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Ground beetle assemblages (Coleoptera, Carabidae) and plant dwelling non-target arthropods in isogenic and transgenic corn crops

Abstract - This paper reports the results of a two-year field study aimed at a better understanding of the influence of transgenic corn on non target entomofauna, with particular emphasis on the community structure and biodiversity of a typical soil fauna like Coleoptera Carabidae. A comparison was made of ground beetle assemblage abundance, community structure and the degree of specific biodiversity in transgenic and conventional corn crops. A total of 3,768 individuals belonging to 42 species were collected from sowing to harvest time over a two year period. The Carabidae faunal composition and the individual species abundance varied more according to the spatial and temporal distribution rather than to the maize hybrid. Different indexes of biodiversity (Index of Shannon-Weaver H', Hill's numbers: N_0, N_1, D, N_2, N_{inf}, hierarchical richness index HRI, Index of Pielou J') and similarity (Sörensen's index QS) were applied to the data. Although there was little biodiversity in the Carabidae communities throughout the study period there was no effect due to the transgenic corn.

Consideration was also given to the effects of transgenic corn crops on plant dwelling non-target arthropods that normally live on corn plants; and other insects living in close contact with these or with the European Corn Borer (*Ostrinia nubilalis*), such as Hymenoptera parasitoids and Diptera Syrphidae. Statistical analyses revealed no significant differences in the abundance of plant dwelling non-target arthropods in conventional corn and transgenic corn.

Riassunto - *Coleotteri Carabidi e Artropodi non bersaglio in campi di mais convenzionale e transgenico.*

Si riportano i risultati di due anni di studio indirizzati a meglio comprendere l'influenza del mais transgenico sull'entomofauna non bersaglio, con particolare enfasi alla struttura e alla biodiversità delle comunità di Coleotteri Carabidi, quali tipica fauna edifica. Sono stati comparati la struttura di comunità e il grado di biodiversità specifica delle comunità rinvenute in campi di mais transgenico ed isogenico. Sono stati collezionati, dal periodo di semina a quello di raccolta per entrambi i due anni, 3768 carabidi, ascritti a 42 specie. La composizione in specie e l'abbondanza degli individui variava più in termini spaziali e temporali, che non per la presenza del mais transgenico.

Sono stati calcolati differenti indici di biodiversità (Indice di Shannon-Weaver H', Numeri di Hill: N_0, N_1, D, N_2, N_{inf}, Indice di ricchezza gerarchica HRI, Indice di Pielou J') e l'indice di somiglianza di Sörensen. La biodiversità rinvenuta era bassa, ma non si sono riscontrate differenze nei valori dovuti alla presenza di mais transgenico. Ulteriori studi sono stati fatti riguardo all'artropodofauna presente nel mais o che vive a spese di *Ostrinia nubilalis* quali Imenotteri parassitoidi e Ditteri Sirfidi. I risultati dell'analisi statistica non evidenziano differenze nell'abbondanza dei taxa rinvenuti nei campi di mais transgenico ed isogenico.

Key words: Transgenic corn, non target entomofauna, soil biodiversity, Carabidae, *Bacillus thuringiensis*.

INTRODUCTION

The European corn borer, *Ostrinia nubilalis* (Hübner) ranks among the most important pests of corn, *Zea mays* L., and is a key pest in the western world. Transgenic corn, expressing insecticidal proteins derived from *Bacillus thuringiensis* var. *kurstaki* Berliner, provides a new approach to the control of *O. nubilalis* (Koziel *et al.*, 1993). However there is concern that other non target organisms could be negatively affected by the toxins expressed in Bt corn. Results on this point are contrasting. Some authors (MacIntosh *et al.*, 1990, Sims 1995; Orr and Landis, 1997; Pilcher *et al.* 1997; Lozzia *et al.*, 1998) have reported that the Bt plants they used did not create problems for the tested insects, while other authors (Salama *et al.*, 1982; Flexner *et al.*, 1986; Hilbeck *et al.*, 1998, Hilbeck *et al.*, 1999) have detected some negative effects.

Crecchio and Stotzky (1998) reported that the Bt toxins introduced into transgenic plants and microbes tend to persist and accumulate, remaining insecticidal in soil, as a result of binding to humic acids, and in clays. This persistence could pose a hazard to non-target organisms and even enhance the selection of toxin-resistant target species (Tapp & Stotzky, 1998); however Sims and Holden (1996) have reported that the Cry 1Ab protein, a component of the post-harvest transgenic corn plant, dissipates readily on the soil surface. Recent interest has been shown in the characterization of soil biodiversity and the function of such diversity in agricultural crops (Bardgett and Cook, 1998). Both current understanding and regulatory approval of Bt-transgenic plants rest largely on laboratory ecological-effect studies on non target organisms (Nigh *et al.*, 2000). To better describe the ecological impact of Bt corn on natural insect maize communities a field approach is necessary. Investigations into soil biodiversity could highlight the effect, even of different trophic levels, of Bt toxins from transgenic plants.

The Coleoptera Carabidae families are a an outstanding component of soil fauna in almost every ecosystem in temperate climates. The potential use of ground beetle predators, a natural control agent, for crop pests is generally recognized (Ellsbury *et al.*, 1998). Although carabids cannot be directly linked to corn plants, different studies have demonstrated the effectiveness of this group in controlling corn parasites (Brust *et al.*, 1986; Rivard, 1966) and other crop parasites (Kabacik-Wasilik, 1971; Thiele, 1977). Some ground beetles dispersed into cereal fields have been known to eat cereal pests such as the bird cherry-oat aphid, *Rhopalosiphum padi* L. (Chiverton, 1987) while others are mainly phytophagous, although a considerable number exhibit an intermediate behavior, feeding on animal as well as vegetal matter. For these reasons such species are considered a particularly sensitive indicator taxa of land use, and their importance in the ecosystem is, without any doubt, fundamental, especially to describing trophic relationships and biodiversity in the soil (Thiele, 1977; Den Boer, 1979; Molinari and Pradaelli, 1995; Riversmoore and Samways, 1996).

Corn has several other common insect taxa that use the pollen, bolls and leaves as a food source, and also the plant itself as a substrate for oviposition (Coll & Bottrell, 1991). Many other organisms are linked to ECB as predators and parasitoids (Jarvils & Guthrie 1987). A major scientific goal is the use of transgenic corn crops to preserve the natural enemies of the European corn borer and, more in general, non target arthropods (Orr & Landis, 1997; Gould F, 1998; Hilbeck *et al.*, 1998; Lozzia *et al.* 1998).

Thus the research was carried out directly in the field in an effort to assess the influence of a transgenic corn crop on the composition and biodiversity of ground beetle assemblages, and any possible side-effects on non target arthropods.

MATERIALS AND METHODS

The sampling was done over a two year period, 1997-1998, from mid-May (sowing) to the end of September (harvest) in two North Italian agricultural regions located near Pavia and Treviso. Two 10 hectare experimental fields, subjected to the same cultivation practices, were selected in each region. One field was sown with transgenic corn hybrid Tempra (125 days rising), Bt 176 maize (Trade Mark Novartis) and the other with isogenic corn. The same fields were adopted throughout the experimental period, and all had been cornfields since 1994; the distance between the isogenic and transgenic corn fields was 1.5 Km. Each field was planted at a density of 95,000 plants per hectare, with an inter row spacing of 0.8 m. Neither fungicides nor insecticides were used. All the fields were treated with 7 lt/ha of herbicide (terbuthylazine + metolachlor + pendimethalin). The fertilizer and irrigation regimes were left unchanged. Each field was divided into 4 plots of 2.5 hectares. Sampling was done every fourteen days from sowing to harvest.

Ground beetle assemblages

Carabidae were collected by pitfall traps placed in the crops of transgenic corn and isogenic corn (Bt 176 maize is Trade Mark Novartis). Pitfall traps, though having some limits, have been demonstrated to be effective for monitoring Carabidae populations (Thiele, 1977; Den Boer, 1979, Niemelä *et al.*, 1990, Tonhasca, 1993; Ellsbury *et al.* 1998). Each pitfall trap, 10 cm^2 opening and 8 cm deep, was placed in the approximate center of each replicate. The traps were baited with vinegar containing

4% formaldehyde and were changed at each sampling. The insects collected were counted and identified at the species level. Nomenclature suggested by the checklist of Vigna Taglianti (1993) was used.

Plant dwelling non-target arthropods

The research was aimed at studying the overall effect of transgenic corn on the presence of natural enemies and arthropods in the field, rather than at a specific sampling for natural enemies of *O. nubilalis*. The monitoring was performed by a motorized blower-vac aspirator (D-VAC, Kawasaki), Malaise traps (type Townes, 1972) and visual checking.

Malaise traps, used to monitor the different taxa of the flying insects, were placed at the beginning of July in the middle of the transgenic and conventional corn crops, in a square plot of 10 m^2 for each replicate. Two minute aspirations were done for each replicate. The arthropods collected were counted and identified to Order or Family level. Particular attention was paid to potentially harmful arthropods, such as aphids and Cicadellidae, and to those beneficial, such as spiders, Coccinellidae, Hymenoptera parasitoids and Diptera Syrphidae. A visual check was made in order to verify that no species had escaped being caught during the sampling by the various methods. Ten corn plants, randomly selected for each replicate of both conventional and transgenic corn were checked visually.

Data analysis

An analysis of the data of the Carabidae collections was carried out using biodiversity indices: the Shannon-Weaver (1949) index $H' = -\Sigma\, pi \text{ Log } pi$ where pi = is the proportion of the *i*th species among the total collected; the numbers of Hill (1979): No: number of species, $N_1 = \exp(H' \text{x} \ln_2)$ where H' = index of Shannon-Weaver, $N_2 = 1/\Sigma\,(pi)^2$, $N_{inf} = 1/P$ max where P max = absolute frequency of the most representative species, index of equitability of Pielou (1966) J' = H'/Log No. The hierarchical richness index (HRI = $\Sigma\, s_i$ x i where i is species ranked by abundance and s_i, is abundance of the *i*th species), a measure of diversity accounting for both species richness and abundance in a sample from a community (French, 1994), was also calculated.

The affinity of the carabid communities associated with the two types of maize hybrid was compared with the Sörensen similarity index QS = 2C x 100/(A+B), where A and B are the numbers of species respectively found in environments A and B, while C is the number of species common to both biotypes.

Cumulative percentage curves were also constructed to envisage the richness (evenness) of the different fields and to compare their biodiversity; the curves highlight the distribution of the individuals of each Carabidae species in the different communities.

To analyze the total number of ground beetles and the number of dominant species collected, general linear model procedures (ANOVA) were applied with regard to the corn hybrids themselves (isogenic and transgenic), the locality (Pavia, Treviso) and the years (1997-1998). The Carabid data were transformed to log (X+1) before analysis. As the data of up-welling arthropods were highly skewed Kruskal-Wallis one way analysis was used.

RESULTS AND DISCUSSIONS

During the two-year study 3,768 specimens were collected: 2,423 Carabidae were found in the transgenic corn crops while 1,345 ground beetles were caught in the isogenic ones. Although numerically the number of captures was quite different, statistically there was no difference considering the total number of carabids and the hybrid type ($F = 0.4$, $df = 1, 126$ $P>0.05$), the locality ($F = 0.6$; $df = 1, 61$, $P> 0.05$) and the years ($F = 0.4$; $df = 1, 65$, $P> 0.05$). Table 1 shows the number of carabids found in each field for the dominant species. In 1997 the total number of carabids collected in Pavia was 416 for the isogenic corn crop and 1,335 for the transgenic, while in Treviso the isogenic corn was recorded as having 179 ground beetles and the other

Table 1 - Number of Carabidae, for the most abundant species, collected from pitfall traps in cornfield sampled.

Treviso	1997	1997	1998	1998
	Isogenic	Transgenic	Isogenic	Transgenic
Platysma melanarium Illiger	72	272	13	3
Pseudophonus rufipes Degeer	73	136	5	30
Steropus melas Creutzer	1	10	6	1
Other species	33	39	5	9
Total	179	457	29	43
Pavia				
Amara aenea Deg.	42	3	1	0
Anisodactylus signatus Panz.	2	21	1	1
Bembidion quadrimaculatum L.	9	2	168	156
Carabus granulatus interstitalis Dft.	5	119	15	14
Chlaeniellus nitidulus Schrank	0	2	13	2
Cylindera germanica L.	1	11	0	0
Harpalus distinguensis Dft.	17	8	0	0
Poecilus cupreus L.	5	384	406	170
Pseudophonus griseus Panzer	66	49	91	220
Pseudophonus rufipes Degeer	239	699	2	14
Other species	30	37	24	11
Total	416	1335	721	588

hybrid corn crop 457. During 1998, 721 carabids were collected in the isogenic corn crop and 588 in the transgenic one in Pavia, while in Treviso the caches were lower, 29 carabids from the isogenic corn crop and 43 from the transgenic one. The number of carabids found in the transgenic corn crops was higher than in the isogenic corn, except for one case in Treviso in 1998. Carabidae were more abundant in Pavia than in Treviso. In 1997 the total number of carabids caught was 2,387, in 1998 it was only 1,381.

Overall six dominant Carabidae species were found (figure 1): *Pseudophonus rufipes* Degeer, *Poecilus cupreus* L., *Pseudophonus griseus* Panzer, *Platysma melanarium* Illiger, *Bembidion quadrimaculatum* L., *Carabus granulatus interstitialis* Duftschmid. It appeared that *P. cuprus* (30.71%) dominates in the isogenic corn crop while *P. griseus* (29.44%) is the most abundant species in transgenic corn field . As shown in Table 2, the transgenic corn crop of Pavia in 1997 was dominated by the species *P. rufipes* (52.36%), *P. cupreus* (28.76%) and *C. granulatus interstitialis* (8.91%), *P. rufipes* (57.52%) also being dominant in the isogenic corn crop, followed by *P. griseus* (15.80%). *C. granulatus interstitialis* was almost always present only in the transgenic crop and *P. melanarium* predominated in the same hybrid corn crop. Instead *B. quadrimaculatum* and *P. rufipes* prevailed in the isogenic one. All these species have a principally zoophagous diet and are typical of cultivated fields.

It can also be seen in Table 2 that in 1997 the ground beetle assemblages of the transgenic and isogenic corn crops in Pavia had a very similar spectrum species. In

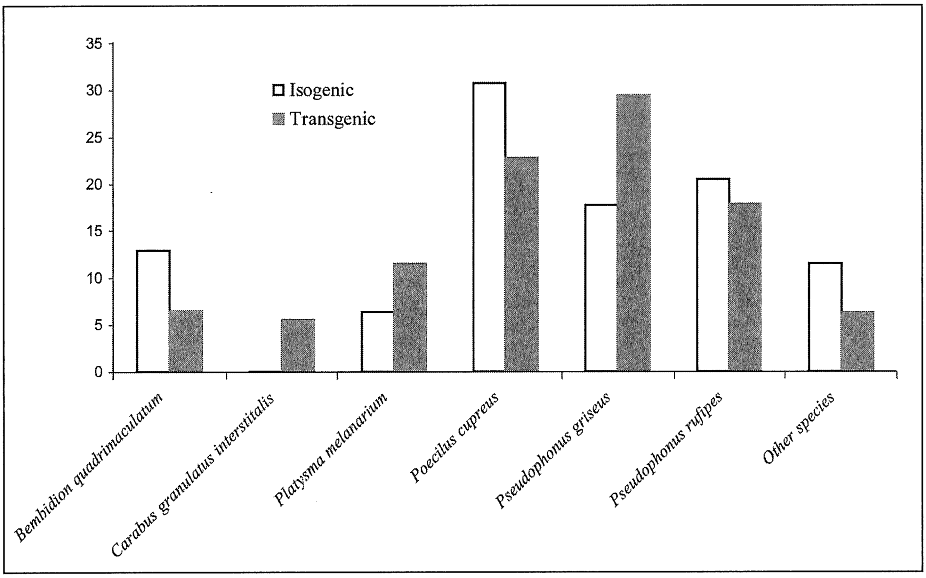

Fig. 1 - Carabidae collected from pitfall traps during 1997 and 1998 in isogenic and transgenic corn crops of Pavia and Treviso showing percentage of total.

Table 2 – Percentage of Carabidae species collected from pitfall traps.

Treviso	1997	1997	1998	1998
	Isogenic	Transgenic	Isogenic	Transgenic
Agonum moestum Dft.	0.56	0.00	3.45	0.00
Anchomenus dorsalis Dft.	1.12	0.44	0.00	0.00
Bembidion quadrimaculatum L.	0.56	0.88	0.00	4.65
Brachinus crepitans L.	0.56	0.00	0.00	0.00
Brachinus psophia Serv.	0.56	0.00	0.00	0.00
Calathus fuscipes Goeze	0.56	2.63	0.00	4.65
Calathus melanocephalus L.	0.56	0.00	0.00	0.00
Carabus germari Sturm	0.00	0.44	0.00	2.33
Chlaeniellus nitidulus Schrank	0.56	0.22	0.00	0.00
Clivina fossor L.	0.00	0.22	0.00	0.00
Cylimdera germanica L.	0.00	0.88	0.00	0.00
Harpalus affinis Dej.	2.23	0.00	0.00	0.00
Harpalus dimidiatus Rossi	2.79	0.22	0.00	0.00
Harpalus distinguendus Dft.	1.12	0.44	0.00	0.00
Harpalus oblitus Dej.	1.12	0.00	0.00	0.00
Microlestes corticalis Duf.	0.56	1.31	0.00	0.00
Microlestes minutulus Goeze	0.56	0.00	0.00	4.65
Ophonus azureus F.	0.00	0.00	0.00	2.33
Platysma melanarium Illiger	40.22	59.52	44.83	6.98
Platysma macrum Marsham	1.68	0.22	3.45	0.00
Poecilus cupreus L.	0.56	0.00	10.34	0.00
Pseudophonus griseus Panzer	0.00	0.22	0.00	0.00
Pseudophonus rufipes Degeer	40.78	29.76	17.24	69.77
Scyabalicus oblolongiscus L.	1.12	0.22	0.00	0.00
Steropus melas Creutzer	0.56	2.19	20.69	2.33
Trechus quadristriatus Schrank	1.68	0.22	0.00	2.33
Pavia				
Agonum moestum Dft.	0.00	0.00	0.42	0.00
Agonomum mulleri Dft.	0.00	0.37	0.00	0.00
Amara aenea Deg.	10.10	0.22	0.14	0.00
Amara familiaris Dft.	0.24	0.00	0.00	0.00
Amara nitida Sturm	2.16	0.00	0.00	0.17
Anchonomus dorsalis Dft.	1.44	0.22	0.00	0.00
Anisodactylus signatus Panz.	0.48	1.57	0.14	0.17

(Continued table 2)

Argutor vernalis Dft.	0.24	0.00	0.83	0.00
Bembidion quadrimaculatum L.	2.16	0.15	23.30	26.53
Brachinus ganglbaueri Apfbk.	0.00	0.15	0.00	0.00
Carabus granulatus interstitalis Dft.	1.20	8.91	2.08	2.38
Chlaeniellus nitidulus Schrank	0.00	0.15	1.80	0.34
Chlaenius spoliatus Rossi	0.00	0.07	0.00	0.00
Clivina fossor L.	0.00	0.15	1.11	0.34
Cylindera germanica L.	0.24	0.82	0.00	0.00
Dolichus halensis Shall	0.48	0.37	0.00	0.68
Elaphropus parvulus Dej.	0.00	0.00	0.14	0.00
Harpalus affinis Dej.	0.72	0.30	0.55	0.00
Harpalus dimidiatus Rossi	0.00	0.00	0.00	0.17
Harpalus distinguensis Dft.	4.09	0.60	0.00	0.00
Metallina properans (Steph.)	0.24	0.00	0.00	0.00
Microlestes corticalis Duf.	0.00	0.37	0.28	0.00
Microlestes minutulus Goeze	0.24	0.07	0.14	0.00
Phonias strenuus Panzer	0.00	0.00	0.14	0.17
Platynus assimile Paykull	0.00	0.00	0.14	0.00
Platysma melanarium Illiger	0.24	0.30	0.14	0.00
Platysma nigrum Schaller	0.00	0.07	0.14	0.51
Poecilus cupreus L.	1.20	28.76	56.31	28.91
Pseudophonus griseus Degeer	15.87	3.67	12.62	37.41
Pseudophonus rufipes Panzer	57.45	52.36	0.28	2.38
Stenolophus teutonus Dej.	1.20	0.30	0.14	0.17

1998 the specific spectrum, compared to that of 1997, was rather restricted, especially in the Treviso corn crop, this could have been due to a rather dry season (Table 3). The variation in rainfall could be one of the reasons for the different number of cara-

Table 3 - Average of rainfall from 15 June to 15 September (sampling period).

		Rainfall
1997	Pavia	105.3 mm
	Treviso	98.3 mm
1998	Pavia	83.4 mm
	Treviso	18.4 mm

Data Meteo from Bollettino Agrometereologico Nazionale bids collected, especially with regard to species belonging to the genus *Harpalus* and the abundance of *B. quadrimaculatum,* which prefers dry seasons. In 1998 only twelve species of Carabidae were collected in Treviso while in 1997 there were twenty-six species. In both years the Carabidae assemblages were dominated by *P. melanarium* and *P. rufipes*, the former in the isogenic corn crop during 1997 and in the transgenic in 1998, the latter in the other two fields. The data for both years show that *P. rufipes* was more abundant in the transgenic corn crop than in the isogenic. This situation was confirmed also in Treviso, where this species dominated in the transgenic crop during both 1997 and 1998. Also *B. quadrimaculatum* was always present, though it was dominant only in one case (fig. 1); also Tonhasca (1993) and Ellsbury *et al.* (1998) found this species to be dominant in other corn crop ground beetle assemblages.

In both the isogenic and the transgenic corn crops the abundance of many species was less than 3% of the total catch, and several species were collected only in either the transgenic corn crop or the normal one (Table 2). Moreover several species such as *Agonum moestum* Dft., *Amara familiaris* Dft., *Argutor vernalis* Dft., *Brachinus crepitans* L., *B. psophia* Serv., *Calathus melanocephalus* L., *Harpalus oblitus* Dej., *Elaphoropus parvalus* Dej., *Metallina prosperans* (Steph.) and *Platymus assimilis* Paykull were present only in the isogenic corn crop, while *Agonum mulleri* Dft., *Brachinus ganglbaueri* Apfbk., *Chlaenius spoliatus* Rossi, *Carabus germari* Sturm, *Harpalus dimidiatus* Rossi, and *Ophonus azureus* F. were collected only in the transgenic corn crops. A different list, but just as long, could be made considering the year and/or the locality.

There were no significant differences in the total number of individuals or species captured, although the abundance of some species was quite different, especially comparing the localities. On comparing the two types of hybrid corn crop, rather than giving consideration to other variables, it becomes evident that the structure of the ground beetle assemblages is similar.

Diversity and species richness

The Carabidae caught belong to 23 genera and 42 species, 6 species being the minimum (Treviso 1998) and 22 the maximum (in the transgenic corn crop of Pavia during 1997) and, if the two years are plotted together, the maximum was 22 in an isogenic crop in Pavia. Carabidae diversity was relatively low (diversity index H'< 0.99) indicated from the biodiversity indices. H' was highest for the transgenic corn crop in Pavia in 1998 and lowest in the transgenic corn crop of Treviso during 1997. Considering the two years, the values of H' were higher for the conventional corn crops than for the transgenic, although this difference is tangible only for the transgenic corn crop of Treviso. The data collected was analyzed with the above mentioned indices and the results are summarized in Table 4 . An alternative calculation, J' (relative diversity) expresses H' as a proportion of the maximum possible diversity for a given number of species. The magnitude of J' was higher for carabids collected from the transgenic corn crop in Pavia during 1998 (J'=0.82), the magnitude for the same

Table 4 - Diversity indices for ground beetles assemblages.

			H'	**N_0**	**N_1**	**N_2**	**N_{inf}**	**J'**
1997	Isogenic	Pavia	0.66	19	1.58	2.78	1.75	0.51
		Treviso	0.68	21	1.60	3.03	2.44	0.51
	Transgenic	Pavia	0.59	22	1.51	2.70	1.91	0.44
		Treviso	0.50	17	1.41	2.27	1.69	0.40
1998	Isogenic	Pavia	0.58	20	1.49	2.56	2.86	0.44
		Treviso	0.63	6	1.54	3.44	2.22	0.79
	Transgenic	Pavia	0.91	13	1.88	3.45	2.70	0.82
		Treviso	0.53	9	1.44	2.00	1.45	0.55
97-98	Isogenic	Pavia	0.80	29	1.74	4.76	2.85	0.55
		Treviso	0.79	22	1.73	3.26	2.44	0.56
	Transgenic	Pavia	0.73	26	1.66	4.00	2.70	0.59
		Treviso	0.53	20	1.44	2.42	1.81	0.35

Number of carabid collected were grouped by dates. The sample were taken every two weeks from half of May to the end of September. H' Shannon-Weaver diversity index. N_0-N_{inf} Hill's numbers. J' Evenness.

hybrid corn in Treviso the same year was J'=0.55. Considering both years, the lowest value of evenness (J'=0.35) was recorded for the transgenic crop in Treviso (Table 4).

Figure 2 shows the hierarchical richness index indicating both species richness and diversity. The highest HRI value, 2,089.1, was found in the 1998 transgenic corn crop of Pavia, this was followed by an HRI of 1,912.9 in the other corn crop for the same year and locality. The HRI values were consistently lower in Treviso during 1998, in both the isogenic and the transgenic corn crops (482.8 and 709.2 respectively).

The value of N_1 (Table 4), that gives an equivalent number of species if all the species contain the same number of individuals, ranged between a maximum of 1.88 (Transgenic - Pavia - 1998) and a minimum of 1.41 (Transgenic - Treviso - 1997). Considering both years the value of N_2, that expresses the probability of finding individuals belonging to the same species when sampling at random, was generally higher for the conventional corn crops than for the transgenic. The lowest value was found in the isogenic corn crop in Pavia during 1997, while the highest, found in 1998, was in the same locality but in the transgenic corn crop. The dominance diversity value N_{inf} was highest in the conventional corn crop of Pavia (1998) and lowest in the Treviso Bt corn crop (1997). This indicates a high incidence of one species from among all the species present. Therefore, basically, the community appears poorly structured, being dominated by one species, *P. melanarium* 59.52%.

Figure 3 shows the cumulative curves. The highest biodiversity, found in the tran-

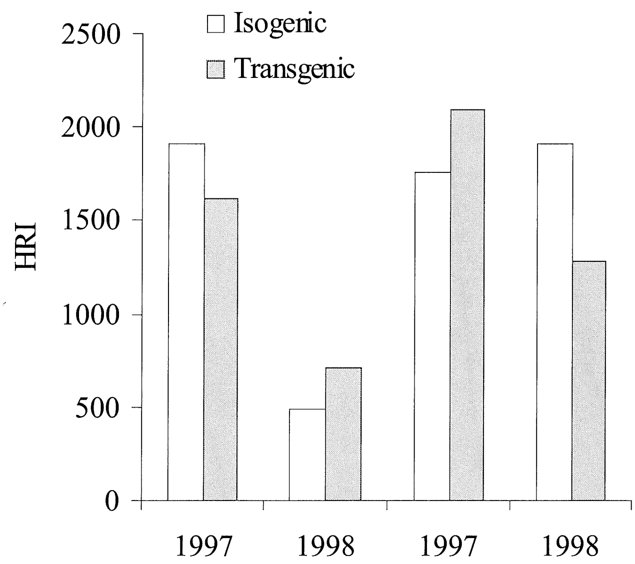

Fig. 2 - Hierarchical richness index (HRI) calculated for both localities during both years.

sgenic corn crop in Pavia (1997), is clearly evident, the lowest being in the isogenic crop of Treviso (1998). For Treviso the curves belonging to the transgenic corn crops are similar in shape and fall in the middle while those of the isogenic crops fall along the border, indicating the worst and the best diversity situations. The situation in Pavia is exactly the contrary.

Sörensen's index (Table 5) shows a high species similarity in the two types of corn crops in Pavia (QS= 71.42) during 1997, while for the same year in Treviso there was little similarity (QS= 40.00).

On passing from the first to the second year there was no trend towards a decrease in the biodiversity indices (Table 4) and, considering the data as a whole, the two years appear comparable. The difference in biodiversity recorded for some indices is

Table 5 - Sörensen's index to calculate the affinity of ground beetles communities found in transgenic and isogenic corn crops.

		Sörensen's index
1997	Pavia	71.42
	Treviso	68.40
1998	Pavia	62.85
	Treviso	40.00

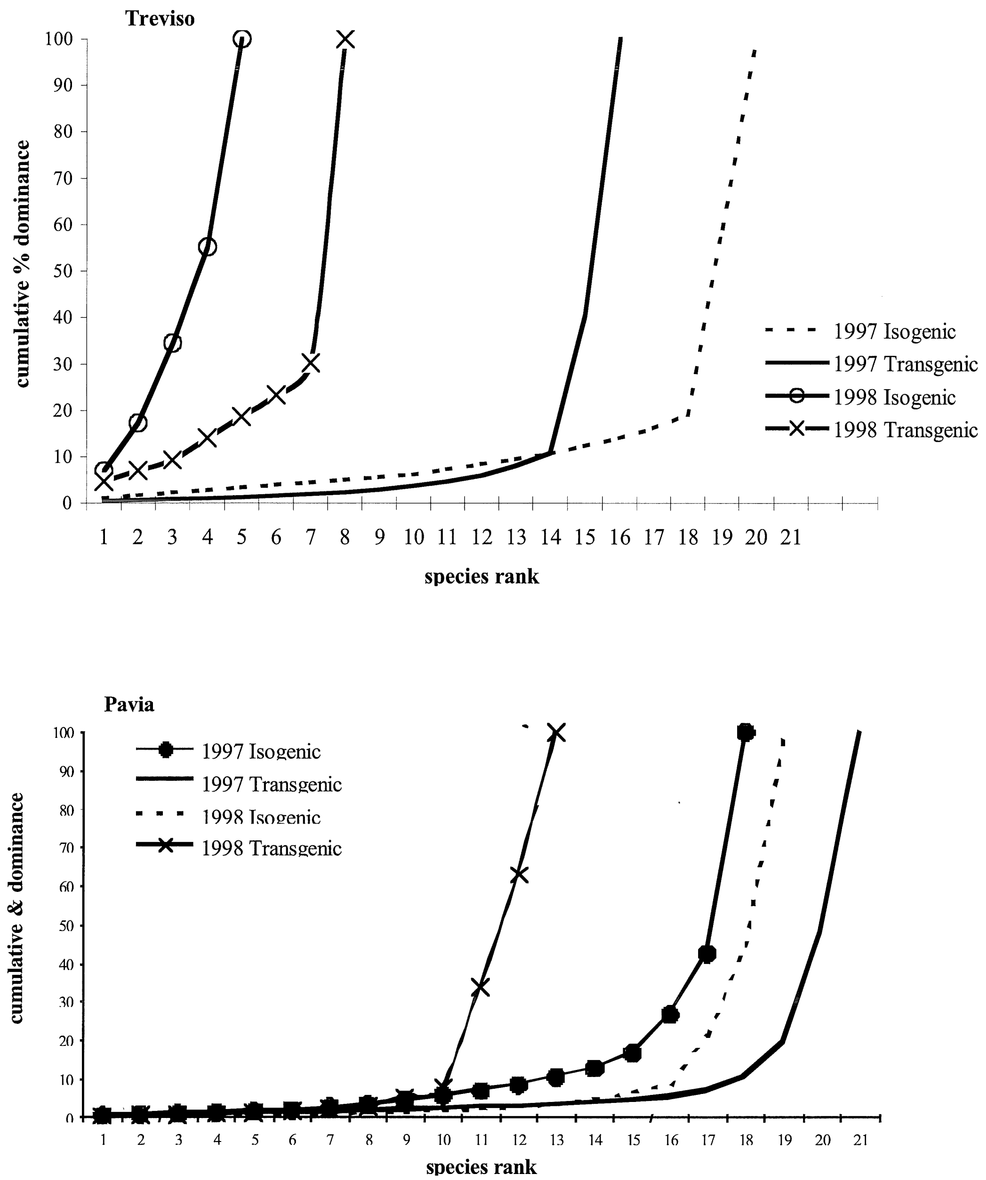

Fig. 3 - Cumulative percentage for Carabidae collected with pitfall in transgenic and isogenic corn crops during the 1997 and 1998.

not due to the presence of transgenic corn, where as for the case of H' calculated for Pavia (1998) is even the highest one. Moreover the highest value of J' recorded for this thesis demonstrates that the individuals are spread throughout the species recorded. This tendency is also confirmed by the value of N_1 (0.82) and the fact that there was no really dominant species (*sensu* Connell), the community of the carabids being characterised by the three species *Pseudophonus rufipes* (39%), *Poecillus cupreus* (28.9%) and *Bembidion quadrimaculatum* (26.5%) (Table 1).

The low value of HRI, and of the other diversity indices in Treviso during 1998, is probably due to the low rainfall (Table 3) rather than to the presence of Bt.

Plant dwelling non-target arthropods

Figure 4 shows the mean of the captures using the Malaise trap, that collected many different taxa; only the most numerous groups and the taxa connected ecologically to maize are reported here. The most abundant in the isogenic and transgenic corn crops was taxon Diptera, especially the Culicidae (not a typical corn crop fauna), followed by Coleoptera (an average of 83.41 individuals in the isogenic, and 76.6 in the transgenic); the most abundant among the Coleoptera were Chrysomelidae (52.36 in the isogenic field and 53.21 in the transgenic), followed by Hymenoptera (69.40 in isogenic corn and 65.41 in transgenic) and Cicadellidae (respectively 67.2 and 65.2).

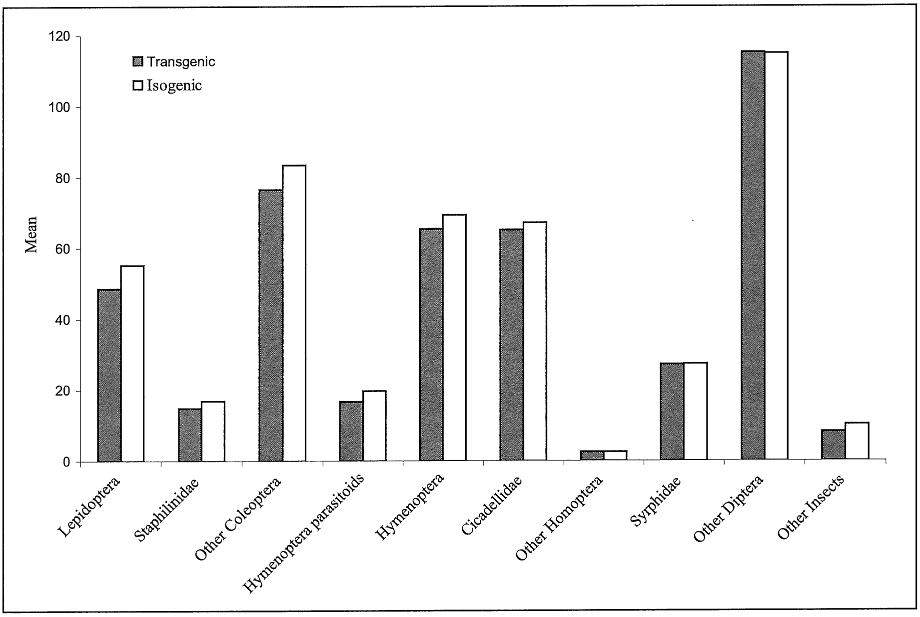

Fig. 4 - Mean of the captures (1997 and 1998) of entomofauna using the Malaise traps in isogenic and transgenic corn crops of Treviso and Pavia.

Although in the isogenic corn crops the mean of the individuals of the taxa collected was always a little bit higher than in the transgenic ones, no statistical differences were observed. In fact the results of the Mann-Whitney U test, calculated for each group and/or for the total number of arthropods collected in either isogenic or transgenic corn crops (for both years and both localities), were always $p>0.05$ (Diptera $p= 0.96$, Lepidoptera $p= 0.71$, Coleoptera, $p=0.75$, Staphilinidae $p=0.82$, Hymenoptera $p= 0.45$, Hymenoptera parasitoides $p= 0.49$, Cicadellidae $p=0.84$, other Homoptera $p=0.67$, Syrphidae $p=0.58$).

Figure 5 shows the average of the captures using the Blower-vac aspirator. The most abundant taxon in the isogenic and transgenic corn crops was Cicadellidae (parti-

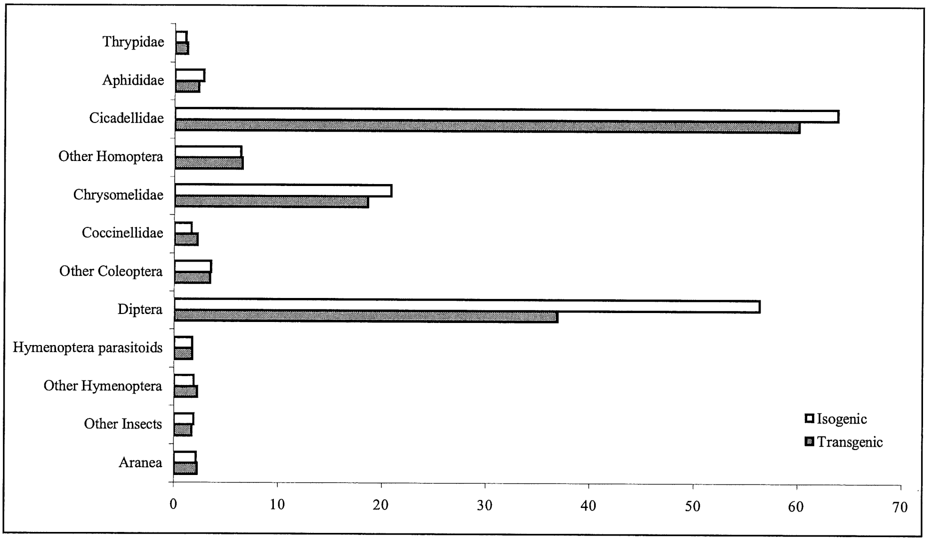

Fig. 5 - Mean of arthropods caught using a Blower-vac aspirator on isogenic and transgenic corn crops for both localities and during all sampling period.

cularly *Cicadella viridis* L.), followed by Diptera, and Chrysomelidae, that are characteristic of maize. The average of Diptera caught can be seen from the figure to be higher in isogenic corn than in transgenic. Moreover it is evident that Hymenoptera (also the parasitoid one), an important group for pollination and as parasitoids, are more abundant in the transgenic corn crops than in the isogenic. However no differences were observed in the number of arthropods colonising the isogenic (13.61 ± 3.2) and transgenic corn (12.9 ± 2.6), calculated for both years and the two localities. These data are confirmed by the results of the Mann - Whitney U test calculated for each group ($U=17$, $W=39$, 2-tailed $p =0.65$). Nor were there statistical differences in abundance for each group (Table 6). In fact the value of 2-tailed p was never significant ($p<0.05$). All the sampling methods and the statistical analysis, supported by visual checking, show that there was no significant difference in abundance, composition or biodiversity of non target arthropods in conventional and transgenic corn crops.

Table 6 - Results of the Mann-Whitney U test of the captures of arthropodofauna using the Blower-vac aspirator in the transgenic and isogenic corn crops for both years and for both localities.

TAXA	U	W	2-tailed p
Aphididae	18.0	39.3	0.73
Cicadellidae	16.5	44.5	0.55
Other Homoptera	16.0	38.2	0.93
Thripidae	8.5	29.3	0.13
Coccinellidae	16.3	44.4	0.81
Aranea	16.2	37.1	0.94
Hymenoptera	16.5	37.3	0.93
Hymenoptera parasitoids	17.1	38.2	0.94
Diptera	15.5	36.5	0.45

CONCLUSIONS

The lack of any significant statistical difference concerning Carabidae assemblages and plant dwelling entomofauna from transgenic and isogenic corn crops shows no potential plant antibiosis (Bt corn) beyond different trophic levels. The data confirm other findings (Orr & Landis, 1997; Pilcher *et al.*, 1997; Gould, 1998, Lozzia *et al.*, 1998).

The values of biodiversity indices calculated for the Carabidae assemblages are quite low, as can be expected for an agricultural environment. Moreover the data are comparable with the biodiversity indices calculated by Ellesbury *et al.* (1998) for ground beetle assemblages in corn fields in South Dakota during 1993 and 1994 (H' = 0.86 and H' = 0.84, J' = 0.63 and J' = 0.57, N_0 = 23 and N_0 = 29, respectively). During the second year of our study the biodiversity of Carabidae was even higher (Pavia) in the transgenic hybrid corn. The differences in the community structure seem to be due to factors other than the presence of transgenic corn.

The structure of the Carabidae communities did show differences, although these appear more relevant to the place and the year rather than to the two types of hybrid corn.

French and Elliot (1999) found that ground beetle assemblages appear influenced also by riparian habitats and rainfall levels. Moreover the ecology of Carabidae is often extremely specialized, and does not depend on the specific crop (Thiele, 1977). The Carabidae communities found in our study show a fundamental resemblance, though there are some differences, to the list of Carabidae from the European agriculture regions studied by Thiele (1977) and Molinari *et al.* (1995), the most characteristic feature being the abundance of zoophagous species like that belonging to the genus *Pseudophonus*, *Steropus*, *Poecilus*, *Amara.*

Generally speaking, the effect of changes in species richness is more likely to be stronger in species-poor communities than in species-rich communities (Ekschmitt & Griffiths, 1998). If this hypothesis holds true, then also in this case Bt corn would have some deleterious effect on non target entomofauna, an influence that would be very evident, especially on biodiversity and community structure.

Observations concerning the impact of agricultural management on soil fauna populations and communities, and their interaction, confirm that high input like insecticides and intensively managed systems tends to promote low diversity, while low input systems like integrated pest management tend to maintain diversity (Rivard, 1996; Den Boer, 1979). In fact, Kruger and Scholtz (1998) reported that the use of the insecticidal compound ivermectin affected community structure, leading to less diversity in the species and an increase in species dominance, while Càrcamo *et al.* (1995) found that an input of chemical fertilizer and herbicide, associated with intensive conventional agriculture, had a negative effect on the Carabidae population. From the results it appears that the effect of a transgenic corn crop is comparable with a situation of integrated pest management, resulting in a low environmental impact level. However one of the major goals of ecologists is to understand all the variables affecting biodiversity. In fact, not so long ago Bardgett and Cook (1998) claimed that research is needed to test the hypothesis that soil biodiversity is positively associated with stability, and to elucidate relationships between productivity, community integrity and the functioning of soil biotic communities.

In the light of scenarios for global change, the maintenance of overall biodiversity levels in agro-ecosystems could become just as important for ecological sustainability as keeping up a high abundance of presently well-adapted beneficial organisms (Duelli, 1997). Furthermore Johnson *et al.* (1997) have highlighted the importance of natural enemies to control resistant insects to transgenic plants. Other studies could be helpful to assess the sustainability of transgenic corn in Integrated Pest Management projects.

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