traps were maintained during the day between the two night-cycles, day-flight activity could also be recorded. However, no lacewing adults were recorded on traps between 08:00 and 16:00, which was expected since the Neuroptera are nocturnal (Duelli 1986; New 2007). During daytime, lacewings rest on the underside of leaves and twigs (Duelli 2007). In this study lacewings started flying after 16:00 h and reached peak activity by 22:00. From 23:00 onwards the activity

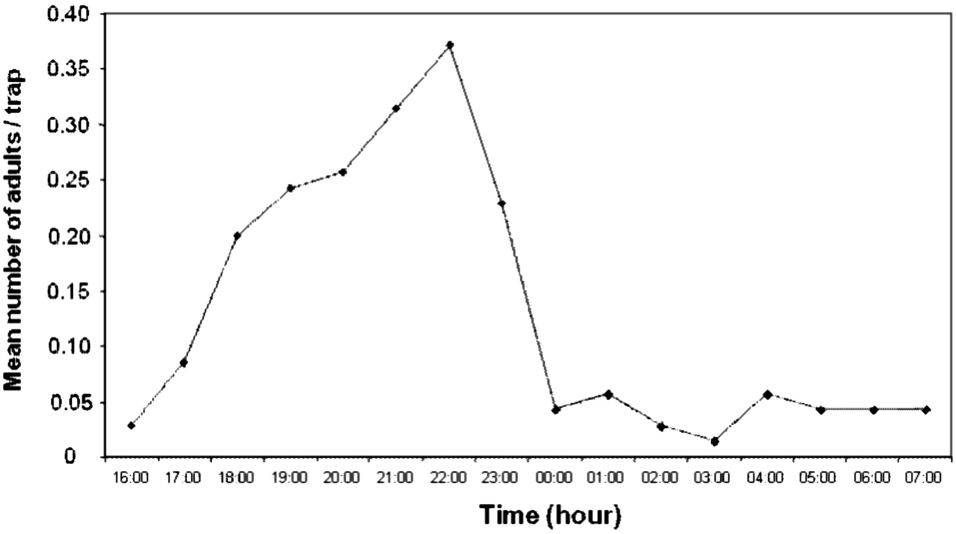

Fig. 4. Flight activity pattern of lacewing adults between 16:00 and 07:00 in a lucerne field at the Vaalharts irrigation scheme (2-hour moving average).

decreased rapidly and occurred only at a very low level until 08:00 (Fig. 4). Duelli (1986) studied flight activity patterns of *C. carnea* under laboratory conditions and observed that most lacewing species started flying after sunset, before it was completely dark, and that they have a short but consistent activity peak after the onset of flight. If environmental conditions remained favourable, flight activity was observed until dawn, when flight activity decreased sharply.

Fifty-three of the 73 lacewings caught (71.6 %) were trapped between 0.5 and 2.5 m above soil level (Fig. 5). The highest position that lacewings were trapped was at 5.5 m. Duelli (1980) found that the average height of flight of *C. carnea* females during the first 2 to 3 nights after eclosion was between 6 and 12 m, whereas the average for females in the oviposition stage was around 3 m. The mean flight height for males and females was between 6 and 12 m.

Seasonal abundance of lacewings in different vegetation types

No lacewings were collected in any of the sweep-net samples taken in the grassland vegetation at the Vaalharts study site. This may be because of a more suitable environment (lucerne) nearby, which provided food in the form of aphids for the largest part of the year, or a total absence of suitable food in the grassland.

Adult lacewings were present in the lucerne

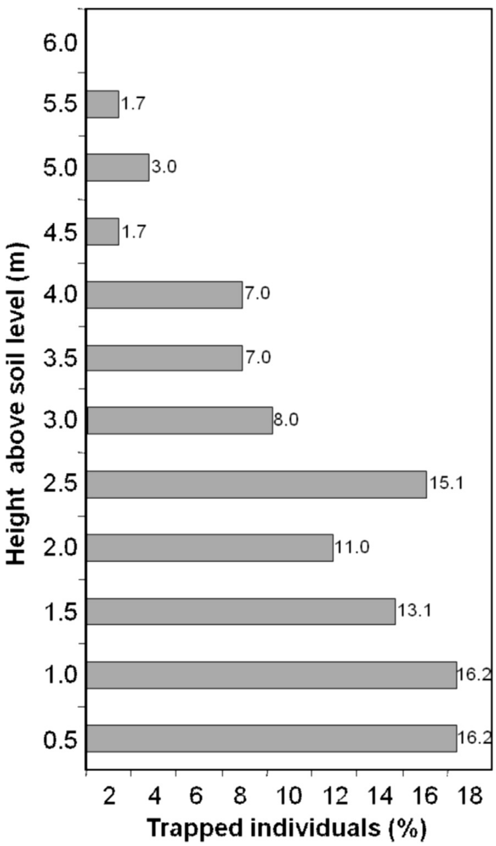

Fig. 5. Flight height of lacewing adults in a lucerne field at the Vaalharts irrigation scheme.

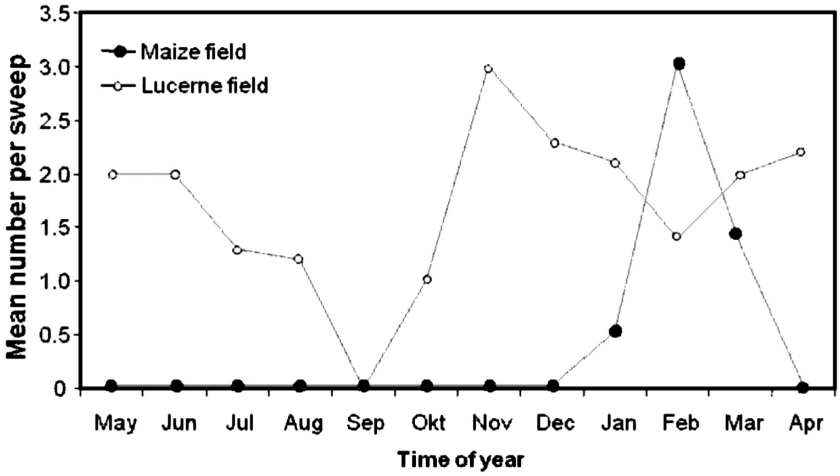

Fig. 6. Mean number of lacewing adults caught in sweep nets from May to April in adjacent habitats.

field throughout the season (Fig. 6). However, the population fluctuated during the season with peaks from April to May, and October to December (Fig. 6). Adult numbers declined from June until September (when no adults were caught), possibly because of decreasing temperatures from autumn to winter. As the temperatures increased with the onset of spring (September to November) so did the population numbers, and by November the maximum mean number of three adults were found per 36 m^2, which equates to 833 adults per ha. The observed fluctuations in population numbers over time in the lucerne field are difficult to explain. Although low temperatures and poor aphid host plant quality could have resulted in a shortage of food for lacewing larvae towards the end of the winter months (August to September), these factors alone cannot explain the variation in numbers and should be investigated further.

No adults were found in the maize field from May to December (Fig. 6). This is ascribed to the change in habitat which becomes unsuitable for lacewing adults as the maize dries off from March onwards, together with the simultaneous decrease in abundance of lacewing prey. Low numbers of lacewings appeared in maize from early December, and numbers increased to a maximum of 2.8 adults per 36 m^2 in February when the crop matured. This equates to 777 adults per ha. The lacewing population in the maize field most likely originated from the population that was sustained in the adjacent lucerne field, and their movement to the maize field is most likely due to an increasing amount of food becoming available on maize.

Although limited data were collected on the incidence of lacewings inside the different vegetation types, data showed that in this study no lacewing adults occurred in the wild grassy habitat, and that lucerne acted as the source of lacewings that colonized maize. The high numbers recorded in maize illustrate that, at least in this study, the Bt maize field hosted a much larger population of lacewings compared to the surrounding non-crop environment.

This study provides a scouting strategy for lacewing eggs in maize and showed that searching in the region of maize ears will facilitate easy finding of eggs. The scouting strategy described here will be useful in monitoring of lacewing eggs, both for general IPM purposes or for monitoring of possible impacts (positive or negative) of Bt maize on these beneficial species. Depending on the aims of a monitoring programme and the accuracy of scouting data needed, this study also showed that searching for eggs can be limited to only the upper or lower surfaces of leaves since eggs are generally evenly distributed.

ACKNOWLEDGEMENTS

The technical assistance of all colleagues is highly appreciated. This project was partially funded by Biosafety South Africa and also formed part of the Environmental Biosafety Cooperation Project between South Africa and Norway coordinated by the South African National Biodiversity Institute. *Chrysoperla pudica* was identified by M. Mansell, USDA-Aphis, Pretoria, South Africa.

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Accepted 18 September 2012