

Effect of agroecosystem diversity on natural enemies of maize stemborers in coastal Kenya

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Abstract. A study was conducted at Mtwapa in the northern coastal area of Kenya during the long and short rainy seasons of 1999 and 2000 to assess the benefits of agroecosystem diversification—through agroforestry and intercropping—on the activity of natural enemies of maize stemborers. Treatments consisted of maize and cowpea intercrops or maize monocrops planted within hedgerows of *Leucaena leucocephala* and *Gliricidia sepium*. The plots were mulched or unmulched and insecticide-treated or not. The maize stemborers encountered, in order of abundance, were *Chilo partellus*, *Chilo orichalcociliellus* and *Sesamia calamistis*. The egg parasitoids *Trichogramma* spp. and *Telenomus* spp. were recovered from stemborer eggs. Ants, ladybird beetles, earwigs and crab spiders were found predated on the eggs. The larval parasitoids recovered included *Cotesia sesamiae*, *Cotesia flavipes* and *Goniozus indicus*, and the pupal parasitoid was *Pediobius furrus*. Mean rates of stemborer egg parasitism were generally high (>70%) while larval and pupal parasitism rates were low (<10%) for all the treatments. The observed rates of parasitism did not support the natural enemies hypothesis, which predicts that natural enemy activity increases with increasing agroecosystem diversity. Predation, larval and pupal mortality rates were generally low in all the treatments (<10%), with no significant differences between treatments.

Key words: maize stemborers, natural enemies, parasitoids, predators, natural enemies hypothesis, agroecosystem diversity, Kenya

Résumé. Une étude a été conduite à Mtwapa sur la côte sud du Kenya pendant les longues et courtes saisons des pluies de 1999 et 2000 afin d'évaluer l'incidence de la diversification des agrosystèmes, en conditions d'agroforesterie et de cultures associées, sur l'activité des ennemis naturels des foreurs du maïs. Les traitements ont consisté en une culture associée de maïs et de niébé ou une monoculture de maïs plantée entre des rangées de *Leucaena leucocephala* et de *Gliricidia sepium*. Les parcelles ont été paillées ou non et, ont été traitées ou non avec un insecticide. Les espèces de foreurs récoltées par ordre d'abondance sont *Chilo partellus*, *Chilo orichalcociliellus* et *Sesamia calamistis*. Les parasitoïdes d'œufs *Trichogramma* spp. et *Telenomus* spp. ont été obtenus des œufs des foreurs. Des fourmis, des coccinelles, des perce-oreilles et des araignées crabes ont été observés se nourrissant des œufs. On a obtenu les parasitoïdes larvaires *Cotesia sesamiae*, *Cotesia flavipes* et *Goniozus indicus* ainsi que le parasitoïde nymphal *Pediobius furrus*. Le taux moyen de parasitisme des œufs est généralement élevé (> 70%) alors que les taux de parasitisme larvaires et

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nymphals sont faibles ($< 10\%$) dans tous les traitements. Les taux de parasitisme observés ne confirment pas l'hypothèse selon laquelle l'activité des ennemis naturels est plus importante lorsque la diversité des agrosystèmes augmente. La prédation ainsi que les taux de mortalité larvaires et nymphals sont généralement faibles dans tous les traitements ($< 10\%$), sans différence significative entre traitements.

Mots clés: foreurs du maïs, ennemis naturels, parasitoïdes, prédateurs, hypothèse des ennemis naturels, diversité des agrosystèmes, côte kényanne

Introduction

Lepidopteran stemborers are major pests of maize (*Zea mays* L.) and sorghum (*Sorghum bicolor* Moench) in Africa (Youdeowei, 1989). Among the stemborer species infesting maize at the Kenyan coast is *Chilo partellus* (Swinhoe) (Lepidoptera: Crambidae), a species that was accidentally introduced from Asia into Africa around 1930 (Tams, 1932) and which has become the most abundant and injurious stemborer in the warmer lowland areas of eastern, central and southern African region. Recent studies indicate that *C. partellus* may be displacing some native species (Kfir, 1997; Overholt, 1998; Kfir *et al.*, 2002). Other stemborer species found at the Kenyan coast include *Chilo orichalcociliellus* Strand (Lepidoptera: Crambidae) and *Sesamia calamistis* Hampson (Lepidoptera: Noctuidae) (Ogol *et al.*, 1998; Bonhof, 2000). Estimates of yield losses due to stemborers range from 4 to 73% of potential yield (Seshu Reddy and Walker, 1990).

Many of the strategies commonly recommended for stemborer control are not practical or affordable for smallscale farmers, while the effectiveness of cultural methods for borer control is not guaranteed (Van den Berg *et al.*, 1998). However, indigenous natural enemies may be able to reduce stemborer populations in the field (Bonhof, 2000).

The natural mortality of stemborers in the field can be very high (Mathez, 1972; Oloo, 1989; Skövgard and Päts, 1996; Ogol *et al.*, 1998; Bonhof, 2000). For instance, Mathez (1972) found that only 5% of eggs laid produce adults that survive to die of old age, while Oloo (1989) working in western Kenya found that only a small proportion of *C. partellus* eggs reached the adult stage.

Larval parasitism of maize stemborers has been reported to be less than 10% at the coast (Skövgard and Päts, 1996; Ogol *et al.*, 1998) and less than 20% in western Kenya (Ogol *et al.*, 1998). Parasitism of pupae ranged from 0–10% at the coast (Skövgard and Päts, 1996; Ogol *et al.*, 1998) up to 58% in western Kenya (Oloo, 1989). Khan *et al.* (1997) observed improved larval parasitism by *Cotesia sesamiae* Cameron (Hymenoptera: Braconidae) in an intercrop of maize and molasses grass, *Melinis*

minutiflora, Beauv (Poaceae), indicating that agroecosystem diversification may boost natural enemy abundance and impact against stemborers (Ogol *et al.*, 1998).

Diversification is generally thought to increase ecosystem stability and decrease the incidence of major insect pest outbreaks often prevalent in monocultures (Perrin, 1977, 1980; Altieri and Letourneau, 1982; Risch, 1983; Risch *et al.*, 1983; Andow, 1991; Khan *et al.*, 2001; Midega and Khan, 2003). Agroforestry and intercropping may enhance productivity, by increasing the diversity of the agroecosystem.

The ecological basis for reduced pest populations in diverse systems has been explained in part by the 'natural enemies hypothesis' (Root, 1973). The hypothesis predicts that population densities of natural enemies will be higher, and insect pest populations are lower, in more diverse habitats, owing mainly to the availability of alternate prey, nectar sources and suitable microhabitats. The performance of natural enemies may also be enhanced by chemical cues from associated plants (Altieri *et al.*, 1981; Nordland *et al.*, 1988; Khan *et al.*, 1997, 2000).

Experiments to test the natural enemies hypothesis have yielded variable results, with some studies showing increase in natural enemy activity and others showing no change or a decline (Russell, 1989; Andow, 1991).

Although agroforestry is increasingly gaining ground as a cropping system approach, especially in the tropics, more evaluations are needed before the way in which natural enemies respond to vegetational diversity in agroecosystems is understood.

Studies were conducted to test the natural enemies hypothesis at the egg, larval and pupal stages of maize stemborers in agroforestry and intercropping systems. Maize, cowpea (*Vigna unguiculata* L.) and the tree species *Leucaena leucocephala* (Lam.) de Wit and *Gliricidia sepium* Jacq. (Steud) (Leguminosae) were used in various combinations. It was hypothesized that there would be a significantly greater level of activity by natural enemies in the maize–cowpea–leucaena–gliricidia cropping system than in the relatively less complex systems, with activity increasing with agroecosystem complexity.

Materials and methods

Study site

Studies were conducted at the Kenya Agricultural Research Institute (KARI) Regional Research Centre at Mtwapa, Coast Province, Kenya (3°56' S, 39°44' E; 15 m above sea level). Average rainfall is about 1200 mm per year, with a long rainy season between April and August and a short rainy season between October and December. Temperatures are generally high (25–30°C) throughout the year. Agriculture in the area consists predominantly of tree-based systems, under which trees such as coconut palms (*Cocos nucifera* L.), cashews (*Anacardium occidentale* L.) and mangoes (*Mangifera indica* L.) are intercropped with cassava (*Manihot esculenta* L.) and/or maize with or without livestock grazing.

Experimental design and plot layout

Five-month-old seedlings of leucaena and gliricidia were planted in hedgerows at Mtwapa during the long rains of 1999, in 16 × 13 m plots separated by 4 m buffer strips. Hedgerow trees were spaced 3.2 m between rows and were 0.65 m apart. Treatments consisted of plots of leucaena only (two plots), gliricidia only (one plot), alternating rows of leucaena and gliricidia (two plots), and four control plots without trees. This gave a total of nine treatments, which were laid out in a randomized complete block design and replicated four times. Two days before planting maize and cowpea, the leucaena and gliricidia trees were pruned to 0.3 m above the ground level and prunings from each plot were weighed and applied as mulch on the plot from which they were taken.

Maize (Pwani 4 hybrid) was planted at a spacing of 0.3 m within rows, 0.8 m between rows during the long and short rainy seasons of 1999 and 2000. In one of the leucaena–gliricidia hedgerow plots, a row of cowpea (variety k80) was planted between the rows of maize at an intra-row spacing of 0.1 m. Three of the plots without trees were planted to maize alone, while in the other maize and cowpea were intercropped. Foliage of leucaena and gliricidia from a separately developed plantation (of the same age as those in the experimental plots) was used to mulch the plots without trees, except for one of the maize monocrop plots.

Maize plants from one of the two mulched maize monocrop plots and one of the two leucaena–maize plots were fully protected from stemborers using insecticide application of Bulldock™ (betacyfluthrin) granules weekly from one week after plant emergence to crop maturity at the rate of 3.1 g a.i./ha. Plots were hand-weeded three times during each cropping season.

Stemborer egg parasitism and predation

During the short rains of 1999 and the long and short rains of 2000, a procedure adapted from Ogol *et al.* (1998) was used to study stemborer egg parasitism and predation. Beginning at crop emergence, the foliage of all maize plants was carefully inspected, and freshly laid stemborer egg batches were counted. All plants bearing egg batches were marked with a wooden peg in the soil, and all unmarked plants inspected again 24 h later to identify additional egg batches. Ten plants with egg batches were selected and the location of each egg batch was marked with a permanent marker on the reverse side of the leaf surface. On the third day, each egg batch was inspected and its condition recorded as healthy, partially eaten, or missing. Missing or partially eaten egg batches were assumed to have been predated upon. Data were expressed as percentage of eggs predated per plot.

All healthy and partially eaten eggs were cut out with a portion of the leaf, taken to the laboratory in labelled glass vials plugged with cotton wool to prevent emerging larvae and parasitoids escaping, and with a wet blotting paper maintained under the eggs to prevent their desiccation. The eggs were counted under a dissecting microscope and observed for two weeks until they hatched, parasitoids emerged, or they failed to develop. The data obtained were expressed as percentage of eggs parasitized per plot. The procedure was repeated biweekly for eight weeks.

Larval and pupal parasitism

Sampling for larval and pupal stages in maize started two weeks after plant emergence and continued until harvest during the long and short cropping seasons of 1999 and 2000. Ten maize plants were randomly sampled from each plot each week. The stalks were then dissected to recover the immature stages of stemborers. Both dead and live larvae and pupae were recovered. Live larvae were placed individually in vials with natural diet (pieces of maize stalks) until they pupated or died. Similarly, pupae were kept until they emerged as adults or died. They were checked daily for parasitoid emergence. The parasitoids were preserved in 70% alcohol and representative samples sent to the ICIPE laboratory in Nairobi for identification. Data were expressed as percentage parasitism per plot for each treatment.

Larval and pupal mortality

Dead larvae and pupae collected during the same sampling programme and those that died while being held in the laboratory from causes other than

parasitism were counted. The cause of mortality was not identified, but would include death due to pathogens. The data were expressed as percentage mortality per plot for each treatment.

Data analysis

Data were averaged across individual plots during each cropping season, then subjected to arcsine transformation. The data conformed to the assumptions of analysis of variance (ANOVA) as indicated by tests of normality (PROC UNIVARIATE, SAS Institute 2001), and analysed by two-way (treatment \times seasons) ANOVA (PROC GLM, SAS Institute, 2001). Thereafter, pre-planned orthogonal contrasts were used to test for the effects of mulching, intercropping, agroforestry, tree species, multiple trees and pesticide on natural enemy activity levels.

Results

The maize stemborers encountered, in order of abundance, were *Chilo partellus*, *C. orichalcociliellus* and *S. calamistis*.

Egg parasitism and predation

Trichogramma spp. (Hymenoptera: Trichogrammatidae) and *Telenomus* spp. (Hymenoptera: Scelionidae) were recovered from stemborer eggs. The proportion of eggs parasitized was generally high (>70%) for all the treatments (Table 1), with no significant differences between treatments ($F = 0.98$; df 8, 81; $P = 0.455$). The pre-planned contrasts did not show any differences between treatments (Table 2), implying that the agroforestry and intercropping systems used in the study did not influence the activity of egg parasitoids.

From visual observation of maize foliage, ants (Hymenoptera: Formicidae), ladybird beetles (Coleoptera: Coccinellidae), earwigs (Dermaptera: Forficulidae) and crab spiders (Araneidae: Philo-

dromidae) were found predating on stemborer eggs. Predation rates were generally low (15%) and not different between treatments ($F = 1.03$; df 8, 81; $P = 0.366$) (Table 1). Stemborer egg predation rate was lower in the mulched maize–cowpea intercrop than in the mulched maize monocrop ($P = 0.019$) (Table 2)—a negative response to the natural enemies hypothesis. There were no other statistically significant differences in predation rates.

Larval and pupal parasitism and hyperparasitism

The parasitoids recovered from the stemborers included *Cotesia sesamiae*, *C. flavipes* Cameron (Hymenoptera: Braconidae), and *Goniozus indicus* Ashmead (Hymenoptera: Bethyridae) from larvae, and *Pediobius fuscus* Gahan (Hymenoptera: Eulophidae) from pupae. Two hyperparasitoids were recovered: *Aphanogmus fijiensis* (Ferriere) (Hymenoptera: Ceraphronidae) (from *C. sesamiae* cocoons) and *Exoristobia* sp. (Hymenoptera: Encytridae) (from *C. flavipes* cocoons), but these had negligible impact on parasitism. Parasitism rates were generally low (<10%) in all the treatments and were not significantly different ($F = 0.65$; df 6, 84; $P = 0.558$) (Tables 1 and 2).

Larval and pupal mortality

Mean larval and pupal mortality rates were low across the treatments (<10%) and uniform during the four cropping seasons ($F = 0.74$; df 6, 84; $P = 0.511$) (Table 1). Some of the larvae and pupae under this category had a characteristic common dark coloration of the entire body, suggesting a microbial mortality factor (Hoekstra and Kfir, 1997; Ogol *et al.* 1998). There were, however, no differences in this type of mortality between the treatments, suggesting that the microbial mortality factors were not affected by the vegetation structures and cultural treatments studied (Table 2).

Table 1. Mean (\pm SE) percentage of stemborer eggs, larvae and pupae preyed upon, parasitized and dead per plot during the long and short rainy seasons of 1999 and 2000. Means represent treatment averages over four cropping seasons

Activity	Treatments ⁺								
	LMMu	GMMu	LGCMMu	LGMMu	MCMu	MMu	MPMu	LPMMu	Mm
Egg parasitism	75.1 \pm 3.0	71.6 \pm 3.1	76.9 \pm 2.4	76.6 \pm 2.1	79.9 \pm 1.5	73.7 \pm 4.6	71.3 \pm 4.8	74.1 \pm 2.7	77.4 \pm 2.6
Egg predation	11.6 \pm 2.5	12.4 \pm 2.5	8.9 \pm 2.0	7.3 \pm 0.5	6.7 \pm 1.4	13.0 \pm 3.4	5.7 \pm 1.7	9.1 \pm 1.6	7.8 \pm 1.7
Larval & pupal parasitism	7.3 \pm 0.9	6.6 \pm 0.9	6.0 \pm 0.4	8.1 \pm 0.7	7.7 \pm 1.1	6.9 \pm 0.5	–	–	6.2 \pm 0.9
Larval & pupal mortality	9.6 \pm 0.9	9.6 \pm 0.8	7.8 \pm 1.2	8.9 \pm 1.2	7.8 \pm 0.8	9.3 \pm 1.0	–	–	8.6 \pm 0.8

Means within a row are not statistically different. –, insufficient larvae for analysis due to pesticide effect.

⁺ Key: L, leucaena; G, gliricidia; M, maize; Mm, maize monocrop; C, cowpea; Mu, mulch; P, pesticide.

Table 2. Probabilities of orthogonal contrasts for pooled data on maize stemborer egg parasitism and predation, larval and pupal parasitism, and larval and pupal mortality for four cropping seasons

Activity	Treatment contrasts (<i>P</i> -values) ⁺							
	Mm/ MMu	Mmu/ MCMu	MMu/ GMMu	MMu/ LMMu	LGMMu/ GMMu	LGMMu/ LMMu	LGCMMu/ LGMMu	MMu/ MPMu
Egg parasitism	0.791	0.1932	0.942	0.381	0.343	0.202	0.741	0.934
Egg predation	0.093	0.019	0.166	0.685	0.309	0.222	0.914	0.914
Larval and pupal parasitism	0.308	0.837	0.777	0.503	0.361	0.114	0.561	*
Larval and pupal mortality	0.633	0.252	0.797	0.754	0.969	0.492	0.543	*

*Lack of larvae and pupae for analysis due to effect of pesticide.

⁺ Key: L, leucaena; G, gliricidia; M, maize; Mm, maize monocrop; C, cowpea; Mu, mulch; P, pesticide.

Discussion

Egg parasitism was generally high while larval and pupal parasitism were low for all the treatments during all cropping seasons. However, parasitism did not vary between treatments, indicating that agroforestry and intercropping did not promote recruitment or activity of stemborer parasitoids. Ogot *et al.* (1998) reported parasitism rates similar to ours on maize stemborer eggs (>75%) and low larval and pupal parasitism rates (<10%) at the Kenyan coast, with no significant differences among monocropped, weeded, unweeded and a leucaena-maize intercrop. Similarly, studies by Skövgård and Päs (1996) at the Kenyan coast concluded that intercropping maize with cowpea did not consistently influence the abundance or activity of the natural enemies of *Chilo partellus*, although a complex of 26 parasitoid species has been recovered from this pest at the coast (Zhou *et al.*, 2003). Pavuk and Barret (1993) also reported a neutral response to agroecosystem diversification by larval parasitoids of the green cloverworm, *Hyponomeuta scabra* (Fabricius) (Lepidoptera: Noctuidae).

Most of the studies that support the enemies hypothesis have involved generalist natural enemies (Sheehan, 1986; Russel, 1989). The impact of specialist natural enemies could be diminished in diverse agroecosystems, because of disrupted host plant and patch-olfactory cues, or to reduced host abundance (Sheehan, 1986).

Predation rates were generally low in all the treatments, with no significant differences among the treatments. A negative response to the natural enemies hypothesis was seen in the maize-cowpea intercrop. Although the mechanism has not been provided, Pollard (1971) suggests that the efficacy of highly mobile predators is not likely to be enhanced by the presence of alternate vegetation in a diverse agroecosystem. Some of the predators observed in this study included highly mobile ants, ladybird beetles, earwigs and spiders. Sheehan

(1986) found that predators of green cloverworm were no more active in soybean intercropped with sorghum than in a soybean monocrop, corroborating our findings.

In this study, neither vegetation structure nor cultural practice influenced the mortality of larvae and pupae due to pathogens. These results are consistent with those of Ogot *et al.* (1998) who found that intercropping leucaena and maize did not influence the activity of microbial agents against maize stemborers. Ogot *et al.* (1998) suggested that the microclimate in the crop canopy created by intercropping would have little influence on the conditions inside the plant stems, where older larvae and pupae reside. Williams *et al.* (1995) reported that the incidence of infection with the entomopathogenic fungus *Nomuraea rileyi* (Farlow) Sampson was not significantly different between green cloverworms in monocropped soybean and those in soybean intercropped with sorghum.

The lack of consistent effects of agroecosystem diversification on pests and their natural enemies suggests that each case must be considered individually (Nordland *et al.*, 1984; Ogot *et al.*, 1998). Also pertinent is the origin of the various agroforestry tree species, as this could influence their relationship with natural enemies and other biotic and abiotic components of their agroecosystems. The exotic leucaena and gliricidia used in this study may have little effect on the behaviour of native African natural enemies (Ogot *et al.*, 1998).

A knowledge of the direct and multi-trophic effects present in a particular agroecosystem may open up opportunities for increasing both the abundance and effectiveness of its natural enemies.

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