Energy control of matter fluxes through land–water ecotones in an agricultural landscape

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Abstract

Ecotones play an important role in control of matter input into water bodies. The impacts of shelterbelt and meadow ecotones on ground water passage from cultivated fields to pond were studied. The reduction of water flux due to evapotranspiration by shelterbelts and meadows on slopes of different steepness were estimated. The horizontal passage of heat energy between cultivated fields and ecotones, which enhances evaporation in shelterbelts and meadows was demonstrated. The reduction of ground water flux by a ten meter wide shelterbelt or meadow surrounding a pond can reach as much as 100 per cent when the slope is about 1 degree, during a sunny day. Shelterbelts are a more effective measure for control of cycling matter than meadows. The greater the slope of the water table and the more intensive the radiation and advective processes, the more distinct the differences between shelterbelt and meadow impacts on groundwater flow are.

Introduction

Studies on landscape ecology indicate that the spatial pattern of landscape elements modifies not only movements of organisms, including pests and pathogens, but also influences the water and chemical discharge of watersheds (Forman & Gordon, 1986; Turner, 1987). Thus, the quantity and quality of water exported from a watershed cannot be predicted solely from the characteristics of its cycling, in any ecosystem, within the watershed (Brinson et al., 1984; Preston & Bedford, 1988). In this context the concept of ecotone as a transition zone between adjacent ecological systems was reevaluated, in terms of its role in the control of matter fluxes and biotic diversity in various landforms (Di Castri et al., 1988). Concerning water quality in drainage systems, it was found that riparian ecotones play an important role in the control of matter input into water bodies (Naiman et al., 1988; Naiman & Décamps, 1990). The practical aspects of ecotone studies are expressed in the attempt to use riparian forests or meadows for limiting nonpoint sources of pollution (Pauliukevičius, 1978; Peterjohn & Correll, 1984; Ryszkowski & Bartoszewicz, 1989; Ryszkowski et al., 1989). The results of numerous studies of this important problem have been summarized by Ryszkowski et al. (1990).

Apart from this practical aspect of studies aimed at limiting nonpoint sources of pollution, it has been demonstrated that the structure of plant cover also influences the chemical composition of water occurring in catchment basins. Experimental changes induced in the watershed plant cover (such as defoliation, various patterns of tree cut-
ting etc.) have demonstrated the great role of forests in determining the water chemistry in streams trespassing upon the forest (Likens & Borman, 1972; Swank & Douglass, 1975; Likens, 1984; Risser, 1990; and others). All these studies have strengthened the opinion that plant cover of watersheds exerts control over the flow of materials in the landscape. But the control mechanisms of matter fluxes through ecotones or whole plant cover structures in various ecosystems are still only vaguely understood. For example, there is only sketchy information available on the impact of geomorphic characteristics, such as the steepness of slope, on water flow through ecotones. Because water flow is important for chemical exchange between ecosystems, the recognition of factors modifying water flow rate through ecotones, such as the steepness of slope, is of paramount importance for understanding the function of ecotone. To achieve this goal, the energies of water transport through ecotones, as well as the impact of changes in weather conditions involving incoming solar radiation, were evaluated.

**Area of study**

The agricultural landscape studied is situated in the vicinity of the village Turew, about 40 kilometers south of Poznan (16°45′ to 16°50′ E and 52°01′ to 52°06′ N). The area is slightly undulating, with slopes not exceeding 4 per cent and was formed as a ground moraine during the last glaciation. Height differences between its lower and higher parts do not exceed a few meters. Soils on the uplands (Udipsamment, Hapludalfs) are sandy and well drained to the ground water table, whereas those in the depressions (Haplaquolls, Psammaquents and Medisaprists) are poorly drained and rich in bases and organic matter (Marcinek et al., 1990). The landscape is crossed by a drainage canal (4 m wide) which collects water from drainage pipes and open ditches in the area.

The local climate, is rather warm, with an average annual temperature of 8 °C. The plant growing season, at air temperatures higher than +5 °C, lasts on average for 225 days. Mean annual precipitation for the period 1956–1975 was 604 mm (Paslawski, 1990), of which almost 85 per cent was used for evapotranspiration (Ryszkowski & Kędziora, 1987). Western winds, with an annual average speed of 4.0 m s⁻¹, prevail. The most frequent winds have a velocity of up to 2.0 m sec⁻¹ which is little over 60 per cent of all winds during the year (Woś, 1990). There is no problem of wind erosion in the study area, although in the period of dry springs, strong dust-winds occur once in several years.

About 82 per cent of the area is cultivated fields, grasslands, meadows and orchards. Generally, the crop structure of arable fields consists of 50 per cent cereals (rye, wheat, barley, oats), 25 per cent row crops (beets, potatoes), 10 per cent perennial fodder corps, and 15 per cent ‘others’. Shelterbelt (rows or clumps of trees) are characteristic of the landscape, together with small forests (14 per cent of the total area). The shelterbelts are located between fields, along ditches and canals, as well as along roads.

Our studies on influence of ecotones on passage of ground water were carried out in shelterbelts of 10 m width, separating cultivated fields from small ponds with an area of about 1000 square meters. Shelterbelt was composed mainly of black alders (*Alnus glutinosa* (L.)). The ecotone studied was a stretch of meadows of 10 m width, composed mainly of reed-grass (*Phalaris arundinacea* L.) smooth-stalked meadow grass (*Poa pratensis* L.) rough cock's-foot (*Dactylis glomerata* L.), and thistle (*Carduus crispus* L.).

**Methods**

The energy flow and water cycling were studied by a variety of climatological, hydrological and ecological methods described in detail by Kędziora *et al.*, 1987; Ryszkowski & Kędziora, 1987; Olejnik, 1988; Kędziora *et al.*, 1989; Kędziora & Tamulewicz, 1990; Marcinek *et al.*, 1990; Paslawski, 1990.

Climatological characteristics, such as air and
soil temperature, sunshine, wind speed, vapour pressure, saturation deficit, precipitation and humidity were measured by standard methods under field conditions. The incoming and reflected solar radiation were measured under field as well. Net radiation was either measured directly by a net-radiometer or estimated by empirical equations.

The water balance of the watersheds was calculated from empirically derived values for precipitation and water runoff from the area by the balance method (Paslawski, 1990). Water infiltration rates for the soil were obtained empirically (Marcinek et al., 1990).

Results

**Coupling of energy flow and water cycling**

It is well known that solar energy is the driving force of water cycling in ecosystems. To keep the cycle going, solar energy charges water into an upgraded potential energy state through evapotranspiration. Shifting the solar energy flow within an ecosystem in favor of evapotranspiration, not only influences the rate of water cycling but also changes the relationship between the individual components of the water balance, such as vaporization, surface runoff, percolation through soil and so on. Thus, factors which stimulate the use of solar energy for evapotranspiration simultaneously influence the distribution of water from precipitation into various fluxes in the ecosystem. Ryszkowski & Kedziora (1987) have shown that the structure of plant cover, such as the roughness of its surface, influencing reflection of solar energy, a well developed root system enhancing the uptake of ground water and the air turbulence at the canopy, stimulating evaporation, influence the use of solar energy for evapotranspiration. Thus, for example, in the landscape studied the lowest net radiation value (amount of energy available for internal work of the system) during the plant growth season was observed in meadows (1494 MJ m\(^{-2}\)), while the highest was in the shelterbelt (1730 MJ m\(^{-2}\)) (Table 1). But because of the interplay of the above described factors influencing evapotranspiration, the amount of solar energy used for evapotranspiration in a shelterbelt was 272 MJ m\(^{-2}\) higher than in a meadow, and 432 MJ m\(^{-2}\) higher than in a wheatfield, while being 656 MJ m\(^{-2}\) higher than in a bare soil. Therefore, shelterbelt evaporates 108 mm of water more than a meadow, 173 mm more than a wheatfield, and 262 mm more than bare soil.

The above estimates show differences in evapotranspiration rates for the whole plant growth season. However, during the plant growth
season, changes in water availability occur, as well as considerable changes in plant cover structure of cultivated fields. This results in appreciable intra-seasonal changes in heat balance structure of ecosystems, which are not reflected in the overall estimates for the whole plant growth season. In order to assess the intra-seasonal changes in heat balance, evaluations were carried out at monthly intervals based on the field measurements taken, in April (spring), July (midsummer) and September (late summer). In the shelterbelt and in the meadow, where a well developed plant cover exists throughout the whole plant growth season, relatively stable relations are maintained between the amount of energy used for air heating (the air sensible flux $S$) and the energy used for evapotranspiration (latent heat flux $LE$). This relationship, which is called the Bowen ratio, remained almost constant in the shelterbelt throughout the whole plant growth season. In the meadow, apart from the time of spring thaws when the Bowen ratio was slightly higher, the heat balance structure during summer was comparable to that in autumn (Table 2).

In the spring, the bare soil intercepts more heat for evapotranspiration, which leads to drying of the soil (Bowen ratio = 0.56). In summer and autumn, when the soil surface is dry and evaporation, because of low moisture, is rather low, the heat balance structure stabilizes in favour of high values of air heating flux (Bowen ratio in July and September equal to 0.93 and 0.95, respectively). In a cultivated field (wheat), because of fast plant growth, followed by plant cutting during harvest, the heat balance structure is subject to the greatest changes. Evapotranspiration consumes high amounts of energy when plant cover is in full development (summer). After harvest, the heat balance closely resembles that observed in bare soil. The higher the evapotranspiration, the greater the effects of ecotones on the ground water flowing under them, carrying various chemical substances. The above relationship may be used for a potential evaluation of the ecotone role in

Table 2. Typical values of heat balance components for different ecosystems and season.

| Ecosystem     | Month | Heat balance component W m$^{-2}$ | Bowen ratio |
|---------------|-------|----------------------------------|-------------|
|               |       | $R_n$ $G$ $LE$ $S$               |             |
| Bare soil     | Apr.  | 71 $-14$ $-37$ $-20$            | 0.56        |
|               | Jul.  | 126 $-6$ $-62$ $-58$            | 0.93        |
|               | Sep.  | 48 $+2$ $-26$ $-24$            | 0.95        |
| Grain crop    | Apr.  | 65 $-6$ $-43$ $-16$            | 0.38        |
|               | Jul.  | 117 $-5$ $-97$ $-15$            | 0.15        |
|               | Sep.  | 47 $+2$ $-28$ $-22$            | 0.76        |
| Shelterbelt   | Apr.  | 77 $-4$ $-65$ $-8$              | 0.13        |
|               | Jul.  | 135 $-3$ $-115$ $-17$          | 0.15        |
|               | Sep.  | 53 $+1$ $-47$ $-7$             | 0.15        |
| Meadow        | Apr.  | 65 $-6$ $-45$ $-14$             | 0.31        |
|               | Jul.  | 117 $-3$ $-96$ $-8$            | 0.21        |
|               | Sep.  | 43 $+1$ $-36$ $-8$             | 0.21        |
| Pond          | Apr.  | 90 $-27$ $-53$ $-10$           | 0.19        |
|               | Jul.  | 157 $-16$ $-103$ $-38$         | 0.37        |
|               | Sep.  | 64 $+6$ $-51$ $-19$            | 0.37        |

$R_n, G, LE, S$ as in Table 1.
the control of ground water flow. It is only a potential evaluation, since, in order to perform such a function, the plants of an ecotone have to be in physical contact with the groundwater. If such a criterion is used, it may be established that it is the shelterbelt ecotone which affects most substantially the groundwater flow (the lowest, and almost identical, Bowen ratios). Stretches of meadows as ecotones are more effective as controlling factors during summer and autumn, compared to spring, although their potential possibility of affecting groundwater flow is appreciably larger than that of plants in cultivated fields.

Another possibility of enhancing the energy input for evapotranspiration is provided by horizontal transfer of heat from one ecosystem to another by advection (Rao et al., 1974; Kanemasu et al., 1979). In uniform landscapes composed, for example, only of huge cultivated fields or only of grassland, the heat advection between the parts of the landscape is small. But in a mosaic landscape, composed of cultivated fields, shelterbelts, meadow stretches and especially water bodies, there are surfaces which are heated differently. This gives rise to large horizontal temperature gradients, which cause the heat energy to flow by means of advection from one ecosystem to another. To obtain a complete picture of energy fluxes, the heat balance equation should therefore take into consideration those components which also describe the transfer of heat by advection.

The heat balance of an ecosystem, including the possibility of energy passage by advection, is described by the following equation:

\[ R_n + LE + S + G + A = 0 \] (1)

where \( R_n \) is net radiation; \( LE \) - latent heat used for evapotranspiration; \( S \) - air sensible heat flux; \( G \) - Soil sensible heat flux; \( A \) - advection heat flux. All components of equation (1) can be expressed in Watts per square meter (W m\(^{-2}\)) if intensity of energy is considered, or in J m\(^{-2}\) if the sum of energy for a given period of measurement is required. The fluxes have a positive value when energy flows towards the active surface under question.

\( R_n \) was directly measured and its value, during the plant growing season for sunny days (relative sunshine is above 0.6) ranged from 80 W m\(^{-2}\) to 150 W m\(^{-2}\) mean value for 24 hours in the studied landscape. For evapotranspiration on an average sunny day, a representative value 100 W m\(^{-2}\) was taken. For cloudy days (relative sunshine below 0.3) the representative value of net radiation was 50 W m\(^{-2}\). Ryszkowski & Kędziora (1987) found that for the whole vegetation season the soil-sensible heat flux (\( G \)) ranged from 2 per cent to 5 per cent in meadows and shelterbelts. An estimation of energy used for evapotranspiration is presented below, where a mean value of 3 per cent was used. Thus, the \( G \) value for a meadow or shelterbelt was 0.03 \( R_n \).

The flux \( S \) was calculated from the following formula:

\[ S = \rho \cdot c_p \cdot h_s \cdot (T_e - T_a) \] (2)

where

\( \rho \) = air density (1.2 kg m\(^{-3}\)),
\( c_p \) = specific heat of air (1004 J kg\(^{-1}\) K\(^{-1}\)).
\( T_e \) = temperature of the evaporating surface [°C].
\( T_a \) = temperature 2 m above the active surface [°C].
\( h_s \) = coefficient of turbulent exchange of energy [dimensionless], which was calculated from the following formula:

\[ h_s = v \cdot k^2 : [(\ln z : z) - \phi] \cdot \ln z : z \]

(3)

where

\( v \) = wind speed 2 m above the active surface [m s\(^{-1}\)].
\( k \) = von Kármán’s constant; equals 0.41 [dimensionless].
\( z \) = height at which measurements were taken [m].
\( z_s \) = roughness parameter for heat transfer [m].
\( z_o \) = roughness parameter for momentum transfer [m].
\( \phi_s, \phi_m \) = dimensionless functions of the thermodynamic equilibrium influence on heat and matter transfer.
(Kanemasu et al., 1979), which are calculated by using the following equations:

\[
\phi_s = \phi_m \left(1 - (1 - 5R_i)^{-1}\right) \quad \text{when } R_i > 0 \tag{4}
\]

\[
\ln \phi_s = 0.598 + 0.390 \ln(-R_i) - 0.090 \quad \text{when } R_i < 0 \tag{5}
\]

\[
\ln \phi_m = 0.032 + 0.448 \ln(-R_i) - 0.132 \quad \text{when } R_i < 0 \tag{6}
\]

\[
R_i = g(t + 273)^2 \cdot \left(\frac{dt}{dz}\right)^2 \cdot \left(\frac{dv}{dz}\right)^2 \tag{7}
\]

where:

- \(R_i\) = Richardson number [dimensionless],
- \(g\) = acceleration due to gravity (9.81 m s\(^{-2}\)),
- \(t\) = temperature averaged for calculation layer of air [°C],
- \(\frac{dt}{dz}\); \(\frac{dv}{dz}\) = vertical air temperature gradients [K m\(^{-1}\)] and wind speed gradients in the measurement layer [s\(^{-1}\)].

Estimates of evapotranspiration for a shelterbelt and meadow during sunny and cloudy days, with and without advection, ranged from 1.7 mm to 3.8 mm for a meadow and from 1.8 mm to 5.8 mm for shelterbelt (Table 3).

Usually, during sunny days, temperature inversions occur over a well developed plant canopy and may be enhanced when there are favourable conditions for heat advection. The record achieved under such conditions, vertical temperature gradients in the field reached as much as 0.3 °C m\(^{-1}\). During cloudy days, the vertical gradient in temperature is much smaller, i.e. about 0.1 °C m\(^{-1}\). The essential difference, as far as meteorological conditions are concerned, between meadows and shelterbelts is that wind speed over a shelterbelt is much higher than over a meadow, because wind speed increases logarithmically with increasing height. Shelterbelt trees are rather tall (15 m). The value of the roughness parameter is accordingly high and the coefficient of turbulent air exchange is four times higher (0.093 m\(^2\) s\(^{-1}\)) than for a meadow (0.024 m\(^2\) s\(^{-1}\)). For this reason, in a situation with a radiation balance of 100 W m\(^{-2}\), under conditions of advection, an additional heat flux of 67 W m\(^{-2}\) is intercepted from air moving over the shelterbelt. A similar air flux over a meadow is only 12 W m\(^{-2}\) (Table 3).

On a cloudy day, net-radiation equals 50 W m\(^{-2}\) and the ratios \(S/R_n\) for the shelterbelt and meadow are 0.444 and 0.20, respectively. The additional heat intercepted from flowing air above the canopy by the advection process is equal to 22 W m\(^{-2}\) and 10 W m\(^{-2}\) for shelterbelts and meadows, respectively. The difference between shelterbelts and meadows, decreases with the decline of the intensity of incoming solar radiation. When there is no advection input of heat from the air to an evaporating surface, evaporation rates in both types of ecotones are similar.

**Water flow parameters of the landscape studied**

Under the climatological conditions of the area studied, the drainage of precipitation water into water reservoirs by surface runoff, is irregular and occurs mainly in early spring after a thaw or after particularly intensive rainfall. During the plant growth season, on average 7 to 13 days were observed with precipitation higher than 10 mm, but a wide variation in rainfall is generally observed between different years. It was found that the value of total precipitation in July, which is the month with the mean of the highest precipitation may vary in different years from 10 mm to above 200 mm (Woś, 1990). The level of ground water, in the same place, also varied considerably in different years. For example, from 1984 to 1990 the depth of groundwater level varied from 3.85 m in a dry year, to 1.20 m in a wet year (Bartoszewicz Λ. – personal communication). Despite of this variability, which is important for delimitation of unsaturated zone depth, the ground water flows continually and its flux depends on obvious factors, such as the amount of precipitation, the steepness of the groundwater table and the hydraulic conductivity of the water-bearing soil layer. The slope steepness varies in the landscape.
Table 3. Climatic conditions, heat balance structure and ratio of evapotranspiration to groundwater flux passing through two types of ecotones (meadows and shelterbelts).

| Rn W m$^{-2}$ | Micrometeorological conditions |  |  |  |  |
|---------------|--------------------------------|------------------|-----------------|------------------|------------------|
|  | Temp. | (T : m) | Plant height m | Wind speed m s$^{-1}$ | Coeff. of turbulent exchange m$^2$ s$^{-1}$ |
|  | °C | °C/m |  |  |  |
| Advection | | | | | |
| 100 shelterbelt | 18.9 | + 0.3 | 17.0 | 5 | 0.093 |
| meadow | 19.1 | + 0.2 | 2.5 | 3 | 0.024 |
| 50 shelterbelt | 17.5 | + 0.1 | 17.0 | 5 | 0.093 |
| meadow | 17.7 | + 0.1 | 2.5 | 3 | 0.024 |
| Without advection | | | | | |
| 100 shelterbelt | 18.9 | + 0.05 | 17.0 | 3 | 0.056 |
| meadow | 19.1 | + 0.05 | 2.5 | 2 | 0.016 |
| 50 shelterbelt | 17.5 | + 0.01 | 17.0 | 3 | 0.056 |
| meadow | 17.7 | + 0.01 | 2.5 | 2 | 0.016 |

Heat balance components and ratios of evapotranspiration to ground water fluxes

| S, G, LE | ETR mm | 10 · ETR/J1 | 10 · ETR/J2 |
|---------|--------|-------------|-------------|
| W m$^{-2}$ | |
| Advection | 100 shelterbelt | 67 | -2 | -165 | 5.8 | 0.44 | 2.15 |
| meadow | 12 | -5 | -106 | 3.8 | 0.29 | 1.41 |
| 50 shelterbelt | 22 | -1 | -71 | 2.5 | 0.19 | 0.93 |
| meadow | 10 | -2 | -57 | 2.0 | 0.15 | 0.74 |
| Without advection | 100 shelterbelt | 7 | -2 | -105 | 3.7 | 0.28 | 1.37 |
| meadow | 2 | -5 | -97 | 3.4 | 0.26 | 1.26 |
| 50 shelterbelt | 1 | -1 | -50 | 1.8 | 0.14 | 0.67 |
| meadow | 1 | -2 | -48 | 1.7 | 0.13 | 0.63 |

ETR – daily evapotranspiration.
J – groundwater flux (great slopping – index 1, small slopping – index 2).
(T : m) – temperature gradient.
S, G, LE as in Table 1.

studied from 0.01 to 0.04. The hydraulic conductivity changes from 0.03 m per 24 hours to 12.8 m per 24 hours in different soils (Marcinek et al., 1990; Drainage Principles and Applications, 1979).

Estimated water runoff from the landscape amounts – for a normal year – to 100.7 mm (Pasławski, 1990); but the annual variation is greater. For the studied ecotones groundwater flows were estimated, taking into account:

(a) hydraulic conductivity (K): 5 m day$^{-1}$
(Drainage Principle and Applications 1979);
(b) effective porosity of the filtrating layer ($n_e$):
0.2 m$^3$ m$^{-3}$;
(c) the depth of the filtrating layer: 4 m.

These characteristics represent the conditions prevailing in the landscape studied.

The groundwater flux passing during 24 hours through one meter border length of water rese-
voir can be calculated from the following equation (Drainage Principles and Applications, 1979):

\[ J = K \cdot n_e \cdot D \cdot (dh/dl) \]  

(8)

where \( J \) – daily water flux (m³ day⁻¹); \( K \) – hydraulic conductivity (m day⁻¹); \( n_e \) – effective porosity of the filtrating layer (m³ m⁻³); \( D \) – depth of filtrating layer (m); and \( dh/dl \) – hydraulic gradient of groundwater table (m m⁻¹).

The length of the slope in question was 150 m. In the case where groundwater table slope steepness was 0.01, the hydraulic gradient of groundwater was 0.0066 m m⁻¹, while for a slope steepness of 0.04, the hydraulic gradient was 0.026 m m⁻¹. Where higher slope steepness occurred, the water flux was estimated by the equation (8) as equal to \( I_1 = 0.104 \text{ m}^3\text{ day}^{-1} \). For the smaller slope steepness, the water flux was \( I_2 = 0.027 \text{ m}^3\text{ day}^{-1} \). The water infiltrating through the ground is absorbed by plants if the groundwater is within direct or indirect (capillary ascension) reach of the root system.

Assuming a 10 meter wide ecotone zone (shelterbelt or meadow) around the water body, the reduction of groundwater flow to the water reservoir can be calculated as follows:

\[ r = \frac{(10 \times \text{daily evapotrans. rate})}{\text{daily ground water flux}} \]  

(9)

During a sunny day, under the conditions analyzed, both the meadow and shelterbelt reduce the water flux completely (ratio of evaporation to groundwater flux is above a value of 1) when the slope steepness is 0.01, and by factor of about one third (0.33 meadow and 0.36 shelterbelt) when the steepness of slope is 0.04. On a cloudy day, the water flux of a small slope is reduced by two-thirds (0.63 meadow and 0.67 shelterbelt) and by a factor one-sixth (0.16 meadow and 0.17 shelterbelts) when slope steepness is 0.04. In these situations, ecotone zones composed of meadows or shelterbelts function with the same efficiency.

When additional energy is intercepted by an ecotone due to advection, and evapotranspiration is enhanced, the flux of water under the ecotone shelterbelt on sunny days is reduced by 0.56 when the slope steepness is 0.04. Under the same conditions, a meadow ecotone reduces groundwater flux by a factor 0.36. In both kinds of ecotones the groundwater flux is stopped during a sunny day when a process of advection is appearing, and steepness of slope is small. On cloudy days, with advection on slopes with steepness 0.04, a meadow reduces the ground flux by 0.19, and a shelterbelt by 0.24. Under the same weather conditions but, on a week slope the groundwater flux is reduced, in the meadow ecotone by 0.74, and in the shelterbelt ecotone by 0.93 (Table 3).

In general, one can conclude that the larger the flux of energy used for evapotranspiration, and the higher the steepness of slope, the greater the differences in efficiency of shelterbelt and meadow ecotones on regulating groundwater flow will be.

**Discussion and conclusion**

The water transport of soluble as well as unsoluble material is one of the main routes of matter exchange between ecosystems. Hence, the mechanisms and factors modifying water fluxes across land-water border ecotones are of paramount importance for understanding the control of the migration of chemical compounds in the landscape. In the majority of studies hitherto conducted, the authors restricted themselves to the descriptions of capacities of ecotones to modify the migration of materials and chemical compounds. Papers evaluating the efficiency with which ecotones control matter cycling, are not available. The analysis presented not only permits to relate effects of the solar energy influxes during bright and cloudy days on groundwater flow, but also to quantify the different effects of meadow and shelterbelt ecotones on groundwater flow. The analysis also permits to relate quantitatively the effects of ecotones on groundwater flow to steepness of the slope on which the ecotones are situated. The results obtained should be regarded as preliminary. However, they point towards important general conclusions. The larger the influx of energy to the ecotone, the more important the differences in the plant cover structure (trees or grass) for the control of groundwater flow through
an ecotone are. On a bright day, and on a steep slope, the shelterbelt ecotone limits the groundwater flow about 1.5 times more effectively than a meadow ecotone. On the other hand, during cloudy days when there is less solar radiation, or when energy transfer by advection is reduced, as well as on flat areas, shelterbelt and meadow ecotones have comparable efficiencies in limiting groundwater flow.

The results of this study have an important bearing on control of nitrogen and phosphorus passage through ecotone habitats. Paulukevičius (1978), Peterjohn & Correll (1984), Ryszkowski & Bartoszewicz (1989), Ryszkowski et al. (1989) measured a substantial decrease in nitrate and phosphate loss, caused by riparian forest, shelterbelts and meadow ecotones. But exact processes responsible for control of the passage of these compounds through an ecotone were not empirically shown. Evapotranspiration rates denote the intensity of water uptake by a root system of plants together with the groundwater-dissolved chemical compounds, which are also absorbed by plants. Hence, the recognition of factors modifying water fluxes across ecotones provides important information on nitrogen and phosphorus control by vegetation in land–water border zones of landscapes.

However, in general, when analyzing the effects of the two types of ecotones during the whole plant growth season it should be stated that, compared to meadow ecotones, shelterbelts are more effective structures in controlling groundwater flow. Across the whole plant growth season, they intercept the largest amounts of energy for evapotranspiration. Another conclusion from our study is that processes of energy transfer by means of advection may constitute an important factor in the heat balance of ecosystems.

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