Effects of forest edges on the yield of silage maize *(Zea mays L.)*

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Der Einfluss von Windschutzgürteln auf den Ertrag von Mais *(Zea mays L.)*

1 Introduction

Habitat edges are the boundaries between two or more distinct vegetation types (JOHNSTON, 1947) having an importance for wildlife because of their higher diversity of organisms (LEOPOLD, 1933; ODUM, 1971; WIENS et al., 1993; HERSPERGER and FORMAN, 2003). Crop margins or headlands (WILCOX et al., 2000) are edge strips of cropfields that significantly support biodiversity in farmland (RANDS, 1985; MARSHALL, 1989; TWOREK, 2002; VICKERY et al., 2002), protect water reservoirs from contamination by agrochemicals (RYSZKOWSKI, 1992), and prevent soil erosion (HOBBS, 1993; KOWALCHUK and DE JONG, 1995).

Yields near to crop edges are affected by various factors, e.g. soil compaction (HÅKANSSON et al., 1988), supply of organic matter through leaf decomposition (GARTEN et al., 1994), incidence of pests and diseases (THIES and TSCHARNTKE, 1999) or weed competition (COUSENS, 1985). Competition between tree and crop roots involves a wide range of physical, chemical and biological interactions (SCHROTH, 1998). The shading effect of trees can bring not only negative impacts on crop yield but also some positive features, e.g. reduction of weed biomass (JAMA et al., 1991) or greater top-soil water (DE COSTA and CHANDRAPALA, 2000). Yield losses have been generally observed in the order of 15–30 % (BOATMAN and SOTHERTON, 1988; FISCHER et al., 1988; DE SNOO, 1997), while increased yields due to a sheltering effect are less common (MARSHALL, 1967).

Putting the biological importance and low yield effectiveness of crop edges together, we may consider these habitats rewarding for other uses than intensive farming. The principal objective of this study was therefore to quantify the negative effects of forest edges on crop yields of silage maize (*Zea mays* L.), a widely used corn, in terms of its strength and depth of action into the field interior. Most studies have

Zusammenfassung

Windschutzgürteln besitzen eine wichtige Funktion für den Aspekt der biologischen Diversität, dennoch ist wenig über deren Einflüsse auf den Ertrag der angrenzenden Bewirtschaftungsflächen bekannt. Das Hauptziel der vorliegenden Arbeit war festzustellen, inwieweit Nähe, Lage und Veränderung der Vegetation eines Windschutzgürtels Einfluss auf Wachstum und Ertrag von *Zea mays L.* hatten. Der Maisertrag wurde zweimal jährlich (Juni und September) auf acht 150 m Quadrate auf intensiv genutztem Ackerland in Zentralböhmen, Czech. Rep., erhoben. Die durchschnittliche Höhe der Hecken betrug 25 ± 2 m. Die höchsten Ertragseinbußen waren dort festzustellen, wo sich die Hecke südlich des Feldes befand, es ergaben sich Einbußen bis zu 70 % gegenüber der Feldmitte. Der Einfluss der Hecke war bis auf 60 cm Abstand nachzuweisen (2,4mal der Höhe der Hecke). Andere Positionierungen der Hecke hatten geringeren Einfluss, wobei den geringsten Effekt nördlich gelegene Hecken hatten (z.B. 20 m, 0,8 h, mit 20 % Ertragseinbußen). Der Lichteinfluss war ein bedeutender Faktor. Die Biomasseakkumulation zwischen Juni und September variierte stark, war aber unabhängig von der Distanz zur Hecke. Der Biomassezuwachs war in 80–100 m Entfernung von der Hecke am höchsten (3,2–4 h), dies galt für alle Versuchsflächen an beiden Proben…terminen. Die vorliegende Studie soll eine Hilfe für die Entscheidung bei der Neuanlage von Windschutzgürteln darstellen, wobei ein Kompromiss zu finden ist zwischen den Interessen der Bewirtschafter und einer Bewahrung der biologischen Vielfalt.

Schlagworte: Randeffekt, Silomais, Deckungsbeitrag, Heckenabstand, Belichtung.

Summary

Edges between cropfields and forests are significant for biological diversity, but little is known as to their effects on crop production. The principal objective of this study was to assess the growth and yield of silage maize in relation to: (1) distance to the forest edge, (2) edge orientation, and (3) changes in forest edge effect during the vegetation period. The yield of maize was sampled twice a year (June and September) on eight 150 m transects in four edge positions in intensive agricultural land in Central Bohemia, Czech Republic. The average height of the forest edges was 25 ± 2 m. The strongest yield decline occurred along the forest edges located south of the field, reducing plant growth up to 70 % right at the edge, in comparison with midfield. The decline in yields subsided 60 m (2.4 h, i.e. multiple of forest edge height) away from the edge. Other positions have less impact, with the lowest effect being recorded north (20 m, i.e. 0.8 h, with a reduction of less than 20 %). Light exposure was found to be an important factor. Biomass accumulation between June and September varied widely, but was not significantly affected by distance from the edge. Biomass yield was highest 80–100 m (i.e. 3.2–4 h) from the edge in all transects and at both samplings. The findings of this study may be relevant for the design of cropfields and new woodlots within the mosaic of rural landscape, and may support the compromise cultivation of crop margins in the interest of biological diversity conservation, on the one hand, and of yield loss compensation, on the other.

Key words: Edge effect, Silage maize, Crop margins, Headlands, Edge distance, Illumination.

hitherto focussed on the immediate crop margins, although some authors have pointed to a continuing edge effect further into the field (Kroulik, 1991; Cermanek, 1994). Moreover, we tested whether shading by trees may cause differences in patterns of edge effect among the four cardinal points. If so, there are reasons for considering them differently in assigning proper use and management.

2 Site description and methods

The study sites were located around Kostelec nad Cernymi lesy (50°01′ N, 14°51′E), in the Central Bohemian region of the Czech Republic on Cambisol (FAO/Unesco, 1990) clay-loam soils. The area is a part of a rural landscape mosaic consisting of arable land (matrix), woodlands, meadows and pastures. According to Quitt (1975), the study area is located in the mild climatic district MT 9 (Table 1). Eight fields (15–30 ha) were selected, two in each of the four edge positions (north, south, west and east) of the forest in relation to the field. Every field was under silage maize, hybrid Romario (FAO 250), harvested in September each year in milk wax ripeness. Field management included tillage and fertilizer application with recommended rates of 140 kg N, 30 kg P and 120 kg K per ha. Weeds were controlled chemically with atrazine-containing compounds throughout all fields, including the crop edges. The fields were determined by the following criteria: at least 300 m wide, with a sharply defined line between forest and crop; a maximum slope of 3 %; a similar soil type; an average forest height of 25 ± 2 m. The forest edges without a shrub strip comprise oak (*Quercus robur* L.), pine (*Pinus sylvestris* L.), ash (*Fraxinus excelsior* L.), beech (*Fagus sylvatica* L.) and birch (*Betula pendula* Roth.).

Sampling was carried out twice a year, in late June and early September 1997 through 2001 on a transect perpendicular to the forest up to 150 m into the field. In 1997, we sampled one treatment on each of the four cardinal points, while every following year the sampling continued with one experimental field (1998: south, 1999: west, 2000: east and 2001: north). The minimum and maximum distances between two transects were 0.6 km and 4.8 km, respective-

Table 1: Average year temperatures, sums of precipitation and duration of sunshine in the sampling area (MT9)
Tabelle 1: Durchschnittliche Jahrestemperatur, Niederschlagsmengen und Sonnenscheindauer im untersuchten Gebiet (MT9)

Year	1997	1998	1999	2000	2001	30-year mean (1961–1990)
Annual mean temperature [°C]	8.2	8.7	8.9	9.6	8.3	7.9
Annual total precipitation [mm]	520.4	437.5	426.7	456.1	605.9	525.9
Annual duration of sunshine [h]	1679.1	1781.8	1793.7	1801.4	1681.2	1668.3

ly. The time period between the two samplings represents the growth development in the mid-season stage, including flowering and grain setting (over 70 % of harvesting biomass; DOORENBOS and PRUITT, 1977), and the late season stage up to milk wax ripeness. The height of the maize plants (n = 10) was measured at each sampling point (i.e. at distances of 1, 5, 10, 20, 40, 60, 80, 100, 125 and 150 m from the forest and in each of the four cardinal points and particular fields). At the same time, 20 plants from each sampling point were collected in order to assess the mean plant dry matter.

The average plant height [cm] of ten measured individuals in each position was multiplied by an index of dry biomass calibrated for each field and distance from the relationship between height and actual dry biomass. The coefficient of determination (R^2 between 0.83 and 0.97) indicated that the dry biomass index (further referred to as biomass) calculated from the plant height could be taken as a measure of crop yield for the purposes of this study.

Concurrently, different levels of light intensity were investigated across the transects. The integrated values at each of the distances were derived from five point measurements divided regularly through a whole day (dawn to dusk) using two PU 550 digital luxmeters situated immediately above the level of the plants. The relative light intensity [%] was calculated as the ratio of illumination intensity [lx] at each distance to the value of 150 m.

The means of the biomass of all plants at particular distances from the edge and the positions were considered as independent units (explained variable). The log-transformed biomass values were fitted using general linear models (GLM) for both June and September data sets in which the site, edge position and distance from the edge represented the explanatory factors. The light exposure of the fields was fitted using multiple logistic regression in a generalized linear model with binomial error term ($\text{GLIM}_{\text{binom}}$) and the same explanatory factors mentioned above (i.e., site, edge position and distance from the edge). The presented most parsimonious models (Tables 2 and 3) are based on minimizing the AIC (Akaike Information Criterion) statistic (CRAWLEY, 2002). All statistical calculations were performed with S-Plus for Windows (S-Plus, 1999).

Table 2: Significance of edge position and distance from the edge in accumulation of maize biomass on experimental fields until June and September (GLM, Type III tests)
Tabelle 2: Signifikanter Zusammenhang zwischen Heckenausrichtung bzw. Disanz von der Hecke und Biomassenakkumulation auf … Versuchsflächen bis Juni bzw. September (GLM, Type III-Test)

Period/Factor	***F* – value**	***P***
June		
Edge position	$F_{3,75}$ = 11.88	< 0.0001
Distance from the edge	$F_{1,75}$ = 73.51	< 0.0001
Edge position * Distance from the edge	$F_{3,72}$ = 6.63	0.0005
September		
Edge position	$F_{3,75}$ = 5.57	0.0017
Distance from the edge	$F_{1,75}$ = 47.55	< 0.0001
Edge position * Distance from the edge	$F_{3,72}$ = 7.64	0.0002

Table 3: Significance of edge position and distance from the edge on the illumination along transects from the edge to the midfield on eight experimental fields until June and September (logistic regression, Type III tests)
Tabelle 3: Signifikanter Zusammenhang zwischen der Heckenausrichtung und Entfernung von der Hecke auf den Lichteintrag entlang der Versuchsflächen vom Heckenrand bis zur Feldmitte bis Juni bzw. September (Type III-Test)

Period/Factor	***F* – value**	***P***
June		
Edge position	$F_{3,75}$ = 56.87	< 0.0001
Distance from the edge	$F_{1,75}$ = 184.09	< 0.0001
Edge position * Distance from the edge	$F_{3,72}$ = 0.19	0.90
September		
Edge position	$F_{3,75}$ = 22.93	< 0.0001
Distance from the edge	$F_{1,75}$ = 90.28	< 0.0001
Edge position * Distance from the edge	$F_{3,72}$ = 0.52	0.67

3 Results

The most parsimonious models for the June and September data set includes a highly significant distance from the edge nested within edge positions (Table 2). These results indicate that both distance from the edge and edge position strongly affected the growth of maize biomass. Moreover, the highly significant interaction between edge position and distance from the edge rejects the assumption of a consistent pattern in biomass accumulation along the transects from the edge to the midfield among the four edge positions. The June model explains 68.1 % of the total variance and the September model explains 57.3 % of the total variance of biomass accumulation.

In general, maize biomass accumulation increased positively with distance from the field edge, but the patterns along each transect varied among the edge positions. The most marked contrast among edge positions in June was that north field positions achieved 162 g ± (SD) 37.3 g of individual plant biomass compared to only 108 g ± 56.1 g in south positions, while the remaining west and east posi-

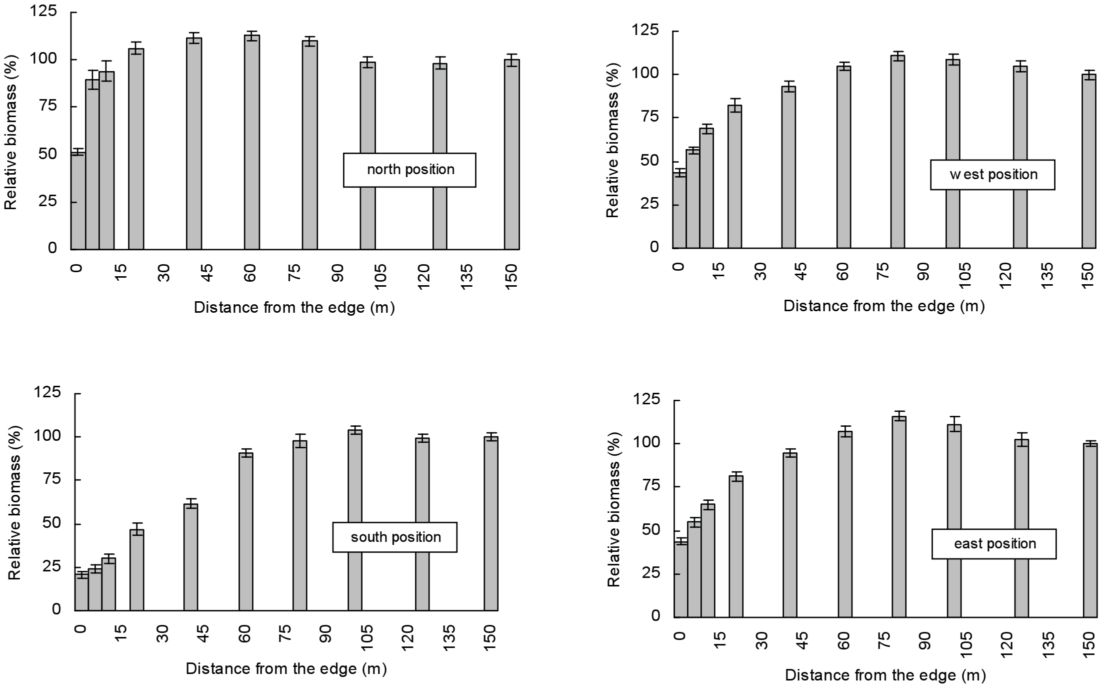

Figure 1: Patterns of relative biomass along edge-field gradient in four edge positions in June. The standard errors are indicated. The mean yield at 150 m distance from the edge represents 100 %

Abbildung 1: Verläufe des relativen Biomassegehaltes in Abhängigkeit von der Distanz zur Hecke für alle Arten der Heckenausrichtung im Juni (Biomasseer.... in 150 m Entfernung … 100 %)

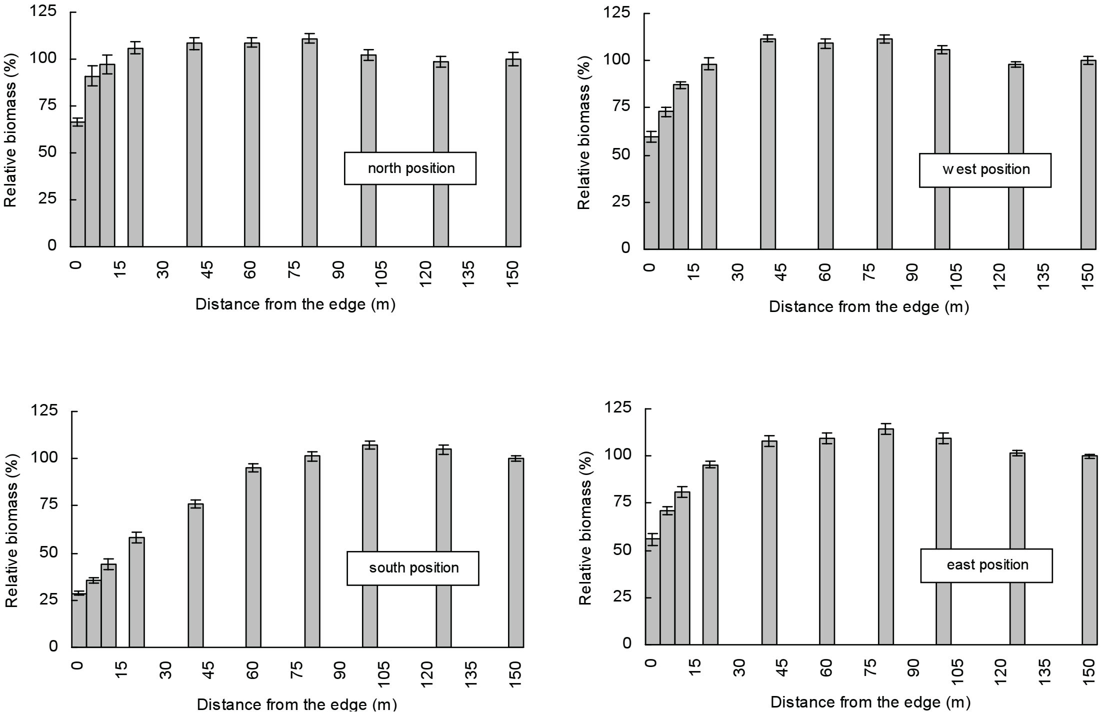

Figure 2: Patterns of relative biomass along edge-field gradient in four edge positions in September. The standard errors are indicated. The mean yield at 150 m distance from the edge represents 100 %

Abbildung 2: Verlauf des Biomassegehaltes in Abhängigkeit von der Distanz zur Hecke für alle Arten der Heckenausrichtung im September tions demonstrated intermediate values (127 g ± 37.8 g and 130 g ± 39.8 g, respectively). September biomass was accumulated in a similar pattern, i.e. 181 g ± 26.2 g in north positions contrasting with 147 g ± 62.7 g in south positions and intermediate biomass in west and east positions (174 g ± 35.3 g and 178 g ± 41.3 g, respectively).

The strongest edge effect appeared in south field positions (similarly in June and September; Figs 1 and 2) where maize plants situated between 1 and 5 m from the edge stagnated in growth deeply below 50 g in June and below 100 g in September, achieving only 22–31 % of the field biomass maximum in 80–150 m (161 g ± 20.9 g and 201 g ± 28.9 g in June and September, respectively). In contrast, north field positions were characterized by only a narrow strip being afflicted by an edge effect: the plants positioned immediately at the edge (1 m) achieved 47–61 %, but at 5–10 m from the edge they already achieved 83–87 % of the field maximum, which was at 20–80 m (184 g ± 20.7 g and 199 g ± 14.0 g in June and September, respectively). The west and east edge positions showed similar results (intermediate in comparison with the south and north positions), a slowly attenuating edge effect up to 40–60 m from the edge. Plant biomass in this position varied between 38–39 % (June) and 48–53 % (September) right at the edge (1–5 m) compared to the field maximum at 80 m, where the biomass rose up to 166 g ± 18.6 g in June and 209 g ± 26.3 g in September.

The accumulation between June and September did not correlate with June biomass and distance from the edge (GLM: $F_{1,74}$ = 0.70, P = 0.41 and $F_{1,74}$ = 0.32, P = 0.57, respectively). However, it differed significantly among edge positions ($F_{3,74}$ = 7.94, P = 0.0001). The north positions accumulated little biomass in comparison with west and east positions, which gathered the most biomass, and south positions, which achieved intermediate values (Figure 3).

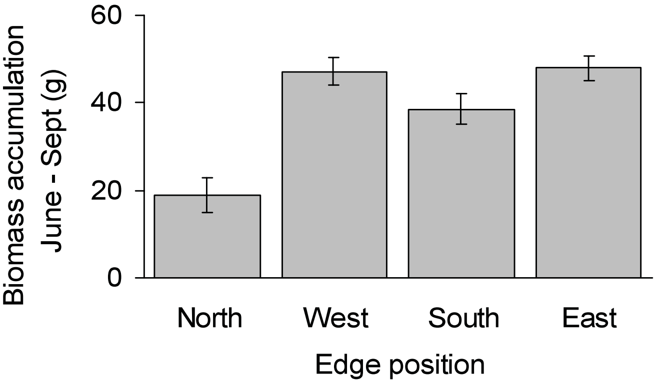

Figure 3: Biomass accumulation from June to September in edge positions (The standard errors are indicated)

Abbildung 3: Biomasseanreicherung von Juni bis September für alle Formen der Heckenausrichtung (Standardabweichung ivL ausgewiesen)

The model describing the pattern of illumination along transects from the edge to the midfield in June presents both factors, distance from the edge and edge positions, as highly significant (Table 2). A similar pattern was found producing such a regression model for the September illumination data. The increase in illumination from field edge to the midfield (as a standard pattern) was strongest at south field positions in both periods, while the smallest differences were found in north and west positions (Figure 4). The June model explains 77.1 % of the total deviance and the September model explains 62.8 % of the total deviance of relative light intensity.

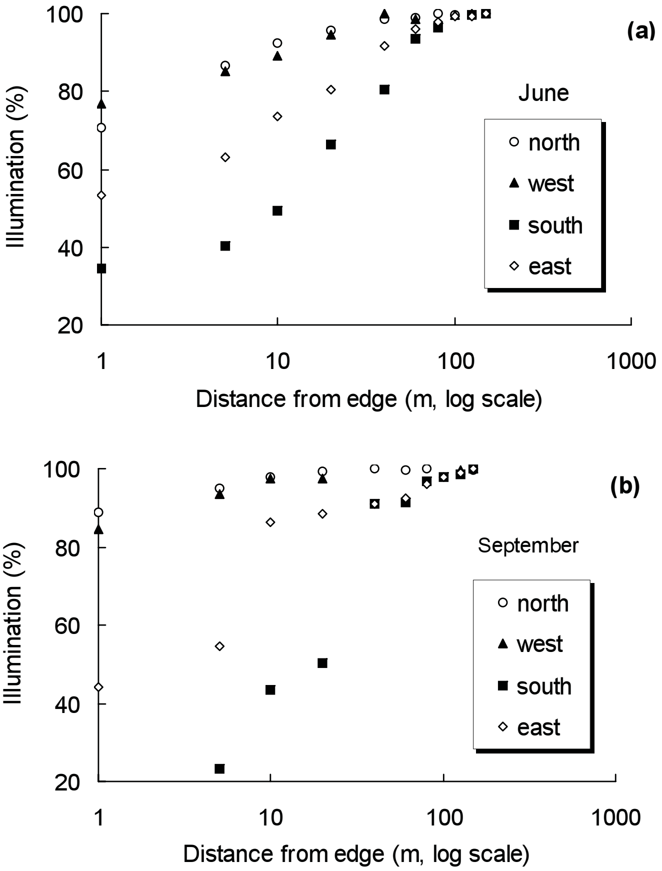

Figure 4: Relative illumination [100 % = in distance 150 m] in maize fields in relation to the edge in four edge positions (north to east) in June (a) and September (b)

Abbildung 4: Lichteintrag abhängig von der Distanz zur Hecke für alle Formen der Heckenpositionierung (100 % = in 150 m Entfernung)

4 Discussion and conclusions

The negative effect of edges located north of the crop did not extend beyond the first 20 m, and all plants accumulated at least 80 % of the biomass of plants from further field. For south situated edges, the dry yield declines up to 60 m from the edge, with up to 70 % growth reduction right at the edge compared with the field interiors. Edges located west and east have an impact up to 40 m but growth reduction did not exceed 50 %. Edges located north contrasted strongly with the edges in south position. In fact, the south positions are also open to north winds. However, the east positions should be affected in a similar way by the prevalent west winds, and the plant growth pattern should thus differ from the west positions, which is evidently not true. Comparable pattern of plant growth in the west and east edge positions thus seem to be rather a result of light exposure (measured on the sites) and of shade duration, because our treatments showed that the pattern of light exposures in west positions resembled those in the north positions more than those in the east positions.

We hypothesized that growth intensity of maize between June and September will follow a growth corresponding to the previous period, i.e. until June, as a result of microhabitat features given by the distance of the edges. In fact, biomass accumulation between June and September was not primarily affected by distance from the edge. We suggest that the north positions were the most productive until June (due to low edge effect) but their accumulation was retarded late in the summer in comparison with other positions (probably due to effect on phenology), so that the differences decreased in the period shortly before harvesting. Such a result may have been obtained due to the compensatory effect of plant growth under favourable weather conditions during late summer.

The results of this study reflect an aggregate impact of forest edges on crop production under conventional management, and an intimate estimation of individual factors would not be correct. Shading and root competition of forest edges are suggested to be relevant factors resulting in yield variability. Light exposure appears to be a key factor determining the distance of negative effects, while tree root competition is a substantial factor having an effect at relatively short distances from the edge. Mentioned negative factors reducing yields at the edges constrained positive effect of organic matter supply through leaf fall and decomposition. The criteria of site selection and crop management (especially pesticide use) suppressed some other potentially relevant factors (e.g. weed competition, pest and disease incidence, water erosion, etc.), except for soil compaction, which can be a significant negative factor a few metres from the edge due to more intensive agricultural wheel traffic in the crop margins (SKLENICKA et al., 2002).

Our results correspond with the general trends revealed by SPARKES et al. (1994) and COOK and INGLE (1997) for yields to increase with distance. We detected the highest yields of dry biomass at a distance between 80 and 100 m from the edge in all transects and at both times of sampling. However, after this distance the yields again decreased slightly (probably as an effect of winds). This observation corresponds with the results of KROULIK (1991) and CERMANEK (1994), and might mean that there are positive aspects of the edge effect in action, which are still strengthening at distances where negative aspects (shading and root competition from trees, soil compaction) no longer have any effect. Positive aspects are provided by natural habitats surrounding crop fields affecting microclimatic parameters of field margins (KUEMMEL, 2003), comprising a broad range of natural enemy species to assist in biological pest control, e.g. ground beetles (FRENCH et al., 2001) or birds (JOBIN et al., 2001). Another positive effect of tree edges is to provide shelter from wind – i.e. to alter the mean windspeed, wind direction and turbulence of airflow modifying plant and soil environment (e.g. water use by plants), reducing leaf damage etc. (EASTERLING et al., 1996; CLEUGH, 1998). However, small differences of biomass accumulation along the transects between edges located west (prevailing wind direction) and east do not confirm a key role of this factor in our study. These effects have rarely been evaluated in yield or monetary terms at farm level (OSTMAN et al., 2003). Our observations carried out on maize correspond with findings for other crop species (e.g. BOATMAN, 1992; COOK and INGLE, 1997; WILCOX et al., 2000). The results can be implemented in landscape planning for the design of new woodlots within the mosaic of rural landscape. The results may also be a relevant basis for cropfield design in a land-consolidation programme to divide the crop margins among several landowners, or to find the optimal landowner, taking into account the specific function of these buffer zones. New woody elements in rural landscapes should be predominantly designed with a minimum portion of forest edges located south of crop in order to minimize the negative edge effect on crop yields in the crop margins. Alternatively, the south crop margins along the forest edges could be considered as an extensive part of the farmland, and should thus be preferentially treated as unsprayed crop edges or grassy strips and set aside as refuges for biological diversity in wildlife management programs (e.g. MURPHY, 1997; PITKÄNEN and TIAINEN, 2001; DENYS and TSCHARNTKE et al., 2002). Moreover, such crop margin management minimizes the deleterious effects on bordering wildlife habitats.

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