

Insect Diversity in Switchgrass Grown for Biofuel in South Carolina¹

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ABSTRACT Switchgrass (*Panicum virgatum* L.) has tremendous potential as a biomass and stock crop for cellulosic ethanol production or combustion as a solid fuel. A three-year study was conducted to assess insect and weed diversity in a perennial switchgrass crop in Florence, SC. Insects were sampled from 2007 to 2009, using pitfall traps and sweep-nets. Collected specimens were identified to family and classified by trophic groups, and the predominant species were identified. The diversity and density of weeds in the field during the establishment year (2007) were greater than the following years. The ratio of dry weight of switchgrass to weeds increased from 2.4 in January 2008 to 15.3 in January 2009. Insect diversity at the family level varied significantly across sampling dates only for sweep-net samples, with diversity peaks in May of each year. Diversity at the trophic-group level showed significant differences for predators in pitfall traps and for predators and herbivores in sweep-net samples across dates. Diversity of herbivores in pitfall traps tended to decrease over time. *Draeculacephala* sp., *Melanoplus* sp., and a species of Tettigoniidae were the predominant herbivores, while *Solenopsis invicta* Buren was the predominant predator. Assessing arthropod diversity in switchgrass is a first step in identifying potential pest and beneficial insects in this crop.

KEY WORDS Sweep-net, pitfall traps, sampling, Shannon index, weed diversity

Interest in agricultural products grown for biofuel has increased in recent years because of concerns over energy security and climate change (Farrell et al. 2006). Fossil fuels (oil, coal, and natural gas) currently represent more than 85% of energy consumed in the United States (Parrish & Fike 2005). The use of biofuel not only slows the depletion of fossil fuel resources, but also reduces the release of fossil carbon (Lynd et al. 1991). Ethanol production (mainly from corn, *Zea mays* L.) represents 99% of the biofuels produced in the United States (Farrell et al. 2006). However, the net energy yield of corn [80–100 gigajoules (GJ)/ha of crop] is less than those of perennial crops and grasses (200–300 GJ/ha of crop), and

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sugarcane, *Saccharum* spp. (400 GJ/ha of crop) (Rogner 2000). In addition, increasing demands on grain supplies and prices can limit the expansion of ethanol biofuel produced from monoculture crops grown on fertile soils (Schmer et al. 2008).

A warm season perennial (C₄) species native to North America, switchgrass (*Panicum virgatum* L.) has good potential for biomass production throughout the United States because of its wide geographic distribution and adaptability to diverse environmental conditions (Sanderson et al. 1996, Parrish & Fike 2005). Belonging to the family Poaceae and subfamily Panicoideae, switchgrass is one of the dominant grasses of North American tallgrass prairies; the others are Indiangrass, *Sorghastrum nutans*, big bluestem, *Andropogon gerardii*, and little bluestem, *Schizachyrium scoparium* (Whiles & Charlton 2006). Perennial grasses such as switchgrass can reduce erosion and runoff, increase incorporation of carbon in the soil, and reduce the use of pesticides compared to annual crops (Vaughan et al. 1989, Hohenstein & Wright 1994, Sanderson et al. 1996). Switchgrass also requires relatively low amounts of water and nutrients, grows on marginally productive land, provides habitat for wildlife, and can be used for conservation buffers, stream-bank stabilization, and filter strips (Sanderson et al. 1996, McLaughlin & Walsh 1998, Parrish & Fike 2005). On the Coastal Plain in South Carolina, frequent droughts can decrease yield and increase production costs of traditional crops. The drought-tolerant switchgrass provides an alternative crop for farmers.

Research on the production of switchgrass as a biofuel crop has centered on breeding for improved biomass yield and developing practices for nitrogen fertilization, weed control, and harvest (Sanderson et al. 1996, Parrish & Fike 2005). Insects, however, have been sparsely studied (Parrish & Fike 2005, Landis & Werling 2010). The few insects reported to feed on switchgrass include grasshoppers, the yellow sugarcane aphid, *Sipha flava* (Forbes) (Kindler & Dalrymple 1999), thrips (Gottwald & Adam 1998), and the fall armyworm, *Spodoptera frugiperda* (J. E. Smith) (Dowd & Johnson 2009). Resistance to *S. frugiperda* has also been shown to vary considerably among switchgrass cultivars (Dowd & Johnson 2009). In addition, new potential pests on switchgrass reported in South Dakota include a gall midge species, *Chilophaga virgati* Gagné, (Boe & Gagné 2010), and a stem-boring caterpillar, *Blastobasis repartella* (Dietz) (Prasifka et al. 2010). Also, insect pests may not become a threat to the production of biofuel from energy plants, such as switchgrass, until they are grown as an extensive monoculture (Parrish & Fike 2005).

Intensive agriculture with extensive use of monocultures may reduce the diversity of insects (Bourn & Thomas 2002, Gurr et al. 2004). With the anticipated widespread planting of switchgrass as a monoculture crop, the diversity of insects in switchgrass fields may be considerably reduced compared to the smaller-scale plots currently planted mainly as wildlife habitats. In addition, competition from weeds in a switchgrass field is most intense during the establishment year (Parrish & Fike 2005). The weed community in a perennial crop can change substantially from year to year (Parrish & Fike 2005); the impact of such a shift in plant diversity on insect diversity has not yet been quantified in switchgrass. However, arthropod responses can be specific to the functional group or feeding guild (Nickel & Hildebrandt 2003). For instance, densities of herbivores are often higher in monocultures where host plants are concentrated

(Root 1973, Koricheva et al. 2000). In contrast, natural enemies of herbivores are often more abundant in polycultures, having increased prey diversity and abundance of alternative food sources such as pollen and nectar (Root 1973). Therefore, insect herbivore outbreaks typically are more frequent in systems with reduced plant diversity (Andow 1991).

To better understand the insect and weed dynamics in a switchgrass agroecosystem in South Carolina, we evaluated insect diversity and host plant diversity over three years. Moreover, we assessed changes over time in the densities of major insect trophic groups, particularly for potential pests and natural enemies.

Material and Methods

Eight hectares of switchgrass (lowland cultivar 'Alamo') were planted on 3 May 2007 at the Clemson University Pee Dee Research and Education Center in Florence, SC. Land preparation included double disking, broadcast planting at a seeding rate of 8.9 kg of pure live seed per hectare, and deep tilling with a six-shanked ParaTill equipped with a roller bar that firmed the seed into the soil. No nitrogen was applied in 2007, and weeds were controlled by mowing twice (19 June 2007 and 6 August 2007) at the switchgrass canopy height. Fertilizer was applied on 6 May 2008 (67 kg N/ha), 15 April 2009 (258 kg P/ha and 775 kg K/ha), and 29 April 2009 (67 kg N/ha). The entire field was previously mapped for soil type (Morton et al. 2007) on a 15-m grid basis for soil characteristics such as depth to clay, thickness of the E soil horizon, and soil organic matter in the upper 15 cm of soil. The field contains large areas of Bonneau sand (loamy, siliceous, thermic Arenic Paleudults having organic matter less than 0.5%), Norfolk loamy sand (fine-loamy, siliceous, thermic Typic Kandiodults having organic matter around 1.0%), and Rains sandy loam (fine-loamy, siliceous, thermic Typic Paleaquults with organic matter near 1.5%). The Bonneau soil series has relatively little clay in the upper soil profile and the argillic horizon (horizon of clay accumulation) is as deep as 91 cm or more, while in the Norfolk series the depth to the argillic is about 38 cm (Morton et al. 2007). Rains sandy loam is similar to Norfolk loamy sand except that Rains is usually higher in organic matter and moisture. Although diverse in soil characteristics, these three soil types are common in the Pee Dee region of the Coastal Plain (Morton et al. 2007). No herbicides or insecticides were applied to the switchgrass field. A portion of the field was randomly divided into five plots (24.4 m \times 24.4 m) where insect and weed sampling was conducted. Plots were surrounded by a 1.2-m mowed alley within the switchgrass field. Distance among plots was at least 27 m. A buffer of at least 6 m of switchgrass separated the plots from adjacent habitat surrounding the field.

Plant sampling. Densities of switchgrass and weed plants (identified to species or genus) were measured in nine randomly selected 30.5-cm² areas in each plot on 21 June 2007, 18 June 2008, and 24 July 2009. Dry weights of switchgrass and combined weed species were determined in each plot in four randomly selected 0.3-m² areas on 2 August 2007 (switchgrass only) and in two 1-m² samples on 30 January 2008, 31 July 2008, 10 January 2009, and 29 July 2009. The increase in area sampled from 2007 to subsequent years provided a more representative sample of the average switchgrass dry weight. Plants were

cut at approximately 5 cm above soil level and were dried for 5 days at 60°C. Switchgrass height, defined as the distance from soil level to the top of the tallest tiller of the plant, was recorded in 20 randomly selected plants per plot on 19 June 2007, 23 May 2008, 18 June 2008, 21 August 2008, and 16 July 2009.

Insect sampling. Plots were monitored monthly from May to August 2007, 2008, and 2009, using pitfall trapping and sweep-net sampling. Two pitfall traps (plastic cups, diameter: 10 cm and depth: 7.5 cm) containing antifreeze (ethylene glycol) were randomly placed in each plot once a month and left in the field for 14 days. The traps were collected, the antifreeze removed, and the insect samples preserved in vials with 75% ethanol. Two 25-sweep-net samples per plot were also taken once a month. Sweeps were randomly taken in each plot; therefore transects varied with sample date. Insects collected were transferred to plastic bags and placed in a freezer in the laboratory. For soil insect density estimation, five samples were taken in each plot near the root of the plant on 12 June 2008 using a post-hole digger (diameter: 10 cm and depth: 15 cm). Samples were processed using a soil sieve with a mesh size of 1.7 mm.

All insects were counted and identified morphologically to family, using the keys of Johnson & Triplehorn (2004). Some arthropods, such as spiders and springtails, were identified to order using Johnson & Triplehorn (2004), and mites were identified to suborder using Krantz (1978). To understand the potential role each taxon may have in a switchgrass agroecosystem, all arthropods were classified by trophic levels according to the feeding habit and functionality in the switchgrass agroecosystem: herbivores, predators, scavengers, and parasitoids (Siemann et al. 1998, Koricheva et al. 2000, Johnson & Triplehorn 2004). When possible, groups that contain two feeding habits were identified to genus or species in the case of insects and to suborder for mites. Groups for which a specific guild was difficult to assign were classified in the different possible guilds and data were analyzed for each guild. In addition, the most frequent insects that were either potential pests or natural enemies of these pests were identified to species, using the reference collection in the insect museum at the Clemson University Pee Dee Research and Education Center. Target species were selected based on their consistent presence in sampling over time, as these species appeared to be well established in the switchgrass agroecosystem.

Data analyses. Sub-samples for all variables were pooled prior to analyses. The diversity of plant species, insect families, non-insect orders, and trophic groups was estimated by sampling method for each sampling date during the three years of study, using the Shannon index (H) (Southwood & Henderson 2000) (eq. 1):

$$H = - \sum_{i=1}^S p_i \ln p_i \quad (1)$$

where $i = i$ -th species; $p_i =$ the proportional abundance of the i -th species (n_i/N); $n_i =$ abundance of the i -th species; $N =$ total number of all individuals; and $S =$ observed number of species (species richness). For the plant biomass, and the abundance and diversity indices of selected arthropod taxa, a one-way ANOVA was used with date as a fixed effect and a repeated measures statement with a

first-order autoregressive covariance structure (PROC MIXED, SAS Institute 1999). Tukey's HSD (Tukey 1953) was used for mean separation. Densities were transformed ($\sqrt{x + \frac{3}{8}}$) prior to ANOVA to normalize their distributions (Zar 1999). ANOVAs were conducted for all variables with non-zero values on two or more dates.

Results

Plant measurements. A total of 16 weed species were found in switchgrass plots across the three years of study. In the first growing season (2007), *Mollugo verticillata* (carpet weed) was the dominant species, followed by *Helenium* sp. (sneezeweed) (Table 1). Pigweed, *Amaranthus* sp., was one of the more prevalent species in 2007, but was not found in following years. Only *Oxalis corniculata* (creeping woodsorrel) was found in both 2007 and 2008. The overall density of weeds present in 2007 was greater than in 2008 and 2009 (Table 1). The density of switchgrass in 2007 (166.7 ± 41.1 plants per m^2) was low compared with 2008 (542.5 ± 36.3) and 2009 (396.8 ± 26.3) ($F = 23.6$; $df = 2,8$; $P = 0.0004$), and increased substantially relative to the density of weeds. The height of switchgrass increased significantly over time: 40.3 ± 5.6 cm in June 2007, 46.3 ± 4.1 cm in June 2008, 70.3 ± 4.0 cm in June 2009, and 145.4 ± 8.7 cm in July 2009 ($F = 250.2$; $df = 4,16$; $P = 0.0001$).

Dry weights varied significantly across sampling dates for switchgrass ($F = 104.2$; $df = 4,16$; $P = 0.0001$) but not for weeds ($F = 2.9$; $df = 3,12$; $P = 0.0801$) (Fig. 1). A substantial increase of switchgrass biomass occurred relative to weed biomass across sampling dates. The ratio of the dry weight of switchgrass to weeds increased from 2.4 in January 2008 to 15.3 in January 2009. The diversity of plant species (switchgrass and weeds) expressed by Shannon's index, decreased significantly from 2007 (0.88 ± 0.09) to 2008 (0.16 ± 0.09) and 2009 (0.10 ± 0.15) ($F = 102.1$; $df = 2,8$; $P = 0.0001$).

Insect diversity. A total of 13,746 arthropods was collected from 2007 to 2009 across all sampling methods and dates from three classes: Arachnida (spiders and mites), Entognatha (Collembola), and Insecta (Tables 2 and 3). All mites belonged to the suborder Oribatida. Insects belonged to seven orders and 41 families. In pitfall trap sampling, 9363 individuals were found across the three years, comprising six orders and 31 families. In sweep-net samples, fewer individuals were found (1927), representing five orders and 27 families.

Insect diversity based on pitfall trap sampling did not show significant differences among sampling dates ($F = 1.04$; $df = 6,27$; $P = 0.4244$), while diversity based on sweep-net sampling was higher in May and decreased in the following months in 2008 and 2009 ($F = 5.54$, $df = 6,27$; $P = 0.0007$).

Arthropod abundance also varied significantly ($P < 0.05$) among sampling dates. In pitfall traps, Araneae, Collembola, Formicidae, and Gryllidae were the most abundant and consistently present groups over time (Table 2). In sweep-net samples, Cicadellidae was the most abundant group and Cicadellidae, Acrididae, and Tettigoniidae were the most consistently captured groups for this sampling method (Table 3). Flies (e.g., Sciaridae, Phoridae, and Chloropidae) and beetles (e.g., Carabidae) in pitfall traps and Curculionidae in sweep-net samples were collected on most dates although at low levels. Anthicidae, Tenebrionidae,

Table 1. Density (\pm SEM) of weed species per square meter in field study in Florence, SC, 2007–2009.

Plant species	Plant density per square meter			F^a	$P > F$
	2007	2008	2009		
<i>Amaranthus</i> sp.	15.3 \pm 5.7	0.0	0.0	—	—
<i>Cyperus esculentus</i>	3.6 \pm 2.0	0.0	0.0	—	—
<i>Mollugo verticillata</i>	47.4 \pm 29.0	0.0	0.0	—	—
<i>Helenium</i> sp.	21.9 \pm 11.0a ^b	0.0b	0.2 \pm 0.2b	7.93	0.013
<i>Digitaria</i> sp.	4.8 \pm 4.5	0.0	0.0	—	—
<i>Oxalis corniculata</i>	2.6 \pm 2.6a	1.7 \pm 1.7a	0.0a	0.52	0.614
<i>Silene antirrhina</i>	0.0	2.4 \pm 1.3	0.0	—	—
<i>Conyza canadensis</i>	0.0a	1.0 \pm 1.0a	4.3 \pm 3.2a	1.78	0.229
<i>Rumex acetosella</i>	0.0	0.7 \pm 0.7	0.0	—	—
<i>Solidago</i> sp.	0.0	2.6 \pm 1.3	0.0	—	—
<i>Oenothera</i> sp.	0.0b	2.6 \pm 1.3a	0.2 \pm 0.2b	7.07	0.017
<i>Richardia brasiliensis</i>	0.0	0.0	0.5 \pm 0.5	—	—
<i>Senna obtusifolia</i>	0.0a	0.2 \pm 0.2a	0.5 \pm 0.3a	1.20	0.350
<i>Croton glandulosus</i> var. <i>septentrionalis</i>	0.0	0.0	1.0 \pm 0.7	—	—
Unidentified species	0.0	5.7 \pm 5.7	0.0	—	—
<i>Acer rubrum</i>	0.0	0.0	0.2 \pm 0.2	—	—
Total	95.4 \pm 21.4a	11.2 \pm 4.3b	11.2 \pm 4.3b	23.73	0.0004

^adf = 2,8.

^bMeans within the same row followed by the same letter are not significantly different [$P < 0.05$; Tukey's (1953) HSD].

Cydnidae, and Gryllotalpidae were most numerous in 2007, decreased in 2008, and were not sampled in 2009 for pitfall traps. Geocoridae and Berytidae were only present in 2007 and 2008 for sweep-net samples. Lygaeidae showed the same trend for both sampling methods (Tables 2 and 3). Other groups of insects, however, were found only in samples in 2009. These groups included Reduviidae, Cercopidae, and Elateridae for pitfall traps, and Pipunculidae, Dolichopodidae, Syrphidae, and Coenagrionidae for sweep-net samples (Tables 2 and 3).

Among the four trophic groups (Table 4), insects that belonged to the families Lygaeidae, Pentatomidae, Miridae, Carabidae, and Cecidomyiidae can be either predators or herbivores. As a result, Lygaeidae, Pentatomidae, Carabidae, and a species of Miridae (the most predominant in this group) were identified to genus or species (Tables 5 and 6) and classified as herbivores. We were not able to identify specimens of Cecidomyiidae to genus or species; the trophic group was arbitrarily assigned as herbivore. The same criteria were used for another undetermined species of Miridae. Species of the genus *Gryllus* can be predators or can feed on seedling plants (Walker 1986) or on dead material (Gangwere 1961). Gangwere (1961) suggests that field crickets prefer plant material; however, Carmona et al. (1999) reported that *Gryllus pennsylvanicus* Burmeister had high densities and activity in switchgrass used as a filter strip, but its specific role was undetermined. Because the function of this field cricket is unknown in the

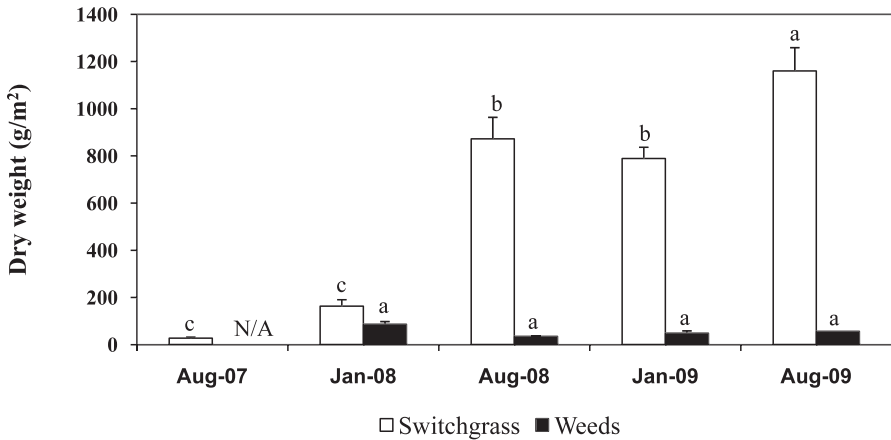


Fig. 1. Biomass (\pm SEM) of switchgrass and weeds in field study in Florence, SC, 2007–2009. Bars for switchgrass ($P < 0.05$) and weeds ($P > 0.05$) with the same letter are not significant different [Tukey's (1953) HSD].

present study, the family Gryllidae was classified in two trophic groups, herbivores and predators. Mites were classified as scavengers because the individuals collected belonged to the suborder Oribatida and are known to be mycophagous and saprophagous, acting as decomposers of organic material in the soil (Krantz 1978, Jordan 2001).

In pitfall traps, the diversity of herbivores differed significantly across sampling dates [herbivores ($F = 3.74$; $df = 6,28$; $P = 0.0074$)], but not predators ($F = 1.21$; $df = 6,28$; $P = 0.3308$) and scavengers ($F = 2.04$; $df = 6,28$; $P = 0.0936$). Diversity of herbivores showed a peak in May 2008 and tended to decrease across time. For sweep-net samples, diversity of herbivores was lowest in June 2009 and highest in May 2008 ($F = 3.28$; $df = 6,28$; $P = 0.0143$). Diversity of predators sampled with sweep nets did not show a clear pattern across sampling dates ($F = 9.25$; $df = 6,28$; $P = 0.0001$).

The abundance of trophic groups in pitfall traps varied significantly over time only for herbivores and predators (Table 4). For both groups, abundance was higher in June of each year and abundance of predators was higher than abundance of herbivores. For sweep-net samples, herbivores and predators were also the only groups that varied significantly over time (Table 4). Both groups decreased from 2007 to the end of 2008 and increased in 2009 in June. In contrast to pitfall traps, abundance of herbivores was always greater than the abundance of predators sampled with sweep-nets.

Some of the more abundant and consistently sampled species (referred to as target species) in pitfall traps were *Solenopsis invicta* Buren (predator) and *Gryllus* sp. (undetermined trophic role) (Table 5). In sweep-net samples, target species were *Draeculacephala* sp. (herbivore), *Melanoplus* possibly *sanguinipes* (herbivore), and two undetermined species of Tettigoniidae. In 2008 and 2009, *Gryllus* sp. and *Draeculacephala* sp. showed a peak in June and then decreased at the end of the season (Table 6), while *Melanoplus* and a species of

Table 2. Summary of arthropods collected in pitfall traps (\pm SEM) (2 per plot, n = 5 replications) across sampling dates in switchgrass field study in Florence, SC, 2007–2009.

Order/family	31 May 2007	6 May 2008	30 June 2008	22 July 2008	31 May 2009	30 June 2009	23 July 2009	$P >$ F^b
Araneae	21.6 \pm 2.5 ^{bc}	6.2 \pm 2.7b	9.4 \pm 2.6ab	6.6 \pm 2.5b	3.4 \pm 1.0b	5.4 \pm 1.0b	1.7 \pm 1.0b	33.15 <0.0001
Oribatida	17.6 \pm 5.1a	0.0b	0.0b	0.0b	30.0 \pm 1 0.1a	15.6 \pm 8.7b	18.2 \pm 3.3a	8.76 <0.0001
Coleoptera								
Anthicidae	15.6 \pm 3.7a	0.8 \pm 0.6 b	0.0b	0.0b	0.0b	0.0b	0.0b	33.15 <0.0001
Carabidae	6.8 \pm 0.7a	11.0 \pm 5.4a	0.0b	0.0b	0.6 \pm 0.2b	0.2 \pm 0.2b	0.2 \pm 0.2b	9.34 <0.0001
Scarabaeidae	34.2 \pm 14.0a	0.0b	0.0b	0.0b	3.4 \pm 2.7b	0.0b	0.0b	12.16 <0.0001
Diptera								
Cecidomyiidae	0.0b	0.4 \pm 0.2b	0.0b	1.0 \pm 0.5a	0.0b	0.0b	0.0b	3.32 0.0167
Hemiptera								
Lygaeidae	0.0b	6.8 \pm 1.5a	0.0b	1.8 \pm 1.3b	0.0b	0.0b	0.0b	13.07 <0.0001
Hymenoptera								
Formicidae	345.2 \pm 19 0.8ab	225.6 \pm 195.5ab	651.2 \pm 397.0a	135.0 \pm 88.9ab	46.4 \pm 15.5b	41.4 \pm 18.5b	42.5 \pm 28.8b	3.68 0.0104
Orthoptera								
Gryllidae	0.8 \pm 0.2c	18.0 \pm 6.6abc	72.6 \pm 26.3ab	8.2 \pm 1.2ab	16.8 \pm 6.3bc	72.6 \pm 24.6a	23.2 \pm 8.3abc	8.27 <0.0001
Thysanoptera								
Thripidae	15.3 \pm 7.6a	0.7 \pm 0.5b	0.0b	0.0b	0.0b	0.0b	3.9 \pm 2.7ab	4.03 0.0067

^adf = 6,23.

^bStatistical results for insect families collected in switchgrass plots that did not show significant differences across time: Acrididae ($F = 0.79$, $P = 0.5840$); Cercopidae ($F = 1.77$, $P = 0.1510$); Chloropidae ($F = 1.14$, $P = 0.3689$); Cicadellidae ($F = 1.46$, $P = 0.2349$); Collembola ($F = 0.76$, $P = 0.6061$); Curculionidae ($F = 0.79$, $P = 0.5840$); Cydidae ($F = 0.82$, $P = 0.5654$); Elateridae ($F = 1.41$, $P = 0.2516$); Geocoridae ($F = 1.05$, $P = 0.4197$); Gryllotalpidae ($F = 1.84$, $P = 0.1352$); Phoridae ($F = 1.83$, $P = 0.1376$); Proctotrupidae ($F = 1.53$, $P = 0.2126$); Reduviidae ($F = 0.96$, $P = 0.4704$); Scarabaeidae ($F = 1.43$, $P = 0.2462$); Sciariidae ($F = 2.41$, $P = 0.0589$); Tenebrionidae ($F = 1.25$, $P = 0.3163$).

^cMeans within the same row followed by the same letter are not significantly different [$P < 0.05$; Tukey's (1953) HSD].

Table 3. Summary of arthropods collected in sweep-net samples (\pm SEM) (two 25-sweep samples per plot, $n = 5$ replications) across sampling dates in switchgrass field study in Florence, SC, 2007–2009.

Order/family	14 August 2007	16 May 2008	20 June 2008	24 July 2008	27 May 2009	24 June 2009	25 July 2009	F^a	$P > F^b$
Araneae	0.0b	0.0b	0.0b	0.0b	0.0b	1.6 \pm 0.4a	0.6 \pm 0.2b	9.36	<0.0001
Coleoptera									
Coccinellidae	0.2 \pm 0.2b	0.80 \pm 0.4b	0.0b	0.0b	2.2 \pm 0.4a	0.2 \pm 0.2b	0.0b	12.38	<0.0001
Chrysomelidae	4.8 \pm 1.4a	0.0b	0.0b	0.0b	0.0b	0.2 \pm 0.2b	0.0b	12.91	<0.0001
Curculionidae	4.0 \pm 2.3a	0.2 \pm 0.2ab	0.2 \pm 0.2ab	0.0b	0.2 \pm 0.2ab	0.6 \pm 0.2b	0.2 \pm 0.2ab	3.19	0.0190
Diptera									
Dolichopodidae	0.0c	0.0c	0.0c	0.0c	3.2 \pm 1.3b	8.6 \pm 1.4a	0.4 \pm 0.2c	24.70	<0.0001
Hemiptera									
Aphididae	0.0b	1.8 \pm 0.9a	0.0b	0.0b	0.2 \pm 0.2b	0.0b	0.0b	4.21	0.0050
Berytidae	0.2 \pm 0.2b	0.6 \pm 0.2a	0.0b	0.0b	0.0b	0.0b	0.0b	3.86	0.0078
Cicadellidae	78.2 \pm 20.8a	3.0 \pm 1.0bc	1.4 \pm 0.5c	1.4 \pm 0.9c	9.8 \pm 1.9bc	100.8 \pm 21.5a	21.4 \pm 4.2b	27.32	<0.0001
Geoceridae	4.6 \pm 2.1a	0.4 \pm 0.2b	0.4 \pm 0.2b	0.0b	0.0b	0.0b	0.0b	10.29	<0.0001
Miridae	3.4 \pm 1.2a	3.8 \pm 3.1ab	0.0b	0.2 \pm 0.2ab	0.2 \pm 0.2ab	0.0b	0.6 \pm 0.3b	3.77	0.0087
Nabidae	3.4 \pm 1.3a	1.2 \pm 1.2ab	0.0b	0.0b	0.0b	0.2 \pm 0.2b	0.8 \pm 0.4b	3.70	0.0096
Reduviidae	6.6 \pm 2.7a	0.0b	0.0b	0.0b	0.0b	0.2 \pm 0.2b	0.4 \pm 0.4b	10.72	<0.0001
Orthoptera									
Tettigoniidae	3.0 \pm 1.8a	8.0 \pm 2.6a	1.4 \pm 0.2a	9.2 \pm 3.5a	1.6 \pm 0.5a	2.0 \pm 0.6a	9.4 \pm 2.9a	4.43	0.0038

^adf = 6,24.^bStatistical results for insect families collected in switchgrass plots that did not show significant differences across time: Acrididae ($F = 0.99$, $P = 0.4518$); Anthicidae ($F = 2.10$, $P = 0.0905$); Cercopidae ($F = 0.85$, $P = 0.5429$); Chloropidae ($F = 0.87$, $P = 0.5284$); Coenagrionidae ($F = 0.83$, $P = 0.5561$); Curculionidae ($F = 3.2$, $P = 0.0190$); Cydidae ($F = 2.10$, $P = 0.0905$); Lygaeidae ($F = 1.46$, $P = 0.2331$); Pentatomidae ($F = 2.21$, $P = 0.0773$); Pipunculidae ($F = 0.85$, $P = 0.5429$); Syrphidae ($F = 0.85$, $P = 0.5429$).^cMeans within the same row followed by the same letter are not significantly different [$P < 0.05$; Tukey's (1953) HSD].

Table 4. Abundance (\pm SEM) of arthropods by trophic groups in pitfall traps (2 per plot, n = 5 replications) and sweep-net samples (two 25-sweep samples per plot, n = 5 replications) in switchgrass field study, Florence, SC.

Date	Sampling method	Herbivores	Predators	Parasitoids	Scavengers
31 May 2007	Pitfall	19.8 \pm 5.8ab ^b	427.8 \pm 179.1ab	0.0a	74.0 \pm 14.0a
6 May 2008	Pitfall	27.6 \pm 7.8ab	261.6 \pm 192.4abc	4.4 \pm 1.8a	82.2 \pm 45.3a
30 June 2008	Pitfall	80.6 \pm 28.3a	735.6 \pm 376.7a	6.2 \pm 3.3a	42.4 \pm 13.7a
22 July 2008	Pitfall	11.2 \pm 2.1b	149.8 \pm 89.1bc	0.2 \pm 0.2a	37.6 \pm 11.2a
31 May 2009	Pitfall	17.6 \pm 6.2ab	70.6 \pm 13.5bc	2.2 \pm 1.5a	74.0 \pm 13.1a
30 June 2009	Pitfall	76.0 \pm 25.5a	119.8 \pm 22.0bc	0.6 \pm 0.6a	67.2 \pm 26.5a
23 July 2009	Pitfall	22.2 \pm 8.1ab	54.4 \pm 19.7c	0.0a	83.6 \pm 26.8a
<i>F</i> ^a		3.92	4.82	3.48	0.61
<i>P</i> > <i>F</i>		0.0072	0.0023	0.0129	0.7176
14 August 2007	Sweeping	109.6 \pm 18.5a	15.6 \pm 5.2a	0.0a	0.0a
16 May 2008	Sweeping	60.2 \pm 43.5ab	3.2 \pm 1.3bc	1.8 \pm 1.2a	0.0a
20 June 2008	Sweeping	7.4 \pm 3.2b	0.4 \pm 0.2c	0.0a	0.0a
24 July 2008	Sweeping	13.2 \pm 4.5b	0.4 \pm 0.2c	0.0a	0.0a
27 May 2009	Sweeping	16.0 \pm 2.1b	6.0 \pm 1.1ab	0.0a	0.8 \pm 0.6a
24 June 2009	Sweeping	107.6 \pm 19.4a	11.8 \pm 0.9a	0.4 \pm 0.4a	0.2 \pm 0.2a
25 July 2009	Sweeping	32.8 \pm 5.2ab	1.6 \pm 0.5bc	0.2 \pm 0.2a	0.0a
<i>F</i> ^a		8.27	14.67	2.03	1.82
<i>P</i> > <i>F</i>		<0.0001	<0.0001	0.1004	0.1369

^adf = 6,24.

^bFor each sampling method, columns with the same letter are not significantly different [*P* < 0.05; Tukey's (1953) HSD].

Table 5. Summary of densities (\pm SEM) of species collected in pitfall trap samples during three years of sampling (summers of 2007, 2008, 2009), Florence, SC. Rows with the same letter are not significantly different [$P < 0.05$; Tukey's (1953) HSD].

Insect species	14 August 2007	16 May 2008	20 June 2008	24 July 2008	27 May 2009	24 June 2009	25 July 2009	F^a	$P > F^b$
Herbivores									
Gryllidae									
<i>Gryllus</i> sp.	0.6 \pm 0.2d ^c	18.0 \pm 6.6ab	72.6 \pm 14.3ab	8.2 \pm 1.2a	16.8 \pm 6.3ab	72.6 \pm 14.3a	27.6 \pm 6.6abc	8.98	<0.0001
Predators									
Anthicidae									
<i>Notoxus</i> sp.	22.6 \pm 10.1a	0.4 \pm 0.4b	0.0b	0.0b	0.0b	0.0b	0.0b	15.41	<0.0001
Carabidae									
<i>Harpalus</i>									
<i>protractus</i>	1.8 \pm 0.5a	1.8 \pm 1.6ab	0.0b	0.0b	0.0b	0.0b	0.0b	3.83	0.0081
<i>Amara litoralis</i>	0.2 \pm 0.2b	2.4 \pm 1.0a	0.0b	0.0b	0.2 \pm 0.2b	0.0b	0.0b	6.57	0.0003
<i>Anisodactylus</i>									
<i>rusticus</i>	0.6 \pm 0.2a	0.4 \pm 0.2ab	0.0b	0.0b	0.0b	0.0b	0.0b	3.67	0.0100
<i>Calathus</i>									
<i>opaculus</i>	0.4 \pm 0.2a	0.4 \pm 0.2a	0.0b	0.0b	0.0b	0.0b	0.0b	2.67	0.0398
Formicidae									
<i>Solenopsis</i>									
<i>invicta</i>	345.2 \pm 190.7a	225.4 \pm 195.5a	786.2 \pm 544.9a	135.0 \pm 88.9a	46.4 \pm 14.2a	41.4 \pm 18.5a	41.6 \pm 16.1a	2.98	0.0255

^adf = 6,24.

^bStatistical results for some insect species collected that did not show significant differences across time: *Amara* sp. 1 ($F = 1.57, P = 0.1984$); *Amara* sp. 2 ($F = 1.29, P = 0.2973$); *Agonum punctiforme* ($F = 0.83, P = 0.5561$); *Geocoris* sp. ($F = 1.07, P = 0.4052$); *Megacephala carolina* ($F = 0.60, P = 0.7264$); *Prosapia bicincta* ($F = 1.77, P = 0.1471$); *Tochiomera nodosa* ($F = 1.40, P = 0.2543$); *Selenophorus palliatus* ($F = 0.75, P = 0.6160$).

^cMeans within the same row followed by the same letter are not significantly different [$P < 0.05$; Tukey's (1953) HSD].

Table 6. Summary of densities (\pm SEM) of species of insects collected in two 25-sweep samples during three years of sampling (summers of 2007, 2008, 2009), Florence, SC. Rows with the same letter are not significantly different [$P < 0.05$; Tukey's (1953) HSD].

Insect species	14 August 2007	16 May 2008	20 June 2008	24 July 2008	27 May 2009	24 June 2009	25 July 2009	F^a	$P > F^b$
Herbivores									
Cicadellidae									
<i>Stirellus bicolor</i>	11.8 \pm 3.4a ^c	0.0b	2.6 \pm 0.6b	1.2 \pm 0.6b	0.8 \pm 0.6b	1.0 \pm 0.3b	1.0 \pm 0.5b	10.18	<0.0001
<i>Draeculacephala</i> sp.	2.0 \pm 1.0bc	1.0 \pm 0.4c	0.8 \pm 0.4c	0.2 \pm 0.2c	1.8 \pm 0.7bc	93.4 \pm 19.9a	14.6 \pm 5.4b	35.86	<0.0001
Cydnidae									
<i>Sehirus cinctus</i>	0.0b	1.0 \pm 0.5a	0.0b	0.0b	0.2 \pm 0.2ab	0.0b	0.0b	3.36	0.0150
Rhyparochromidae									
<i>Neopamera bilobata</i>	0.0b	1.0 \pm 0.5a	0.0b	0.0b	0.2 \pm 0.2ab	0.0b	0.0b	3.36	0.0150
Pentatomidae									
<i>Oebalus pugnax</i>	1.8 \pm 1.1a	0.0a	0.0a	0.2 \pm 0.2a	0.0a	0.0a	0.0a	3.54	0.0118
Acrididae									
<i>Melanoplus</i> pos. <i>sanguinipes</i>	0.0b	0.0b	0.2 \pm 0.2b	0.6 \pm 0.4b	0.2 \pm 0.2b	3.6 \pm 0.9a	0.0b	14.92	<0.0001
Predators									
Dolichopodidae									
<i>Condylostylus</i> sp.	0.0c	0.2 \pm 0.2c	0.0c	0.0c	3.2 \pm 1.3b	11 \pm 2.3a	0.4 \pm 0.2bc	22.53	0.0001
Geocoridae									
<i>Geocoris</i> sp.	4.6 \pm 2.1a	0.4 \pm 0.2b	0.2 \pm 0.2b	0.0b	0.0b	0.0b	0.0b	10.76	0.0001
Nabidae									
<i>Nabis</i> sp.	3.4 \pm 1.3a	0.4 \pm 0.2b	0.0b	0.0b	0.2 \pm 0.5b	0.6 \pm 0.4b	0.0b	5.65	0.0009

^adf = 6,24.

^bStatistical results for some insect species collected that did not show significant differences across time: *Coleomegilla maculata* ($F = 1.93$, $P = 0.1175$); *Lygus lineoralis* ($F = 4.08$, $P = 0.0559$); *Notatus* sp. ($F = 1.93$, $P = 0.1173$); *Nysius raphanus* ($F = 1.00$, $P = 0.4459$); *Zelus* sp. ($F = 2.48$, $P = 0.0522$).

^cMeans within the same row followed by the same letter are not significantly different [$P < 0.05$; Tukey's (1953) HSD].

Tettigoniidae were less abundant than the other herbivores selected as target species across the three years of sampling.

Discussion

A total of 16 species of weeds were found in the switchgrass field used in our study. Weed species that can compete with switchgrass vary from region to region and are in general perennial forbs and warm-season grass species (Parrish & Fike 2005). In our switchgrass plots, *M. verticillata*, *Helenium* sp., and *Amaranthus* sp. were the most abundant species and were mainly collected in the first year after planting (2007) (Table 1). Weed competition can be a major limiting factor for switchgrass growth in the year of establishment (Martin et al. 1982, Parrish & Fike 2005). However, Martin et al. (1982) also found that switchgrass, along with big bluestem grass (*Andropogon gerardii*), excluded weeds more efficiently during the establishment year than other grasses, such as Indiangrass (*Sorghastrum* sp.) and side-oats grama (*Bouteloua curtipendula*). Moser & Vogel (1995) also indicated that switchgrass is more competitive than other warm-season grasses. In our study, the weed species found in the first year did not always persist in subsequent years (Table 1). In addition, as the density of switchgrass increased relative to the density of weeds, switchgrass dry weight also increased significantly compared to weeds (Fig 1). Plant diversity (weeds and switchgrass) estimated by the Shannon index was also significantly higher in the establishment year compared to years two and three. These results suggest that switchgrass out-competed weeds after the establishment year and there was not a dominant weed species associated with switchgrass in our study in years two and three. The disturbed habitat after switchgrass was planted may explain the high densities of weeds in 2007, particularly of the dominant species *M. verticillata*. Parrish & Fike (2005) affirmed that new weed species can appear in well-established switchgrass stands, mainly because of management practices. Our work was conducted in a single field, and further work is necessary under a wider range of conditions to confirm these results in South Carolina.

Three different methods of estimating insect abundance and diversity were used in this study. Pitfall traps are inexpensive, easy to manipulate in the field, and have been extensively used to sample active ground-dwelling arthropods from a wide range of taxa (Luff 1975, Thomas & Marshall 1999, Ward et al. 2001), particularly Coleoptera and Araneae (Luff 1975). In our plots, spiders, springtails, and ants were the most abundant and consistent groups collected with this method. Sweep-net sampling can be a fast and easy method to measure relative abundance and relative species richness of insects, and has been widely used for sampling aerial insects (Siemann et al. 1998, Southwood & Henderson 2000). In our study, the dominant families of insects collected using sweep-nets were Cicadellidae, Lygaeidae, and Tettigoniidae. These potential pests of switchgrass are very mobile species and can be difficult to collect with sweep-nets, which were likely more efficient earlier in the season with smaller switchgrass plants. Soil sampling is usually used to estimate arthropod densities in a specific area, for instance, near the roots of plants (Missa et al. 2009). Although only limited sampling was conducted with this method, the absence of soil herbivores suggests that switchgrass may not be significantly impacted by root-feeding insects. The combined use of these three methods enabled the

sampling of a broad range of insects, such as ants, crickets, and ground beetles with pitfall traps, and leafhoppers and grasshoppers with sweep-nets. However, as switchgrass plants grew throughout the season, sweep-net sampling in particular was likely a less efficient sampling method. Follow-up studies may investigate the use of methods better suited for insects in the top portion of the canopy. Future work may also evaluate other sampling methods more appropriate for certain insects, which may include direct counting of insects on the lower leaf surface for thrips, leaf miners, and aphids or using a white cloth or enamel pan under the plant for planthopper sampling (Wilson & Wheeler 2005).

Shannon's diversity index using family-level classification did not differ significantly across sampling dates for pitfall traps; however, peaks of diversity were observed in May of each year for sweep-net samples. Diversity analysis using trophic groups allowed the detection of trends that were not observed for family-level classification (Koricheva et al. 2000). In pitfall traps, herbivore diversity showed significant differences over time, indicating that trophic group classification may be more informative when studying temporal changes in diversity. In sweep-net samples, herbivores and predators varied significantly over time with a peak in May 2007 and 2008, respectively. These results support the findings using family-level classification that also showed peaks in May of each year. This pattern may be explained by greater emergence of insect adults in early summer (Unsicker et al. 2006).

Many authors have found a positive correlation between plant diversity and arthropod diversity (Andow 1991, Siemann et al. 1998, Borges & Brown 2001). In our study, the higher insect diversity observed in May was usually followed by a decline across sampling dates for herbivores in both sampling methods and predators for sweep-net samples, despite a significant decrease in plant diversity in 2008 and 2009. Numerous studies have demonstrated that intensive agriculture with widespread use of monocultures has a negative effect on insect diversity (e.g., Bourn & Thomas 2002). In our study, several families were collected only in the establishment year before weed diversity declined (Tables 2 and 3). Some of these families may have been associated with weed species present in 2007. For example, species of *Amaranthus* are hosts of weevils and leaf beetles (Bürki et al. 2001) that were mostly found in our study in 2007. Thrips were also collected mainly in 2007, although appropriate sampling methods were not used. High densities of species of the genus *Frankliniella* have been found on *Amaranthus palmeri* S. Wats and *M. verticillata* in North Carolina (Kahn et al. 2005). As a Poaceae species, switchgrass will likely recruit specialist insect herbivores from grasses from the same subfamily and generalist herbivores that can feed on several subfamilies. Some of the specialist insects sampled in our study could have been on the *Digitaria* species (subfamily Poaceae) found during the establishment year. Many leafhopper specialist herbivores are known to use native, dominant, perennial hosts, whereas generalists utilize a large number of grass species, including subdominants and annuals (Whitcomb et al. 1987). Insect herbivores sampled in our switchgrass plots may also have originated from grass hosts surrounding experimental plots, in addition to grass hosts within plots.

Root (1973) stated that herbivores are more likely to find and remain on host plants in pure stands than in polycultures because monocultures provide concentrated food resources. Other authors have corroborated this concept (Letourneau 1987, Borges & Brown 2001, Midega et al. 2004, Unsicker et al.

2006). In our study, although herbivore diversity tended to decrease with plant diversity in 2008 and 2009, herbivore abundance increased in June 2009 for both sampling methods. Plant diversity could potentially have affected insect diversity in our switchgrass plots. Root (1973) also stated that higher plant diversity can have a positive correlation with the densities of generalist natural enemies. In our study, however, plant diversity declined after 2007 without a corresponding decline in predator diversity.

The predominant families of herbivores collected using sweep-net samples were Cicadellidae, Acrididae, and Tettigoniidae. The dominant genus of leafhopper in our study, *Draeculacephala* sp., is recognized as an important pest in grasses and is also associated with the transmission of some diseases (Hewitt et al. 1946, Cabrera-La Rosa et al. 2008). Koricheva et al. (2000) and Nickel & Hildebrandt (2003) showed that Cicadellidae were more abundant in monoculture stands rather than in more diverse habitats. Leafhoppers are specialized herbivores and might find the host plant more readily in monocultures (Joshi et al. 2000, Koricheva et al. 2000, Nickel & Hildebrandt 2003). This may explain the higher abundance of *Draeculacephala* in June 2009, although we did not observe this leafhopper feeding on switchgrass. Leafhoppers are primary consumers that ingest cell contents, phloem, or xylem sap, resulting in the assimilation of plant biomass (Nickel & Hildebrandt 2003).

Other herbivores found consistently in our study were orthopterans (Tettigoniidae and Acrididae), typical of grass ecosystems (Welch et al. 1991, Craig et al. 1999). Grasshoppers have also been reported in switchgrass but not as frequently as on preferred hosts such as *Bothriochloa caucasica*, *Dichanthium* sp., *Sorghum bicolor*, and *Digitaria ciliaris* (Kindler & Dalrymple 1999, Parrish & Fike 2005). Craig et al. (1999) classify grasshoppers as residents or accidentals based on the incidence of individual insects caught rather than by densities to determine the stability of a species in an ecosystem. In our study, although the densities were low compared to other herbivores, grasshoppers were considered a target group because of the persistence of these families across sampling dates.

The predominant group of predators was Formicidae, collected in pitfall traps. Ants in general are susceptible to habitat changes, disturbance and agriculture intensification (Andersen et al. 2002, Bruhl et al. 2003, Philpott & Armbrecht 2006). In our switchgrass plots, the recently disturbed habitat in the first year after planting may explain the high densities of fire ants in 2007. Canopy closure in subsequent years likely caused a reduction in fire ant densities.

Gryllidae was also a predominant family, but it was considered in our analysis as both an herbivore and a predator due to its undetermined trophic role. Crickets showed peaks of abundance in June 2008 and 2009 (Table 5). Carmona et al. (1999) studied the abundance of *G. pennsylvanicus* in soybean and two adjacent filter strips, alfalfa and switchgrass. The highest activity and densities of *G. pennsylvanicus* were found in switchgrass rather than in soybean or alfalfa, but the role of the insect was undetermined. Further studies are recommended to identify the function of crickets in a switchgrass agroecosystem.

In our study, switchgrass out-competed weeds after the establishment year, and there was not a dominant weed species in years two and three after establishment. Peaks of diversity of insects were found in May of each year. Herbivores and predators were the only groups that showed significant differences across sampling dates. Large-scale commercial planting of switch-

grass may lead to a reduction of natural diversity of insects across the landscape compared with that observed in the small plots used in our work. The reduction in ecological diversity in monocultures can lead to increased pest problems because food, hosts, prey and overwintering sites of many natural enemies are reduced (Gurr et al. 2004). Unless natural enemies are present before colonization, pests can colonize crops and attain high densities before control can be achieved. Future work should investigate farmscape dynamics of insects in and around switchgrass crops to quantify the impact of this new crop on the sustainability of pest management systems. This study has provided the basis for identifying pest and beneficial insects in switchgrass in South Carolina.

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References Cited

- Andersen, A. N., B. D. Hoffmann, W. J. Müller & A. D. Griffiths. 2002.** Using ants as bioindicators in land management: Simplifying assessment of ant community responses. *J. Appl. Ecol.* 39: 8–17.
- Andow, D. A. 1991.** Vegetational diversity and arthropod population response. *Annu. Rev. Entomol.* 36: 561–586.
- Boe, A. & R. J. Gagné. 2010.** A new species of gall midge (Diptera: Cecidomyiidae) infesting switchgrass in the Northern Great Plains. *Bioenergy Res.* DOI 10.1007/s12155-010-9102-6.
- Borges, P. A. V. & V. K. Brown. 2001.** Phytophagous insects and web-building spiders in relation to pasture vegetation complexity. *Ecography* 24: 68–82.
- Bourn, N. A. D. & J. A. Thomas. 2002.** The challenge of conserving grassland insects at the margins of their range in Europe. *Biol. Conserv.* 104: 285–292.
- Bruhl, C. A., T. Eltz & E. Linsenmair. 2003.** Size does matter – effects of tropical rainforest fragmentation on the leaf litter ant community in Sabah, Malaysia. *Biodivers. Conserv.* 12: 1371–1389.
- Bürki, H. M., J. Lawrie, M. P. Greaves, V. M. Down, B. Jüttersonke, L. Cagán, M. Vráblová, R. Ghorbani, E. A. Hassan & D. Schroeder. 2001.** Biocontrol of *Amaranthus* spp. in Europe: State of the art. *BioControl* 46: 197–210.
- Cabrera-La Rosa, J. C., N. W. Johnson, E. L. Civerolo, J. Chen & R. L. Groves. 2008.** Seasonal population dynamics of *Draeculacephala minerva* (Hemiptera: Cicadellidae) and transmission of *Xylella fastidiosa*. *J. Econ. Entomol.* 101: 1105–1113.
- Carmona, D. M., F. D. Menalled & D. A. Landis. 1999.** *Gryllus pennsylvanicus* (Orthoptera: Gryllidae): Laboratory weed seed predation and within field activity-density. *J. Econ. Entomol.* 92: 825–829.
- Craig, D. P., C. E. Bock, B. C. Bennett & J. H. Bock. 1999.** Habitat relationships among grasshoppers (Orthoptera: Acrididae) at the western limit of the Great Plains in Colorado. *Am. Midl. Nat.* 142: 314–327.

- Dowd, P. F. & E. T. Johnson. 2009.** Differential resistance of switchgrass *Panicum virgatum* L. lines to fall armyworms *Spodoptera frugiperda* (J. E. Smith). *Genet. Resour. Crop Evol.* 56: 1077–1089.
- Farrell, A. E., R. J. Plevin, B. T. Turner, A. D. Jones, M. O'hare & D. M. Kammen. 2006.** Ethanol can contribute to energy and environmental goals. *Science* 311: 506–508.
- Gangwere, S. K. 1961.** A monograph on food selection in Orthoptera. *Trans. Am. Entomol. Soc.* 87: 67–230.
- Gottwald, R. & L. Adam. 1998.** Results of entomological surveys and on the weed control in *Miscanthus* and other C4 plants. *Arch. Phytopathol. Plant Prot.* 31: 377–386.
- Gurr, G. M., S. D. Wratten & M. A. Altieri. 2004.** *Ecological Engineering for Pest Management.* Cornell Univ. Press, Ithaca, NY.
- Hewitt, W. B., B. R. Houston, N. W. Frazier & J. H. Freitag. 1946.** Leafhopper transmission of the virus causing Pierce's disease of grape and dwarf of alfalfa. *Phytopathology* 36: 117–128.
- Hohenstein, W. G. & L. L. Wright. 1994.** Biomass energy production in the United States: An overview. *Biomass Bioenergy* 6: 161–173.
- Johnson, N. F. & C. A. Triplehorn. 2004.** *Borror and DeLong's Introduction to the Study of Insects*, 7th ed. Brooks Cole Publishing, Belmont, CA.
- Jordan, M. E. 2001.** Population dynamics of oribatid mites (Acari: Oribatida) on horse pastures of North Central Florida. M.S. Thesis. Univ. Florida, Gainesville, FL.
- Joshi, J., D. Matthies & B. Schmid. 2000.** Root hemiparasites and plant diversity in experimental grassland communities. *J. Ecol.* 88: 634–644.
- Kahn, N. D., J. F. Walgenbach & G. G. Kennedy. 2005.** Summer weeds as hosts for *Frankliniella occidentalis* and *Frankliniella fusca* (Thysanoptera: Thripidae) and as reservoirs for tomato spotted wilt tospovirus in North Carolina. *J. Econ. Entomol.* 98: 1810–1815.
- Kindler, S. D. & R. L. Dalrymple. 1999.** Relative susceptibility of cereals and pasture grasses to the yellow sugarcane aphid (Homoptera: Aphididae). *J. Agric. Urban Entomol.* 16: 113–122.
- Koricheva, J., C. P. H. Mulder, B. Schmid, J. Joshi & K. Huss-Danell. 2000.** Numerical responses of different trophic groups of invertebrates to manipulations of plant diversity in grasslands. *Oecologia* 125: 271–282.
- Krantz, G. W. 1978.** *A Manual of Acarology.* Oregon State Univ., Corvallis, OR.
- Landis, D. A. & B. P. Werling. 2010.** Arthropods and biofuel production systems in North America. *Insect Sci.* 17: 220–236.
- Letourneau, D. K. 1987.** The enemies hypothesis—tritrophic interactions and vegetational diversity in tropical agroecosystems. *Ecology* 68: 1616–1622.
- Luff, M. L. 1975.** Some features influencing efficiency of pitfall traps. *Oecologia* 19: 345–357.
- Lynd, L. R., J. H. Cushman, R. J. Nichols & C. E. Wyman. 1991.** Fuel ethanol from cellulosic biomass. *Science* 251: 1318–1323.
- Martin, A. R., R. S. Moomaw & K. P. Vogel. 1982.** Warm-season grass establishment with atrazine. *Agron. J.* 74: 916–920.
- McLaughlin, S. B. & M. E. Walsh. 1998.** Evaluating environmental consequences of producing herbaceous crops for bioenergy. *Biomass Bioenergy* 14: 317–324.
- Midega, C. A. O., C. K. P. O. Ogol & W. A. Overholt. 2004.** Effect of agroecosystem diversity on natural enemies of maize stemborers in coastal Kenya. *Int. J. Trop. Insect Sci.* 24: 280–286.
- Missa, O., Y. Basset, A. Alonso, S. E. Miller, G. Curletti, M. De Meyer, C. Eardley, M. W. Mansell & T. Wagner. 2009.** Monitoring arthropods in a tropical landscape: Relative effects of sampling methods and habitat types on trap catches. *J. Insect Conserv.* 13: 103–118.

- Morton, R., E. H. Earles & C. M. Ogg. 2007.** Soil Survey of Darlington County, South Carolina. USDA, Nat. Res. Conserv. Serv., S. C. Agric. Exp. Stn., and S. C. Dept. Nat. Res. <http://soildatamart.nrcs.usda.gov/Manuscripts/SC031/0/Darlington.pdf>.
- Moser, L. E. & K. P. Vogel. 1995.** Switchgrass, big bluestem, and indiangrass. *Forages* 1: 409–420.
- Nickel, H. & J. Hildebrandt. 2003.** Auchenorrhyncha communities as indicators of disturbance in grasslands (Insecta, Hemiptera) - a case study from the Elbe flood plains (northern Germany). *Agric. Ecosyst. Environ.* 98: 183–199.
- Parrish, D. J. & J. H. Fike. 2005.** The biology and agronomy of switchgrass for biofuels. *Crit. Rev. Plant Sci.* 24: 423–459.
- Philpott, S. M. & I. Armbrrecht. 2006.** Biodiversity in tropical agroforests and the ecological role of ants and ant diversity in predatory function. *Ecol. Entomol.* 31: 369–377.
- Prasifka, J. R., J. D. Bradshaw, A. A. Boe, D. Lee, D. Adamski & M. E. Gray. 2010.** Symptoms, distribution and abundance of the stem-boring caterpillar, *Blastobasis repartella* (Dietz), in switchgrass. *Bioenergy Res.* 3: 238–242.
- Rogner, H. H. 2000.** World energy assessment: energy and the challenge of sustainability, pp. 135–171. *In* J. Goldemberg [Ed.], *World Energy Assessment: Energy and the Challenge of Sustainability*. UNDP/UN-DESA/World Energy Council, NY.
- Root, R. B. 1973.** Organization of a plant-arthropod association in simple and diverse habitats: The fauna of collards (*Brassica oleracea*). *Ecol. Monogr.* 43: 95–120.
- Sanderson, M. A., R. L. Reed, S. B. McLaughlin, S. D. Wullschleger, B. V. Conger, D. J. Parrish, D. D. Wolf, C. Taliaferro, A. A. Hopkins, W. R. Ocumpaugh, M. A. Hussey, J. C. Read & C. R. Tischler. 1996.** Switchgrass as a sustainable bioenergy crop. *Bioresour. Technol.* 56: 83–93.
- SAS Institute. 1999.** User's manual, version 8.0. SAS Institute, Cary, NC.
- Schmer, M. R., K. P. Vogel, R. B. Mitchell & R. K. Perrin. 2008.** Net energy of cellulosic ethanol from switchgrass. *Proc. Natl. Acad. Sci. USA* 105: 464–469.
- Siemann, E., D. Tilman, J. Haarstad & M. Ritchie. 1998.** Experimental tests of the dependence of arthropod diversity on plant diversity. *Am. Nat.* 152: 738–750.
- Southwood, R. & P. A. Henderson. 2000.** *Ecological Methods*. Blackwell, London, UK.
- Thomas, C. F. G. & E. J. P. Marshall. 1999.** Arthropod abundance and diversity in differently vegetated margins of arable fields. *Agric. Ecosyst. Environ.* 72: 131–144.
- Tukey, J. W. 1953.** Some selected quick and easy methods of statistical analysis. *Trans. N. Y. Acad. Sci.* 16:88–97.
- Unsicker, S. B., N. Baer, A. Kahmen, M. Wagner, N. Buchmann & W. W. Weisser. 2006.** Invertebrate herbivory along a gradient of plant species diversity in extensively managed grasslands. *Oecologia* 150: 233–246.
- Vaughan, D. H., J. S. Cundiff & D. J. Parrish. 1989.** Herbaceous crops on marginal sites - erosion and economics. *Biomass* 20: 199–208.
- Walker, T. J. 1986.** Monitoring the flights of field crickets (*Gryllus* spp.) and a tachinid fly (*Euphasiopteryx ochracea*) in north Florida. *Fla. Entomol.* 69: 678–685.
- Ward, D. F., T. R. New & A. L. Yen. 2001.** Effects of pitfall trap spacing on the abundance, richness and composition of invertebrate catches. *J. Insect Conserv.* 5: 47–53.
- Welch, J. L., R. Redak & B. C. Kondratieff. 1991.** Effect of cattle grazing on the density and species of grasshoppers (Orthoptera, Acrididae) of the Central Plains Experimental Range, Colorado: A reassessment after two decades. *J. Kans. Entomol. Soc.* 64: 337–343.
- Whiles, M. R. & R. E. Charlton. 2006.** The ecological significance of tallgrass prairie arthropods. *Annu. Rev. Entomol.* 51: 387–412.
- Whitcomb, R. F., J. Kramer, M. E. Coan & A. L. Hicks. 1987.** Ecology and evolution of leafhopper-grass host relationships in North American grasslands. *Curr. Top. Vector Res.* 4: 121–178.

- Wilson, S. W. & A. G. Wheeler, Jr. 2005.** An African grass, *Eragrostis curvula* (Poaceae), planted in the southern United States recruits rarely collected native planthoppers (Hemiptera: Fulgoroidea: Dictyopharidae, Fulgoridae). *J. N. Y. Entomol. Soc.* 113: 174–204.
- Zar, J H. 1999.** *Biostatistical Analysis*. Prentice-Hall, Upper Saddle River, NJ.
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