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Comparative Diversity of Arthropods on Bt Maize and Non-Bt Maize in two Different Cropping Systems in South Africa

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ABSTRACT The biodiversity of an agroecosystem is not only important for its intrinsic value but also because it influences ecological functions that are vital for crop production in sustainable agricultural systems and the surrounding environment. A concern about genetically modified (GM) crops is the potential negative impact that such crops could have on diversity and abundance of nontarget organisms, and subsequently on ecosystem functions. Therefore, it is essential to assess the potential environmental risk of the release of a GM crop and to study its effect on species assemblages within that ecosystem. Assessment of the impact of Bt maize on the environment is hampered by the lack of basic checklists of species present in maize agroecosystems. The aims of the study were to compile a checklist of arthropods that occur on maize in South Africa and to compare the diversity and abundance of arthropods and functional groups on Bt maize and non-Bt maize. Collections of arthropods were carried out during two growing seasons on Bt maize and non-Bt maize plants at two localities. Three maize fields were sampled per locality during each season. Twenty plants, each of Bt maize and non-Bt maize, were randomly selected from the fields at each site. The arthropods collected during this study were classified to morphospecies level and grouped into the following functional groups: detritivores, herbivores, predators, and parasitoids. Based on feeding strategy, herbivores and predators were further divided into sucking herbivores or predators (piercing–sucking mouthparts) and chewing herbivores or predators (chewing mouthparts). A total of 8,771 arthropod individuals, comprising 288 morphospecies and presenting 20 orders, were collected. Results from this short-term study indicated that abundance and diversity of arthropods in maize and the different functional guilds were not significantly affected by Bt maize, either in terms of diversity or abundance.

KEY WORDS arthropod, biodiversity, diversity index, GM maize, South Africa

One concern about growing genetically modified (GM) crops is the potential negative impact that such crops could have on diversity and abundance of nontarget organisms (Eckert et al. 2006). The biodiversity of an agroecosystem is not only important for its intrinsic value but also because it may influence ecosystem functions that are vital for sustainable crop production and for the surrounding environment (Hilbeck et al. 2006). Species assemblages in agroecosystems fulfill a variety of ecosystem functions that may be negatively impacted if changes occur in these assemblages (Dutton et al. 2003). For example, guild rearrangement due to the elimination of a target pest and the subsequent changes in guild structure can lead to the development of secondary pests. Therefore, it is essential to assess the potential environmental risk that the release of a GM crop may hold and to study its effect on species assemblages within that ecosystem (Van Wyk et al. 2007). To identify possible secondary pests and nontarget effects of GM crops with insecticidal properties, it is necessary to determine the arthropod species occurring in maize ecosystems. This information will be useful in the evaluation of the possible impact of Bt maize on nontarget organisms at different trophic levels. Assessment of the impact of Bt maize on the environment is hampered by the lack of basic knowledge regarding arthropod diversity in maize ecosystems. There is also a need to identify indicator or representative organisms and develop simple methods that combine suitability for ecological risk assessment under field conditions and cost efficiency of assessments (Eckert et al. 2006).

Several studies related to the potential impact of Bt crops on nontarget organisms have examined the interaction of one or more species under laboratory conditions (Sims 1995; Hilbeck et al. 1998a,b; Dutton et al. 2002, 2003, 2004; Meissle and Romeis 2009; Li and Romeis 2010). Some results indicated no significant effects on nontarget organisms, whereas others reported negative effects.

While most field studies assessing impacts of Bt crops have focused on limited numbers of species (Wilson et al. 1992, Hardee and Bryan 1997, Wold et al. 2001, Liu et al. 2003, Schoenly et al. 2003, Wolfenbarger et al. 2008), it is important to also study effects

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on arthropod communities. The few studies previously conducted on arthropod community diversity were on Bt rice in China (Li et al. 2007), Bt cotton in the United States (Torres and Ruberson 2007), and Bt maize in Spain (De la Poza et al. 2005). These three studies concluded that Bt crops did not have adverse effects on arthropod diversity at the field level.

The aims of this study were to describe the biodiversity of arthropods on maize by compiling a checklist of species that occur on maize in South Africa and to compare the diversity and abundance of arthropods and the functional groups on Bt maize and non-Bt maize.

Materials and Methods

Collections of arthropods were carried out during the 2008–2009 and 2009–2010 growing seasons in Bt maize and non-Bt maize fields at two localities, i.e., Vaalharts in the Northern Cape province (S24° 48′ 693, E27° 38′ 330) and Tshiombo in the Limpopo province (22° 48′05″ S, 30° 27′07″ E), South Africa. Sampling was done only once on each field, 2–3 wk after anthesis, and took place during April and November (in both 2008 and 2009) at Vaalharts and Tshiombo, respectively. During this study the focus was on collecting plant-dwelling arthropods that occur on plants only during the reproductive stage of plant growth. Other studies have shown that arthropod diversity during this plant growth stage, particularly on plant ears, capture different trophic levels, and thus could be a good method to sample a comprehensive arthropod community (Eckert et al. 2006). Dively (2005) also showed that arthropod biodiversity on maize during the period after anthesis is very high compared with the rest of the growing period.

Study Areas. *Tshiombo.* This area is a low-input small-farming area where crop production is done on small fields (1–2 ha) on which the main crop, maize, is often rotated with groundnut, brassicas, or sweet potato. Bt maize and non-Bt maize were planted in, 50 by 10-m plots, separated by a 3-m inter-plot area. Plots were bordered by strips (≈15 m in width) of sweet potato plantings or Napier grass (*Pennisetum purpureum* Schumach [Poales: Poaceae]) planted on contours between fields. Many small maize fields (<1.0 ha) at different stages of development were present within a 200-m radius from these experimental fields.

Vaalharts. The Vaalharts irrigation scheme is situated in the semiarid Northern Cape province, South Africa, where maize is produced under monocrop conditions on 25- to 30-ha fields with high inputs and either flood- or center-pivot irrigation (Kruger et al. 2009). Bt maize and non-Bt maize fields are planted adjacent to each other, with the non-Bt area applying to the current refuge requirement of either a 5 or 20% area planted to non-Bt maize.

Sampling of Arthropods. Arthropods were collected from maize plants in commercial maize fields at the Vaalharts irrigation scheme and from small fields of maize planted with seed provided to resource-poor farmers in the Tshiombo area. The Bt maize sampled during this study was from the event MON810 expressing Cry1Ab protein for control of the stem borers, *Busseola fusca* (Fuller) (Lepidoptera: Noctuidae) and *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae), and its near-isogenic non-Bt counterpart. Pest pressure (target and nontarget) is usually very high in the Vaalharts area, where Bt maize has been planted since 1998. In the Tshiombo area, pest pressure is usually much lower than in the Vaalharts area, and resource-poor farmers had not been introduced to GM crops before this study.

Three maize fields were sampled for each of the two localities once during each season (12 fields in total per site). Sampling was not done on the same field over two seasons because of crop rotation practices followed at both sites. Twenty plants, each of Bt maize and non-Bt maize (from the refuge area of the field), were randomly selected from the fields at each site (480 plants in total). Each plant was bagged, and all arthropods were removed later and placed in 70% ethanol in 40-ml bottles. Each plant was carefully inspected for any arthropods by removing leaves, leaf sheaths, and husk leaves and ears. All arthropods were collected and kept such that abundance and diversity could be calculated on a per-plant basis.

Arthropods were classified to morphospecies level and grouped into functional groups to provide information on the potential exposure of species to Bt toxin produced by Bt maize. Where possible, morphospecies were further identified to family and species level. Morphospecies can be defined as a group of individuals that are considered to belong to the same species on the basis of morphology alone (Lawrence 2011).

Data Analysis. The Shannon diversity index (H^1), which describes diversity (species richness and evenness), and the Margalef richness index (d), which describes species richness, were used to analyze data. The Shannon diversity and Margalef richness indices were calculated using Primer 5 (Version 5.2.9, PRIMER-E Ltd., Plymouth, United Kingdom; Clarke and Gorley 2001). Statistical analysis was done using the Statistica software (Version 10, StatSoft Inc., Tulsa, OK). Data were not normally distributed, and therefore the nonparametric Mann–Whitney *U*-test was used. Because the latter test uses a rank of numbers, a median value was calculated to indicate abundance and numbers. Because abundance was generally low, median levels were expressed per 20 plants.

Statistical analyses were done to compare total arthropod diversity and different functional groups on Bt maize and non-Bt maize. The following functional groups were identified: detritivores, sucking herbivores, chewing herbivores, sucking predators, chewing predators, and parasitoids. Using the Shannon (H^1) and Margalef (d) indices, the total number of species and the total number of individuals for each site were compared over seasons and between maize varieties (Bt vs. non-Bt) for determining total arthropod diversity and different functional guilds. A randomized species accumulation curve was generated, with the average based on 100 permutations, using PRIMER 5 (Version 5.2.9) (Clarke and Gorley 2001).

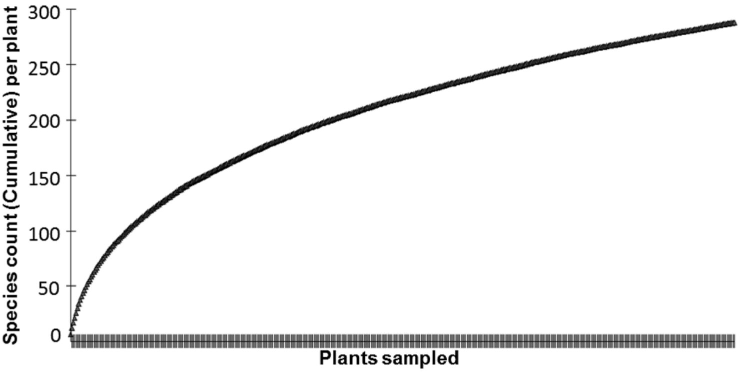

Fig. 1. Species accumulation curve of arthropods collected on 480 Bt maize and non-Bt maize plants during two growing seasons at two localities.

Results

A total of 8,771 arthropod individuals, comprising 288 morphospecies, were collected from the 480 plants sampled during this study. A detailed list of these species is provided in *Appendix* 1. At the Vaalharts locality, a total of 4,154 arthropod individuals (2,566 and 1,588 in 2008 and 2009, respectively), comprising 169 morphospecies, were collected during the month of April. At Tshiombo, a total of 4,617 arthropod individuals (2,216 and 2,401 in 2008 and 2009, respectively), comprising 202 morphospecies, were collected during the month of November. These 288 morphospecies were representative of 20 arthropod orders. Only 28.8% of these species occurred at both localities. The species accumulation curve for these 480 plants had not reached an asymptote (Fig. 1), suggesting that the number of species will further increase as more maize plants are sampled.

Total Arthropod Diversity. Arthropod diversity indicated no statistical significant differences between Bt maize and non-Bt maize for the indices and the number of species or individuals at any of the sites (Table 1). However, for Vaalharts, there was a significant difference in the Shannon index values over the two seasons ($P = 0.03$) because of a lower diversity during Season 2, but for Tshiombo there was no significant difference in index values over the two seasons (Table 2).

Detritivores. The diversity indices, number of species, or number of detritivore individuals per plant did not differ significantly between Bt maize and non-Bt maize for either site or season (Table 1). However, there was a significant difference between the Shannon index value ($P = 0.01$), number of species ($P = 0.02$), and number of individuals per plant between the two seasons at Tshiombo (Table 2), with the diversity and abundance being lower in Season 2.

Chewing and Sucking Herbivores. Chewing and sucking herbivore diversity and abundance did not differ between Bt maize and non-Bt maize at any of the sites or seasons (Table 1).

There were also no significant differences in abundance, diversity, and species richness on Bt maize and non-Bt maize at any of the sites (Table 2). A low evenness for Bt maize and non-Bt maize during both seasons was observed, which can be ascribed to the dominant species of Nitidulidae, Lathridiidae, and Anthicidae at both localities.

Chewing Predators. Abundance, species richness, or diversity of chewing predators did not differ significantly between Bt maize and non-Bt maize at any of the sites (Table 1).

There was a significant difference in the Margalef richness index ($P = 0.04$) for chewing predators over the two seasons at Tshiombo with species richness being higher in Season 2 (Table 2).

Sucking Predators. Sucking predator diversity, number of species, or abundance did not differ significantly between Bt maize and non-Bt maize at any of the sites (Table 1).

There was a significant difference between the number of sucking predator individuals over the two seasons at Vaalharts ($P = 0.01$), with the numbers being significantly lower in Season 2 (Table 2). The low evenness can be ascribed to the dominant species of Anthocoridae and Miridae.

Parasitoids. The diversity, number of parasitoid species, or individuals per plant did not differ significantly between Bt maize and non-Bt maize at any of the sites (Table 1).

The Shannon index value showed a significant difference ($P = 0.02$) in diversity and in the number of parasitoid species ($P = 0.04$) over the two seasons at Tshiombo (Table 2). The index value and number of species were lower in Season 1.

Discussion

Although arthropod diversity (288 morphospecies from 8,771 arthropod individuals) described in this study was high compared with studies on other crops (Li et al. 2007, Torres and Ruberson 2007), the total number of arthropod individuals sampled in this study was low relative to other studies. A 3-yr study of arthropod abundance and diversity in Bt rice and non-Bt rice fields recorded 17,706 arthropod individuals (Li et al. 2007), while a 3-yr study on ground-dwelling arthropods in Bt cotton and non-Bt cotton collected 38,980 individuals of

Table 1. Descriptive statistics and *P* values for comparison of diversity index values, abundance and number of functional group species between Bt maize and non-Bt maize over seasons at the Vaalharts and Tshiombo sites

Functional groups	Vaalharts						Tshiombo					
	Season 1			Season 2			Season 1			Season 2		
	Means (±SE)		*P* value	Means (±SE)		*P* value	Means (±SE)		*P* value	Means (±SE)		*P* value
	Bt	Non-Bt		Bt	Non-Bt		Bt	Non-Bt		Bt	Non-Bt	
Total arthropods												
Shannon index	2.78 (±0.01)	2.67 (±0.16)	0.66	2.43 (±0.12)	2.12 (±0.15)	0.38	2.30 (±0.08)	2.82 (±0.22)	0.66	3.02 (±0.06)	2.68 (±0.23)	0.38
Margalef index	7.89 (±0.64)	7.25 (±0.49)	0.66	7.14 (±0.22)	6.65 (±0.65)	0.66	7.81 (±0.98)	8.40 (±0.13)	0.66	8.21 (±0.95)	7.94 (±1.29)	1.00
Number of species/20 plants	48.0 (±4.93)	45.0 (±5.51)	0.66	40.0 (±2.89)	37.6 (±2.73)	0.66	47.6 (±7.13)	49.6 (±2.40)	1.00	44.0 (±8.02)	50.0 (±11.68)	1.00
Number of individuals/20 plants	389.0 (±63.04)	466.3 (±149.26)	1.00	265.0 (±96.77)	264.3 (±55.23)	0.66	389.0 (±66.09)	350.3 (±79.88)	0.38	212.6 (±88.32)	587.3 (±324.88)	0.38
Detritivores												
Shannon index	1.53 (±0.25)	1.01 (±0.19)	0.19	1.61 (±0.08)	1.50 (±0.19)	0.66	1.62 (±0.28)	1.41 (±0.10)	0.66	0.70 (±0.35)	0.89 (±0.15)	1.00
Margalef index	2.13 (±0.30)	1.54 (±0.53)	0.38	2.07 (±0.29)	2.14 (±0.10)	0.66	2.23 (±0.54)	1.72 (±0.19)	0.66	1.59 (±0.22)	1.27 (±0.11)	0.39
Number of species/20 plants	8.6 (±2.03)	7.6 (±3.48)	1.00	7.3 (±1.33)	6.3 (±0.67)	1.00	7.3 (±1.76)	6.0 (±1.00)	0.51	2.6 (±0.88)	3.3 (±0.67)	0.66
Number of individuals/20 plants	39.6 (±16.90)	85.0 (±60.23)	1.00	21.0 (±4.58)	13.0 (±3.46)	0.38	16.3 (±2.19)	18.6 (±5.24)	0.66	4.3 (±2.40)	9.6 (±4.33)	0.38
Chewing herbivores												
Shannon index	1.57 (±0.15)	1.67 (±0.15)	1.00	1.79 (±0.09)	1.43 (±0.33)	0.38	1.65 (±0.14)	1.76 (±0.27)	1.00	1.62 (±0.21)	1.36 (±0.18)	0.38
Margalef index	1.81 (±0.20)	2.19 (±0.30)	0.66	2.18 (±0.28)	1.64 (±0.53)	0.66	2.23 (±0.12)	2.41 (±0.58)	1.00	2.13 (±0.30)	2.39 (±0.28)	0.38
Number of species per 20 plants	8.3 (±0.33)	10.0 (±2.08)	0.83	8.0 (±1.15)	7.0 (±1.73)	0.83	10.3 (±0.67)	11.0 (±2.31)	1.00	7.6 (±2.03)	12.0 (±4.58)	0.66
Number of individuals per 20 plants	74.6 (±32.18)	74.0 (±30.57)	1.00	41.0 (±27.00)	60.0 (±27.39)	0.38	85.6 (±34.72)	67.3 (±16.90)	1.00	32.0 (±20.66)	253.3 (±164.73)	0.66
Sucking herbivores												
Shannon index	1.52 (±0.29)	1.43 (±0.27)	1.00	1.00 (±0.09)	0.94 (±0.09)	0.66	1.31 (±0.26)	1.25 (±0.38)	1.00	1.84 (±0.13)	1.46 (±0.39)	0.66
Margalef index	2.53 (±0.14)	1.95 (±0.21)	0.19	1.80 (±0.09)	1.77 (±0.29)	1.00	2.62 (±0.51)	2.44 (±0.14)	0.66	2.66 (±0.32)	2.30 (±0.60)	1.00
Number of species per 20 plants	14.3 (±1.2)	11.3 (±0.33)	0.13	10.0 (±1.15)	10.0 (±1.15)	1.00	14.3 (±3.18)	12.3 (±0.33)	0.66	11.6 (±2.19)	12.0 (±3.06)	1.00
Number of individuals per 20 plants	202.6 (±48.06)	253.6 (±86.02)	1.00	169.0 (±71.16)	181.0 (±38.19)	0.66	158.0 (±43.09)	124.6 (±46.69)	0.66	71.0 (±35.09)	150.3 (±81.54)	0.66
Chewing predators												
Shannon index	1.85 (±0.19)	1.97 (±0.05)	1.00	2.00 (±0.03)	2.02 (±0.16)	0.66	1.45 (±0.20)	1.87 (±0.21)	0.38	2.10 (±0.10)	2.00 (±0.15)	0.66
Margalef index	2.63 (±0.46)	2.88 (±0.13)	0.66	2.69 (±0.28)	3.03 (±0.32)	0.38	1.91 (±0.43)	3.03 (±0.18)	0.08	3.46 (±0.48)	3.35 (±0.06)	0.66
Number of species per 20 plants	9.3 (±2.33)	11.0 (±0.00)	0.66	11.0 (±1.53)	11.0 (±1.00)	1.00	9.6 (±1.86)	13.3 (±1.2)	0.28	14.6 (±3.18)	15.6 (±2.60)	1.00
Number of individuals per 20 plants	25.6 (±9.06)	33.6 (±5.21)	0.66	42.3 (±8.67)	27.3 (±1.20)	0.51	99.3 (±14.68)	84.0 (±34.03)	1.00	67.0 (±32.52)	127.3 (±69.89)	0.83
Sucking predators												
Shannon index	0.82 (±0.17)	1.07 (±0.11)	0.38	1.10 (±0.09)	1.12 (±0.09)	1.00	1.06 (±0.12)	0.93 (±0.15)	0.83	0.69 (±0.20)	0.54 (±0.25)	0.51
Margalef index	0.94 (±0.20)	1.11 (±0.08)	1.00	1.14 (±0.20)	1.17 (±0.04)	0.66	1.25 (±0.22)	1.01 (±0.13)	0.51	0.83 (±0.14)	0.79 (±0.29)	1.00
Number of species per 20 plants	4.6 (±0.88)	4.7 (±0.33)	1.00	3.6 (±0.33)	4.0 (±0.58)	0.83	5.0 (±1.15)	4.6 (±0.88)	1.00	4.0 (±0.58)	4.0 (±1.15)	1.00
Number of individuals per 20 plants	46.6 (±5.49)	27.6 (±3.28)	0.08	12.0 (±3.61)	17.3 (±7.89)	1.00	27.0 (±12.58)	41.6 (±14.97)	0.51	36.0 (±2.65)	41.6 (±5.24)	0.51
Parasitoids												
Shannon index	0.21 (±0.21)	0.22 (±0.22)	1.00	0.00 (±0.00)	0.21 (±0.21)	0.66	0.40 (±0.20)	0.37 (±0.37)	1.00	1.42 (±0.24)	1.09 (±0.27)	0.51
Margalef index	0.46 (±0.46)	0.31 (±0.31)	1.00	0.00 (±0.00)	0.46 (±0.46)	1.00	0.79 (±0.07)	0.91 (±0.91)	1.00	2.03 (±0.36)	1.43 (±0.53)	0.83
Number of species per 20 plants	1.0 (±0.58)	1.0 (±0.58)	1.00	0.3 (±0.33)	1.3 (±0.33)	0.19	1.6 (±0.88)	1.6 (±0.67)	1.00	5.0 (±1.53)	3.6 (±1.20)	0.51
Number of individuals per 20 plants	4.3 (±2.96)	6.6 (±4.41)	0.83	0.3 (±0.33)	2.0 (±0.58)	0.13	4.6 (±2.91)	2.3 (±0.67)	0.66	7.6 (±2.91)	9.0 (±3.06)	1.00

Table 2. Descriptive statistics and *P* values for comparison of diversity index values, abundance, and number of functional group species between two seasons at Vaalharts and Tshiombo

Functional groups	Vaalharts			Tshiombo		
	Means (±SE)		*P* value	Means (±SE)		*P* value
	Season 1	Season 2		Season 1	Season 2	
Total arthropods						
Shannon index	2.72 (±0.09)	2.28 (±0.11)	0.03*	2.76 (±0.11)	2.85 (±0.13)	0.47
Margalef index	7.57 (±0, 39)	6.90 (±0.32)	0.30	8.1 (±0.46)	8.07 (±0.72)	0.94
Number of species per 20 plants	46.5 (±3.37)	38.8 (±1.85)	0.09	48.6 (±3.39)	47.0 (±6.48)	0.87
Number of individuals per 20 plants	427.6 (±74.50)	264.6 (±49.83)	0.09	369.6 (±47.17)	400.0 (±172.30)	0.30
Detritivores						
Shannon index	1.27 (±0.18)	1.56 (±0.09)	0.38	1.51 (±0.14)	0.8 (±0.18)	0.01*
Margalef index	1.84 (±0.30)	2.11 (±0.14)	0.58	1.98 (±0.28)	1.4 (±0.12)	0.17
Number of species per 20 plants	8.1 (±1.82)	6.8 (±0.70)	0.63	6.6 (±0.95)	3.0 (±0.52)	0.02*
Number of individuals per 20 plants	62.3 (±29.76)	17.0 (±3.13)	0.26	17.5 (±2.59)	7.0 (±2.52)	0.02*
Chewing herbivores						
Shannon index	1.62 (±0.10)	1.61 (±0.17)	0.69	1.7 (±0.14)	1.49 (±0.14)	0.17
Margalef index	1.96 (±0.18)	1.91 (±0.29)	1.00	2.32 (±0.27)	2.26 (±0.19)	0.81
Number of species per 20 plants	9.2 (±1.01)	7.5 (±0.96)	0.42	10.6 (±1.09)	9.8 (±2.44)	0.81
Number of individuals per 20 plants	74.3 (±19.85)	50.5 (±17.72)	0.20	76.5 (±17.75)	142.6 (±89.23)	0.69
Sucking herbivores						
Shannon index	1.48 (±0.18)	0.97 (±0.06)	0.09	1.28 (±0.21)	1.65 (±0.20)	0.38
Margalef index	2.24 (±0.17)	1.79 (±0.13)	0.09	2.53 (±0.24)	2.48 (±0.31)	0.94
Number of species per 20 plants	12.8 (±0.87)	10.0 (±0.73)	0.07	13.3 (±1.50)	11.8 (±1.68)	0.58
Number of individuals per 20 plants	228.2 (±45.52)	175.0 (±36.22)	0.69	141.3 (±29.37)	110.6 (±43.48)	0.30
Chewing predators						
Shannon index	1.91 (±0.09)	2.01 (±0.07)	0.47	1.66 (±0.16)	2.05 (±0.09)	0.07
Margalef index	2.75 (±0.22)	2.86 (±0.20)	0.94	2.47 (±0.33)	3.4 (±0.22)	0.04*
Number of species per 20 plants	10.2 (±1.11)	11.0 (±0.82)	0.87	11.5 (±1.28)	15.2 (±1.85)	0.26
Number of individuals per 20 plants	29.6 (±5.00)	34.8 (±5.26)	0.94	91.6 (±16.93)	97.2 (±37.02)	0.81
Sucking predators						
Shannon index	0.95 (±0.11)	1.11 (±0.06)	0.23	0.99 (±0.09)	0.62 (±0.15)	0.07
Margalef index	1.03 (±0.10)	1.16 (±0.09)	0.58	1.13 (±0.13)	0.81 (±0.14)	0.30
Number of species per 20 plants	4.6 (±0.42)	3.8 (±0.31)	0.17	4.8 (±0.65)	4.0 (±0.58)	0.42
Number of individuals per 20 plants	37.2 (±5.12)	14.6 (±4.06)	0.01*	34.3 (±9.34)	38.8 (±2.91)	1.00
Parasitoids						
Shannon index	0.22 (±0.14)	0.11 (±0.11)	0.63	0.38 (±0.19)	1.25 (±0.18)	0.02*
Margalef index	0.38 (±0.23)	0.46 (±0.46)	1.00	0.85 (±0.37)	1.73 (±0.31)	0.17
Number of species per 20 plants	1.0 (±0.37)	0.8 (±0.31)	0.81	1.6 (±0.49)	4.3 (±0.92)	0.04*
Number of individuals per 20 plants	5.5 (±2.43)	1.2 (±0.48)	0.26	3.5 (±1.43)	8.3 (±1.91)	0.09

only 65 taxa (Torres and Ruberson 2007). In addition, an arthropod diversity study on Bt maize ears that involved sampling of 900 ears, recorded 48,521 individuals of only 23 taxa (Eckert et al. 2006). Therefore, we realize that data from this study cannot be compared with that from studies that used different sampling methods in different geographic regions. However, the mentioned studies on cotton, rice, and maize are among the few other studies that provide comparative data on arthropod abundance and diversity in agroecosystems.

Chewing predator richness and the diversity and number of parasitoid species were lower during the first season than during the second season at Tshiombo. A possible reason for the latter, during the first season at Tshiombo, could be ascribed to poorer plant growth, and because plants did not reach their normal height due to drought stress. Because maize cropping at the Tshiombo site is done in rotation with groundnut and sweet potatoes, the reduced diversity on maize could also be associated with the previous crop, which could have hosted a different arthropod species complex. The significant difference between seasons in the numbers of sucking predator individuals, of which *Orius* sp. occurred in high numbers (*Appendix* 1) at Vaalharts, cannot be explained because food sources were equally abundant during both two seasons.

In this study, we did not find a significant difference in abundance and diversity of the different functional groups (detritivores, herbivores, predators, and parasitoids) between Bt maize and non-Bt maize. However, a study on Bt cotton showed a decrease in diversity of natural enemy subcommunities (Men et al. 2003). A long-term study on cotton in Arizona showed essentially no effects of Bt cotton on natural enemy function, and only minor reductions in the density of several predator taxa in Bt cotton were observed (Naranjo 2005). Similarly, no detrimental effect of Bt maize was observed on any predator taxa or on the whole functional group of predators in a farm-scale study in Spain (De la Poza et al. 2005). Li et al. (2007) also found no significant differences in subcommunities of phytophages, parasitoids, predators, and detritivores between Bt rice and non-Bt rice.

In this study, abundance and diversity of the arthropod complex in maize were not significantly affected by Bt maize. Other studies on the effect of transgenic crops on arthropods also reported similar results. Torres and Ruberson (2007) found that abundance and diversity of ground-dwelling arthropods were not significantly different between Bt cotton and non-Bt cotton. A study on diversity and dominance distribution of arthropods in Bt rice and non-Bt rice also found no significant difference (Li et al. 2007).

Men et al. (2003) indicated that Bt cotton increased the diversity of arthropod communities and pest subcommunities. A slight difference between total arthropod communities was found in unsprayed conventional and Bt cotton in Australia (Whitehouse et al. 2005). No effects of Bt maize on the communities of soil-dwelling and nontarget plant-dwelling arthropods were observed by Candolfi et al. (2004). Dively (2005) also reported that the densities of nontarget taxa exposed to Bt maize and non-Bt maize showed no significant difference, whereas a multiyear study showed that Bt cotton has no significant adverse impact on nontarget arthropod populations (Head et al. 2005). In China, the diversity of arthropod communities in transgenic cotton was reported to be similar to that in conventional, unsprayed cotton fields (Li et al. 2004).

It is concluded from this short-term study that abundance and diversity of arthropods were not significantly affected by Bt maize. This study provided a start in the study of biodiversity of arthropods on maize in South Africa and generated a basic checklist of these species.

We realize that this study was limited in its extent, and that the contribution of soil arthropods was not recognized at all. Larger and long-term studies and surveys of biodiversity, both inside and adjacent to maize fields, should be conducted and other sampling techniques should be included to provide improved assessment of total biodiversity.

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Appendix 1. List of arthropod species and their abundance sampled on Bt maize and non-Bt maize plants at Vaalharts and Tshiombo. Mean values were rounded to two decimals, and therefore are not shown for species of which fewer than four individuals were recorded

Order and Family	Species name	Functional groups	Total no.	Mean per plant
Hemiptera				
Pentatomidae	*Gynenica marginella*	SH	2	-
	Veterna sp. 2	SH	1	-
	Nezara sp. 3	SH	4	0.01
Anthocoridae	*Orius* sp. 1	SP	401	0.84
Hemiptera nymph	Nymph sp.1	SH	237	0.49
	Nymph sp. 2	SH	1	-
Cicadellidae	Cicadellidae sp. 1	SH	41	0.09
	Cicadellidae nymph sp. 1	SH	14	0.03
Miridae	Miridae sp. 1	SH/SP	8	0.02
	Miridae sp. 2	SH/SP	20	0.04
	Miridae sp. 3	SH/SP	2	-
	Miridae sp. 4	SH/SP	1	-
	Miridae sp. 5	SH/SP	71	0.15
	Miridae sp. 6	SH/SP	2	-
	Miridae sp. 7	SH/SP	2	-
Lygaeidae	*Geocorus* sp. 1	SP	5	0.01
	Lygaeidae sp. 2	SH	17	0.04
	Lygaeidae sp. 3	SH	2	-
	Lygaeidae sp. 4	SH	7	0.01
	Lygaeidae sp. 5	SH	34	0.07
Delphacidae	*Peregrinus maidis*	SH	822	1.71
Corixidae	Corixidae sp. 1	-	6	0.01
Berytidae	*Metacanthus* sp. 1	SH	78	0.16
	Berytidae sp. 2	SH/SP	1	-
Tingidae	Tingidae sp. 1	SH	1	-
Reduviidae	Reduviidae sp. 1	SP	1	-
Psyllidae	Psyllidae sp. 1	SH	1	-
Aphididae	Aphididae sp. 1	SH	1552	3.23
	Aphididae sp. 2	SH	17	0.04
	Aphididae sp. 3	SH	65	0.14
	Aphididae sp. 4	SH	17	0.04
	Aphididae sp. 5	SH	8	0.02
	Aphididae sp. 6	SH	2	-
	Aphididae sp. 7	SH	2	-
Pseudococcidae	Pseudococcidae sp. 1	SH	1	-
Coleoptera				
Coleoptera larva	Larva sp. 1	SH	2	-
	Larva sp. 2	SH	11	0.02
Anthicidae	*Formicomus caeruleus*	D	20	0.04
	Notoxus monoceros	CH	167	0.35
Scydmaenidae	Scydmaenidae sp. 1	CH	6	0.01
Lathridiidae	*Carticaria japonica*	CH	147	0.31
Chrysomelidae	*Monolepta bioculata*	CH	5	0.01
	Chrysomelidae sp. 2	CH	6	0.01
	Chrysomelidae sp. 3	CH	28	0.06
	Chrysomelidae sp. 4	CH	6	0.01
	Chrysomelidae sp. 5	CH	7	0.01
	Chrysomelidae sp. 6	CH	2	-
	Chrysomelidae sp. 7	CH	1	-
	Chrysomelidae sp. 8	CH	1	-
	Chrysomelidae sp. 9	CH	1	-
	Chrysomelidae sp. 10	CH	17	0.04
	Chrysomelidae sp. 11	CH	1	-
	Chrysomelidae sp. 12	CH	1	-
	Chrysomelidae sp. 13	CH	3	0.01
	Chrysomelidae sp. 14	CH	1	-
	Chrysomelidae sp. 16	CH	27	0.06
	Chrysomelidae sp. 17	CH	15	0.03
	Chrysomelidae sp. 18	CH	8	0.02
	Chrysomelidae sp. 19	CH	1	-
	Hispinae larva sp. 20	SH	25	0.05
	Chrysomelidae larva sp. 1	CH	5	0.01
Chrysomeloidea	Chrysomeloidea sp. 1	SH	15	0.03
	Chrysomeloidea sp. 2	SH	12	0.03
Coccinellidae	*Scymnus nubilus*	CP	71	0.15
	Coccinellidae sp. 2	CP	20	0.04
	Cheilomenes sp. 3	CP	54	0.11
	Coccinellidae sp. 4	CP	2	-
	Epilachna sp. 5	CH	1	-
	Coccinellidae sp. 6	CP	39	0.08

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Appendix 1. Continued

Order and Family	Species name	Functional groups	Total no.	Mean per plant
	Coccinellidae sp. 7	CP	21	0.04
	Coccinellidae sp. 8	CP	4	0.01
	Coccinellidae sp. 9	CP	1	-
	Coccinellidae sp. 10	CP	1	-
	Coccinellidae larvae sp. 1	CP	36	0.08
Bruchidae	Bruchidae sp. 1	SH	26	0.05
Nitidulidae	*Carpophilus* sp. 1	CH	514	1.07
	Carpophilus sp. 2	CH	83	0.17
	Carpophilus sp. 3	CH	352	0.73
	Carpophilus larva sp. 1	CH	15	0.03
	Carpophilus larva sp. 2	CH	169	0.35
Melyridae	*Astylus atromaculatus*	SH	16	0.03
Curculionidae	*Sitophilus* sp. 1	SH	11	0.02
	Curculionidae sp. 2	SH	89	0.19
	Curculionidae sp. 3	SH	2	-
	Curculionidae sp. 4	SH	30	0.06
	Curculionidae sp. 5	SH	1	-
Buprestidae	Buprestidae sp. 1	SH	1	-
Elateridae	Elateridae sp. 1	SH	2	-
	Elateridae sp. 2	SH	1	-
Staphylinidae	*Oxytelus* sp. 1	CP	53	0.11
	Staphylinidae sp. 2	CP	1	-
Bostrichidae	Bostrichidae sp. 1	CH	1	-
	Bostrichidae sp. 2	CH	1	-
Silvanidae	Silvanidae sp. 1	CP	1	-
Carabidae	Carabidae sp. 1	CP	1	-
	Carabidae sp. 2	CP	1	-
Apionidae	Apionidae sp. 1	SH	3	0.01
Cucujidae	Cucujidae sp. 1	CP	1	-
Tenebrionidae	Tenebrionidae sp. 1	D	1	-
Unknown		?	18	0.04
Thysanoptera				
Thripidae	*Chirothrips* sp. 1	SH	187	0.39
Phlaeothripidae	*Haplothrips gowdeyi*	SH	117	0.24
	Haplothrips sp. 2	SH	174	0.36
	Thysanoptera sp. 3	?*	66	0.14
	Thysanoptera sp. 4	?*	1	-
	Thysanoptera sp. 5	?*	3	0.01
	Thysanoptera sp. 6	?*	15	0.03
	Thysanoptera sp. 7	?*	75	0.16
	Thysanoptera sp. 8	?*	55	0.11
Lepidoptera				
Crambidae	*Chilo partellus*	CH	13	0.03
Noctuidae	*Busseola fusca*	CH	47	0.10
	Helicoverpa armigera	CH	37	0.08
	Sesamia calamistis	CH	15	0.03
	Leucania loreyi	CH	5	0.01
Geometridae	Geometridae sp. 1	CH	5	0.01
Lepidoptera larvae	Larva sp. 1	CH	1	-
	Larva sp. 2	CH	12	0.03
	Larva sp. 3	CH	6	0.01
	Larva sp. 4	CH	5	0.01
	Busseola fusca pupa	-	6	0.01
	Helicoverpa armigera pupa	-	1	-
	Busseola fusca moth	-	2	-
Micro-Lepidoptera	Larva sp. 1	CH	2	-
Unknown		?	6	0.01
Hymenoptera				
Braconidae	Braconidae sp. 1	P	36	0.08
	Braconidae sp. 2	P	4	0.01
	Cotesia sp. 3	P	4	0.01
Formicidae	*Anaplolepis custodiens*	CP	2	-
	Polyrhachis schistacea	CP	6	0.01
	Dorylus sp. 1	CP	16	0.03
	Camponotus sp.1	CP	5	0.01
	Pheidole sp. 1	CP	316	0.66
	Pheidole sp. 2	CP	133	0.28
	Lepisiota sp. 1	CP	2	-

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Appendix 1. Continued

Order and Family	Species name	Functional groups	Total no.	Mean per plant
Vespidae	Vespidae sp. 1	CP	1	-
	Vespidae sp. 2	CP	1	-
Apidae	Apidae sp. 1	P	1	-
Ichneumonidae	Ichneumonidae sp. 1	P	1	-
	Ichneumonidae sp. 2	P	1	-
Eulophidae	Eulophidae sp. 1	P	2	
Scelionidae	Scelionidae sp. 1	P	15	0.03
	Scelionidae sp. 2	P	15	0.03
Ceraphronidae	Ceraphronidae sp. 1	P	2	-
Hymenoptera	Hymenoptera sp. 1	P	1	-
	Hymenoptera sp. 2	P	7	0.01
	Hymenoptera sp. 3	P	1	-
	Hymenoptera sp. 4	P	2	-
	Hymenoptera sp. 5	P	1	-
	Hymenoptera sp. 6	P	11	0.02
	Hymenoptera sp. 7	P	6	0.01
	Hymenoptera sp. 8	P	2	-
	Hymenoptera sp. 9	P	2	-
	Hymenoptera sp. 10	P	2	-
	Hymenoptera sp. 11	P	1	-
	Hymenoptera sp. 12	P	2	-
	Hymenoptera sp. 13	P	1	-
Diptera				
Diptera	Diptera sp. 1	D	16	0.03
	Diptera sp. 2	D	3	0.01
	Diptera sp. 3	D	1	-
	Diptera sp. 4	D	4	0.01
	Diptera sp. 5	D	1	-
	Diptera sp. 6	D	4	0.01
	Diptera sp. 7	D	1	-
	Diptera sp. 8	D	2	-
	Diptera sp. 9	D	5	0.01
	Diptera sp. 10	D	8	0.02
	Diptera sp. 11	D	1	-
	Diptera sp. 12	D	2	-
	Diptera sp. 13	D	1	-
	Diptera sp. 14	D	4	0.01
	Diptera sp. 15	D	1	-
	Diptera sp. 16	D	2	-
	Diptera sp. 17	D	1	-
	Diptera sp. 19	D	2	-
	Diptera sp. 20	D	1	-
	Diptera sp. 21	D	1	-
	Diptera sp. 22	D	1	-
Syrphidae	Syrphidae sp. 1	CP	5	0.01
	Syrphidae sp. 2	CP	4	0.01
Chloropidae	*Anatrichus erinaceus*	D	2	-
Psychodidae	Psychodidae sp. 1	D	2	-
Sciaridae	Sciaridae sp. 1	D	19	0.04
Muscidae	*Atherigona* sp. 1	D	2	-
	Muscidae sp. 2	D	3	0.01
	Muscidae sp. 3	D	1	-
Dolichopodidae	Dolichopodidae sp. 1	CP	21	0.04
Culicidae	Culicidae sp. 1	D/SH	6	0.01
	Culicidae sp. 2	D/SH	1	-
Diptera larva	Larva sp. 1	D/SH	55	0.11
Tabanidae	Tabanidae larva sp. 1	D	2	-
	Tabanidae pupa	-	3	0.01
Stratiomyidae	Stratiomyidae sp. 1	D/SH	2	-
Unknown		?	1	-
Orthoptera				
Acrididae	Acrididae sp. 1	CH	1	-
	Acrididae sp. 2	CH	1	-
	Acrididae sp. 3	CH	1	-
Bradyporidae	*Acanthoplus armiventris*	CH	1	-
Gryllotalpidae	Gryllotalpidae sp. 1	CP	1	-
	Gryllotalpidae sp. 2	CP	1	-
Gryllidae	Gryllidae sp. 1	CP	1	-
Tettigoniidae	Tettigoniidae sp. 1	CH	4	0.01
Neuroptera				
Chrysopidae	*Chrysoperla* larva sp. 1	SP	14	0.03

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Appendix 1. Continued

Order and Family	Species name	Functional groups	Total no.	Mean per plant
	Chrysoperla adult sp. 1	CH	1	-
Hemerobiidae	Hemerobiidae larva sp. 1	SP	4	0.01
Collembola				
Entomobryoidea	Entomobryoidea sp. 1	D	151	0.31
	Entomobryoidea sp. 2	D	1	-
Sminthuridae	Sminthuridae sp. 1	D	1	-
Poduroidea	Poduroidea sp. 1	D	14	0.03
Phthiraptera				
Thaumastocoridae	*Thaumastocoris peregrinus*	-	3	0.01
Phthiraptera	Phthiraptera sp. 1	-	3	0.01
Dermaptera				
Labiduridae	Labiduridae sp. 1	CP	5	0.01
Forficulidae	Forficulidae sp. 1	CP	164	0.34
	Forficulidae larva sp. 1	CP	253	0.53
Psocoptera				
	Psocoptera sp. 1	D	31	0.06
Blattodea				
Blatellidae	Blatellidae sp.1	D	2	-
Blattodea	Blattodea sp. 1	D	1	-
	Blattodea sp. 2	D	5	0.01
	Blattodea sp. 3	D	3	0.01
	Blattodea sp. 4	D	1	-
Araneae				
Salticidae	*Thyene* sp. 1	CP	2	-
Salticidae	*Heliophanus debilis*	CP	1	-
Salticidae	*Enoplognatha* sp. 3	CP	10	0.02
Clubionidae	*Clubiona* sp. 4	CP	21	0.04
Theridiidae	*Enoplognatha* sp. 5	CP	10	0.02
Theridiidae	*Theridion* sp. 6	CP	3	0.01
Linyphiidae	*Meioneta* sp. 7	CP	6	0.01
Oonopidae	*Gamasomorpha* sp. 8	CP	2	-
Sparassidae	*Olios correvoni*	CP	5	0.01
Miturgidae	*Cheiracanthium* sp. 10	CP	1	-
	Arachnida sp. 11	CP	3	0.01
	Arachnida sp. 12	CP	1	-
	Arachnida sp. 13	CP	1	-
	Arachnida sp. 14	CP	25	0.05
	Arachnida sp. 15	CP	2	-
	Arachnida sp. 16	CP	18	0.04
	Arachnida sp. 17	CP	1	-
	Arachnida sp. 18	CP	7	0.01
	Arachnida sp. 19	CP	2	-
	Arachnida sp. 20	CP	1	-
	Arachnida sp. 21	CP	7	0.01
	Arachnida sp. 22	CP	7	0.01
	Arachnida sp. 23	CP	1	-
	Arachnida sp. 24	CP	6	0.01
	Arachnida sp. 25	CP	2	-
	Arachnida sp. 26	CP	1	-
	Arachnida sp. 27	CP	1	-
	Arachnida sp. 28	CP	2	-
	Arachnida sp. 29	CP	1	-
	Arachnida sp. 30	CP	1	-
	Arachnida sp. 31	CP	1	-
	Arachnida sp. 32	CP	1	-
	Arachnida sp. 34	CP	1	-
	Arachnida sp. 35	CP	1	-
	Arachnida sp. 36	CP	4	0.01
	Arachnida sp. 37	CP	1	-
	Arachnida sp. 38	CP	1	-
	Arachnida sp. 39	CP	1	-
	Arachnida sp. 40	CP	1	-
	Arachnida sp. 41	CP	2	-
	Arachnida sp. 42	CP	3	0.01
	Arachnida sp. 43	CP	1	-
	Arachnida sp. 44	CP	1	-
	Arachnida sp. 45	CP	1	-
Unknown		?	2	-
Acari				
Phytoseiidae	Phytoseiidae sp. 1	SP	70	0.15

Continued on following page

Appendix 1. Continued

Order and Family	Species name	Functional groups	Total no.	Mean per plant
	Phytoseiidae sp. 2	SP	51	0.11
	Phytoseiidae sp. 3	SP	11	0.02
	Phytoseiidae sp. 4	SP	3	0.01
Tetranychidae	Tetranychidae sp. 1	SH	127	0.26
Anystidae	Anystidae sp. 1	CP	23	0.05
Eupodidae	Eupodidae sp. 1	D	1	-
Ascidae	Ascidae sp. 1	CP	17	0.04
	Ascidae sp. 2	CP	1	-
Acaridae	*Caloglyphus* sp. 1	D	4	0.01
	Rhizoglyphus sp. 1	D	11	0.02
	Tyrophagus sp. 1	D	5	0.01
Tydeidae	Tydeidae sp. 1	D	2	-
Oppiidae	Oppiidae sp. 1	D	166	0.35
Rhodacaridae	Rhodacaridae sp. 1	D	5	0.01
Eremobelbidae	Eremobelbidae sp. 1	D	11	0.02
Stigmaeidae	Stigmaeidae sp. 1	D	2	-
Tarsonemini	Tarsonemini sp. 1	D	1	-
Crustacea				
	Crustacea sp. 1	-	6	0.01
Myriapoda				
	Myriapoda sp. 1	D	1	-
Stylommatophora				
	Agriolimax sp. 1	CH	35	0.07
Unknown				
	Unknown	?	73	0.15

SH, Sucking herbivores; CH, Chewing herbivores; SP, Sucking predators; CP, Chewing predators; P, Predators; D, Detritivores. ?, Identifications were not done because it consists of unknown species. **?*,** Because identifications were not done to the species level, it was not possible to distinguish between predatory and herbivorous species. -, Species was not included in functional groups.