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THE NETWORK OF SHELTERBELTS AS AN AGROFORESTRY SYSTEM CONTROLLING THE WATER RESOURCES AND BIODIVERSITY IN THE AGRICULTURAL LANDSCAPE

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ABSTRACT: Long-term human activity has led to many unfavourable changes in landscape structure. The main negative effect has been a simplification of landscape structure reflecting the removal of stable ecosystems, such as forests, shelterbelts, strips of meadows and so on, which were converted into unstable ecosystems, mainly farmlands. Thanks to these changes, serious threats have been posed to the sustainable development of rural areas. The most hazardous of these involve a deteriorating of water balance, increased surface and ground water pollution, and impoverishment of biodiversity. An agroforestry system can serve as a toolkit which allows counteracting such negative changes in the landscape. This paper presents the main findings emerge from long-term investigations on the above issues carried out by the Institute for the Agricultural and Forest Environment of the Polish Academy of Sciences.

KEY WORDS: agroforestry, shelterbelts, landscape structure, water balance, water pollution, biodiversity.

INTRODUCTION – WHY ARE SHELTERBELTS SO IMPORTANT?

Over the last century, and in the last few decades especially, great changes in the Earth's natural environment have taken place. These have mainly concerned the planet's surface (above all entailing the removal of vegetation), as well as the atmosphere and its chemical composition, in which changes have led to an acceleration of climate change. A rapidly growing human population necessitates increased food production, while the development of civilization and technology increase the potential for human activity to impact upon the environment. These factors in turn lead to overexploitation of natural resources (particularly water, forests and energy carriers), and to a substantial simplification of landscape structure. Ecosystems stable in terms of energy flow and matter circulation, such as forests, aquatic systems and grasslands, have been transformed into unstable ones, mostly farmland. This impairs the environment's ability to neutralize phenomena and processes negative to the functioning of the Earth system, such as environment pollution, disruption of the hydrological cycle, depletion of biodiversity, a deterioration of storage capacity in the environment (for water and nutrients), loss of organic matter from soils, etc. Too much attention has been paid to economic effects, with resulting neglect when it comes to the adoption of laws seeking to ensure proper management of the environment and the sustainable development of civilization.

To maintain and even strengthen the capacity of the environment to perform its basic functions, and to enhance its resistance to human pressure in the coming years, we need to take measures allowing for intensive agricultural production while minimizing the negative human impact. Above all, measures should increase complexity of the landscape by enriching vegetation, restoring damaged ecosystems, and introducing stable features of the landscape allowing the flow of energy and circulation of matter to be controlled. Such measures would involve the agroforestry system - and especially the introduction of a network of shelterbelts into a monotonous agricultural landscape, and they would be provided for in legal and administrative regulations taken account of in spatial planning.

Agroforestry is a collective name for land-use systems and practices in which woody perennials are deliberately integrated with crops and/or animals in the same land management unit. The integration in question can entail either a spatial mixture or a temporal sequence, and there are normally both ecological and economic interactions between woody and non-woody components (ICRAF 1993, Somarriba 1997, Kędziora 2011a, Kędziora 2011b).

Agroforestry combines agriculture and forestry technologies to create more-integrated, diverse, productive, profitable, healthy and sustainable land-use systems (Auclair and Dupraz 1999). This means making intentional use of trees within agricultural systems. The ecological integrity of an agroforest entails a state of system development whereby the habitat structure, natural functions and species composition of the system interact in ways affording sustainability in the face of changing environmental conditions, as well as both internal and external stresses. (Wyant 1996).

A windbreak or shelterbelt is a plantation usually comprising one or more rows of trees or shrubs planted around the edges of fields on farms, along roads and ditches and across large fields, with landscape structure in this way improved in the direction of the maintenance and enhancement of ecosystem services.

According to studies carried out by the Institute for the Agricultural and Forest Environment, the system of shelterbelts in Poland helps ensure the sustainable development of the country's rural areas by:

- modifying microclimatic conditions and heat and water balances,
- controlling the chemical composition of water (diffuse pollution),
- limiting erosion by water and the wind,
- protecting biodiversity,
- increasing survival in populations of game animals,
- enhancing a given region's recreational value,
- providing wood and other products,
- promoting aesthetically valuable features of the countryside.

The first four functions are of greatest importance to the functioning of the landscape as a whole, and so will be presented in greater detail below.

Agroforestry system improve micrometeorological conditions, which is to say that they reduce wind speeds (Fig. 1) and potential evapotranspiration, as well as concentrations of the compounds of nitrogen and phosphorous in ground and surface waters. Shelterbelts also represent very favourable habitat for animals and plants.

Interdisciplinary investigations carried out by the Institute focus on integrated analysis of the fundamental ecological processes that are the driving forces behind agricultural landscape functions, as well as on possibilities for the above to be modified with a view to environmental threats originating from farmers' activity, as well as from

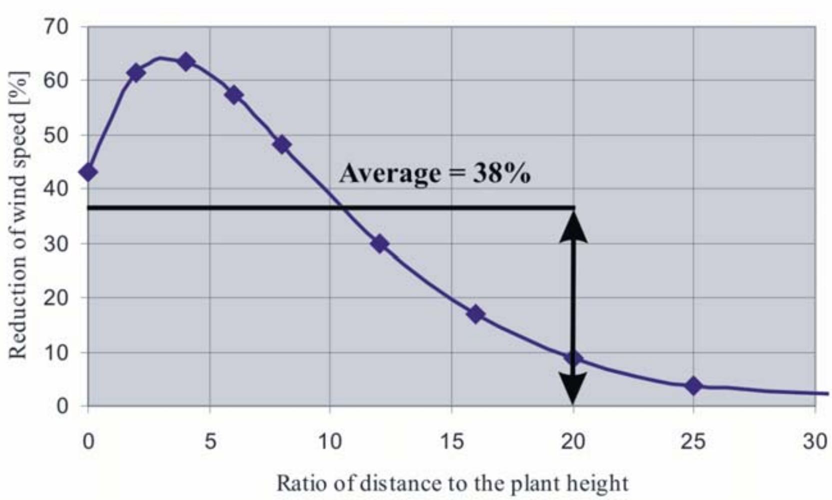

Figure 1. Reduction of wind speed as a function of distance from shelterbelt

climate change, being counteracted. The many errors made as regards management of the agricultural landscape – last century in particular – encouraged the development of many threats in the landscape. Among these, the main threats to the environment originating from simplification of landscape structure entail:

- a worsening of water-balance structure (growing water shortages),
- increased pollution of ground waters and surface waters,
- increased concentrations of biogens,
- impoverished biodiversity (reduced density and number of species) – Kędziora *et al.* 2012.

The role of shelterbelts in shaping environmental conditions conducive to agricultural production is particularly important in periods of water scarcity and high winds. Under Polish climatic conditions, dry years occur every 5–6 years, and very dry ones every 10–11 years. Dry periods usually last for a few weeks, though periods of water shortage can arise each year. These pose a threat to agricultural production, especially on the light soils that account for more than half of the arable land in Poland. Threats are especially severe in the case of spring crops, *inter alia* one of the most important of these – barley.

Observed and predicted climate changes will impact to a high degree on the processes and threats listed above (Kędziora, Kundzewicz 2011). Increasing air temperature would combine with increasing net radiation to bring about a greater saturation water deficit in the atmosphere. This will in turn give rise to a marked increase in potential evapotranspiration, mainly in winter time. Precipitation may decrease, or might increase mainly in winter and in the form of rain, rather than snow, with the result that surface runoff increases. Along with increasing winter evaporation, this would reduce the possibility of water storage in soil being rebuilt. That would in turn make dry periods in summer a more frequent occurrence, with the result that crop yields for farmers are reduced. On the other hand, an increased incidence of extreme precipitation events would give rise to erosion of the soil mediated by water. Reduced evapotranspiration in the summer period would also limit the latent heat flux and thus increase air temperature and the kinetics of the atmosphere, with the result being greater wind speeds and an increase in the frequency of storms and tornadoes, and in consequence increasing frequency and intensity of wind erosion. A reduced ratio of summer: winter precipitation would also combine with the process of aridification to leave climatic conditions in Poland more similar to those in the Mediterranean region. Such a process is called mediterranization.

Investigations into the impact of landscape structure on the quantity and quality of water in the agricultural landscape, as well as on biodiversity, have been carried out since the 1970s. They *inter alia* involve an experimental catchment located 50 km south of Poznań in the Wielkopolska region, with field measurements obtained in this way augmented by results from the laboratory, as well as modeling. Meteorological data have in turn been obtained using a standard, automatic station, while data on hydrological parameters derive from the network of hydrological observation stations.

THE EXPERIMENTAL LANDSCAPE IN THE TUREW AREA

PHYSIOGRAPHICAL FEATURES AND SOILS

The "Turew Mosaic Landscape" referred to in this chapter is part of the larger Kościan Plain study area located c. 40 km south of Poznań – the capital of Wielkopolska region, which is known as the "bread basket" of Poland. Agriculture is the dominant activity in the region.

The study area is a ground moraine created during the Baltic Glaciation, which terminated about 10 000 years ago. Although the differences in altitude are limited (from 75 to 90 m a.s.l.), with the area consisting of a rolling plain made up of slightly undulating ground moraine, there are many valleys. In general, uplands feature light-textured soils (Hapludalfs, Glossudalfs, and the Udipsamments only met with less frequently), in which the water-infiltration conditions are favorable. Deeper strata are only of limited permeability, with percolating water seeping into valleys and ditches or the main drainage channel; in depressions, Endoaquolls that are poorly drained collect water runoff, and discharge water into the surface drainage system (Marcinek 1996). The soils of bottom moraine in the upper layers (30–120 cm) of the soil horizon have a high sand content. The elevation of the rolling plain ranges from 85 to 90 m above sea level, while those in the drainage valley range from 75 to 77 m a.s.l. The differences in elevation between the surface of the rolling plain and valleys range from 2 to 6 meters. In general, uplands have light-textured soils (Hapludalfs and Glossudalfs and the Udipsamments met with less frequently) in which the water infiltration conditions are favorable. Deeper strata are poorly permeable and percolating water seeps into valleys, ditches, and main drainage watercourses. The water table in uplands depends on elevation and ranges from 1.2–3.5 m below the surface, fluctuating substantially in the course of a year. In the valleys, the water table on poorly-drained soils (Endoaquolls) may be near the surface or up to 0.8 m down, while in mineral intrazonal hydromorphic soils (Haplaquolls and Psammaquents) it is at depths ranging from 0.5 to 1.2 m. The natural drainage conditions range from imperfectly or poorly-drained valleys to well- or excessively-drained in the case of the sandy uplands.

CLIMATE

The climate of the region is shaped by conflicting air masses from the Atlantic, Eastern Europe and Asia (arctic 6%, polar maritime 59%, polar continental 28% and tropical 7%), which are modified by strong Arctic and Mediterranean influences. This results in great changeability of weather conditions, with a predominance of westerly winds ensuring a strong oceanic influence that is manifested in milder winters and cooler summers than in the central and eastern parts of Poland. Within the country, the area under study is one of the warmest, with an annual mean temperature above 8°C, (range from 6.9 to 8.5°C). But average annual temperature in the period 2003–2014 was one degree higher than the long-term average, equaling 9°C. Mean annual global radiation amounts to 3 700 MJm^{-2} and mean annual net radiation equals 1 315 MJm^{-2}.

The thermal conditions existing in the Turew landscape are favorable to the growth of crop plants. The mean length of the growing season – with temperatures above 5°C – lasts 225 days, from 21st March through to 30th October. In the reference (1961–1990) period, the mean annual precipitation was of 595 mm, of which 365 mm falls between April and September, and 230 mm in the period October–March. Although the amount of precipitation in the spring-summer period is higher than in autumn and winter, a shortage of water arises frequently during the growing season. This situation is aggravated by the dominance of light soils with poor water-storing capacities. The uptake of water by plants in this period is dependent on the supply accumulated in soil. This accounts for the great importance to crop-growing of the recharge of soil water during the winter-spring period. More-severe water deficits in the growing season occur in the year following a dry year, if precipitation during winter has been low and insufficient to ensure soil-water recharge. In a given decade, there are on average 2 wet years, 5 normal years, 1.5 dry years, and 0.75 very dry and 0.75 extremely dry years. In dry years with 20 per cent less precipitation than normal, water deficits in light soils can be of up to 50 mm (50 liters per square meter). In very dry years (80–62% normal), water deficits are observed in all types of soil and range from 70 mm in loamy soils to 130 mm in sandy soils. In extremely dry years when precipitation only reaches half of normal, water deficits can be of as much as 70 mm in loamy soils and 170 mm in sandy soils.

Average annual evapotranspiration amounts to 500 mm (485 mm in the country as a whole), while water runoff is equal to 95 mm (212 mm for Poland). However, in the warm and dry period of 1996–2006, evapotranspiration was of as much as 580 mm, this resulting in c. 70 mm decrease in the retention of water by soil. The result was a worsening of the conditions for plants where water availability is concerned (Fig. 2).

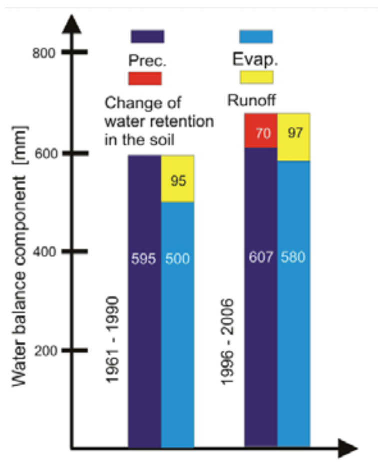

Figure 2. Water balance in Wielkopolska in 1961–1990 reference period and in 1996–2006 warm and dry period

The main environmental threat to agricultural production (both plant and animal) is thus a shortage of water reflecting climatic conditions, the limited water storing capacities of soils, mistakes made in the course of drainage projects, a loss of small bodies of water and insufficient control over evaporation from fields exerted by a network of shelterbelts.

The specific landscape in the vicinity of Turew (Wielkopolska region) was shaped during the 1820s by General D. Chłapowski, who farmed 10 000 acres. He introduced essential changes into the farming system, as well as in the field that is now called landscape engineering. Conversion of the open and uniform agricultural landscape into a mosaic that is rich in stable elements like shelterbelts and small mid-field bodies of water was the results of his activity (Photo 1). Many wooded patches, shelterbelts and lines and clumps of trees were planted in the landscape. They were designed as shelter for domestic animals and as measures combating wind erosion. Since the 1950s, it has been in this area that agricultural landscape functioning has been investigated. About 100 km of linear planting and 10 ha of new shelterbelts and woody patches are said to have been planted over the last two decades.

Photo 1. Mosaic and uniform landscapes in Turew surrounding (photo: K. Kujawa)

While in 1985 cereals accounted for 48.1% of all arable land, by 1997 this contribution had increased to 63.5%, while by 2002 cereals were being cultivated on 73.9% of arable land. The figure rose still further to as much as 75.8% in 2005. Among the cereals, it is first and foremost wheat and triticale that are cultivated.

THE IMPACT OF SHELTERBELTS ON THE STRUCTURE OF THE WATER BALANCE IN THE AGRICULTURAL LANDSCAPE

The network of shelterbelts serves many environmental functions in the agricultural landscape that resemble those played by forests, albeit it over much more-limited areas. The functions in question are, above all:

- an impact on water regime (evapotranspiration, surface runoff, percolation through the soil);
- control of the chemical composition of waters(the control of diffuse pollution);
- modification of microclimatic conditions;
- limitation of water and wind erosion;
- protection of biodiversity;
- the increased survival of game animals;
- enhanced recreational value of the region;
- the provision of wood and other products;
- the promotion of aesthetic values of the countryside.

The various ecosystems use net radiation energy in different ways (Tab. 1). A shelterbelt uses about 40% more energy for evapotranspiration than does a wheat field, the disparity first reflecting a difference in plant-cover structure, in that the much-longer roots of trees (as opposed to wheat) can absorb water from deeper layers of the soil, ensuring that far more water is within their reach. Since trees have these greater amounts of water available, their leaves are characterized by more limited stomatal resistance than those of cereals. Shelterbelts also feature greater canopy roughness than wheat, this combining with a higher wind speed in the shelterbelt canopy to ensure a more intensive turbulent exchange over the latter. Also, the springtime melting of snow sees more water infiltrate into the soil in a landscape covered by a network of shelterbelts than in an open landscape (Molga 1983).

Table 1. Heat balance structure and evapotranspiration during the plant growing season (20th March–31st October) in Turew agricultural landscape. Modified after Ryszkowski and Kędziora (1987)

Parameter	Landscape elements					
	shelterbelt	meadow	rapeseed field	beet field	wheat field	bare soil
Rn	1730	1494	1551	1536	1536	1575
LE	1522	1250	1163	1136	1090	866
S	121	215	327	339	385	651
G	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

Explanations: The components in $MJ \cdot m^{-2}$: Rn – net radiation (incoming solar radiation minus outgoing radiation), LE – energy used for evapotranspiration (latent heat flux), S – energy used for air heating (sensible flux), G – energy used for soil heating (soil heat flux), E – evapotranspiration in mm.

In a landscape composed of cultivated fields and shelterbelts it is possible to observe two opposite trends where the cycling of water is concerned (Kędziora 1996**).** While trees increase evapotranspiration rates, the protecting effects they provide stimulate a decrease in wind speed and a lower saturation of vapor pressure deficits which both serve to reduce evapotranspiration. It is for this reason that fields between shelterbelts conserve moisture, to the extent that yields may be raised (Ryszkowski and Karg 1976, Grace 1988, Brandle *et al.* 2004). The shelterbelts introduced into grain monoculture landscape change the microclimatic conditions of the field as well as aerodynamic characteristics of an active surface (Jansz 1959, Rosenberg 1974, Kędziora *et al.* 2011). Shelterbelts by reducing wind speed, stomatal resistance and increasing the humidity, turbulence, and net radiation cause a little increase of actual evapotranspiration of landscape taken as a whole, but decrease it from the cultivated field lying between shelterbelts (Ryszkowski and Kędziora 1987) – Table 2.

Table 2. Heat balance of different landscapes of Turew surrounding during plant growth season (20th March–31st October, Ryszkowski and Kędziora 1987)

Landscape type	**Heat balance components in MJ · m^{-2}**						**Evapotraspiration**	
	Rn	**LE**	**S**	**G**	**LE/Rn**	**S/Rn**	**potential**	**real**
Uniform-with cereal cultures	1542	–1035	–495	–12	–0.67	–0.32	650	414
Cereals with shelterbelt network	1586	–1078	–496	–12	–0.68	–0.31	586	431
Cereals with artificial barriers against wind	1567	–1010	–456	–11	–0.64	–0.29	581	404
Uniform under advection	1542	–1258	–271	–13	–0.81	–0.17	898	504
Cereals with shelterbelts under advection	1586	–1161	–412	–13	–0.73	–0.26	592	464

Explanations: Rn – net radiation, LE – latent energy used for evapotranspiration, S – sensible heat (energy used for air heating), G – energy used for soil heating; Evapotranspiration in mm.

The landscapes under analysis can be characterized as follows:

- The whole landscape comprises cereals only. Plant germination starts at the beginning of September and the harvest is gathered at the end of July the following year;
- The landscape is composed of cereals, but with the addition of shelterbelts (trees and bushes which evaporate water), which are permeable, 15 m high, 21 m wide and spaced 300 m apart, so as to occupy about 10% of the landscape area overall;
- The landscape is structured like landscape No. 2, but only (non-evaporating) windbreaks are introduced, instead of trees. These reduce the wind speed, but otherwise leave meteorological conditions the same as in landscape No. 2;
- The landscape is the same as landscape No. 1, but with heat advection taking place;
- The landscape is the same as landscape No. 4 but with shelterbelts.

In estimating energy fluxes in these landscapes the assumptions made (Jansz 1959, Rosenberg 1974) were that the shelterbelts reduce wind speed by a factor of 0.6, increase the air temperature by a factor of 1.1, and increase the vapor pressure by a factor of 1.15.

The shelterbelts in the humid climatic conditions of the Turew region induce only slight changes in the heat balance structure (Tab. 2. compare landscapes No. 1 and No. 2). They cause a small increase in absorbed net radiation due to their lower albedo. Also, latent heat flux (energy used for evapotranspiration) is higher in the landscape with shelterbelts than the open one. This means that more water evaporates from the landscape with shelterbelts. Although the latter cause a distinct decrease of potential evapotranspiration from (650 to 586), they also bring about an increase in real evapotranspiration because of the decrease in stomatal resistance of trees and higher air turbulence in shelterbelt canopies.

A quite different situation can be observed where strong advection occurs (Tab. 2, landscapes No. 4 and No. 5). The landscape with shelterbelts evaporates about 40 mm less water per season than the open one. A landscape under the impact of strong advection thanks to the presence of shelterbelts thus achieves a real saving of water.

Comparisons of the ratios of latent and sensible heat to net radiation (LE/Rn and S/Rn) show that ecosystem uses for evapotranspiration from 64% of net radiation (landscape with artificial windbreaks, under normal conditions) to 81% (landscape without shelterbelts, under advection conditions) while for heating of air ecosystem uses from 17% of net radiation (landscape without shelterbelts under advection conditions) to 32% (uniform landscape with cereal cultures) – Table 2.

The ratio of real to potential evapotranspiration (ETR/ETP – Tab. 2) shows that the more arid the climatic conditions of the landscape (very high potential evapotranspiration), the lower the real evapotranspiration in relation to the atmospheric evaporative demand (potential evapotranspiration. This means that under such conditions intensive irrigation can be applied with good benefit to yields. Because the ratio of runoff to precipitation in the Turew region during the growing season is very low (at approximately 0.1), while total precipitation in the growing season amounts to 420 mm, evapotranspiration exceeds water incoming into the ecosystem by as much as 43–83 mm. Water stored in soil during winter decreases during the growing season, and a lowering of the water table of as much as 1–2 m is to be observed in the Turew region.

The importance of shelterbelts in controlling water balance structure can be seen clearly when that structure is compared by reference to irrigated alfalfa fields under conditions of advection, where one field lacks shelterbelts, while the other has a network of them. In the growing season, a field without shelterbelts evaporated about 830 mm of water, as compared to just 508 mm in the case of a field with a network of shelterbelts. Because the rainfall amounts to 400 mm, the field without shelterbelts must take as much as 450 mm of water from the soil, as compared with only 150 mm in the case of the field with a network of shelterbelts (Fig. 3). During the growing season, the introduction of shelterbelts can save as much as 40 mm of water in a non-irrigated field, and as much as 200–300 mm in a strongly-irrigated field surrounded by dry and hot areas.

On the basis of the results presented it may be concluded that shelterbelts enhance the water deficit of the Turew landscape under normal weather conditions. This conclusion is confirmed if only the evapotranspiration rate is considered. 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 the thaw in springtime is more limited in landscapes with shelterbelts. Additionally, rainwater remains longer in landscapes with shelterbelts, while water is lost more rapidly from open landscapes (Ruellan 1976). We can therefore conclude that a landscape with shelterbelts is characterized by a more efficient water economy for crop production than an open one.

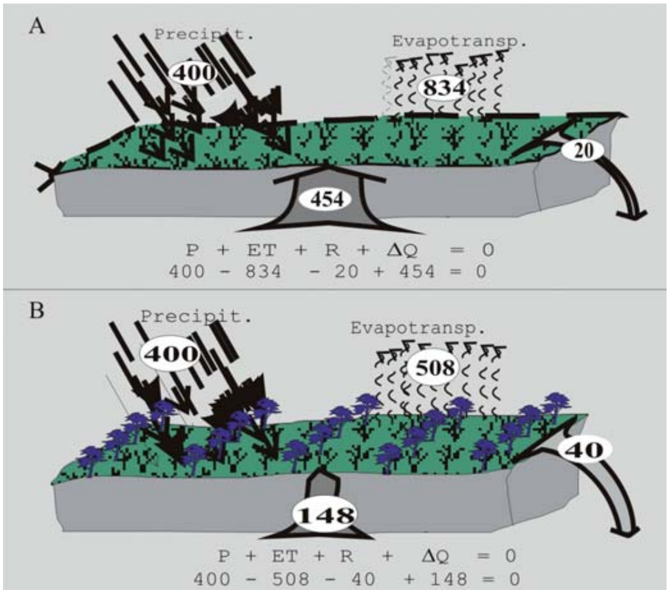

Figure 3. Water balance of alfalfa fields with (A) and without (B) shelterbelts under advection conditions

The plant cover structure of a landscape is the most important factor determining of the level of evapotranspiration, and by that token also the water balance. Variability to evapotranspiration is found to be greater within agricultural ecosystems than within complexes of forest ecosystems. The lower level of moisture conditions the more marked differences between forest and cultivated-field evapotranspiration. The introduction of shelterbelts into an agricultural landscape is the most efficient tool by which water management in the countryside may be improved.

THE ROLE OF A SHELTERBELT IN CONTROLLING OF GROUNDWATER POLLUTION

The increasing use of artificial fertilisers, as well as liquid manure from big farms, usually applied in one dose combines with the increased use of pesticides and the simplification of the agricultural landscape structure to lead to very severe pollution of the environment (OECD 1986).

Nitrate concentrations have been shown to decrease substantially when ground water carrying them from under fields passes under biogeochemical barriers. A decrease in phosphate concentrations under such biological barriers is also clearly evident, though not in cases in which plant residues undergo rapid decomposition and release phosphorus compounds (Bartoszewicz 1990, Hillbricht-Ilkowska *et al.* 1995, Kędziora *et al.* 1995).

The great influence plant cover structure is able to exert on the output of elements from watersheds was made clear by Bartoszewicz (1994) – Table 3. The studies in question were carried out in two small watersheds located nearby. The first was 99% covered by cultivated fields and hence referred to as uniform, while the second (mosaic) one was 83% cultivated fields plus meadows (14%) and shelterbelts (3%). The mean annual precipitation for the two watersheds was the same, and amounted to 514 mm. On average, annual water output during the three years of study was 32 mm lower from the mosaic watershed than from the uniform one. Given that the water input (precipitation) was the same in the two watersheds, the observed differences in runoff rates are attributable to differences in evapotranspiration rates between cultivated fields and meadows or shelterbelts (Ryszkowski and Kędziora 1987). When the waterborne migration of mineral compounds from the mosaic watershed was compared with their outputs from the uniform drainage basin it was found that outputs of inorganic ions were only one-tenth as high (Tab. 3).

Table 3. Annual mean water output (mm) and nutrient loss ($g \cdot m^{-2} \cdot year^{-1}$) from two small watersheds in period November 1988–October 1991 (after Bartoszewicz 1994)

Seasons	**Precipitation**	**Uniform watershed**			**Mosaic watershed**		
		water output	**$N–NO_3^-$**	**$N–NH_4^+$**	**water output**	**$N–NO_3^-$**	**$N–NH_4^+$**
Winter season November–April	220.7	60.8	12.3	3.0	56.8	0.90	0.95
Summer season May–October	292.9	41.2	4.0	1.1	13.4	0.05	0.25
Whole year	513.6	102.0	16.3	4.1	70.2	0.95	1.20

Non-point or diffuse water pollution is attributed to an increase above natural rates in inputs of chemical compounds into subsurface and surface water reservoirs. A cleansing effect of vegetation on subsurface and surface fluxes of chemical compounds carried by water was demonstrated early on in the case of strips of riparian vegetation (Lowrance *et al.* 1983, Peterjohn and Correll 1984, Muscutt *et al.* 1993, Haycock *et al.* 1997). In turn, long-term studies carried out at the Institute for Agricultural and Forest Environment in Poznań, Poland, indicated that shelterbelts and stretches of meadows located in upland parts of watersheds also influence the chemistry of water flowing within reach of plants' root systems (Ryszkowski and Bartoszewicz 1996, Ryszkowski *et al.* 1997, 1999, 2002). Nitrate concentrations are reduced substantially when ground water containing dissolved nitrates passes under shelterbelts or grassy strips. The decrease in $N–NO_3^-$ concentrations in water flowing from cultivated fields through shelterbelts amounts to between 63 an 98% of the input. In meadows the detected decrease in nitrate concentrations is similar, in the range 79–98%. These results were obtained in studies of waterborne nitrate migration through 6 shelterbelts and 8 meadow strips in the Turew agricultural landscape (Ryszkowski *et al.* 2002).

Studies on $N–NO_3^-$ concentration in five small watersheds of areas 7–216 ha showed that, the higher the coverage of catchments by shelterbelts or grasslands, the lower the nitrate concentrations at the outlet (Ryszkowski 2000). The relationship between the share by area of permanent vegetation in a watershed and $N–NO_3^-$ concentration in discharged water is exponential, and for a growing season lacking in heavy-rain events is given by the equation (Fig. 4):

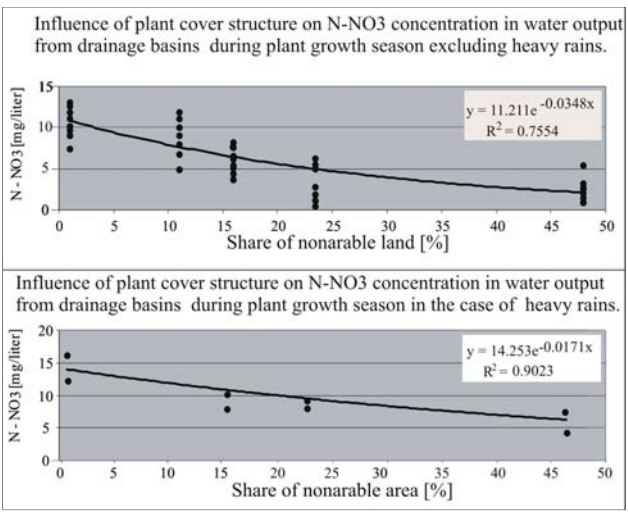

Figure 4. Influence of landscape structure on $N–NO_3^-$ concentration in water output from drainage basins

$$y = 11.211e^{-0.0348x} \quad (R^2 = 0.7554)$$

where: y is $N–NO_3^-$ concentration and x the share of biogeochemical barriers in the overall area.

Where heavy rain does take place, the relationship is $y = 14.253e^{-0.0171x}$ ($R^2 = 0.9023$).

The efficiency of nitrate control by permanent vegetation is more limited in winter than in the growing season.

Plants like trees with deep root systems or alfalfa can use, not only the water stored in the aeration zone of the soil, but also that from the saturated zone (where there is shallow ground water). A model by which to estimate plant uptake of water from the unsaturated soil zone and shallow ground water was developed (Kędziora and Kayser 2012). The uptake of ground water is an important characteristic of water uptake from the flux driving water out a watershed into the drainage system. This is one of the intra-landscape mechanisms of water recycling. The ratio of ground water uptake to real evapotranspiration shows the intensity of withdrawal for ecosystem uses of water flowing out. This ratio (p) depends on actual evapotranspiration (ETR) and ground water depth (GWL). The following equation describes this relationship for shelterbelts in the Turew landscape:

$$P = 0.56 - 0.49 \cdot \exp [0.29 \cdot (ETR/GWL)]$$

The mean ETR value is calculated for a half-month period, with GWL being the average value for the same time span.

The proportion of water uptake from the ground aquifer for shelterbelt evapotranspiration is greater in warmer weather and in the circumstances of a shallow water level. The estimations of ground water's average share in evapotranspiration during the growing season varied from 0.244 during cold weather and with a deep ground water level (1.5 m down) to 0.439 in the circumstances of warm weather and a superficial water table (0.5–1.0 m down). At the beginning of the growing season in a cold-weather year a shelterbelt was found to use only 18% of ground water in real evapotranspiration, as compared with 37% in a warm-weather year.

It seems that, when there is enough moisture in springtime, trees mainly use water from the unsaturated zone of the soil. When temperature and evapotranspiration increase and water supplies in the upper part of the soil decrease, trees use more and more water from the aquifer. In June, the ratio of uptake of ground water to evapotranspiration increases to 30% if there is cold weather and up to 50% during warm weather. One can suppose that, besides greater withdrawal of ground water for evapotranspiration which denotes a higher rate of recycling, shelterbelts are probably also more efficient in controlling diffuse pollution in ground water during the summer.

The long-term studies carried out at Institute for Agricultural and Forest Environment in Poznan, Poland, indicated that shelterbelts and stretches of meadows located in upland parts of watersheds also influence the chemistry of water flowing within reach of plant root systems (Ryszkowski and Bartoszewicz 1996, Ryszkowski *et al.* 1997, 1999a, 2002). Nitrate concentrations decreased substantially when ground water containing dissolved nitrates passed under shelterbelts or grassy strips.

BIODIVERSITY PROTECTION AND ENHANCEMENT

Conversion of pristine ecosystems into cultivated fields combines with the intensification of agricultural production to impoverish biological diversity. This has been recognized, not only by scientists (e.g. Wilson 1992, Collins and Qualset

1999, Loreau *et al.* 2002), but also by politicians (Convention on Biological Diversity opened in 1992 at the "Earth Summit" in Rio de Janeiro – COM 1999 and many other documents). The crucial factor in the maintenance of numerous and favorable habitats for various groups of animals are a well-developed structure of the landscape. Mid-field shelterbelts are an important element in the agricultural landscape for small mammals. Shelterbelts are mid-field refuges, food sources, and ecological corridors.

The results of long-term studies on above-ground insects show that representatives of more insect families are to be found in mosaic landscapes with shelterbelts, and their recurrent detections are more frequent in consecutive years (Fig. 5). The distribution of insect families along a distance gradient from a refuge site (shelterbelt) was described well by a negative exponential equation. An increase in the share of crop patterns taken by cereals, as well as changes in precipitation, had a much more limited impact on insect diversity than a mosaic of perennial vegetation patches. The main factors counteracting the decline in biodiversity in agroecosystems is the mosaic structure of the landscapes, achieved in shelterbelts.

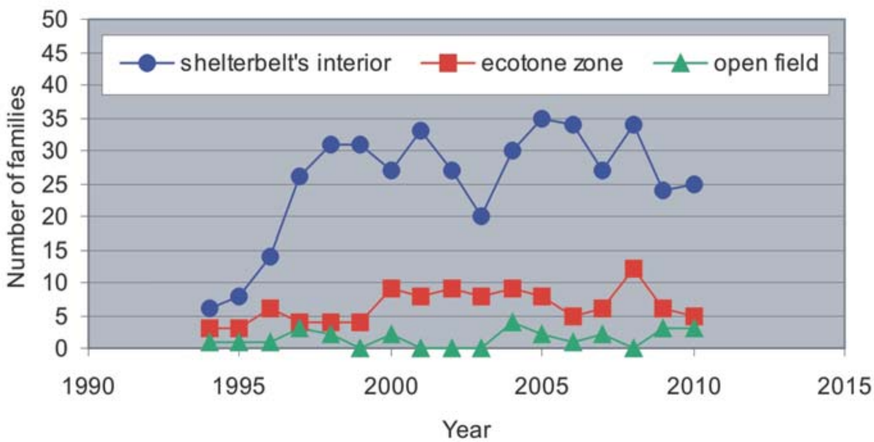

Figure 5. Number of insect families wintering in young shelterbelts and in adjacent crop fields (after Kędziora and Kayzer 2012)

The negative impacts of various agrotechnologies on biodiversity are well documented, but refuges in mosaic landscapes counterbalance the loss of insect biodiversity reflecting the intensification of agriculture production. The number of families and diversification of residual families is fount to depend on distance from shelterbelts.

The same can be observed in relation to plant species (Tab. 4). The richest in vascular plants are the grasslands of the estate's parks and shelterbelts.

The structure of mid-field afforestation also has an established influence on the diversity of bird species. It is in small mid-field patches of forest and shelterbelts

Table 4. Number of vascular plant species in various habitats of the Turew agricultural landscape (updated data of Ryszkowski, Gołdyn and Arczyńska-Chudy 1998)

Habitat	Grasslands	Shelterbelts and afforestations	Manor's park	Road-sides	Water reservoirs	Cultivated fields	Total landscape
Number of species	321	266	306	220	211	193	805

composed of several parallel rows of trees that the greatest number of species is to be detected. The smallest number in turn characterizes single-row avenues of trees (Tab. 5). A recent 30-year period has brought no more major changes in the composition of the bird community in the Turew landscape, beside some changes in the densities of populations (Kujawa 2002). The share of the agricultural landscape that is afforested is in turn shown to have a positive impact on the number of bird species, as well as the density of population in terms of pairs of birds (Fig. 6).

Table 5. Breeding birds communities in various mid-field afforestations (after Ryszkowski, Karg and Kujawa 1999b)

Characteristic	Tree patches N = 21	Shelterbelts N = 33	Alleys N = 20
Number of species	60.0	51.0	32.0
Density (pairs × ha^{-1})	14.9	18.3	9.8

Explanation: N = number of estimates.

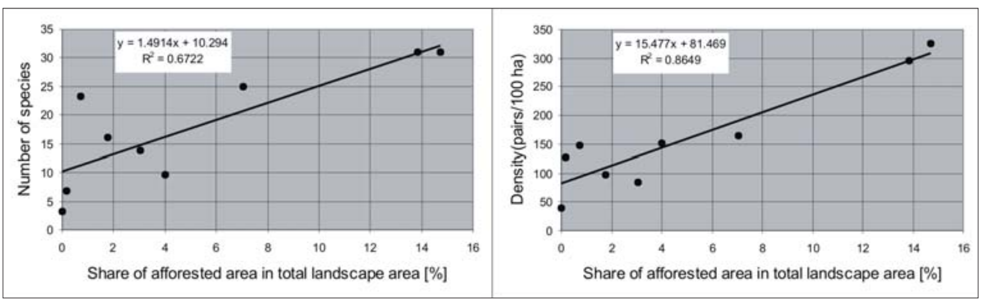

Figure 6. Impact of landscape afforestation on number and density of birds (after Kędziora *et al.* 2012)

In soil of old shelterbelts as well as newly-planted ones the number of overwintering insects is 12–15 greater than in the soil of cultivated fields (Tab. 6). Thus, through the introduction of refuge sites like hedges, shelterbelts, stretches of meadow, small mid-field wetlands, or small bodies of water, the negative effects of agriculture intensification may be mitigated to some extent.

Table 6. Insects overwintering in young (1–4 year old) and mature (160 years old) shelterbelts as well as in fields adjoining to shelterbelts (100 m apart) – after Ryszkowski *et al.* 1999b

Insect development stage	**Density (in d × m^{-2})**			**Biomass (mg × dw × m^{-2})**		
	shelterbelts		**field**	**shelterbelts**		**field**
	old	**young**		**old**	**young**	
Larvae	73.1	42.3	5.3	456.9	323.7	32.7
Adults	199.1	190.3	13.8	625.3	460.3	25.8
Total	272.3	232.6	19.1	1082.0	787.0	58.5

CONCLUSIONS

The diversification of agricultural landscape structure induced by the introduction of shelterbelts modifies evapotranspiration and water run-off rates, and therefore influences water cycling in a region. The reported cleansing effects of shelterbelts on ground water chemistry allow for the use of higher doses of fertilizer and by that token achieve greater crop production without any stimulation of water pollution by chemicals leached from fields (of the kind that will take place in an agricultural landscape consisting of large cultivated fields only). The introduction of shelterbelts into an agricultural landscape will thus aid in the development of new environment-friendly agro-technologies which at the same time allow for intensive production as balanced with the ability of an agricultural landscape to absorb the side effects of agriculture without being damaged. Landscape, agronomic and technical methods should be mutually supportive in order that an effective and economical system of water management in rural areas can be achieved.

Many results of investigations carried out in Poland's Wielkopolska region support the idea that landscape structure is the most important factor determining the natural resistance of the environment to threats. The more mosaic-like the structure of the landscape, the greater the degree of landscape resistance. The best way of improving landscape structure is shown to be to introduce shelterbelts, plant trees, and strips of meadows or bushes, rebuild damaged postglacial ponds, and maintain wetlands and riparian ecosystems. The saturation of landscapes by ecotones and biogeochemical barriers is confirmed as the most efficient tool by which to control energy flow and matter cycling, and the same is also necessary for the sustainable development of agriculture.

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