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The effects of vegetation on the abundance of lepidoptera stemborers and their larvae parasitism

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Abstract **The impact of maize fields, grass abundances, forest, and grass species on stemborers abundances and their larval parasitism were studied in natural conditions ~~in this paper~~. The results indicated that the number of maize fields around the experimental field positively affects the maize infestation rate by stemborers and can also increase stemborer densities in the experimental field, the intensity of this effect depend~~ent~~ upon maize stages. The grasses which surround~~ing~~ the maize field were strongly encouraging stemborers movement into maize fields and largely reduced stemborer larval parasitism by *Cotesia flavipes*, but grass stage was not important in our study. Forest, especially closed forest, around maize field significantly reduced maize infestation rate by stemborers and stemborers densities in maize field, but closed forests could also reduce stemborer larval parasitism. Specific grass species can be classified into four groups. One cluster contains grass~~es~~ species *E. haploclata, S. verticilliflorum*, and *H. rufa*, they strongly reduced stemborers abundance in maize field. The second cluster consists of grass~~es~~ species *E. pyramidalis, H. nyassae, S. aethiopicum, P. maximum*, and *S. arundinaceum*, they can increase stemborers abundance while negatively affect on larval parasitism in**

the maize field. The third group includes grasses species of *P. purpureum*, *H. dissolula* and especially *R. exaltata*, they have positive effect on both stemborers abundances and their parasitism. The last group of grasses has no or little effect on both stemborers and their parasitoid. There was significant regional differences of stemborers abundance and their larval parasitism, the distribution of maize fields, grasses abundances and forest around maize field are the driving forces which lead to this regional differences. Our result on the relationships between grasses abundances and stemborers occurrence can be used in the development of the habitat management programme for stemborer control.

Key words: Stemborer, larval parasitism, grass species, forest, maize

Introduction

One of the main purposes of ecology is to study the relationships between biotic and abiotic compounds (components) of the environment (Begon et al. 1996). Environmental heterogeneity can strongly affect the distribution and abundance of species. Among the biotic-environment relationships, insect-plant interactions, or in a more general sense, insect-vegetation interactions, is one of the major components of insect ecology (Price 1984). The living components in the environment constitute the biotic factors affecting insects, and include food, natural enemies, and competitors (Pfadt 1985). Hence, the environmental conditions in/surrounding a crop field, like the diversity of vegetation and the physical conditions of the crop plants, are also important factors that affect insects. This, in turn, may affect the third trophic level.

In east Africa, maize is the major food crop (Nadar and Faught 1984), lepidoptera stemborers cause serious yield loss each year (Darling 1993, Youdeowei 1989). Among the 20 some economically important stemborer species, the exotic Asian stemborer, *Chilo partellus* (Swinhoe) (Lepidoptera: Pyraloidea), is ~~of them~~ the most damaging species, especially in lower warmer areas (Mohyuddin and Greathead 1970, Harris 1990, Overholt et al. 1994a). Yield loss to maize can reach as high as 73% due only to the damage of *C. partellus* in some areas (Seshu Reddy and Walker 1990). Some studies have shown that surrounding vegetation, especially some grass species, can strongly affect the stemborer abundance in crop field (Bowden 1976, Nye 1960, Wheatley 1961, Roome 1976, Ingram 1958, Harries 1990, Gebre-Amlak 1988, Seshu Reddy 1983). Simpson and Kumar (1986) believed that wild grasses are reservoir for stemborers and responsible for pest outbreaks on crops. *Sesamia calamistis* Hampson (Lepidoptera: Noctuidae) and *Eldana saccharina* Walker (Lepidoptera: Pyralidae) are two widely distributed stemborer species (Shanower et al. 1993; Schulthess et al. 1997) in Africa continent, Shanower et al. (1993) found that both had a high preference for *Pennisetum polystachion* grass, and they have found that *Sorghum arundinaceum* was suitable for borers development to adulthood. Kaufmann (1983) found that grasses such as *Panicum maximum* and *P. purpureum* were attractive for stemborer oviposition but caused high mortalities of *S. calamistis* and *E. saccharina* larvae, thereby acting as trap plants. Schulthess et al (1997) found that highest borer densities for all species were found in the dense rainforest in Nigeria or Cameroon, where grasses are scarce, and the higher the grass abundance score, the lower the proportion of infested maize plants. In laboratory experiments, *C. flavipes* and *C. sesamiae*, both are stemborer parasitoids in Kenya, were attracted to *P. purpureum* (Ngi-Song et al. 1995) and wild sorghum (Potting et al.1995) suggesting that *C. flavipes* and *C. sesamiae* may be able to locate these wild grasses when actively growing maize is not available, such as after harvest or during off-season. Songa (1999) has found that *C. partellus* recovery mainly from wild sorghum, *Sorghum versicolor*, *P. purpureum* and *P. maximum*, and *S. calamistis* recovery mainly from *P. maximum*, and these three grasses were all season infested by stemborers, she found that both *C. flavipes* and *C. sesamiae* were able to survive successfully in *S. versicolor*.

On the other hand, Khan et al (1997a, 1997b) have found that intercropping maize with molasses grass repelled stemborers and attracted at least one important natural enemy. In their trails (Khan et al 1997a), molasses grass showed no colonization by stemborers, this means that the molasses grass can be a barrier that protects maize from the damaging of stemborer and thus significantly reduced yield losses (Khan et al 1997b, Schulthess et al. 1997). Some other studies showed also that the presence of some wild grasses species near maize crop filed may contribute to the reduction of stemborer infestation in the maize crop, by facilitating the carryover of natural enemies of stemborer from on cropping season to the next (Altieri et al 1977, Altieri and Whitecomb 1979, Herag and Funderburg 1986).

A recent attempt to control *C. partellus* has envolved the successful introduction of an exotic stemborer parasitoid, *Cotesia flavipes* (Cameron) (Hymenoptera: Braconidae), into east Africa from Asia (Overholt et al 1997, Omwega et al 1995, 1997). *C. flavipes* has released in 1993 in the coastal area and has since spread its distribution to southeastern Kenya (Overholt et al 2000) and it has become one of the two major stemborer parasitoids in coastal area of Kenya. Although the highest parasitism of stemborer by *C. flavipes* is >60% in some areas (Overholt et al 2000), average parasitism was about 12% in the coastal area in 1999 and this number was even lower (about 5%) in the southern coastal area.

What causes this large spatial variation of parasitism? Stemborer distribution is one of the major factors, and climate~~ic~~ is another factor. Obviously, environment is another unignorable (indisputable?) factor. Within the environment, soil and vegetation are the main components, both can affect the abundance of stemborers and their parasitism. Although Khan et al (1997a, 1997b) and other authors have found that grasses are an important factor that affects stemborer distribution, details such as grass stages was ignored, further more, other vegetation components such as cultivations, forests are never mentioned. Besides, many of the above mentioned experiments were laboratory work or cage experiment rather than field investigation, they were using individual grass species rather than put many species together, thus the interaction between grasses were not concerned. The interaction between grasses and other vegetation components was never concerned. We assume that the spatial distribution pattern of maize, i.e., adjacency or not, aggregated or not, is a very important factor that influences the movement and abundance of stemborers and their parasitoids. In this study, we focused only on vegetation, such as the distribution of maize fields, grasses, trees and growth stages of maize and grasses. We analyzed the impact of vegetation in/surrounding the maize on the abundance of stemborers and their larval parasitism.

Methods and materials

Field studies to characterize vegetation at sites where major stemborers and their natural enemies were investigated in Kwale and Kilifi districts, Coast Province of Kenya, were conducted in 30 sites in later October of 1998 during the short rains season of 1998/99 and at early whorl stage of maize. In every site, vegetation within 200m of the four sides surrounding experimental fields was studied to identify grass species composition and to determine the frequency and coverage of grass species within each distribution. Along with the 200m transect of each sampling site, the vegetation cover type, i.e., forest, shrub, cultivations, etc. (see Appendix A), was identified. At each vegetation type, several additional quadrates were used to quantify the frequency of each grass species and coverage of grasses and shrubs. For grasses, a 10 by 10 quadrate with grid size of 10cmx10cm was used, and for shrubs, a 5 by 5 quadrate with grid size of 20cmx20cm was used for quantifying the frequencies and percentage of coverage. The total number of grids within the quadrate ~~e~~ showing presence of a certain species was counted to give the frequency of that species. The distance (m) covered by each vegetation category on each transect was determined.

The second vegetation survey was done in late May of 1999 during the long rains season and this was also at early whorl stage of maize. In addition to Kwale and Kilifi districts, this field survey includes also Taita-Tevata area, which is an inland area of Coast Province. A total number of 36 sites were sampled and these sample sites may be the same as or different from the previous survey. This survey was also using four sides transect method and a transect length of 500m. Some new parameters were added in addition to the parameters used in 1998, the maize stage if the surrounding vegetation type is maize, the stage of grasses that surrounded the maize field, and the frequency and percent coverage of forest that surrounded the maize field.

Stemborers and their parasitoids were surveyed several times during each season following the methods described in Overholt et al (1994b). In 1998, the survey was started in early October and lasted to December, and has (was) repeated 3-4 times in each site. In 1999, field survey was started in early June and lasted to late August, and has (was) repeated 3 times. At each sampling site, eight parameters were measured; the density of the total stemborer complex, the density (and extent) of the 3 ~~extent~~ stemborer species (*C. partellus*, *C. orichalcociliellus*

(Strand), and *Sesamia calamistis* (Hampson)), proportion of maize plants infested by stemborers, total parasitism of stemborers, and parasitism of stemborers by two major larval parasitoids species, i.e., *C. flavipes* and *C. sesamiae* (Cameron). All of the parameters were calculated as a seasonal average measurement.

Results and discussion

Maize fields

Two measurements were made for each maize field; the number of sides (denoted by NoS) around the experiment maize field that contained maize, and the total number of maize fields (denoted by NoM) within 200m around the experimental maize field. The range of NoS is from 0 to 4, but the range of NoM is unknown. NoM was greater than or equal to NoS.

The effect of adjacent maize fields on stemborer occurrences and their parasitism were different between the short rains season and the long rains season (Table 1). During both sampling seasons, the number of maize field that surrounded the experimental field has a significant positive effect on stemborer infestation rate and total stemborer density. The more the maize fields, the higher the infestation rate, and the higher the stemborer density. If we look at specific species of stemborers, the effect of NoS on stemborer densities is quite complex (Table 1). The effect of NoS on stemborer densities of *C. partellus* was significant during both sampling seasons, and the more the maize fields the higher the *C. partellus* density but the lower the *S. calamistis* and *C. orichalcociliellus* density, this effect on densities of *S. calamistis* and *C. orichalcociliellus* has observed in only one season (Table 1). The effect of NoS on stemborers occurrence is high especially during the long rains season, it was about 16% increase of stemborer infestation rate, but doubled the total stemborer density and tripled *C. partellus* density when there was more than one side contained maize fields around the experimental field.

The effect of NoS on stemborer parasitism is significant in both short rain season and long rain season (Table 1), but there is also something interesting. The total stemborer parasitism, parasitism by *C. flavipes* and parasitism by C. sesamiae appear inverse result in the two seasons, i.e., both show the more the maize fields the higher the parasitism in the short rains season, but more maize fields corresponding to lower parasitism during long rain season. This result may be explained by other unknown factors such as climatic factors, etc.

NoM has the similar effect on stemborers abundances and their larval parasitism as NoS did.

Maize stage

The maize stage or age affects the stemborer occurrences and their parasitism in our experimental field, too (Table 2). If we divide the maize stage into three types, i.e., younger than, the same stage as, and older than the maize stage that in the experimental field, we find that if there was more same age maize around the experimental field, then the stemborer infestation rate and the stemborer density in the experimental field were the lowest among the three types

(Table 2). If there were old maize fields around the experimental field, then both infestation rate and total stemborer density will be the highest. The above result was also true for the density of *C. partellus*, but not for both densities of *C. orichalcociliellus* and *S. calamistis* (Table 2). This ~~is~~ may be because ~~of~~ when maize of the same age surrounded the experimental field, all the fields were equally attractive, thus makeing stemborers more evenly distributed. ~~more evenly.~~ When older maize surrounded the field, the stemborers congregated in the young maize in the experimental plants. Our data suggests that *C. orichalcociliellus* and *S. calamistis* may prefer old maize more than young maize. The highest stemborer parasitism by *C. sesamiae* was when there was younger maize around the experimental field suggesting that *C. sesamiae* was more attracted by old maize then young maize (Table 2). In contrast, when there was old maize around the experimental field, the field has the highest parasitism by *C. flavipes,* and we can say that maize stage strongly affects *C. flavipes* performances.

Grasses around maize field

There were 34 species of grasses found in the 1998 field survey, among them, 12 species are considered during data analysis (see appendix B) according to two criteria, 1) ~~affects~~ (effects) on stemborers occurrence or/and their parasitoids, 2) abundances, i.e., coverage and frequency of occurrence, any grass species will be ignored if its frequency of occurrence less than 1%. For analyzing the effect of grasses on stemborer occurrences, we measured the number of sides (denoted by NoG) where any of the 12 grass species occurred around the experimental field, the mean percentage of grass coverage of the four sides around the experimental field, the stage of grasses, i.e., old grass, young grass, and others, and the mean coverage of each species. The value of NoG is range from 0, i.e., no grass, to 4, i.e., with grasses on all of the four sides.

The occurrences of grasses strongly affected the occurrence of stemborers and the performance of their parasitoids (Table 3). With more grasses around the experimental field, the chances that maize was infested by stemborers is significantly higher than when where were no grasses around any side, this was true for both long rains season and short rains season. The more sides with grasses the higher the stemborer densities. The grasses around the experimental field significantly reduced both total stemborer parasitism and the parasitism by *C. flavipes* (Table 3). When there were more than two sides of the experimental maize field with grasses, parasitism by *C. flavipes* was only about one-third of the parasitism when there was no grass or at most one side with grass. The occurrences of grasses had no significant effect on the performances *C. sesamiae*, but it may slightly reduce the abundance of *S. calamistis* in the maize field.

The mean coverage of grasses had a similar effect as number of sides with grasses on stemborer parasitism (Table 4). High coverage of grasses strongly reduced stemborer parasitism by *C. flavipes*, which implies that grasses may be an obstacle which influences the movement of *C. flavipes*. High grass coverage raised the infestation rate by some 20% and stemborer density during the long rains season (Table 4). The grass coverage had no significant effect on *C. orichalcociliellus* or *S. calamistis* abundance. In the long rains season, *C. partellus* doubled its density when there are more grasses around maize field (Table 4), this implies that *C. partellus* may move from the grasses into maize field.

The grass stage had little effect on stemborer occurrence (Table 5). Old grasses may increase the maize infestation rate and stemborer density, but the effect was not significant. The only significant effect of grass stage was on stemborer parasitism by *C. sesamiae* and by *C. flavipes*. The old grasses significantly reduced stemborer parasitism by *C. sesamiae* and *C. flavipes*.

Forest around maize field

In both the long rains season and the short rains season, forest around the experimental maize fields decreased stemborer infestation rate and stemboer density in the maize field (Table 6). Moreover, forest occurrence significantly increased stemborer parasitism during the short rains season (Table 6). In the long rains season of 1999, the maize infestation rate by stemborer was 20% higher in the non-forest protected maize fields than that in the forest protected fields. If the maize field was surrounded by closed forest, the stemborer infestation rate was reduced some 30% compared to the non-forest surrounded fields, stemborer density can be reduced more than 50% (Table 6). However, the forest may increase the density of *C. orichalcociliellus* in maize fields, and the closed forest can also reduce the performance of parasitoids. Forest that around maize field has no significant effect on the performance of *C. sesamiae*. The effect of forest on stemborers occurrences and their parasitism can be easily explained by the effect of grasses. In our case or in most part of coastal Kenya, people are living inside the bushes or grassland, the vegetation ~~that~~ surrounding the maize field is either grasses or forests, thus, no forest around maize field means more grasses around the maize field. As we have seen, grasses were something like a tunnel to stemborers but an obstacle to larvae parasitoids, they encourage~~ing~~ stemborers to move to maize field but block the parasitoids.

Grass species

As Khan et al. (1997a, 1997b) and other ecologists have suggested, some grasses may favor stemborers while others decrease stemborer abundance. It is true and even more than that in our study (Table 7). As we can see in table 7, some grasses have negative effect on stemborer abundance and others may have positive effect on stemborer abundance, and this negative/positive effect may only act on specific stemborer species, e.g., *E. haploclada* had negative effect on *C. parterllus* density, while *H. nyassae* had positive effect on *C. partellus* density (Table 8). Grasses may have negative or positive effects on stemborer parasitism, and this may also only act on specific parasitoid species, e.g., *H. nyassae* had a negative effect on stemborer parasitism by *C. sesamiae*, and *H. rufa* had a positive effect on stemborer parasitism by *C. sesamiae* (Table 8). The effect of grasses on stemborer abundance and their parasitism may occur together, e.g., *P. maximum* had a negative effect on both *S. calamistis* density and stemborer parasitism by *C. sesamiae*.

The effect of grasses on stemborer abundances and their parasitism can be classified as four functional groups (Fig. 1, Table 8) according to the regression coefficients in table 7 and other multiple regression analysis. One cluster contains three grass species, *E. haploclada*, *S. verticilliflorum*, and *H. rufa*, they can reduce stemborers abundance in the maize field. Another cluster can decrease stemborer parasitism while encouraging stemborers move into the maize fields, this cluster consists of grass species of *E. pyramidalis*, *H. nyassae*, *S. aethipicum*, *P. maximum*, and *S. arundinaceum*, and NoG. The third group includes *P. purpureum*, *H. dissolula*, *R. exaltata*, and NoS, this group has positive effect on both stemborers abundance and their parasitism, especially, grass species *R. exaltata* has strong positive effect on stemborer parasitism by *C. flavipes*. Other grass species has little effect on both stemborer abundances and their parasitism.

Our result here supports some laboratory studies such as Ngi-Song et al (1995), Potting (1995), and Shanower et al (1993), but it is different from other studies. Mbapila (1996) suggested *S. arundinaceum* was the most preferred alternate wild host grass species of stemborers at the Kenya coast, but we found that this grass has almost no effect on stemborer occurrences besides it appeared only in few sampling sites during our survey. Songa (1999) found that most *S. calamistis* was recovered from *P. maximum* and both *P. purpureum* and *P. maximum* attracted *C. partellus* very much in eastern Kenya, but we did not find the effect of *P. purpureum* on *C. partellus* in coast area. These differences can be caused by two related reasons. In laboratory or cage experiment, no interaction was considered only one grass species was used. In our field trails, some grasses can live together and they may influence~~s~~ each other and this in turn affects the stemborers occurrence and their parasitism. Another related factor is the composition of grasses species. Different composition of grasses species have different effects on stemborer occurrences and the performance of their parastoids, e.g., combination of *P. maximum* and *E. pyramidalis* will exert a great positive effect on the abundance of *C. partellus*, but we can not guess the resultant effect of combination of *E. haploclada* and *P. maximum* (Table 8) on stemborer abundance.

Regional differences

The regional differences of vegetation, stemborer abundances, and stemborer parasitism are also significant (Table 9), especially in the long rains season of 1999. Table 9 shows clearly that there were more grass, i.e., great number of NoG and grass coverage, in Kwale district than that in both Kilifi district and Taita-Tevata area, but more forest and more maize fields surrounding the experimental fields in Kilifi district than that in Kwale district and less forest and maize fields in Taita-Tevata area than that in Kwale district. The seasonal differences are also significant (Table 9). These make it difficult to determine the factors that driving the regional differences. To eliminate the seasonal effect, we divide all the measurements by the maximum value and calculate all the relative measurements, and then calculate the correlation coefficients between relative stemborer abundances, relative stemborer parasitism, and relative vegetation measurements (Table 10). Table 10 shows the factors ~~that~~ driving the regional differences of stemborer abundances and their parasitism.

From the correlation coefficients (Table 10), we find that forest can significantly reduce *C. partellus* density but increase *C. orichalcociliellus* density. Maize field can not only reduce *C. partellus* density and increase *C. orichalcociliellus* density, but also increase stemborer parasitism by *C. sesamiae* and *C. flavipes*. Grasses can increase maize infestation rate by stemborers and can also significantly reduce stemborer parasitism especially parasitism by *C. flavipes*. None of the factors affects the abundance of *S. calamistis*.

In Taita-Tevata area, there was not many forest and not many maize fields, these may encourage *C. partellus* stays in the experimental maize fields, and grasses was not abundant there, thus it does not affect the performances of *C. flavipes*, the result is clear, i.e., more stemborers and more larval parasitoids. On the other hand, there were a lot of forests and a lot of maize fields in Kilifi district, but grasses were a little there, this could lead to lower stemborer densities and higher stemborer larval parasitism. Finally, there were more maize fields in Kwale district compare to Taita-Tevata area, but there was few forests and very abundant grasses in this district, the vegetation condition is really good for stemborers staying there but it is not suitable for *C. flavipes* to stay, i.e., high stemborer density but lower stemborer larval parasitism.

As we have seen in table 1 and other tables, there was a large seasonal difference of the parameters, i.e., infestation rate, densities, etc., between short rains season and long rains season. Most of our measurements on stemborer abundances and their parasitism have greater values in the long rains season than that in the short rains season, e.g., infestation rate was 79% in the long rains season and 59% in the short rains season, *C. partellus* density was 4.69 larvae per plant in the long rains season and 2.65 larvae per plant in the short rains season. This difference may be explained by both the vegetation changes and climatic differences between the two seasons. As we have seen in table 4, the grasses growing better or there was more grasses growing in the long rains season than that in the short rain season, since we have 18 out of the 30 sampling sites (60% of total sampling sites) with grass coverage less than 10% in the short rains season but there was only about 33% of the sampling sites with grass coverage less than 10% in the long rains season, this is an important factor that affects both stemborer abundances and their parasitism. The climate is may be another important factor that limits the stemborer occurrences and their parasitism, but this needs further study

When we look at the effect of grass species on stemborers occurrence and parasitism, we find that total stemborer density and *C. partellus* density go together, either both positively or both negatively affected by the same species. This is possibly the only combination between total stemborer density and *C. partellus* density, since *C. partellus* is the most abundance stemborer species in coastal Kenya (proportion to total stemborer was 62% in 1998 and 73% in 1999), thus if any factor that strongly affects the abundance of *C. partellus*, whatever positive or negative, this effect can be easily reflected from the abundance of total stemborers density. Thus any positive or negative effect of grass species on total stemborer abundance may not imply that this effect is working on all stemborer species, this is especially not the case to *C. orichalcociliellus* and S. calamistis. In fact, grasses affect on *C. partellus* and *C. orichalcociliellus*/*S. calamistis* go in the opposite directions for many grass species, if one is positive then another one may be negative and vis-à-vis (Table 8). This niche difference can explain partly why *C. orichalcociliellus* did not go extinction after the over-competitor, *C. partellus*, came to Africa continent some 60 years, although they are so similar in many biological and ecological aspects.

Our study on the relationship between grasses abundances and stemborer occurrences suggests that there could be varietal differences in suitability for stemborer development among various varieties of specific grass species. It would therefore be useful to evaluate the suitability of wild host for oviposition and development of specific stemborer species, this can be used in the development of the habitat management programme for controlling stemborers.

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Appendix A. Categories of vegetation types

Forest

Scrub

Scrub savanna

Dwarf scrub

Tall savanna

Low savanna

Tall grass

Short grass

Cultivations (Maize/non-maize)

Open dwarf scrub with closed groundcover

Open forest with closed lower layers

Closed scrub with scattered trees

Dwarf scrub with scattered trees

Open scrub with closed ground cover

Broad-lived herb vegetation

Bare ground/Path/Road

Fallow

Appendix B. Names of the 12 grass species

Echinochloa haploclada (Stapf) Stapf

Echinochloa pyramidalis (Lam.) Hitchc. & Chase

Hyparrhenia nyassae (Rendle) Stapf

Hyparrhenia rufa (Nees) Stapf

Hyparrhenia dissolula (Nees ex Steud) C. E. Hubbard

Panicum maximum Jacq

Pennisetum polystachyon (L.) Schult.

Pennisetum purpureum Schumach

Rottboellia exaltata L.f.

Sorghum aethiopicum Rupr. *Ex* Stapf

Sorghum arundinaceum (Steud) Stapf

Sorghum verticilliflorum (Steud) Stapf

Table 1. The effect of maize field on stemborer occurrence and their parasitism

Parameters	1998*		1999*	
	NoS=0-1 (n=11)	NoS=2-4 (n=19)	NoS=0-1 (n=11)	NoS=2-4 (n=25)
Infestation rate	55.23	61.13**	67.46	83.57***
Density of stemborer complex	2.35	2.83**	2.81	5.32***
Density of Cp*	1.27	1.85**	1.30	4.11***
Density of Co*	0.52	0.51	0.48	0.27**
Density of Sc*	0.35	0.19**	0.59	0.45
Total stemborer parasitism	4.04	8.09**	14.13	8.63**
Parasitism by Cs*	0.79	1.76**	2.75	1.42**
Parasitism by Cf*	1.69	5.13**	10.61	5.87**

* Cp represents C. partellus, Co represents C. orichalcociliellus, Sc represents S. calamistis, Cs represents C. sesamiae, Cf represents C. flavipes, these are also suitable in the other tables. NoS represents number of sides around our experimental maize field that contains maize field

** Exceeds 90% significant level

*** Exceeds 95% significant level

Table 2. The effect of maize stage on stemborer occurrence and their parasitism (1999 only)

Parameters	Maize stage			t-test*
	Young (n=19)	Same stage (n=8)	Old (n=8)	Y-S/Y-O/S-O
Infestation rate	77.83	74.76	86.45	- / ** / **
Density of stemborer complex	4.96	4.01	5.90	- / - / ***
Density of Cp	3.57	2.65	4.80	- / - / ***
Density of Co	0.43	0.42	0.28	- / *** / ***
Density of Sc	0.42	0.50	0.31	- / ** / ***
Total stemborer parasitism	6.20	7.03	8.04	- / ** / -
Parasitism by Cs	3.21	2.02	1.35	- / *** / -
Parasitism by Cf	1.11	3.42	5.64	*** / ** / ***

* Y represents young maize, S represent same age maize, O represents old maize, and Y-S represents comparison was made between measurements in young maize and same age maize, similar mean to Y-O and S-O.

** Represents that the difference is significant at 90% level

*** Exceeds 95% significant level

Table 3. The effect of grasses occurrence on stemborer abundance and their parasitism

Parameters	1998*		1999*	
	NoG=0-1 (n=14)	NoG=2-4 (n=15)	NoG=0-1 (n=15)	NoG=2-4 (n=21)
Infestation rate	55.07	64.17**	74.50	87.46**
Density of stemborer complex	2.34	3.08**	4.09	5.63**
Density of Cp	1.39	2.00**	2.84	4.30***
Density of Co	0.48	0.53	0.25	0.43***
Density of Sc	0.25	0.27	0.59	0.33***
Total stemborer parasitism	7.95	4.60**	11.42	7.34**
Parasitism by Cs	1.53	1.12	1.51	2.14
Parasitism by Cf	5.39	2.03***	9.37	3.40***

* NoG represents number of sides around our experimental maize field that contains any of the 11 listed grass species

** Exceeds 90% significant level

*** Exceeds 95% significant level

Table 4. The effect of grasses coverage on stemborer occurrences and their parasitism

Parameters	1998*		1999*	
	GC<35% (n=18)	GC>35% (n=12)	GC<35% (n=12)	GC>35% (n=24)
Infestation rate	58.44	59.75	69.16	88.82***
Density of stemborer complex	2.63	2.68	3.30	5.93***
Density of Cp*	1.65	1.62	2.03	4.64***
Density of Co*	0.48	0.58**	0.31	0.33
Density of Sc*	0.24	0.27	0.57	0.41
Total stemborer parasitism	8.43	3.86***	14.18	6.28***
Parasitism by Cs*	1.51	1.24	1.99	1.55
Parasitism by Cf*	5.64	1.21***	11.59	2.98***

* GC represents the percentage of grass coverage

** Exceeds 90% significant level

*** Exceeds 95% significant level

Table 5. The effect of grass stage on stemborer occurrence and their parasitism (1999 only)

Parameters	Grass stage			t-test*
	Young (n=8)	Old (n=20)	Other (n=8)	Y-OL/Y-OT/OL-OT
Infestation rate	78.91	83.75	69.64	- / ** / **
Density of stemborer complex	4.46	4.88	4.44	- / - / -
Density of Cp	3.10	3.69	3.01	-/-/-
Density of Co	0.39	0.32	0.25	- / ** / **
Density of Sc	0.51	0.39	0.71	- / ** / ***
Total stemborer parasitism	10.46	8.94	12.22	- / - / **
Parasitism by Cs	3.02	1.65	0.75	** / *** / **
Parasitism by Cf	6.83	5.63	10.83	- / ** / ***

* Y stands for young grass, OL stands for old grass, OT stands for others, and Y-OL represents that the comparison is made between measurements of young grass and of old grass, the similar meaning to Y-OT and OL-OT

** Exceeds 90% significant level

*** Exceeds 95% significant level

Table 6. The effect of forest on stemborer occurrences and their parasitism

Parameters	1998 *		1999*		
	NoF=0 (n=17)	NoF=1 (n=13)	NoF=0 (n=21)	NoF=1 (n=15)	CF=1 (n=7)
Infestation rate	60.86	57.52	87.18	68.84***	60.11***
Density of stemborer complex	3.01	2.38**	5.71	3.26***	2.75***
Density of Cp	1.96	1.39**	4.46	1.93***	1.54**
Density of Co	0.42	0.67**	0.24	0.43**	0.42**
Density of Sc	0.35	0.16***	0.49	0.49	0.54
Total stemborer parasitism	4.81	8.28**	9.70	10.44	5.61***
Parasitism by Cs	1.20	1.72	1.56	2.04	1.47
Parasitism by Cf	2.83	5.42**	7.12	6.96	3.02***

* NoF=0 represents that no forest around our experimental maize field, NoF=1 represents that there is forest around the experimental field, and CF=1 represents that the forest around the experimental field is a closed forest

** Exceeds 90% significant level

*** Exceeds 95% significant level

Table 7. Regression coefficients between stemborer abundance, parasitism and abundances of grasses

a. 1998

Grass species	Infestation rate	Stemborer density	Density of Cp	Density of Co	Density of Sc	Total parasitism	Parasitism by Cs	Parasitism by Cf
E. haplolada	-3.18	-	-	-	-	-	-	-
E. pyramidalis	25.01	2.10	-	0.82	-	-	-	-
H. nyassae	3.92	-	-	-	-	-	-0.84	-
H. dissolula	-	-	-	-	-	-	-	-
H. rufa	1.31	-	-	-	-	-	0.28	-
P. maximum	0.22	0.01	0.01	-	-	-	-	-
P. polystachyon	-	-	-	-	-	-	-	-
P. purpureum	-	-	-	-	-	-	-	-
R. exaltata	0.10	-	-	-	-	0.07	-	0.07
S. aethiopicum	-3.55	-	-	-	-	-0.70	-	-
S. verticilliflorum	-	-	-	-	-	-	-	-
S. aru	-	-	-	-	-	-	-0.23	-
NoS	5.64	0.48	0.41	-	-0.04	2.25	0.50	1.77
NoG	-	-	-	0.05	-	-1.83	-	-1.28
R**	0.70	0.56	0.46	0.62	0.45	0.59	0.52	0.57
p-value**	0.06	0.04	0.10	<0.01	0.01	0.02	0.08	0.01

Table 7. (cont.)

b. 1999

Grass species	Infestation rate	Stemborer density	Density of Cp	Density of Co	Density of Sc	Total parasitism	Parasitism by Cs	Parasitism by Cf
E. haploclada	-	-0.63	-0.62	-	0.11	-	-	-
E. pyramidalis	4.37	0.56	-	-	-	-	-	-
H. nyassae	1.19	0.35	0.35	-	-	-	-	-
H. dissolula	-	-	-	0.02	-	-	-	-
H. rufa	-	-0.29	-0.36	-	-	-1.09	-	-
P. maximum	0.43	0.21	0.22	-	-0.01*	-	-0.14	-
P. polystachyon	-	-	-	-	-	-	-	-
P. purpureum	-	-	-	0.08	-	3.26	-	-
R. exaltata	-	-	-	-	-	-	-	1.66
S. aethiopicum	-	0.17	0.16	0.02	-	-	-	-
S. verticilliflorum	-	-1.82	-2.09	0.19	-	-	-	-
S. arundinaceum	-	-	-	-	-	-0.12	-	-
NoS	-	0.31	0.51	0.08	-	-	-0.70	-3.22
NoG	0.44	-	-	-	-	-	-1.59	-3.42
R**	0.61	0.66	0.66	0.72	0.34	0.46	0.65	0.55
p-value**	<0.01	0.02	0.01	<0.01	0.13	<0.01	<0.01	0.04

* Not exceed 90% enter level

** R represents the correlation coefficient of the regression analysis, p-value is the significant level of the regression analysis

Table 8. The impact of grasses and maize fields on stemborers occurrences and the performance of their parasitoids

Vegetation variables	Infestation rate**	Stemborer density	Density of *C. partellus*	Density of *C. orichalcociliellus*	Density of *S. calamistis*	Stemborer parasitism	Parasitism by *C. sesamiae*	Parasitism by *C. flavipes*
E.haploclada	--	-	---	+	++			
S. verticilliflorum		--	--	+	-			
H. rufa	+	--	--			--	++	
E. pyramidalis	++++	+++		++				
H. nyassae	++	++	++		-		--	
S. aethiopicum		+	+	+		--		
P. maximum	+	+++	+++		-		--	
S. arundinaceum	+					--	-	-
NoG*	+			+		-	-	--
NoS*	+	++	++	+	-	+		
P. purpureum				+++		++		
H. dissolula				++		+		
R. exaltata	+				-	++		+++
P. polystachyon					+			

* NoS represents number of sides with maize fields around the experimental field, and NoG represents number of sides with grasses around the experimental field

** Positive sign '+' means a positive effect and negative sign '-' means negative effect. Scores were calculated from step-wise multiple regression analysis. Firstly, only grasses were used as independent variables, if any grasses species entered into the model then gave it one credit '+/-'; secondly, NoS and NoG were added as independent variables, then redo the step-wise selection. Thereby, for grasses species it may get scores of two, for two seasons, the maximum score is four. For NoS and NoG, the maximum score is two.

Table 9. The regional differences of vegetation, stemborer occurrence and their parasitism

a. 1998

Parameters	Kwale (n=15)	Kilifi (n=15)	t-test
Infestation rate	60.23	57.7	-
Density of stemborer complex	2.85	2.46	-
Density of Cp	1.83	1.44	-
Density of Co	0.40	0.63	**
Density of Sc	0.35	0.16	***
Total stemborer parasitism	4.67	8.53	**
Parasitism by Cs	1.21	1.61	-
Parasitism by Cf	1.89	5.84	**
Forest	6.67	73.33	***
NoS	1.40	2.53	**
NoM	2.07	3.80	***
NoG	2.07	1.20	**
Grass coverage	49.89	33.14	***

a. 1999

Parameters	Kwale (n=14)	Kilifi (n=12)	Taita-Taveta (n=10)	t-test[(a)] Kw-Ki / Kw-Ta / Ki-Ta
Infestation rate	89.11	64.46	84.23	*** / - / **
Density of stemborer complex	5.82	2.73	5.44	*** / - / ***
Density of Cp	4.49	1.29	4.43	*** / - / ***
Density of Co	0.38	0.43	0.08	** / *** / ***
Density of Sc	0.41	0.67	0.38	*** / - / ***
Total stemborer parasitism	5.59	12.65	13.02	*** / *** / -
Parasitism by Cs	2.02	2.62	0.35	** / *** / ***
Parasitism by Cf	1.77	9.62	11.36	*** / *** / **
Forest [(b)]	35.71	66.67	20.00	*** / - / ***
NoS	2.71	3.42	1.30	** / *** / ***
NoM	4.80	5.50	1.90	- / *** / ***
NoG	2.43	0.83	0.20	*** / *** / -
Grass coverage	69.31	41.66	49.78	*** / *** / -

[(a)] Kw stands for Kwale district, Ki stands for Kilifi district, Ta stands for Taita-Taveta area, and Kw-Ki represents that the comparison is made between measurements of Kwale and Kilifi, the similar meaning to Kw-Ta and Ki-Ta

[b] Forest represents the proportion of the experimental fields that surrounding by forest at least on side

* Exceeds 90% significant level

** Exceeds 95% significant level

*** Exceeds 99% significant level

Table 10. Correlation coefficients between relative abundances of stemborer, their parasitism and relative abundances of vegetation (n=66)

Stemborer and parasitoid parameters	Forest	NoS*	NoM	NoG	Grass coverage
Infestation rate	-0.61**	-0.48**	-0.42**	0.54**	0.74**
Total stemborer density	-0.71**	-0.60**	-0.53**	0.48**	0.72**
Density of Cp	-0.75**	-0.68**	-0.62**	0.39**	0.66**
Density of Co	0.76**	0.96**	0.98**	0.39**	0.08
Density of Sc	-0.20	0.00	-0.02	0.20	0.08
Total stemborer parasitism	0.53**	0.17	0.06	-0.89**	-0.94**
Parasitism by Cs	0.66**	0.91**	0.90**	0.45**	0.13
Parasitism by Cf	0.48**	0.12	0.00	-0.88**	-0.91**

* For the definition of NoS, NoM and NoG refer to the text

** Exceeds 99% significant level