Response of ground-dwelling arthropods to a 'push–pull' habitat management system: spiders as an indicator group

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Abstract

Studies were conducted to assess the numerical response of ground-dwelling arthropods to a habitat management system ('push–pull') developed to control maize stemborers using spiders (Araneae) as an indicator group. In this cropping system, maize is intercropped with a stemborer moth-repellent (push) plant while an attractant trap crop (pull) is planted around this intercrop. Two study sites in western Kenya and one site at the Grain Crops Institute of the Agricultural Research Council in Potchefstroom, South Africa, were sampled. Treatments comprised a maize monocrop and an intercrop of maize and desmodium, *Desmodium uncinatum* Jacq., with Napier grass, *Pennisetum purpureum* (Schumach), as a trap crop around the field ('push–pull') in each site. Experiments were laid out in a completely randomized design with four replications at each site. Ground-dwelling spiders were sampled using a combination of pitfall traps and soil samples. A total of 2175 spiders, 78 species in 18 families, were recovered in Kenya and 284 spiders, 34 species in nine families, were recovered in South Africa. Lycosidae was the most abundant family, accounting for >50% of all individual spiders and 27.6% by species richness. Spiders were significantly more abundant at the Kenyan sites than in South Africa while species diversity was significantly higher in South Africa than at the Kenyan sites. At all sites, spider abundance was significantly higher in the 'push–pull' than in the maize monocrop plots. However, the overall spider diversity was only significantly higher in the 'push–pull' than in the maize monocrop plots in South Africa. Moreover, species dominance did not differ between the two cropping systems at all sites. The results showed that the 'push–pull' system evidently enhances overall abundance of spiders, illustrating its potential in further pest control in the maize agroecosystems where spiders may often be one of the most important predatory groups.

Introduction

Ground-dwelling arthropods are important in agroecosystems, with some species having the potential to reduce populations of both weed and insect pests (Thiele 1977; Cardina et al. 1996). These organisms also play an integral part in above- and below-ground food webs and can impact on litter decomposition

(Witkamp and Crossley 1966) and nutrient dynamics within the soil/litter interface (Witkamp and Crossley 1966; Lattin 1993; Wardle 1999). In both natural and managed ecosystems, arthropod species diversity is often positively correlated with the diversity of plant species and with plant density (Risch 1981; Dean and Milton 1995).

Spiders are a major component of the predatory arthropod trophic level in many ecosystems (Marc et al. 1999; Nyffeler 1999; Brown et al. 2003) and may often be one of the most diverse and numerically abundant groups in those systems (Weeks and Holtzer 2000; Nyffeler and Sunderland 2003; Koji et al. 2007). Being one of the major groups of generalist predators, spiders are needed in the development of efficient, sustainable, low-input agricultural systems (Ekschmitt et al. 1997; Marc and Canard 1997; Lang et al. 1999). Intensive management of agricultural systems can negatively affect their abundance, diversity and efficiency (see review by Marc et al. 1999). Comparisons of the effect of insecticides on spider communities in cropping systems (e.g. Epstein et al. 2000) and the effects of other levels of management [e.g. differing intensities of integrated pest management (Miliczky et al. 2000) and the use of flowering plants (Samu et al. 1997)] showed that the spider communities were negatively affected by increased levels of management and positively affected by increased habitat diversity (Brown et al. 2003).

Lepidopteran stemborers are a major constraint on efficient production of cereal crops in sub-Saharan Africa (Ampofo et al. 1986), with *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae) and *Chilo partellus* Swinhoe (Lepidoptera: Crambidae) being the most injurious in eastern and southern Africa (Seshu Reddy 1983; Kfir et al. 2002). Most of the early management strategies for these pests had little impact (Van den Berg et al. 1998). However, recently, a habitat management system has been developed by the International Centre of Insect Physiology and Ecology (ICIPE) and its partners. It involves intercropping maize (*Zea mays* L.) with a repellent plant, *Desmodium uncinatum* (Jacq.), while an attractant plant, Napier grass, *Pennisetum purpureum* (Schumach), is planted as a trap crop around the field (Khan et al. 1997, 2000, 2001; Van den Berg et al. 2001; Khan and Pickett 2004). The intercrop (desmodium) repels gravid female moths which are subsequently attracted to the Napier grass in what is called a 'push–pull' strategy (Khan et al. 1997, 2000, 2001). Effective control of stemborers has been achieved by this strategy (Khan et al. 1997, 2001; Midega et al. 2005, 2006).

An implication of the ubiquitous distribution and functional diversity of the ground- and litter-dwelling arthropods is that site conditions and habitat perturbations may have profound impacts on their abundance and diversity (Rieske and Buss 2001). As the diversity of organisms in an ecosystem may be indicative of the stability, productivity and complexity of that ecosystem (Tilman et al. 1996), it was important to quantify the abundance and diversity of these arthropods in the 'push–pull' cropping system.

In a previous study, it was observed that overall stemborer predators were more abundant in the 'push–pull' than in the maize monocrop plots in western Kenya (Midega and Khan 2003). The objective of the current study was to evaluate species richness, diversity, evenness and abundance of ground-dwelling spiders as an indicator group on the impact of the 'push–pull' system on overall ground-dwelling arthropod abundance and diversity.

Materials and Methods

Study site and plots layout

Studies were conducted in three sites, one in South Africa and two in Kenya. In South Africa, they were conducted at the Grain Crops Institute (26°43′S, 27°03′E) of the Agricultural Research Council, Potchefstroom, henceforth referred to as Potchefstroom, during the 2002/2003 and 2003/2004 (November–March) cropping seasons. In Kenya, they were conducted at Lambwe (0°34′S, 34°22′E) and Homabay Farmers' Training Centre (0°31′S, 34°27′E), henceforth referred to as Homabay, in western Kenya, during the long rainy seasons (March–August) of 2002 and 2003. At all sites, two treatments, a maize monocrop and a 'push–pull', were laid out in four replications. Each treatment was laid in an experimental plot measuring 40 × 40 m at the Kenyan sites and 35 × 38 m in Potchefstroom. The 'push–pull' plot was planted with desmodium between the rows of maize, with Napier grass planted as a trap crop (spaced 1 m from the edge of the plot) around this intercrop. The maize monocrop plot was planted with maize alone. Each of the plots at all sites was subdivided into four subplots measuring 15 × 15 m to facilitate sampling.

Spider sampling

A combination of pitfall traps and soil samples was used to assess the abundance and diversity of ground-dwelling spiders in the experimental plots.

Limitations of the individual techniques were minimized by using a combination of both procedures. Trap captures have an inherent arthropod-activity component that is highly influenced by prevailing weather conditions (Southwood 1978). However, changes caused by daily weather conditions are averaged by the constant exposure of the traps (Tollefson and Calvin 1994). Numbers generated from pitfall trap catches alone do not provide estimates of absolute density. They instead estimate active density, which is a function of a species population size, activity and ease of capture (Topping and Sutherland 1992; French et al. 2001). Sampling continuously for a period of weeks or months with pitfall traps effectively estimates relative abundance of species within a habitat and permits comparison of abundance across years or months or seasons in that habitat (Baars 1979).

In each subplot, five pittraps were laid. The traps were 12 cm diameter by 16 cm high plastic cups set in the ground so that the rim was 2 cm below the soil surface. Formaldehyde (4%) was used in the traps to preserve the captured arthropods. Plastic plates were fastened over the traps as a precaution against raindrops diluting the contents and litter/foliage dropping over the traps thereby blocking them.

To monitor the activity–density of the spiders, the traps were set throughout the seasons and emptied weekly. The captured specimens were sorted and spiders sent to the National Collection of Arachnida at the ARC-Plant Protection Research Institute, in Pretoria, South Africa, for identification and housing of voucher specimens.

Soil samples were dug out, 20 × 20 × 20 cm, in all the plots. Use of a random and systematic sampling was adopted. This ensured that samples were as representative of the plot as possible. Sampling was conducted fortnightly and five samples were taken from each plot. Litter enclosed by the soil sample points and the dug out soils were placed on white plastic trays and spiders hand sorted from it. Samples were preserved and identified as above.

Data analysis

Relative abundance

The data from subplots were pooled and averaged for each plot and relative abundance measured as the overall number of spiders captured per plot and the number of individuals of the most abundant and diverse families, represented by at least five species (Midega and Khan 2003) and 10 individual members per plot.

Species richness (S) and diversity (H')

Species richness is commonly used in entomological work and provides a relatively direct expression of diversity (Magurran 1988; Weeks and Holtzer 2000). This was determined as the average number of species captured per plot and the most abundant and diverse families as above. Shannon's diversity index, H' (Shannon and Weaver 1949) was calculated for spider species in each plot as follows:

$$H' = \sum_{i=1}^{s} \frac{n_i}{n} \log \frac{n_i}{n}$$

where, S is the number of species in a sample, n_i is the number of individuals belonging to species I and n is the number of individuals in a sample from a population.

Community evenness was measured by use of Shannon's equitability ($E_{H'}$) as follows:

$$H'/H'_{\max}$$

where $H'_{\max}$ is the total number of species.

Species dominance (d)

This estimation was conducted by use of the Berger–Parker dominance equation for the most abundant species among the overall captured spider groups thus:

$$d = N_{\max}/N_{\mathrm{Tot}}$$

where, $N_{\max}$ is the number of spiders of the abundant species and N_{Tot} is the number of spiders for all the species measured in the sample (Magurran 1988). This index measures the proportional abundance of the most abundant species, is independent of the number of species and has low sensitivity to sample size (Southwood 1978).

A one-way analysis of variance (ANOVA) using a generalized linear model procedure (SAS Institute, 2001) was used to compare spider abundance and diversity between sites. Thereafter, a two-way ANOVA using a mixed model procedure was used to assess the effect of treatment ('push–pull' and maize monocrop) and cropping year on the parameters studied.

Results and Discussion

A total of 2175 individual spiders, representing 78 species in 18 families, were recovered in Kenya and a total of 284 spiders, representing 34 species in nine families, were recovered in South Africa. Spiders were significantly more abundant at the Kenya sites than in the South African site ($F_{2,9} = 20.8$; $P < 0.01$). Between the Kenyan sites, they were significantly more abundant in Lambwe than in Homabay. Spider diversity on the other hand was significantly higher in Potchefstroom than in Lambwe and Homabay ($F_{2,9} = 14.7$; $P < 0.01$). The observed higher abundance of spiders at the Kenyan sites was probably due to the fact that the study plots in the former were surrounded by higher diversity of vegetation while in the latter, being an on-station field, had less vegetation around plots. Geographical, ecological and climatic variations may also have contributed to these differences through their influences on microclimatic characteristics of these habitats in addition to the growth of prey populations through the physiology of plants (Iperti 1999).

Lycosidae was the most abundant family, accounting for >55% of all the spiders captured by numbers at all sites (table 1) and >25% by species richness. Salticidae and Oxyopidae were the second and third most abundant families at all sites. Lycosids are known to have microhabitat preference in agroecosystems (Marshal and Rypstra 1999) with available moisture, leaf litter and herbaceous vegetation being the cues with which they select microhabitats (Richman 1995). Other reports have shown that lycosids are abundant in the savanna habitats (Russell-Smith 1981), and are frequently encountered in agroecosystems (Van den Berg and Dippenaar-Schoeman 1991). They also have an important potential role in integrated management of crop pests (Dippenaar-Schoeman 1976). Together with the overall spider populations, lycosids were significantly more abundant in the 'push–pull' than in maize monocrop plots at all sites, with significant interactions between treatment and cropping years ($P < 0.05$) (table 2a and b). These results corroborate the findings of Midega and Khan (2003), showing that the 'push–pull' system enhances generalist predator populations and support the natural enemy hypothesis (Root 1973) that natural enemies of pests are more abundant in vegetationally diverse ecosystems than in simple ones.

Table 1 Percentage of the total spiders collected at each site in Kenya and South Africa by family, including only families with more than 10 individuals per site

	Kenya				South Africa	
	Lambwe		Homabay		Potchefstroom	
Family	mm	pp	mm	pp	mm	pp
Lycosidae	72.8	77.2	64.3	62.6	58.3	56.6
Salticidae	13.2	5.9	12.5	12.6	25.0	12.3
Oxyopidae	3.3	5.0	7.1	6.8	0.0	1.0
Gnaphosidae	2.4	1.9	2.7	2.5	4.8	12.8
Corinnidae	1.6	1.1	2.6	5.8	0.0	0.0
Ctenidae	1.3	3.4	0.9	2.9	0.0	0.0
Miturgidae	1.3	0.7	1.8	0.0	0.0	2.0
Philodromidae	0.9	1.0	1.8	2.4	9.5	9.7
Theridiidae	0.9	0.5	1.8	1.0	1.2	1.0
Linyphiidae	0.1	0.6	0.0	0.0	1.2	3.6
All others	2.2	2.7	4.5	3.4	0.0	1.0

mm, Maize monocrop; pp, 'push–pull' system.

Table 2 Mean (±SEM) number of overall spiders (a) and lycosid spiders (b) captured per plot at each site in Kenya and South Africa

		Cropping systems	
Season	Site	Maize monocrop	Push–pull
(a) Mean number of overall spiders			
2002–2003	Lambwe	68.5 ± 5.5	107.5 ± 13.9
	Homabay	30.2 ± 1.7	51.7 ± 3.9
	Potchefstroom	8.5 ± 1.3	20.5 ± 4.9
2003–2004	Lambwe	100.7 ± 8.5	186.7 ± 27.9
	Homabay	30.5 ± 1.8	69.7 ± 6.3
	Potchefstroom	11.2 ± 1.6	28.2 ± 1.7
(b) Mean number of lycosid spiders			
2002–2003	Lambwe	50.7 ± 2.5	95.0 ± 6.4
	Homabay	18.5 ± 1.0	31.0 ± 1.6
	Potchefstroom	5.7 ± 0.7	15.5 ± 3.5
2003–2004	Lambwe	70.7 ± 10.1	141.0 ± 21.2
	Homabay	20.0 ± 1.7	39.5 ± 2.5
	Potchefstroom	6.3 ± 2.2	15.0 ± 3.3

Spiders (overall and lycosids) where significantly more abundant at all sites in both cropping seasons ($P < 0.01$).

Several studies (reviewed in Cromartie 1981 and Andow 1991) have indicated that diverse vegetation may provide natural enemies with shelter, food and alternative prey. The 'push–pull' system described herein is associated with significantly lower maize stemborer populations (Khan et al. 1997, 2000, 2001). The numerical response of the spiders in the current study, therefore, must have been as a result of factors other than maize stemborers as prey. Colonization of this system might have been a consequence of greater attractiveness of the polyculture provided by desmodium and Napier grass, in addition to maize, at least at the host habitat–location phase. Alternatively, because colonization represents not only immigration but also emigration, the greater abundance of the spiders in the 'push–pull' systems may have been caused by a more suitable combination of microhabitats in the polyculture, once the habitat was found by these generalist predators (Midega and Khan 2003). Moreover, this system is associated

Table 3 Mean (±SEM) total number of total (a) and lycosid (b) spider species captured per plot at each site in Kenya and South Africa with their associated mean (±SE) diversity indices (H')

		Maize monocrop		Push–pull	
Season	Site	spp.	H'	spp.	H'
(a) Mean total number of spider species and associated H'					
2002–2003	Lambwe	32	−2.6 (0.2)	36	−2.2 (0.1)
	Homabay	21	−2.4 (0.1)	26	−2.5 (0.1)
	*Potchefstroom	9	−1.4 (0.1)	21	−1.8 (0.1)
2003–2004	Lambwe	49	−2.6 (0.2)	60	−2.9 (0.1)
	Homabay	23	−2.5 (0.1)	27	−2.5 (0.1)
	*Potchefstroom	14	−1.6 (0.1)	31	−2.0 (0.1)
(b) Mean number of lycosid spiders and associated H'					
2002–2003	Lambwe	19	−1.9 (0.1)	17	−1.8 (0.1)
	Homabay	10	−1.7 (0.1)	9	−1.7 (0.1)
	Potchefstroom	4	−0.6 (0.1)	5	−0.8 (0.1)
2003–2004	Lambwe	9	−2.0 (0.2)	22	−2.3 (0.1)
	Homabay	12	−1.9 (0.1)	12	−2.2 (0.1)
	Potchefstroom	5	−0.8 (0.1)	11	−1.0 (0.2)

*Spiders were significantly more species diverse in push–pull than in the maize monocrop plots in Potchefstroom during both cropping years ($P < 0.05$). Otherwise there were no significant differences between the two cropping systems in the rest of the cases.

with reduced soil temperatures and increased relative humidity (Khan et al. 2002).

Despite spider populations being larger in the 'push–pull' system, overall species diversity was not significantly different between the two cropping systems in Lambwe and Homabay ($P > 0.05$) (table 3a). However, in Potchefstoom, species diversity was significantly higher in the 'push–pull' than in the maize monocrop plots (table 3a). Similarly, lycosids species diversity was not significantly different between the two cropping systems at all sites (table 3b). Our findings, therefore, suggest that although the 'push–pull' system enhances spider abundance, its impact on their species diversity is unclear.

When assessing the impact of any agricultural technology on arthropod diversity, monitoring individual families, rather than whole communities, appears to be important, as individual families respond differently to different biotic and abiotic changes in the environment (Mrzljak and Wiegleb 2000). It was, however, interesting to note that although species dominance did not differ between treatments at all sites (table 4b), overall spider community distribution was generally more even under the maize monocrop than in the 'push–pull' plots in Potchefstroom (table 4a). This implies clustering of spiders in the latter and warrants further investigations.

Table 4 Mean (±SEM) spider community distribution (Evenness $E_{H'}$) (a) and dominance (b) per plot. Means represent data averages over two cropping seasons

	Kenya		South Africa
Treatment	Lambwe	Homabay	Potchefstroom
(a) Mean total spider distribution (Evenness $E_{H'}$)			
Maize monocrop	0.11 (0.02)	0.11 (0.01)	0.21 (0.01)
'Push–pull' system	0.08 (0.01)	0.11 (0.01)	0.15 (0.01)
(b) Mean total spider dominance (d)			
Maize monocrop	0.18 (0.02)	0.23 (0.02)	0.42 (0.03)
'Push–pull' system	0.16 (0.01)	0.16 (0.01)	0.37 (0.03)

In all cases, there were no significant differences between the cropping systems, except in Potchefstroom where spiders were significantly more evenly distributed in the maize monocrop than in the 'push–pull' cropping system ($P < 0.01$).

In general, our results showed that the 'push–pull' system enhances the overall spider abundance with an unclear effect on species diversity and community distribution. Some of the spiders that dominate the 'push–pull' system have been shown to prefer lepidopteran and homopteran food sources (Bogya and Mols 1996), but many spiders are known to accept almost any prey that are slightly smaller than the spider (Nyffeler et al. 1994). With spiders being one of the most important predatory groups in cropping systems (Weeks and Holtzer 2000), our findings suggest that the abundance of spiders in the 'push–pull' system should, therefore, be expected to correspond to a high potential for controlling many pest species in the system (Brown et al. 2003). The 'push–pull' system, therefore, has considerable potential in further pest control in the maize agroecosystems. This, therefore, provides a basis for future studies of ground-dwelling arthropod community responses to the 'push–pull' system and to other cropping systems designed to alleviate pest and weed problems. At the same time, further research in this area is likely to increase our understanding of population dynamics and community interactions of the ground-dwelling arthropods associated with agroecosystems (Weeks and Holtzer 2000).

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