Introduction

Increased interest in studies of ecological phenomena across groups of ecosystems is due both to changes within ecology and to attempts to limit environmental hazards. During the past few years, a new ecological discipline has emerged—landscape ecology, which deals with the influence of spatial pattern on biotic and abiotic functioning (Naveh and Lieberman 1984, Forman and Godron 1986, Turner 1987). The problems of spatial heterogeneity significantly distinguish research in landscape ecology from ecosystem studies, the latter typically neglected phenomena occurring in boundary zones. Landscape ecology, in contrast, deals specifically with spatial patterning, including the influence of landscape boundaries on the flow of energy, material, and organisms (Forman 1987, di Castri et al. 1988).

Studies carried out or coordinated by the Institute of the Agrobiology and Forestry of the Polish Academy of Sciences in Poznań provide long-term information on variation of microclimatic conditions, energy flow, and material cycling in agricultural landscapes (Ryszkowski 1974, 1975a, 1979, 1985, Ryszkowski and Karg 1976, Ryszkowski and Kedziora 1987). The results of these investigations are used in this chapter to describe the effects of shelterbelts on the microclimate of adjoining fields. Shelterbelts (midfield rows of trees) are a form of boundary zone or ecotone, which are
common in agricultural landscapes. They are planted primarily because they ameliorate microclimatic conditions in adjoining fields (e.g., Jensen 1954, Caborn 1976, Guyot and Seguin 1976, Karlinski et al. 1979). A brief overview of research on microclimatic characteristics around shelterbelts are presented to provide physical background for discussion of energy and matter fluxes across shelterbelts. The chapter examines the partitioning of solar energy into various components of heat balance in different ecosystems of agricultural landscapes. Ecotones are thought to control material fluxes across landscapes (di Castri et al. 1988). Evidence of this process is scarce and deals mainly with the riparian vegetation control of nutrients leaching from cultivated fields (Peterjohn and Correll 1984, Cooper et al. 1987, Odum 1987). In this chapter, the evidence for ecotone control of material fluxes is expanded to midfield shelterbelts. This control function is explained in terms of the relatively high solar energy use for evapotranspiration caused by the structure of the vegetation stand.

**Description of the Agricultural Landscape**

The study area is near the Research Station of the Institute of Agrobiology and Forestry, Polish Academy of Sciences, near the village of Turew in west central Poland, about 40 km southwest of Poznań. The terrain consists of ground moraine and is slightly undulating; the slope does not exceed 4%. Topographic relief of the area does not exceed several meters. A drainage canal, 4 m wide, runs across the study area. Drain pipes that are distributed over the area carry subsurface water from land to the canal.

The climate is relatively warm, with an average annual temperature of 8°C. Mean temperature is 18°C for July and −2.4°C for January. The growing season, with air temperatures higher than 5°C, lasts 225 days. The average annual precipitation for the period 1881–1985 is 527 mm, of which almost 85% is used for evapotranspiration (Ryszkowski and Kedziora 1987). Mean annual runoff of water is 80 mm per m². Westerly winds prevail, with an annual average speed 2.5 m/s. Wind erosion is not a problem in the area of study, although, dry springs with very strong dust winds happen once every several years.

Generally, the distribution of crops in arable fields consists of 50% cereals (rye, wheat, barley, and oats), about 25% row crops (beet, potato, as well as rapeseed), 10% perennial fodder crops, and 15% other crops. Shelterbelts are characteristic components of the Turew landscape. They were planted in the 1820s and used as enclosures for cattle and sheep pasturing and also served to moderate microclimate conditions of adjoining fields.

Trees common in shelterbelts in the study area include false acacia (*Robinia pseudoacacia* L.), oak (*Quercus robur* L., *Q. petraea* Liebl.), maple (*Acer platanoides* L., *A. pseudoplatanus* L., *A. negundo* L.), poplar (*Populus nigra* L.), linden (*Tilia cordata* Mill.), and birch (*Betula verru-
coso Ehrh.). In the bush layer of shelterbelts there are common hawthorn (Crataegus oxyacantha L.), dog rose (Rosa canina L.), alder buckthorn (Rhamnus frangula L.), and black cherry (Padus serotina Ehrh.). Black alder (Alnus glutinosa L.) prevails along drainage canals. The shelterbelts form an irregular network having a length of 400–700 m, usually in a south–north direction, and a distance interval between them of 200 to 400 m. Most shelterbelts have a height of 12–17 m. Besides shelterbelts, small wood lots of the same tree composition as in shelterbelts also occur in the landscape.

Effect of Shelterbelts on Microclimate of Adjoining Fields and Entire Landscapes

Shelterbelts within an agricultural landscape are considered here to represent a type of ecotone. In this section, I summarize review studies by Ryszkowski (1975b) and by Ryszkowski and Karg (1976) on microclimates near shelterbelts. These works offer insights into how ecotone characteristics can influence local climate.

These studies show that shelterbelts strongly influence wind velocity (Fig. 13.1). The sharpest reduction in the wind velocity extends from 4 to 8 times the shelterbelt height in the leeward direction. A shelterbelt of moderate penetrability to the wind provides more effective shelter than a dense one (Rosenberg 1974). The partially transparent texture of the shelterbelt splits the wind into two streams, one bending over the nontransparent canopy of the trees and the second passing between the stems of the trees. When those two streams of wind meet in a leeward direction of shelterbelt, air turbulence is formed, which slows down wind speed.

The cumulative effect of consecutive shelterbelts on wind speed is a decrease in the mean wind rate over the area covered with shelterbelts. Jensen (1954) showed that the velocity of wind blowing form the North Sea is reduced by almost 50% in the portions of Jutland, Danmark, that are covered with numerous shelterbelts. Wind speed is reduced by only 20% in the southern part of the Jutland, where open areas predominate. Shelterbelts also influence the distribution of rainfall in adjoining fields. The distribution of rain fall and snow cover are affected by the eddy currents around shelterbelts. The change in wind velocity also influences the atmospheric evaporative demand, which, in general terms, is proportional to the square root of wind velocity. The latent heat of water vaporization (2.5 kJ per g) has a cooling effect on soil or plant temperature, whereas moderate moisture increases the heat conductivity of soil. Thus, the balance of these two factors determines the depth of the affected soil layer, which usually is restricted to the uppermost horizon. In the case of Turew's sandy soils, no influence of shelterbelt on soil temperature was detected at a depth of 0.2 m within a zone between 4 and 8 times the height of the shelterbelt in a
Figure 13.1. Effect of shelterbelt on microclimate of adjoining fields. Distance from the shelterbelts is expressed in units equal to shelterbelt height (h) (after Ryszkowski 1975).
leeward direction. The shelterbelts did apparently decrease the evapotranspiration rate in the zone from 4 to 8 times the shelterbelt height in the leeward direction. At the same time, trees in shelterbelts transpire more water than cultivated plants in open fields. Taking all factors influencing evapotranspiration into account, one can show that the landscape with shelterbelts transpires more water during the vegetative season than the landscape composed only of cultivated fields (Ryszkowski and Kedziora 1987). However, in early spring, the landscape area with shelterbelts can collect about 20 to 80 mm more water than an open landscape (Molga 1983). This is due to the fact that surface runoff after spring rains is smaller in landscapes with shelterbelts. Therefore, one can conclude that landscape with shelterbelts is characterized by more efficient water economy that open landscape.

**Energy Flow in the Agricultural Landscape**

The balance among all sources of incoming and reflected solar radiation, as well as energy emitted by the active surface, defines the amount of energy intercepted by the landscape. This balance is termed the net radiation (Rn) and it determines the amount of energy available for the internal working of ecosystems. Net radiation can be partitioned into latent heat used for evapotranspiration (LE), sensible heat used for air heating (A), and soil heat (S).

The flow of energy in the study area was estimated using site-specific, empirical equations (Kedziora et al. 1987, Olejnik 1988) relating climatological characteristics of an ecosystem (air and soil temperatures [T], relative sunshine [u], wind speed [v], vapor pressure [e], saturation deficit [d], precipitation [p], and humidity [h]) and incoming and reflected solar radiation with stage of vegetation growth and components of ecosystem heat balance (LE, A, S). The data on climatological characteristics were obtained from micrometeorological measurements carried out at a height of 2 m above the active surface. In various ecosystems of the Turew landscape during 3–4 days, a series of consecutive samplings were carried out every 1 or 2 hours. Series of 3- to 4-day measurements were repeated each month of the plant growth season (see Kedziora et al. 1987 for more details). The method of mean profiles was used to obtain latent and sensible heat fluxes (Oke 1978); measurements were made with quartz psychrometers with sensitivity of 0.01° C distributed at six heights above ground, with each making 60 measurements every 12 minutes. Soil heat flux was measured using the heat transducer method and the heat capacity method (Taylor and Ashcroft 1972). Incoming and reflected solar radiation was measured under field conditions by use of a Kipp–Zonnen solarimeter. Also, Rn was both measured directly by the use of a Sontag net-radiometer and calculated based on established equations (Ryszkowski and Kedziora 1987).
Table 13.1. Heat Balance Structure (MJm\(^{-2}\)) and Evapotranspiration (mm) During the Growing Season in the Study Area

| Parameter\(^b\) | Shelterbelt | Meadow | Rapeseed Field | Beet Field | Wheat Field | Bare Soil |
|-----------------|-------------|--------|----------------|------------|-------------|-----------|
| Rn              | 1730        | 1494   | 1551           | 1536       | 1536        | 1575      |
| LE              | 1522        | 1250   | 1163           | 1136       | 1090        | 866       |
| A               | 121         | 215    | 327            | 339        | 385         | 651       |
| S               | 87          | 29     | 61             | 61         | 61          | 47        |
| LE:Rn           | 0.88        | 0.84   | 0.75           | 0.74       | 0.71        | 0.55      |
| E               | 609         | 500    | 465            | 454        | 436         | 346       |

*Modified from Ryszkowski and Kedziora 1987.

\(b\) Rn = net available energy; LE = latent heat flux; A = air-sensitive heat flux; S = soil-sensitive heat flux; E = evapotranspiration in mm.

vegetation growth stage, in terms of relative height, was estimated directly for each ecosystem under study.

The results showed that the amount of absorbed radiation energy was relatively high when the area receiving solar radiation had a high moisture content, a rough surface, and dark coloration. For instance, a meadow with a relatively smooth surface and light-colored grasses absorbed about 230 MJm\(^{-2}\) less during the growing season than did a shelterbelt (Ryszkowski and Kedziora 1987; see also Table 13.1). In the absence of drought, the shelterbelts not only intercepted more light than meadows but also used 88% of the absorbed energy for evapotranspiration. This resulted in evapotranspiration of over 100 mm of water more than from the meadow. Similarly, significant differences in the amount of absorbed energy and evapotranspirated water were found between the shelterbelts and the fields under wheat, rapeseed, or best crops (Table 13.1). The fields with crops as different as wheat, rapeseed, and sugar beet showed similar characteristics of the energy flow or evapotranspiration, but all were different from the shelterbelts and the meadows. For example, arable fields used less of the net available radiation for evapotranspiration but used more of intercepted energy for air heating than did shelterbelts and meadows.

The energy exchange across the boundaries separating each ecosystem provide a reason why the value of energy flux at the landscape level is less variable than in the case of the ecosystems considered in separation. For instance, the exchange of heat energy between the ecosystems will take place when there exists a thermal gradient between them (i.e., the direction of energy flux will be a decrease—from the ecosystem using more of the intercepted solar energy for air heating toward the ecosystems using less energy for air heating, Thom 1975). The differences in air temperatures over the ecosystems will result mainly from the differences in evapotrans-
piration rates. Additionally, the flowing energy can be assimilated by an ecosystem only when the positive vertical temperature gradient is formed over it (inversion). Intensively transpiration plant cover with good water supplies causes strong inversions (Thom 1975). Heat flow from one ecosystem to the other (according to temperature gradient) is possible only when the direction of the air mass flow (wind) is in agreement with the thermal gradient (Thom 1975).

That the assimilation phenomena of the horizontal heat flow (heat advection) occurs in the study area is shown by the fact that a greater amount of energy is sometimes used for evaporation and air and soil heating than the net radiation value. As found in studies by A. Kedziora (personal communication, October 1989), rain occurred May 15, 1984, and the next day, an inflow of warm air was observed. The mean 24-hour temperature increased from 11.7°C to 15.8°C (Table 13.2). Because of high rate of evapotranspiration in the rapeseed field, a temperature inversion over the field occurred (change of sign in temperature vertical gradient denoted by dT/dz values) and 75 W m⁻² were absorbed from passing warm streams of air. The temperature inversion could appear not only after rain but also when evapotranspiration is very high. The available Rn was high (relative sunshine was equal to almost 0.6) on June 12 and provided enough energy for evapotranspiration (Table 13.2). However, on May 13, the sky was completely overcast (relative sunshine was equal to 0), while good moisture conditions of soil allowed high evapotranspiration, which cooled the active surface, creating a horizontal temperature gradient between the rapeseed field and the adjoining plowed soil. Under such conditions, 50 W m⁻² were absorbed by the rapeseed field from warmer air passing from the plowed field (Table 13.2). The values of additionally absorbed energy by advection heat amounts to 28% and 35% of the net radiation, respectively. The results show that there is exchange of energy between ecosystems by heat advection, a process not previously documented in the ecological literature. This phenomenon results in the structure of the heat balance of the whole landscape differing from the average of the constituent balances of each ecosystem considered separately. Effects of horizontal energy absorption lead to a decrease in the variability of energy distribution over the landscape. This phenomenon is more pronounced as landscape heterogeneity increases.

**Material Flux across Ecosystem Boundaries**

To understand landscape functioning, it is important to recognize the interchange of water between ecosystems. Flux of water determines the transport of many chemical compounds. Meadows and shelterbelts are biological barriers that can control migration of different chemical compounds with water (Ryszkowski and Bartoszewicz 1989).
Table 13.2. Horizontal Transfer of Heat Energy in Agroecosystems

| Date          | Active Surface (Rapeseed Height) | Mean Weather Conditions for 24 Hours | Vertical Gradients | Heat Balance Component (W · m⁻²) |
|---------------|----------------------------------|-------------------------------------|--------------------|----------------------------------|
|               |                                  | T°C  | v (m/sec¹) | u     | P (mm) | dT/dz | de/dz | dv/dz | Rn | LE | A  | S  | B  |
| May 15, 1984  | 1.3 m                            | 11.7 | 1.4       | 0     | 7.9    | -0.12 | -0.28 | 0.69  | 100 | -53 | -15 | -35 | -2 |
| May 16, 1984  | 1.3 m                            | 15.8 | 2.9       | 0.256 | 0      | +0.27 | -0.64 | 1.84  | 266 | -263 | +75 | -65 | -6 |
| June 12, 1984 | 1.1 m                            | 10.3 | 1.7       | 0.599 | 0      | -0.11 | -0.75 | 0.67  | 333 | -244 | -44 | -24 | -4 |
| June 13, 1984 | 1.1 m                            | 13.2 | 1.9       | 0     | 0      | +0.52 | -0.95 | 0.79  | 142 | -150 | +50 | -36 | -4 |

*After A. Kedziora, personal communication, October 1989. Abbreviations are T = air temperature; v = wind speed; u = relative sunshine, dimensionless; p = precipitation (mm); z = measurement height (m); Rn = net radiation; LE = latent heat; A = sensible heat; S = soil heat; B = heat stored in plant; boldfaced type = absorbed energy from horizontal flow of warm air.*
Table 13.3. Annual Nitrate Leaching Associated with Different Crops

| Crops         | Number of Catchment Areas | Concentration of N–NO₃ in Drainage Water (mg, dm⁻³) | Leaching of N–NO₃ (kg·ha⁻¹) |
|---------------|---------------------------|----------------------------------------------------|-----------------------------|
| Sugar beets   | 7                         | 15.1 ± 2.2                                         | 23.2 ± 20.3                 |
| Maize         | 8                         | 12.1 ± 3.7                                         | 12.4 ± 6.4                  |
| Winter wheat  | 2                         | 12.5 ± 0.7                                         | 9.6 ± 2.0                   |
| Alfalfa       | 4                         | 6.1 ± 1.4                                          | 3.4 ± 2.3                   |

*Modified after Borowiec and Zablocki 1987. Data are means and standard deviations.

Their effects are related to the interesting, though poorly understood, influence of plant cover on chemistry of ground water. Experimental changes in plant cover over watersheds (e.g., defoliation and various methods of tree felling) indicated great influence of plant cover on water chemistry (e.g., Likens and Borman 1972, Likens et al. 1977, Swank and Douglass 1975). The kind of arable crop similarly affects the amount of chemical compounds leached out by water. Analyses of chemical composition of the water carried by drains from the experimental catchment areas indicated that the amount of leached nitrate from under sugar beet and maize is higher than from under winter cereals and alfalfa (Table 13.3; also, Borowiec and Zablocki 1986, 1987). Because of simpler structures than are found in other ecosystems, agroecosystems have a less complex network of interrelations among their components. As a consequence of the simplification of agroecosystem, the functional interrelations among components are changed so that there is less tie-up of the local cycles of matter (Ryszkowski 1975a). This leads to increased leaching, blowing off, volatilization, and eventual escape of various chemical compounds and materials from agroecosystems.

Analyses of concentration of different ions in ground water flowing from cultivated field through shelterbelt root systems revealed a considerable decrease in nitrate concentrations. In 3 consecutive years, A. Bartoszewicz (personal communication, October 1989) found a 19-fold decrease in nitrate concentration in ground water passing under shelterbelts (Table 13.4). She also found a decrease in concentration of other ions, including NH₄⁺, PO₄³⁻, K⁺, Ca²⁺, Mg²⁺, Na⁺, Cl⁻, SO₄²⁻. (This was not true for Ca²⁺, Na⁺, Cl⁻, and SO₄²⁻ during the last year of research, when higher rainfall occurred. The explanation for these exceptions is unknown.) These results confirmed what had been found earlier (Ryszkowski and Bartoszewicz 1989), namely that shelterbelts can effectively limit water migration of various chemical compounds. Similar effects were found in riparian forest by Peterjohn and Correll (1984) and in shelterbelts near lake shores by Pauliukevicius (1978). Trees have well-developed root systems, and therefore much more ground water is within their range than is the case for the
Table 13.4. Mean Concentration of Elements (mg·dm) in Ground Water under Cultivated Fields and under Adjacent Shelterbelts for 3 Consecutive Hydrological years (Nov. 3–Oct. 30)

|                | Field          | Shelterbelt     |
|----------------|----------------|-----------------|
|                | 1985–1986–1987| 1985–1986–1987–|
| Number of samples | 12 (11) (7) | (12) (10) (9)  |
| N–NO₃         | 44.0 51.9 37.9 | 2.3 2.6 8.0   |
| N–NH₄        | 1.4 2.5 2.0   | 1.2 1.3 1.8   |
| P–PO₄⁻³      | 0.14 0.28 0.77 | 0.12 0.11 0.21|
| K⁺             | 8.7 9.3 5.5   | 4.5 3.7 6.7   |
| Ca⁺²         | 241.0 217.0 172.0 | 129.0 126.0 186.0 |
| Mg⁺²         | 57.5 63.3 55.5 | 24.4 29.1 44.5|
| Na⁺            | 31.1 31.4 18.9 | 21.3 23.1 26.0|
| Cl⁻              | 126.0 143.0 97.7 | 38.3 44.3 124.0|
| SO₄⁻²         | 214.0 256.0 189.0 | 128.0 165.0 303.0|

*From A. Bartoszewicz, personal communication, October 1989.

shallower root systems of cereals and other crops. Also, tree crowns are located higher than cereal plant tops, and so they are subjected to stronger air turbulence. This biological structure of shelterbelts results in the fact that 88% of intercepted solar energy is used for evapotranspiration (Table 13.1). In other words, the biological structure of trees results not only in higher interception of solar energy by shelterbelts but also in the partitioning of intercepted energy, promoting evapotranspiration. Shelterbelts, thus, function as “ecological water pumps.” Because trees evapotranspire 22% more water than meadow and 34% more than cultivated fields (Table 13.1), their nutrient uptake is more intensive, and thus they affect changes in chemical composition of ground water that is within direct and indirect (capillary ascent) root range.

Shelterbelts consisting of several tree species (e.g., oak, birch, and pine) have more effective nitrogen uptake than those composed of only one species (Prusinkiewicz et al. 1990). This is because of different preference of these tree species to take up nitrate and ammonium ions during a year. When the three species occur together, both ion forms are taken with similar intensity throughout the whole growing period (Prusinkiewicz et al. 1990). The nutrient uptake by trees during the growing season in the Turew agricultural landscape was 4.5g N; 3 g P; 0.9 g K; 23 g Ca; and 0.33 g Mg per square meter.

Another mechanism effectively limiting ground water migration of various ions across shelterbelts is different cation-exchange capacity of soils under shelterbelts than under cultivated fields. Direct measurements of cation-exchange capacity indicated that absorptive properties of acid soils
Table 13.5. Influence of Plant Cover of Watersheds on Ion Leaching

| Type of Watershed          | Watershed | Percentage of Area |          | Outflow of Elements During 2 years (g · m⁻²) |          |          |          |          |
|----------------------------|-----------|--------------------|----------|--------------------------------------------|----------|----------|----------|----------|
|                            |           | Arable | Forests | Grasslands | N–NO₃⁻ | P–PO₃⁻ | K⁺ | Ca⁺² | Mg⁺² |
| Larger Contribution of Cultivated Fields | 1         | 53     | 12      | 35        | 1.63   | 0.03 | 3.32 | 37.66 | 2.82 |
|                            | 2         | 62     | 8       | 28        | 1.43   | 0.04 | 2.99 | 35.42 | 3.30 |
|                            | 3         | 53     | 32      | 13        | 1.13   | 0.04 | 2.57 | 30.95 | 2.28 |
|                            | 4         | 51     | 21      | 27        | 0.71   | 0.02 | 2.91 | 32.40 | 2.70 |
|                            | mean      | 55     | 18      | 26        | 1.22   | 0.03 | 2.36 | 34.13 | 2.78 |
| Smaller Contribution of Cultivated Fields | 1         | 38     | 44      | 17        | 0.60   | 0.02 | 1.58 | 23.33 | 1.80 |
|                            | 2         | 29     | 45      | 26        | 0.48   | 0.01 | 1.00 | 25.63 | 1.44 |
|                            | 3         | 21     | 65      | 14        | 0.39   | 0.01 | 0.91 | 22.54 | 1.56 |
|                            | 4         | 32     | 47      | 21        | 0.44   | 0.01 | 0.91 | 15.26 | 1.20 |
|                            | mean      | 30     | 50      | 19        | 0.48   | 0.01 | 1.10 | 21.69 | 1.50 |

*After Borowiec et al. 1978.*
in shelterbelts may have a significant role in the interception of nutrients if the soils are unsaturated and have the possibility to absorb passing ions (Prusinkiewicz et al. 1990).

Still another mechanism explaining change in nitrate ion concentration when ground water passes under shelterbelts can be denitrification processes (Peterjohn and Correll 1984). Meadows can also constitute effective barriers reducing migration of different ions from arable fields. It was shown in the study area that on average, 33 to 98 m P m\(^{-2}\) is leached out from fields each year. If the fields are separated from the drainage canal by a meadow about 80–90 m wide, then only 12 to 37 mg P m\(^{-2}\)·year\(^{-1}\) is leached to the canal (Ryszkowski et al. 1989). When the proportion of shelterbelts, forests, and meadows in the watershed area increases then the amount of leached chemical compounds decreases (Table 13.5).

In summary, these studies show that the agricultural landscape rich in ecotones loses fewer nutrients than the catchment area consisting only of cultivated fields.

**Role of Ecological Boundaries in Landscape Functioning**

As shown previously herein, only a part of the solar energy intercepted by an ecosystem is transformed into sensible air heat. For example, bare soil transforms for air heating during the growing season at 651 MJ m\(^{-2}\), while the figure for fields under sugar beets in 339 MJ m\(^{-2}\). The greater the difference in air temperatures between two ecosystems, the greater the possibility of exchange of heat energy between them. In order to approximate a magnitude of energy horizontally exchanged between adjoining components of the studied landscape the following calculations were done. Vertical flux of sensible heat over an ecosystem can be described with the following formula (Thom 1975):

\[
A = d_a \cdot C_p \cdot g \cdot \frac{\Delta T}{\Delta Z}
\]

Where \(A\) = vertical flow of heat in W m\(^{-2}\); \(d_a\) = air density (1.2 kg m\(^{-3}\)); \(C_p\) = specific heat of air (1004 J kg\(^{-1}\) K\(^{-1}\)); \(g\) = coefficient of heat exchange (approximately 0.02 m\(^2\) s\(^{-1}\)); \(\Delta T\) = difference in temperatures in Kelvins (K) between measured levels; \(\Delta Z\) = thickness of air layer meters. In cases where vertical temperature inversions exist and there is a gradient of temperatures between two ecosystems in question, then the horizontal heat flow (\(D_t\) in W m\(^{-2}\)) could be approximated by the following equation (Thom 1975):

\[
D_t = d_a \cdot C_p \cdot V \cdot Z \cdot \frac{\Delta T}{\Delta x}
\]
Where $V =$ wind speed (ms$^{-1}$); $Z =$ thickness of air layer carrying heat in m; $x =$ distance in m, other parameters as in Equation 1. Using the aforementioned equations, one can estimate, for example, the possibility of the exchange of air heat energy between a big shelterbelt and a rapeseed field, assuming the climatic conditions that prevailed in the study area. Thus, one can calculate the horizontal heat flow taking the value of $R_n$ for a summer day in a rapeseed field to be equal to 100 watts and that of shelterbelt to be 110 watts. These are characteristic values of net radiation for these ecosystems in the studied landscape. In the shelterbelt, 7% of net radiation value is transformed into sensible air heat, while on the rapeseed field, 21% of net radiation value is transformed into air heating. The difference in temperature between these ecosystems can amount to 0.6°K, which, assuming that energy flow occurs up to a distance of 100 m, gives a thermal gradient of 0.006 K·m$^{-1}$. Using Equation 2, it can be calculated that for these conditions, horizontal heat flux at a wind speed of 2 m sek$^{-1}$ and a 3-m thick layer of air transporting heat is 43 watts per square meter, which constitutes about 40% of the value of net radiation value for shelterbelts. This figure is an estimate; the real horizontal transfer of heat will be lower, depending on the other circumstances of the transport. Heat energy flowing over shelterbelts can be assimilated by it only when there is an inversion of temperatures (i.e., the shelterbelt surface and adjacent air layer are cooler than that of higher air layers). Then, depending on the inversion size, some part of flowing heat energy will be used for evapotranspiration. Thus, we deal with the following positive feedback: Higher evapotranspiration leads to higher inversion of air temperature, which leads to additional assimilation of heat energy for evapotranspiration. Certainly, this is possible when air movement is in agreement with the temperature gradient direction between ecosystems. If we assume the amount of energy used for evapotranspiration as an indicator of the possibility of producing air temperature inversion, then across the ecotones, when separating shelterbelts from cultivated fields, more heat is absorbed than through ecotones separating meadows and fields, and the least is absorbed across boundaries separating various arable crops. In the last case, exchange of heat energy can occur when there are seasonal differences in the growth rate of plants, which cause differences in evapotranspiration rates between two adjacent arable fields. For example, this can happen when there is rapid growth of stalks in rye cultivation and slow growth of beet seedlings on the other. The preceding analysis indicates the great role of differences in plant structure of the neighboring ecosystems in the exchange of heat energy between them. Large contrasts of plant structure also result in unique microclimatic conditions in ecotones. Changes in microclimate of arable fields brought about by shelterbelts in the study area are a particular example of this rule.

In conclusion, one can state that agricultural landscapes with great numbers of ecotones will function differently than those with more uniform
structures. Different characteristics of energy flow and matter cycling in the landscape with mosaic structure than in the uniform one result from modification of the energy flow and the matter cycling by the ecotones. At the same time, the ecotones play an important role in the control of transfers of energy and materials in the whole landscape, stabilizing their fluxes.

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