International Journal of Pest Management
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/ttpm20

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Version of record first published: 13 Dec 2007.

To cite this article: Gashawbeza Ayalew , Andrea Sciarretta , Johan Baumgärtner , Callistus Ogol & Bernhard Löhr (2008): Spatial distribution of Diamondback moth, Plutella xylostella L. (Lepidoptera: Plutellidae), at the field and the regional level in Ethiopia, International Journal of Pest Management, 54:1, 31-38

To link to this article: http://dx.doi.org/10.1080/09670870701613743

International Journal of Pest Management, January–March 2008; 54(1): 31–38

Spatial distribution of Diamondback moth, *Plutella xylostella* L. (Lepidoptera: Plutellidae), at the field and the regional level in Ethiopia

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Abstract

Pheromone trap catches were used to study the spatial distribution of Diamondback moth (DBM), *Plutella xylostella* L., at both single field and regional levels. At the field level, the DBM population tended to remain within the cabbage field. At the regional level, DBM captures were highly influenced by geographic location and cropping systems. In highland areas, daily maximum temperatures positively influenced the aggregation index, whereas in the lowland areas, rainfall had a negative influence on the aggregation index. The implications for integrated DBM managements are as follows: at the local level, knowledge on spatial dynamics allows the delimitation of areas with high DBM infestations for consideration in both monitoring and biological control programmes. At the regional level, areas with year-round production of *Brassica* spp. and intensive use of pesticides should receive priority in the design and implementation of integrated DBM management systems.

Keywords: *Diamondback moth,* Plutella xylostella*, Pheromone trap catches, local and regional levels, spatial analysis*

1. Introduction

The Diamondback moth (DBM), *Plutella xylostella* L. (Lepidoptera: Plutellidae) is worldwide the most destructive insect pest of *Brassica* spp. crops, and is controlled at the annual cost of US$ 1 billion (Talekar and Shelton 1993). However, unilateral reliance on chemical control is often inefficient, because of DBM's ability to quickly develop resistance to traditional synthetic insecticides (Chen and Sun 1986). This has stimulated the search for additional control methods including cultural control, biological control and the use of growth regulators (Talekar and Shelton 1993; Schroeder et al. 2000; Sarfraz et al. 2005). These different methods are considered in the development and implementation of integrated pest management (IPM) schemes, i.e. control systems that, in the context of the associated environment and the population dynamics of the pest species, utilizes all suitable techniques and methods as compatibly as possible and maintains the pest populations at levels below those causing economic injury (Flint and van den Bosch 1981). Accordingly, an adequate knowledge on the dynamics of the pest both in space and time is a key element in IPM (Brenner et al. 1998; Liebhold and Gurevitch 2002). The bionomics of DBM have been the subject of many studies (Talekar and Shelton 1993) but information on population ecology and on spatial dynamics is scarce. Available relevant information is restricted to long distance wind assisted migration (Chu 1986) and local dispersal (Mo et al. 2003).

Limited knowledge on the spatio-temporal dynamics of DBM populations is seen as a hindrance to further developing and implementing IPM systems. In general, ecologists seek to obtain the required knowledge through the development and use of mathematical models on spatial processes (Renshaw 1993) or through statistical analyses of spatial distributions (Liebhold and Gurevitch 2002; Perry et al. 2002). Here, we rely on the latter approach and follow Odulaja et al. (2001) and Sciarretta et al. (2001) who, among many others, applied geostatistical analyses to trap catch data. We assume that the complexity of *Brassic*a spp. infesting DBM populations in Ethiopia can be partially taken into account by working at both the field and the regional levels. Hence, the work of Sciaretta et al. (2001) is of particular interest to our work because monitoring and analyses of fruit tortricid data have been carried out at both orchard and regional levels.

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ISSN 0967-0874 print/ISSN 1366-5863 online © 2007 Taylor & Francis
DOI: 10.1080/09670870701613743

2. Materials and methods

2.1. Study area

At the local level, the study was conducted in a field with single head cabbage (*Brassica oleracea* var. *capitata*) in the Arsi highland (7°01′N, 38°53′E) (Figure 1). At the regional level, we focused on the brassica-producing area of Wonji, located in the central Rift Valley region of Ethiopia (8°27′N, 39°13′E) (Figure 2).

2.1.1. Single field study. The spatial distribution of adult male DBM in the cabbage field relied on catches in pheromone traps of the delta-type with a rubber lure impregnated with a synthetic sex pheromone containing Z11 – 16:Ald, Z11 – 16:AC and Z11 – 16:OH, obtained from Pherobank (Plant Research International BV, Wageningen, The Netherlands). Inside and outside the field of rectangular shape, 11 traps were deployed at distances of 20 m along three rows in south–north directions. The distance between the rows was 20 m. According to Figure 1, three traps were located within the cabbage field, while the remaining one were distributed either in rangeland or non-brassica crop. The minimum and the maximum distances between any of two traps ranged from 20 to 80 m, with a mean of 37.13 m. Traps were placed 30 cm above the crop surface. Male flight was monitored from November 5 to December 20 (pre-heading stage).

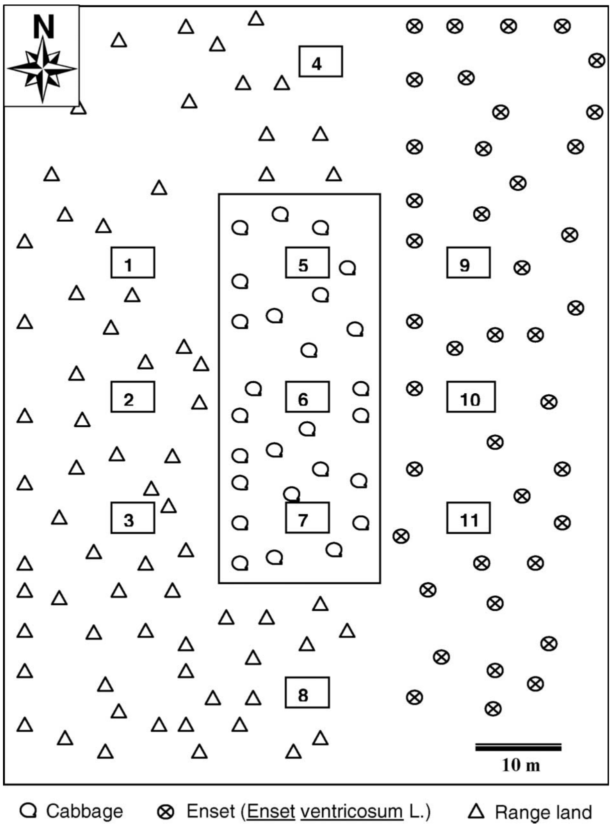

Figure 1. Map of the study area at Kofele, Ethiopia, showing the 11 trapping positions (20 × 30 m).

During this period, individual moths in each trap were counted twice a week at 3 – 4-day intervals; the counts obtained from all traps at the same time are treated as a sample. Weather data (minimum temperature, maximum temperature and relative humidity) were recorded by a data logger installed in the experimental field.

2.1.2. Regional level study. Nineteen delta traps baited with the sex pheromone were irregularly distributed in brassica producing areas of Wonji, in the central Rift Valley region. The minimum distance between any two traps was 96.7 m and the maximum was 16 020 m with a mean of 7619 m. Traps were placed either in brassica fields, non-brassica fields or fallow as shown in Table I. Counts were made weekly for a period of 6 weeks between May and July 2002.

2.2. Data analysis

2.2.1. Autocorrelation analysis. The spatial autocorrelation was measured by Moran's *I* index (Cliff and Ord 1981) which was parametrized by means of the SAAP software (Exeter Software, Setauket, NY, USA)

$$I = \frac{n \sum \sum w_{ij} z_i z_j}{S \sum z_i^2}, \qquad \text{with } z_i = (x_i + \bar{x}),$$

where n is the number of traps, x_i represents the sum of observations at the ith trap, w_{ij} is a weight indicating the connection between traps i and j, S is the sum of the weights. A significant I indicates spatial autocorrelation between traps (Odulaja et al. 2001).

Autocorrelograms were constructed for each sampling period of both the single field study and the regional level study. Correlograms were built using an equal number of point pairs for each distance class refereed to as lag (Odulaja et al. 2001).

2.2.2. Spatial analysis. At the local level, the trap catches are plotted as scale-sized dots on a map, i.e. the size of the circles represents the magnitude of trap catches.

At the regional level, the trap catches (x) were square-root-transformed ($\sqrt{x + 0.5}$) to stabilise variance and subjected to principal component analysis (PCA) to detect areas with similar patterns of trap catches (Odulaja et al. 2001). The trap number 6 was excluded in the analysis because the data of the second week were not available.

At both the field and the regional level, the aggregation index of Perry et al. (1996) was parametrised by using the SADIE software (Rothamsted Research, Harpenden, UK). The acronym refers to the Spatial Analysis by Distance Indices methodology developed for the analysis of georeferenced ecological data. The index is based on the effort needed by single individuals to reach

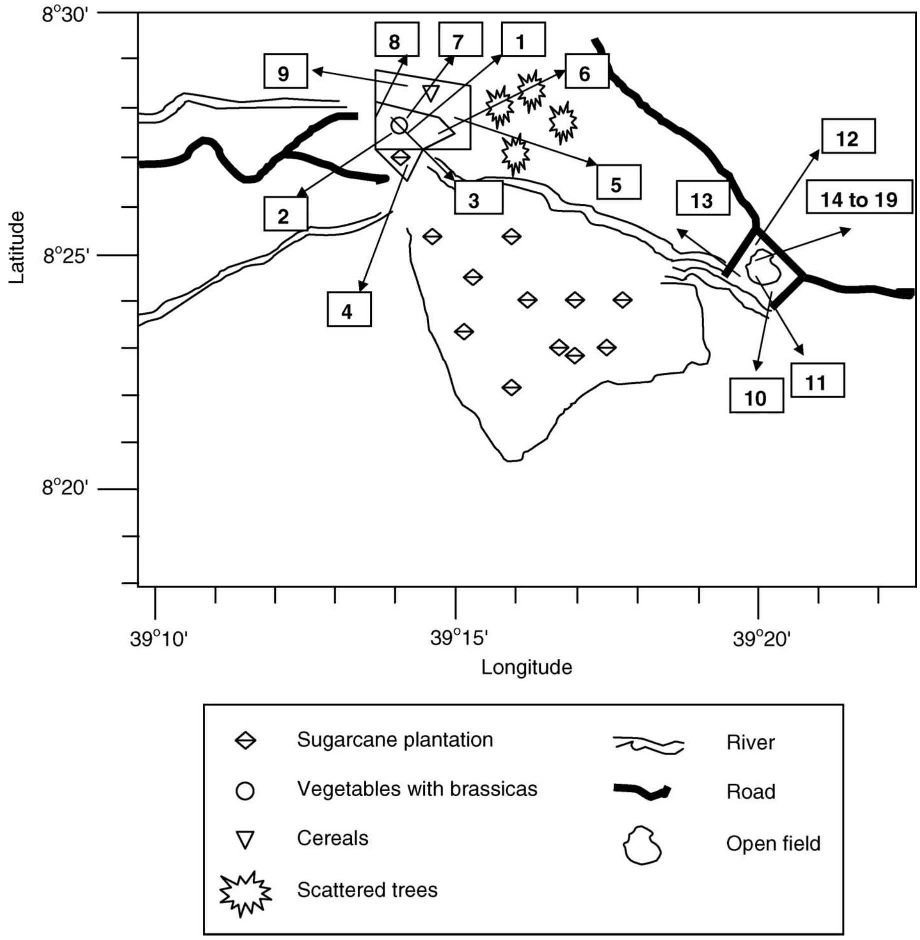

Figure 2. Map of the study area at Wonji, Ethiopia, showing the 19 trapping positions.

Table I. Location details of traps installed at Wonji, Ethiopia.

	Location				
Trap no.	Latitude	Longitude	Crop field	Crop stage	Surrounding crops
1	08°28′08″N	039°13′21″E	Cabbage	Seedling	Kale, tomato, cabbage, tree
2	08°28′15″N	039°13′21″E	Cabbage	Seedling	Tomato, cabbage
3	08°28′20″N	039°13′30″E	Tomato	Flower	Tree (*Eucalyptus*)
4	08°27′05″N	039°13′65″E	Sugar cane	Seedling	Sugarcane, banana, tree
5	08°28′38″N	039°14′17″E	Maize	Seedling	Maize, Road
6	08°28′65″N	039°14′29″E	Tomato	Early fruiting	Pepper, tomato
7	08°29′10″N	039°13′70″E	Cabbage	Seedling	Pepper, cabbage
8	08°28′80″N	039°13′33″E	Cabbage	Preheading	Onion, maize
9	08°28′99″N	039°13′60″E	Maize	Seedling	Cabbage, tomato, maize
10	08°24′00″N	039°19′87″E	Onion	Seedling	Onion
11	08°23′99″N	039°20′09″E	Open field	_	Beans
12	08°24′96″N	039°19′75″E	Open field	_	Open field
13	08°24′58″N	039°19′38″E	Onion	_	Onion
14	08°24′63″N	039°20′00″E	Open field	_	Open field
15	08°24′89″N	039°19′59″E	Cabbage	Seedling	Tomato
16	08°25′00″N	039°19′63″E	Open field	_	Open field
17	08°24′90″N	039°19′62″E	Open field	_	Open field
18	08°24′85″N	039°19′67″E	Open field	_	Open field
19	08°24′84″N	039°19′58″E	Open field	_	Open field

maximum crowding compared with that needed to reach maximum randomness. The technique seeks to identify areas of clustering of two forms: a patch cluster with unit i, and a count c_i that is larger than the sample mean, and a gap cluster with unit j and count c_j that is less than the mean (Perry et al. 1999). Statistically significant values indicate an aggregated distribution.

The influence of weather data on aggregation pattern was analysed using stepwise non-linear regression analysis of the SAS software (SAS Institute 1999).

2.2.3. Assessment of distance. The relationship between similarity of trap catches and the spacing of traps was assessed by regressing Pearson correlation coefficients of trap catches between traps on the distance between the traps, at both local and regional levels (Odulaja et al. 2001).

3. Results

3.1. Single field study

3.1.1. Autocorrelation analysis. The autocorrelation analysis resulted in five class intervals at 20, 28, 40, 44 and 80 m. Moran's indices were significant at 28-m lag of the first ($P = 0.026$), sixth ($P = 0.004$), seventh ($P = 0.003$), eighth ($P = 0.003$), tenth ($P = 0.046$), and eleventh ($P = 0.013$) survey, and at the 40-m lag of the first ($P = 0.004$), fourth ($P = 0.007$), seventh ($P = 0.025$) and eighth ($P = 0.013$) survey (Figure 3). The patterns of autocorrelations in all samples had similar trends: they decreased in the first lag distance of 20 m to reach non-significant negative values, then increased in the second lag distance of 28 m to positive values that were significantly different from zero ($P < 0.05$) in six surveys out of 11, and then remained close to zero until the final 80-m lag distance.

3.1.2. Spatial analysis and assessment of distance. Figure 4 shows the distribution of trap catches for the 11 samples. Greater catches were recorded from traps installed in the cabbage field than in the border traps throughout the study period. At peak density (December 20), the count was highest in the central trap within the cabbage field.

Aggregation indices ranged between 0.99 and 1.52. The fifth, ninth, and eleventh counts with values of 1.44 ($P = 0.0082$), 1.32 ($P = 0.0049$) and 1.52 ($P = 0.0233$), respectively, were significant. Only maximum temperature had a significant influence ($P = 0.0347$) on the aggregation index (Table II). Aggregation indices increased with increasing maximum temperature, which accounted

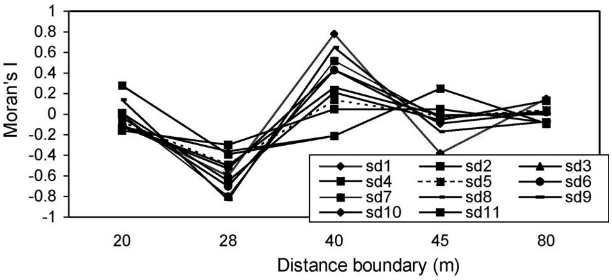

Figure 3. Correlograms describing the autocorrelation pattern for male DBM trap catches at Kofele, Ethiopia (single field study). SD 1 – 11 indicate sampling dates.

for 41% of the variation in the aggregation index. Maximum temperature during the study period fluctuated between 19 and 24°C and minimum temperature between 3 and 7°C.

The correlation coefficient between catches and distances was low and insignificant ($R = -0.14$, $P = 0.3042$).

3.2. Regional level

3.2.1. Autocorrelation analysis. The autocorrelation analysis resulted in seven lag distances of 778, 1760, 2971, 11 487, 13 006, 13 666 and 16 026 m, respectively (Figure 5). In the short distance lags (intervals 1 to 3), values were positive and significant ($P < 0.05$), indicating similarity of captures. In particular, were significant: at 778-m lag, the first ($P < 0.0001$), third ($P = 0.008$), fourth ($P = 0.05$), fifth ($P = 0.001$) and sixth ($P = 0.014$) survey; at 1760-m lag, the first ($P = 0.017$), third ($P = 0.001$) and sixth ($P = 0.004$) survey; at the 2971-m lag, the first ($P = 0.017$), second ($P = 0.010$), third ($P = 0.002$), fourth ($P = 0.010$), sixth ($P = 0.005$) and seventh ($P = 0.018$) survey.

The medium distance lag (interval 4) was not significantly different from 0 indicating absence of autocorrelation. Beyond 11 487 m, Moran's I was negative and significant, indicating a negative correlation greater distances. In particular, were significant: at the 13 006-m lag, the first ($P = 0.003$), third ($P = 0.007$) and fourth ($P = 0.025$) survey; at the 13 666-m lag, the first ($P < 0.0001$), fifth ($P = 0.001$), sixth ($P = 0.006$) and seventh ($P < 0.0001$) survey; at the 16 026-m lag, the first ($P = 0.003$), second ($P < 0.0001$), third ($P < 0.0001$), fourth ($P = 0.001$), sixth ($P < 0.0001$) and seventh ($P = 0.011$) survey.

3.2.2. Spatial analysis and assessment of distance. Figure 6 shows a similarity for trapping positions. The first principal component explained 85% of the variance, while the combined first and second components explained 97%. The groupings of traps appeared to be related to crop type. Traps 1 to 9 appear at the top of the space of principal axes (Figure 6). With the exception of trap 4 deployed in a sugarcane plantation, all traps were set up in brassica fields. The remaining traps appeared at the bottom of the space (Figure 6). While trap 15 was placed in a cabbage field, the other traps caught males in on open field or non-brassica crops. The groupings, particularly in the areas with no brassica production (trap number 10 to 19) indicate a strong relationship between patterns in trap catches between traps in close geographical proximity.

The aggregation index ranged between 1.94 and 3.32. Among the factors tested, only rainfall had a significant influence ($P = 0.0400$) on the aggregation index (Table II) and accounted for 60% of the variation. The aggregation index increased with decreasing rainfall that fluctuated between 0 and

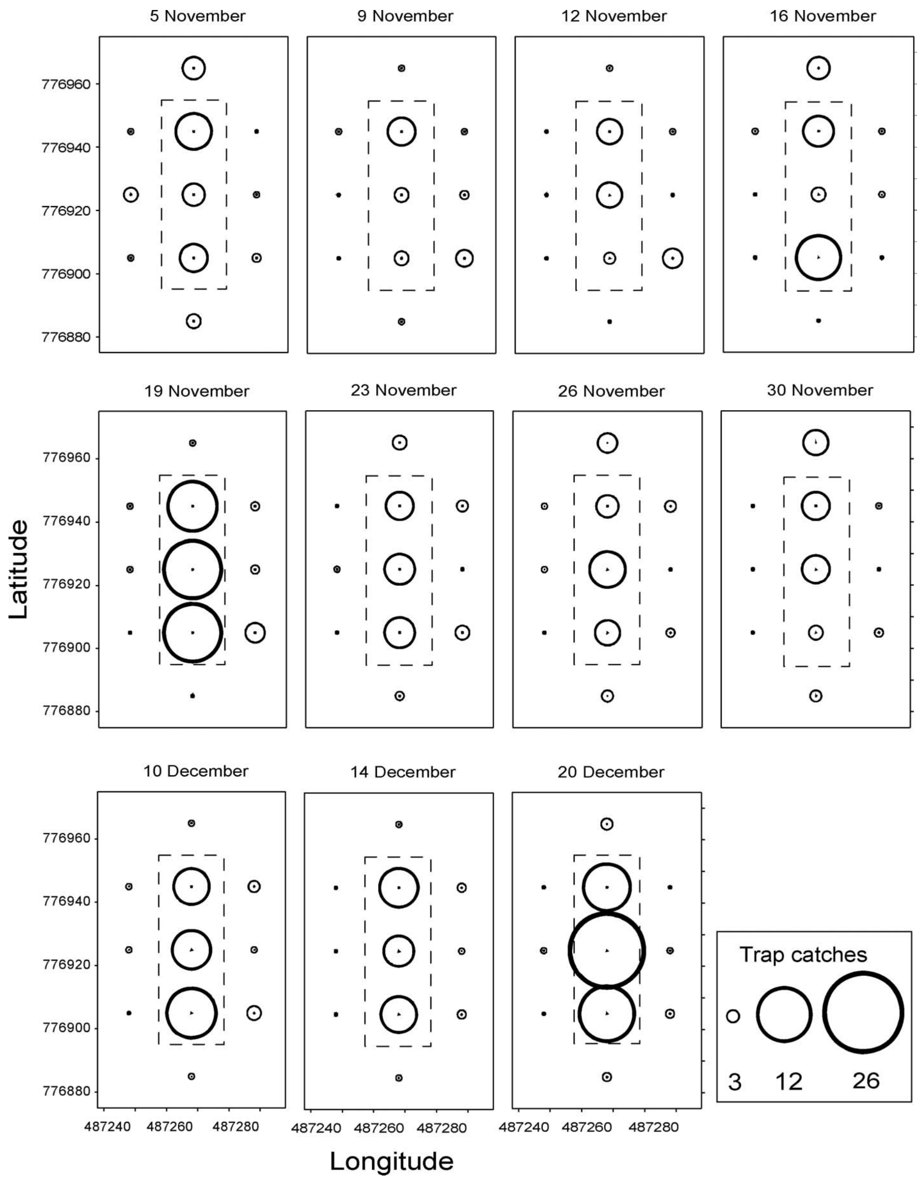

Figure 4. Pheromone trap catches of *Plutella xylostella* L. male adult at the 11 trap locations for consecutive 11 sampling period (6 November to 20 December 2001) at Kofele, Ethiopia. Dotted line represents the field border. Latitude and longitude are indicated in UTM coordinates.

Table II. Aggregation index described by maximum temperature (°C) at Kofele, Ethiopia, and rainfall (mm) at Wonji, Ethiopia, as independent environmental variables with significant effect (slope is different from 0 with $P < 0.05$).

Location	Variable	Intercept	Slope	R^2
Kofele	Max temperature (°C)	−0.65 (0.76)	0.09 (0.04)	0.41
Wonji	Rainfall (mm)	2.80 (0.17)	−0.31 (0.11)	0.60

3.5 mm during the study period. There was no significant correlation between the coefficients of trap catches and distance between traps ($R = 0.0779$; $P = 0.66107$).

4. Discussion

At the field level, the correlogram showed significant negative values at 28 m indicating a discontinuity in trap catches at the edge of the field. Spatial analysis indicated a higher male presence in the field than outside. This is in agreement with Mo et al. (2003) who relied on mark recapture technique to study local dispersal and observed DBM adults do not leave the cabbage field during the growing season. The location of traps outside the field was within the local dispersal range given by Mo et al. (2003). Nevertheless, catches were consistently higher in the field which confirms the strong link to the cabbage fields and little movement to field surroundings. Caprio and Tabashnik (1992) also noted lower DBM numbers in traps located in the fallow field surrounding cabbage fields. In their study, the proportion of catches in the surrounding field was 7.8% of those recorded within field, which is in agreement with the observations in this study. Few individuals were caught outside the field; the significant positive values at the 40-m lag distance indicate a similarity of catches by traps located outside the field.

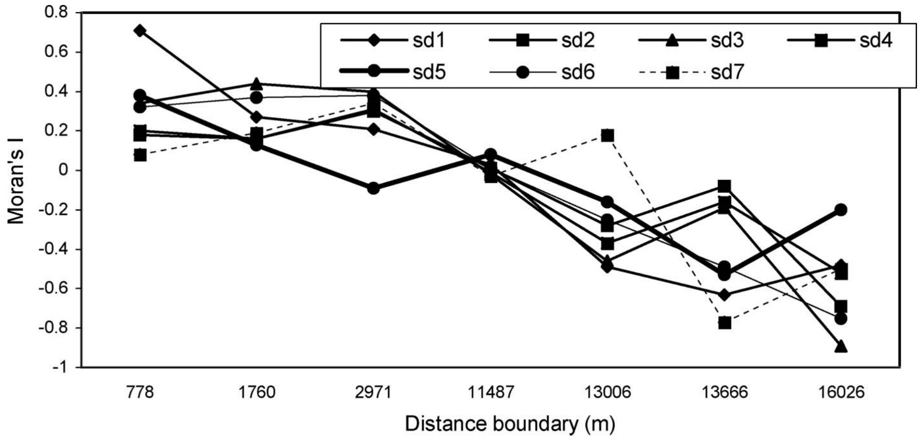

Figure 5. Correlograms describing the autocorrelation pattern for male DBM trap catches at Wonji, Ethiopia (regional level). SD 1–7 indicate sampling dates.

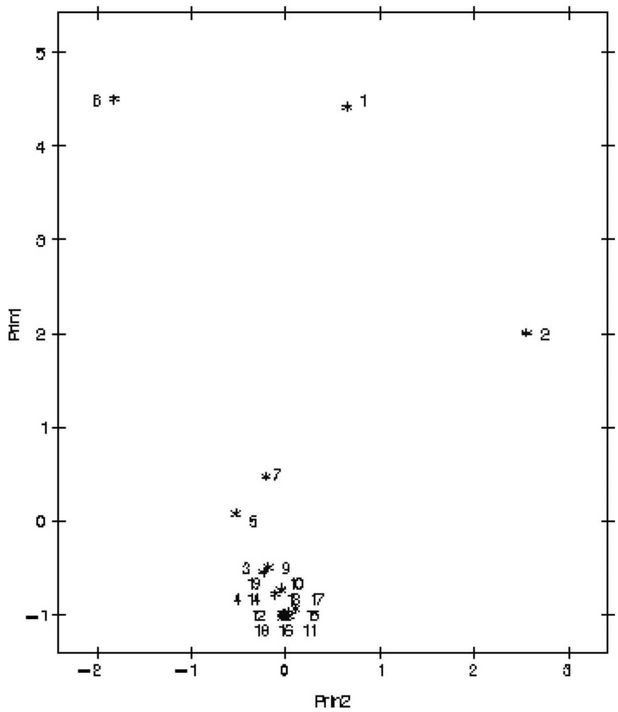

Figure 6. Ordination of traps (except number 6) positioned at Wonji, Ethiopia, in the space of the first two principal components (Prin 1 and Prin 2).

At the regional level, we obtained significant positive values of Moran's Index at short distance lag intervals, i.e. at a range of 1760 m, corresponding to the distance between traps located outside brassica fields, and at a range of 2971 m, distance between traps located inside brassica fields. At the fourth interval, the index was close to zero. The interval between lags 5 and 7 comprises catches by traps deployed between brassica and non-brassica fields. The autocorrelation decreased linearly in this interval, indicating a negative correlation of trap catches between traps inside brassica fields and non-brassica fields. The absence of a significant correlation between trap catches and distance may be due to the dissimilarity between sites. As at the local level, there was no correlation between trap catches and distance. This may be due to the dissimilarity catches by traps deployed inside and traps deployed outside brassica fields, which masked effect of distance. The observations at regional level confirmed the strong DBM association with its cabbage fields. Although trap number 15 was installed in cabbage field but caught similar low numbers of males as traps installed in the surrounding. Since trap 15 has been deployed in an area with little brassica production, the geographic location and the cropping system may influence the regional distribution of DBM.

According to Chu (1986), DBM can migrate long distances and undertake trivial flights close to the ground and often within the plant canopy (Mo et al. 2003). In our study, the traps were installed 30 cm above the crop surface and likely caught insects in trivial flight (Chisholm et al. 1979). The use of trap catch data for the interpretation of dynamic patterns is difficult, but the higher DBM catches in cabbage fields located within crucifer producing areas, compared to cabbage field within non producing areas, might indicate a tendency to remain in the same area rather than engaging in long distance flights to other regions. A possible limited dispersal has important implications for the spread of resistance to pesticides (Tabashnik et al. 1987; Caprio and Tabashnik 1992) and would allow the delimitation of areas with high DBM infestations to undertake precision-target interventions including monitoring and biocontrol operations. The tendency to remain in the field may further facilitate efforts to control the pest through mating disruption as proposed by Talekar and Shelton (1993).

At local and regional levels, environmental variables appear to have a variable influence on the aggregation index. This could be due to climatic difference in the two areas. The single field study was carried out at Kofele (alt. 2450 m a.s.l.) in the cool and wet highland brassica production area. The regional level study was carried out at Wonji (alt. 1550 m a.s.l.) located in the lowland brassica producing region where the climate is hot and dry. At Kofele the maximum temperature positively influenced the aggregation index while at Wonji, it was negatively influenced by rainfall. Temperature influences the initiation of the flight activity and the flight duration (Goodwin and Danthanarayana 1984; Shirai 1991). The optimal flight temperature range of DBM is 18 – 28°C (Shirai 1991) which corresponds to the range of maximum temperature at Kofele. This may explain the relation of aggregation index with maximum temperature at Kofele. At Wonji, however, the maximum temperature is between 28.5 and 33.5°C and hence, above the optimum. This may explain the absence of relationship between aggregation index and temperatures. At Wonji, the scarce rainfall was the only environmental variable with significant effect on aggregation index.

The data and methods provided important, albeit limited information on the distribution of DBM at the field as well as on the regional levels but gave limited insight into the spatio-temporal dynamics of DBM. To overcome the restrictions, number of the pheromone traps should be augmented to complement data representation by scale size dots with geostatistical interpolation techniques (Nansen et al. 2003). In addition, the sampling period should be extended and data on trap catches of males should be completed with data on immature life stages and adult females. These data would provide a more solid ground for passing from analyses of spatial distributions to spatial and temporal population processes as important elements in an emerging IPM programme. As previously stressed, IPM programmes should be developed in the context of the associated environment and the population dynamics (Flint and van den Bosch 1981). The consideration of two spatial levels are seen as the first steps in an emerging IPM programme that should be complemented with an expansion into the time dimensions, should consider a wide range of stakeholders and pass from single-species control to multi-species population assemblages as objects for management (Baumgärtner et al. 2006; Herren et al. 2007). Currently, efforts are under way to complement classical biological control with applications of *Bacillus thuringensis* and to design an IPM programme (Ayalew et al. 2004; Ayalew 2006; Ayalew and Ogol 2006). In agreement with van Driesche and Bellows (1996), we assign a key role to biological control in the emerging IPM programme.

Acknowledgement

Financial assistance was obtained from the German Federal Ministry of Economic Cooperation and Development (BMZ) through the DBM bio-control project of the International Center of Insect Physiology and Ecology (ICIPE) and a scholarship to the senior author from the Deutscher Akademischer Austauschdienst (DAAD) through ICIPE. We thank A. Odulaja (NAEA) for assistance in statistical analysis. We thank the Melkassa Center of the Ethiopian Institute of Agricultural Research for transportation services.

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