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Sustainability and Multifunctionality of Agricultural Landscapes

Lech Ryszkowski
Andrzej Kędziora

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Interdisziplinäre Arbeitsgruppe *Zukunftsorientierte Nutzung ländlicher Räume*
Jägerstr. 22/23
10117 Berlin
Tel. (030) 20370-538
Fax (030) 20370-214
plieninger@bbaw.de
http://landinnovation.bbaw.de

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Lech Ryszkowski, Andrzej Kędziora
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Lektorat: Tobias Plieninger
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Introduction

Since long time ecology thought that processes are interlinked and interdependent. But despite this knowledge, the importance of side effects of human activities as well as natural processes that is their multifunctionality was not recognized before induced degradations of environment had started to limit economy (e.g. increasing costs of environment protection) and had aggravated options to combat poverty. Concept of multifunctionality is one of the important elements of sustainable development idea which helps to protect environment and production processes by focusing awareness of people on possible negative aspects of production or on use of ecosystem or landscape beneficial services.

The human population of 6.1 billion present will probably reach 8 billion in 2050. The food production has to increase by 50% to feed human populations (Millennium Ecosystem Assessment, MEA, 2005). This increased demand will be achieved from less land, with less water. The intensification of agricultural production will have increasing impact on environment (pollution, erosion, abstraction of water, soil degradation, loss of biodiversity etc.). Therefore crop varieties with higher yield potential and yield stability and better management practices are needed to meet both increased crop productivity and sustainability.

This goal can be approached by: selection of more productive cultivars. Modification of physiological processes leading to biomass production, improvement of management practices (soil protection, integrated nutrient management, benign crop rotations, pests control and so on). *Those mechanisms of production increase can be applied at the farm level. Use of multifunctional properties of agricultural landscapes can be helpful to enhance those mechanisms.* Sustainable development implies fundamental change in approach to production processes by recognizing the challenges embedded in awareness that resources are finite, and all earth's systems are interconnected and interdependent.

The stress is put therefore on recycling of resources, management of energy and matter exchange between various systems and relationships between living standards of people and environment conditions. Achieving those goals in practice requires that economic growth supports social progress and respects the environment, that social policy underpins economic performance, and that environmental policy is cost-effective.

Awareness of multifunctionality can help to make use of synergistic influences of various processes side effects for implementation of sustainability goals (e.g. shelterbelt water cleansing and health of people). Economical considerations play important role in the guidelines for sustainable development, but this does not mean that economy is the most important facet of sustainable development. The life supporting processes of environment ensure the existence of all being on the earth and from this perspective the economy forms subsphere of environmental processes.

Principles of ecology providing knowledge on solar energy fluxes, nutrient cycles, hydrological cycle, climate system and regulatory functions of biota have to establish the framework for the formulation of economic policy and economists as well as ecologists should work together to foster new economy. Multifunctional dimensions of human actions and natural processes will play important role in implementation of sustainable development strategy.

The concept of ecosystem services was developed capitalizing on ecological knowledge that ecosystems perform various functions like increasing or retarding water fluxes, cleansing or polluting water, modifying microclimatic conditions, sustaining or impoverishing biological diversity and so on. The ecosystem services are those goods or non-commodities which benefit people (Millennium Ecosystem Assessment 2005).

The ecosystem services can be divided into:

- supporting which underpin other categories of services (solar energy fluxes, matter cycling including water, photosynthesis).
- provisioning providing goods like food, fiber, timber etc.
- regulating that is cleansing water, modifying microclimatic conditions, controlling rates of matter cycling, regulating diseases etc.
- cultural providing non-material benefits from ecosystem.

There is growing body of ecological knowledge that management of agricultural landscape for its structural diversity is becoming the important pillar of the sustainability of rural areas. Programmes of environmental protection in rural areas should aim not only at introduction environmental friendly technologies of cultivation within farm. They should also be concerned with challenge of how to increase the resistance or resilience of the whole landscape against threats.

This could be approached by stimulating natural processes underpinning the control of diffuse pollution and erosion, increase efficiency of water retention and biodiversity conservancy, which can not be controlled only at the farm level but have to be managed by increasing the landscape structure diversity. Understanding landscape functions people can stimulate nature services which can limit or modify intensity of negative effects brought about by an intensification of agricultural production needed for feeding human population.

Recognition of non-commodity effects of diversified agricultural landscape formed by introduction into cultivated fields shelterbelts, stretches of meadows, small mid-field water reservoirs and other biogeochemical barriers provide new options to combine societal demands with environment production. Co-adaptation of human activities with landscape services relies on policy that economic processes should be conformed with ecological processes operating in the region which are enhancing landscape capacities for naturalization of pollution, regeneration of wastes, recycling of water recourses as well as increasing resistance or resilience of the whole system to stresses caused by production of goals required by society. Recognition of system multifunctionality helps to achieve that goal.

The knowledge on processes underpinning ecosystem services opened new frontiers for management of landscapes' structures towards enhancing their capacities to deliver requested services. Forests and shelterbelts show similar functions in the landscape but network of shelterbelts perform many similar services like forests growing on smaller part of landscape area. According to studies carried out by Research Centre for Agricultural and Forest Environment in Poland the following functions of shelterbelts are similar to those shown by forests when 4-5% of the landscape area is under the network of shelterbelts:

- modify the microclimatic conditions and heat and water balances;
- control the water chemistry composition (control of diffuse pollution);
- limit water and wind erosion;
- protect the biodiversity;
- increase the survival of the game animals;
- enhance recreational value of the region;
- provide wood and other products;
- promote aesthetic values of the countryside.

In this review the first four functions of agricultural landscape within Turew neighborhood will be presented.

Characteristics of Turew landscape

General characteristics

The landscape is located between 16°45' to 17°05' E and 51°55' to 52°05' N. The Field Station of the Research Center is situated in the middle of the area under study near a small village called Turew (Foto 1). Therefore, the name Turew is used to identify the landscape (Foto 2). The area of interest is part of a large region called Wielkopolska known as the “bread basket” of Poland. Agriculture is the dominant activity of the region. The majority of farms are small. Above 10 ha in size are 27% of total farms. Land-use structure of total catchment area (18235 ha) is: arable land: 11342 ha (65%); afforestations and shelterbelts: 3272 ha (14.8%), grasslands: 2277 ha (8.6%). Shelterbelts, some introduced as early as in 1830s-1840s, constitute and important element of landscape. There are 763 shelterbelts in the total area. The following tree species occur in forests and afforestations: Pinus sylvestris 65.5%, Quercus petrae and Q. robur 14.5%. Robinia pseudoaccacia 5%, Betula pendula 4.3%, Larix europea 3.6%, Alnus glutinosa 3.3%, Picea abies 1.8% and others. Altogether 24 distinct tree species are found in forest and shelterbelts of the Turew landscape.

Foto 1: Turew Field Station

Foto 2: Turew agricultural landscape

Present structure of the crops is as follows: cereals including maize 76.7%, legumes 16%, potato, seed-rape and sugar beets 6%.

Excluding large agricultural enterprises the average density of animals is equal to 18 large heads per 100 ha of agricultural land with cattle making 75%. In large farms 84 large heads per 100 ha are raised with cattle making 61%. Plant production ($t{\cdot}ha^{-1}$) equals to 3.4 in cereals, 19.6 for potatoes and 49.6 for sugar beets. There is great variability between farms in yields. The average fertilizers doses in last years reached 90 kg $N{\cdot}ha^{-1}$; 50 kg P_2O_5 $\cdot ha^{-1}$, 88 kg $K_2O{\cdot}ha^{-1}$ in large enterprises and in small farms 36 kg $N{\cdot}ha^{-1}$ and about 60 $kg{\cdot}ha^{-1}$ of P_2O_5 and K_2). Some small farms used very small doses of fertilizers. Input of N with fertilizers was estimated for 622692 $kg{\cdot}year^{-1}$ for total area of watershed. The input with precipitation was estimated for 366523 $kg{\cdot}year^{-1}$ for total watershed. There are 19 sewage treatments outlets which on the average introduce about 42000 kg $N{\cdot}year^{-1}$. Mean human population density is 55 persons per hectare.

Physiography of area and soils

The Turew landscape is situated on a rolling plain, a slightly undulating ground moraine with many drainage valleys. The area is drained by the Obra river with the average annual flow of 3.8 $m^3{\cdot}sek^{-1}$ at the Kościan gouge station. The Turew landscape is drained by the Wyskoć canal discharging water into Obra river at the mean annual rate of 0.5 $m^3{\cdot}s^{-1}$. Depending on climatic conditions of the year the discharge of water varied greatly.

The soils of bottom moraine in the upper layers of soil horizon have a high sand content. The elevation of the rolling plain ranges from 85 to 90 m above sea level and drainage valley range from 75 to 77 m above sea level. The differences in elevation between the surface of the rolling plain and valleys range from 2 to 6 meters. In general light textured soils (Hapludalfs and Glossudalfs and less frequently met Udipsamments) with favorable water infiltration conditions are found in uplands. Deeper strata are poorly permeable and percolating water seeps to valleys, ditches and main drainage watercourses. The ground water table in uplands depends on the elevation and ranges from 1.2 m to 3.5 m below the surface and fluctuates substantially in the course of year. In the valleys, the ground water table on poorly drained soils (Endoaquolls) ranges from near to surface down to 0.8 m below the surface while in mineral intrazonal hydromorphic soils (Haplaquolls and Psammaquents) it ranges from 0.5 to 1.2 m. The natural drainage conditions, range from imperfectly or poorly drainage valleys to well and excessively drained in sandy uplands.

Climate

Climatic conditions in the region are determined mainly by air flowing from Atlantic Ocean (polar maritime air masses) with annual mean frequency of 58 per cent and by polar continental air masses from Asia continent (frequency of 29 per cent). Minor influences have arctic air inflows (5 per cent) and tropical one (7 per cent). The winds from west dominate during almost the entire year, and their maximums occurrence is noted in July and August. Mean annual wind velocity is 2-4 m $\cdot sek^{-1}$ with highest velocities noted in winter. The average monthly sunshine ranges from 35 hours in December to 230 hours in June.

Mean annual solar radiation is equal to 3700 $MJ \cdot m^{-2}$ and net radiation denoting energy used for evapotranspiration, air and soil heating as well as primary production of plant amounts to 1315 $MJ \cdot m^{-2}$. The mean annual air temperature is 8 $^{\circ}C$ (ranging from 6.6 ^{o}C to 10.1 ^{o}C) with July the warmest (10.0 ^{o}C) and January the coldest month (-2.4 ^{o}C).

In comparison with thermal characteristic, precipitation is exceptionally variable both in time and space. Very great differences are observed among monthly and annual sums of precipitation over the years. Hence the mean values of precipitation sums are only approximate. Annual mean precipitation ranges about 600 mm (April-September: 365 mm, October-March: 235 mm) with lows of 480 mm and peaks of 1040 mm during the period 1950-2003. About 75 to 85 per cent of precipitation is evaporated and 25 to 15 per cent of fall make runoff. Although the amount of precipitation in the spring-summer period is much higher than in winter a shortage of water occurs frequently in the plant growth season. Often more water is evaporated during the growing season than is precipitated, resulting in the lowering of the groundwater level. Plant water uptake in this period is dependent on the water supply accumulated in soil. That is why the recharge of soil water during the winter-spring period is so important for plant cultivations. The higher water deficits in the growing season occur in the year following a dry year if precipitation during winter was low and insufficient for soil water recharge.

Within a 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 than normal precipitation water deficits in light soils can reach 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 reaches half of normal water deficits can reach 70 mm in loamy soils and 170 mm in sandy soils.

The plant growing season lasts 225 days, from the third ten-day period of March to the end of October. Thus the main environmental threat to agricultural production (both plants and animal) is shortage of water caused by climatic conditions, small water storing capacities of soils, mistakes made by people in drainage projects, loss of small water reservoirs and insufficient control of evaporation from fields by network of shelterbelts.

Non-commodity outputs of agricultural Turew landscape

Modification of microclimatic conditions and heat and water balances

The values of net radiation in ecosystems of the Turew landscape range from 1494 to 1730 MJ·m^{-2} for the vegetation season (Table 1). The lowest net radiation was observed in the meadow ecosystem, while the highest was in the shelterbelt (Table 1). Crops of rape seed, beets, and wheat have practically the same values of net radiation. The net radiation of meadow slightly is lower than that of cultivated fields. The high net radiation in shelterbelts is partly a reflection of the low albedo of these ecosystems.

The various ecosystems use net radiation energy in different ways (Table 1).The range of energy values used for evapotranspiration (LE) is from 866 MJ·m^{-2} (bare soil) to 1522 MJ·m^{-2} (shelterbelt); the shelterbelt uses nearly 5.5 times less energy for heating air (S) than does bare soil. Evapotranspiration energy for crops and meadows also differs. Wheat has the lowest evapotranspiration value and meadow the highest (LE in Table 1). Energy used for heating soil (S) is the smallest part of net radiation and ranges from 29 MJ·m^{-2} in meadow to 87 MJ·m^{-2} in shelterbelts. However the soil heat flux in bare soil, during early spring can reach more than 300 joules per second per square meter which is equal to the net radiation value. The average value of soil heat flux, during the whole vegetation season, is small because warming up of soil ceases at the beginning of August, after which time the soil begins to cool. Thus, although the average values of soil heat flux are rather small in comparison with other components of heat balance during the whole vegetation season, nevertheless, at the beginning and end of the vegetation season the energy used for soil heating in spring or lost in autumn, can be high and can equal or sometimes exceed the net radiation value. These data illustrate the high diversity of the ecosystems. The shelterbelt uses about 40% more energy for evapotranspiration than does the wheat field; while the wheat field diverts approximately three times the energy to air heating than does the shelterbelt (Table 1). This means that a shelterbelt can evaporate about 170 mm more water than a field of wheat. There are two main reasons for this difference. First, there is a difference in the structure of plant cover. Trees have much longer roots than wheat, which allows them to absorb water from deeper layers of the soil. In effect, more water is within reach of the tree roots. Since trees have greater amounts of water available for their use than cereals, tree leaves have smaller stomatal resistance than cereal leaves. Shelterbelts also have a greater canopy roughness than wheat, which together with a higher wind speed in the shelterbelt canopy, results in more intensive turbulent exchange over shelterbelt. The differences among the various crops are mainly related to differences in length of time plant cover exists on the field. After harvest, crop fields resemble bare soil. Study of the heat balance (Table 1) has shown that shelterbelts influence evapotranspiration much more than meadows and at the same time exert a cooling effect on the air. During the vegetation season, water evaporated by shelterbelts surpasses the precipitation of this period by 62% which has a drying effect on surrounding fields. This deficit in the Turew landscape is counterbalanced by late autumn and winter precipitation. The cultivated field has lower evapotranspiration rates than shelterbelts and meadows (Table 1).

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

Parameter ($MJ \cdot m^{-2}$)	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 [mm]	609	500	465	454	436	346

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

The plant cover structure is a factor which channelling solar energy increases the diversity and variability of energy fluxes within the various ecosystems of the landscape. However, stabilising effects on different energy flows are achieved at the landscape level because energy gradients exist between the ecosystems which form the landscape. For example, induced air movement by thermal gradients could transport surplus heat from one ecosystem to another. Thus, the heat balance of the entire landscape will not be the simple sum of heat balance components of all ecosystems treated separately. The shelterbelts introduced into grain monoculture landscape change the microclimatic conditions of the field as well as aerodynamic characteristics of an active surface. Shelterbelts reducing wind speed (Jansz 1959), stomatal resistance and increasing the humidity (Rosenberg 1974), 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 L., Kedziora A. 1987, Kędziora A., Olejnik J. 1996, Kędziora A., Olejnik J., Kapuscinski J. 1989, Kędziora A., Olejnik J. 2002).

In the landscape composed of cultivated fields and shelterbelts one can observe two opposite tendencies in water cycling (Ryszkowski and Kędziora, 1995, Kędziora 1996). The trees increase evapotranspiration rates. At the same time, the protecting effects of trees stimulate a decrease in wind speed and a lower saturation of vapour pressure deficits which decrease evapotranspiration. It is for this reason that fields between shelterbelts conserve moisture which can increase yields (Brandle et al., 2004; Grace, 1988; Ryszkowski and Karg, 1976) (Table 2).

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

Landscape type	Heat balance components in $MJ \cdot m^{-2}$						Evaporation	
	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

Rn - net radiation, LE - latent energy used for evapotranspiration, S - sensible heat (energy used for air heating), G - energy used for soil heating

Table 3: Precipitation and rate of runoff (mm•y-1) in different ecosystems (modified after Werner et al. 1997)

Ecosystem	Precipitation [mm]		
	Dry year	Normal year	Wet year
	627	749	936
Cultivated fields	108	233	351
Grasslands	0	155	271
Forests	0	149	181

During plant growth season, the introduction of shelterbelts can save as much as 40 mm of water in non irrigated field (504 – 464 mm, Table 2). But when the strongly irrigated field is surrounded by dry area the water savings can reach as much as 200 mm.

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 smaller in landscapes with shelterbelts. Additionally, rain water remains longer in landscapes with shelterbelts.

In dry and normal years similar runoff is observed from forests and grassland landscape. With abundant precipitation trees better control runoff than grasses (Table 3). The fast and intensive runoff in spring or after heavy rain events leads to rapid discharge of water from cultivated fields while uptake of slowly percolating water through soil by trees and intensive evapotranspiration stop runoff from forests and grasslands in dry years. The rapid discharge of water is clearly observed in cultivated fields' landscapes of Wielkopolska. By the end of spring draining cultivated fields ditches are dry while in ditches located in forests water can be observed even in the late summer. Thus grasslands and especially forests slow down the discharge of percolating water which therefore store water longer even under conditions that input of infiltrating water into subsurface reservoir is only slightly higher than from cultivated fields.

Thus, in open landscapes water is lost more rapidly. We can conclude that landscape with shelterbelts is characterised by more efficient water economy than open landscape.

Mid-field ponds are the other landscape elements which provide non-commodity outputs. The mid-field ponds play a triple role in environment: improving of microclimatic conditions, storing of water for small scale irrigation, intensifying of water cycling, controlling of chemicals migration and habitat of mezofauna, especially amphibia. Water bodies by intensive evaporation use nearly all solar energy, so the heating of the air is much weaker than over the land. In the night, the heat stored in water prevents the deep cooling of the area in the vicinity. Because small ponds use for evaporation not only absorbed solar energy but also additional sensible heat of advection, they evaporate more intensively than big lakes. A hundred small ponds can evaporate even 30% more water than one big lake of the same surface does. Small ponds store water not only in them self but also cause the increasing amount of water retained in soil thanks to the increase of ground water level (Ryszkowski Kędziora 1996). The ratio of water stored in the soil to water stored in the pond is bigger for the smaller pond. The collection of water in small field reservoirs in the spring can increase water storage in rural catchments by an amount equals to 20 mm of precipitation.

Control the water chemistry composition (control of diffuse pollution)

The increasing use of artificial fertilisers, as well as liquid manure from big farms, usually applied in one dose, and the increasing use of pesticides together with simplification of agricultural landscape structure led to very high pollution of environment.

Table 4: Annual mean water output (mm) and nutrient loss (g m^{-2} $year^{-1}$) from two small watersheds in period Nov. 1988 – Oct. 1991. (After Bartoszewicz 1994)

Season	Precipitation	Uniform watershed			Mosaic watershed		
		Water output	$N\text{-}NO3^-$	$N\text{-}NH4^+$	Water output	$N\text{-}NO3^-$	$N\text{-}NH4^+$
Winter season Nov.-April	220.7	60.8	12.3	3.0	56.8	0.90	0.95
Summer season May-Oct.	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

It was observed that nitrate concentrations were decreasing substantially when ground water carrying them from under fields passed under biogeochemical barriers (Fig. 1).

Both, shelterbelts or small mid-field forests could decrease concentrations of incoming $N\text{-}NO_3$ from fields in range of 63% to 98%. In meadows the detected decrease of nitrate concentrations was similar and ranged from 79% to 98% of the input (Ryszkowski 2000).

The decrease of phosphate concentration under the biological barriers is also clearly evident although not in cases when plant residues underwent rapid decomposition and release phosphorus compounds (Bartoszewicz 1990, Hillbricht-Ilkowska et al. 1995, Kędziora et al. 1995).

The great influence of plant cover structure on output of elements from watersheds was shown by Bartoszewicz (1994). The studies were carried out in two small watersheds located nearby. The first one covered in 99% by cultivated fields was called uniform and the second one (mosaic) was composed by 83% of cultivated fields while the rest of terrain was covered by meadows (14%) and shelterbelt (3%). The mean annual precipitation for both watersheds was the same and amounted to 514 mm. On the average annual water output during three years studies from mosaic watershed was lower by 32 mm than from the uniform one. Because the water input (precipitation) was the same in both watersheds the observed differences in water runoff rates, should be attributed to differences in evapotranspiration rates between cultivated fields and meadows or shelterbelts (Ryszkowski and Kedziora 1987). When the waterborne migration of mineral compounds from the mosaic watershed was compared with their outputs from uniform drainage basin then more than tenfold lower outputs of inorganic ions were detected (Table 4).

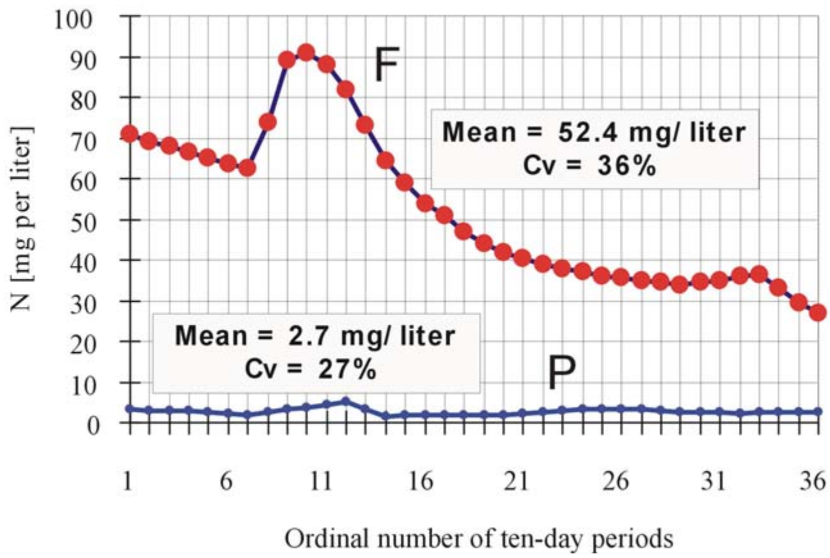

Figure 1: Changes of $N\text{-}NO_3^-$ concentrations in ground water under the field (F) and the pine afforestation (P)

Activities aiming at water pollution elimination in 1970s and up to mid 1980s were focused on treatment of urban and industrial sewage effluents that is on the control of point sources of pollution. But in the late 1980s, it was recognized that problems of water pollution can not be effectively solved if measures to decrease inputs from non-point (diffuse) sources of pollution are not amended (OECD 1986, Halberg 1984, Kauppi 1990, Muscutt et al. 1993, Haycock et al. 1997). Non-point or diffuse water pollution is attributed to increase above natural rates inputs of chemical compounds into subsurface and surface water reservoirs brought by human activity. The cleansing effect of vegetation on subsurface and surface fluxes of chemical compounds carried by water was at the beginning shown in the case of riparian vegetation strips (Lowrance et al. 1983, Peterjohn and Correll 1984, Muscutt et al. 1993, Haycock et al. 1997). The long term studies carried out in the Research Centre for Agricultural and Forest Environment in Poznań, Poland indicated that shelterbelts and stretches of meadows located in upland parts of watersheds also influence on chemistry of water flowing within reach of plants root systems (Ryszkowski and Bartoszewicz 1996, Ryszkowski et. al.1997, 1999, 2002). Nitrate concentrations decreased substantially when ground water containing dissolved nitrates passed under shelterbelts or grassy strips. The decrease of $N\text{-}NO_3$ concentrations in water flowing from cultivated fields through shelterbelts amounted from 63 to 98 per cent of input. In meadow the detected decrease of nitrate concentrations was similar and ranged from 79 per cent to 98 per cent. Those results were obtained in studies of water born nitrates migration through 6 shelterbelts and 8 meadow strips in the Turew agricultural landscape (Ryszkowski et al. 2002).

The intensity of organic matter decomposition processes releasing chemical compounds is very important characteristic determining the control capacities of the biogeochemical barriers. The study on nitrogen balance in clump of trees overgrown by dense stand of old trees, where litter accumulated to 641 gm^{-2} shed biomass is the example indicating the situation in which afforestations can enrich ground water in nitrates. Decomposing litter from March till October released 15.3 $g\ N{\cdot}m^{-2}$ or 153 kg ha^{-1} which equals to high dose of nitrogen fertilizer application (Bernacki 2003). Under such conditions the subsurface output of mineral nitrogen with ground water was by 60% higher than input with ground water. These results clearly show that efficient control of $N\text{-}NO_3$ spreading with ground water can be ensured when accumulated litter is removed from the biogeochemical barrier.

The studies on $N\text{-}NO_3^-$ concentration in five small watersheds of area from 75 ha to 216 ha showed that the higher coverage of catchments by the shelterbelts or grasslands the lower nitrates concentrations at the outlet (Ryszkowski 2000). The relationship between share of permanent vegetation areas in watershed and $N\text{-}NO_3^-$ concentration in discharged water is exponential and for plant growth season with exception of heavy rain events is described by equation:

$$\mathbf{y = 8.6287\ e^{-0.057\,x}} \qquad \mathbf{(R^2 = 0.81)}$$

where y - $N\text{-}NO_3$ concentration and x – share of biogeochemical barriers in total area.

The fields of studied watersheds have Hapludalf and Glossudalf soils and arable fields made from 99 to 52 of their total area. Meadows, shelterbelts and small forests represented perennial vegetation. The input of nitrogen with fertilizers was similar in studied watersheds.

In winter exponent of the equation is lower ($y = 10.626e^{-0.035x}$) but the relationship is statistically significant ($R^2 = 0.96$). Thus, the efficiency of nitrates control by permanent vegetation is lower in winter than in plant growth season.

The following guidelines developed in studies coordinated by the Research Centre for Agricultural and Forest Environment in Poznań could be useful in the control of diffuse pollution by the biogeochemical barriers (Ryszkowski 1998).

As the result of the long-term studies it was found that effectiveness of the biogeochemical barriers could be secured if (Ryszkowski et al. 1997):

1. Ground water table is within direct or indirect (capillary ascension) reach of plants root systems;

2. Shelterbelts are composed of the mix of tree species than in those build by one species because of differentiated preferences for chemical compounds uptake in the different plant species.
3. The slope of groundwater table and hydraulic conductivity is low. It was estimated by that if the values of ground water slope is below 2 degrees and hydraulic conductivity does not overcome 1-1.5 m per day then the width of shelterbelt equal to 10 m very effectively reduces passage of nitrates.
4. The accumulated litter in shelterbelts and forest patches is removed by management practices;
5. The agricultural landscape is covered by the network of biogeochemical barriers. The reliability of the diffuse pollution control in the upland agricultural area having Hapludalf and Udipsamment soils was achieved when biogeochemical barriers made no less than 10% of the total area.
6. The overwintering cultivars are incorporated into crop rotation patterns. From bare soils more nutrients is leached during autumn or winter rains than when overwintering crops cover the soils.
7. The network of biogeochemical barriers consists of mix of the various landscape elements. Cultivated fields should be intersected by shelterbelts, small patches of forests, mid-field ponds or wetlands, stretches of meadows. The mosaic landscape efficiently controls diffuse pollution.

Plants like trees with deep root systems or alfalfa can use not only water stored in aeration zone of soil but also from saturated zone (shallow ground water). The model for estimation of plant's uptake of water from unsaturated soil zone and shallow ground water was developed (D. Kayser PhD thesis). The uptake of ground water is important characteristic of water uptake from flux driving water out watershed to drainage system. This is one of intra landscape mechanisms of water recycling. The ratio of ground water uptake to real evapotranspiration shows intensity of withdrawl of flowing out water for ecosystem uses. This ratio (p) depends on an actual evapotranspiration (ETR) and ground water depth (GWL). The following equation describes this relationship for shelterbelts in Turew landscape:

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

The mean ETR value is calculated for half month period and GWL is the average value for the same time span.

It was found that proportion of water uptaken from ground aquifer for shelterbelt evapotranspiration is greater in warmer weather and in cases of shallow water level (Fig. 2) The estimations of ground water average share in evapotranspiration for plant growth season varied from 0.244 during cold weather and deep ground water level (1.5 m depth) to 0.439 during warm weather and shallow ground water table (0.5–1.0 m depth). At the beginning of the plant growth season in cold weather year the shelterbelt used only 18 per cent of ground water in real evapotranspiration but in warm weather year 37 per cent was used (Fig. 2).

It seems that when there is enough moisture at the spring the trees mainly use water from unsaturated zone of soil. When temperature and evapotranspiration increase and water supplies in upper part of soil decrease the trees use more and more water from ground aquifer. In June the ratio of uptaken ground water to evapotranspiration increase to 30 per cent if there is cold weather and up to 50 per cent during warm weather. One can suppose that besides higher withdrawal of ground water for evapotranspiration which denote it higher rate of recycling the shelterbelts probably more efficient also control diffuse pollution in ground water during summer.

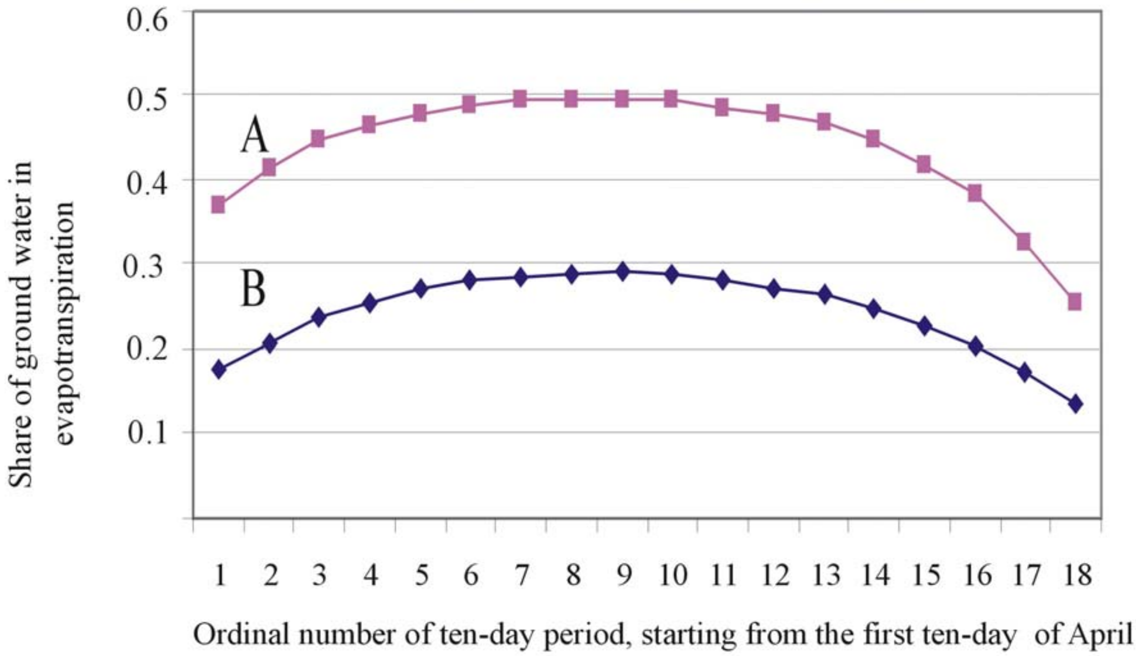

Figure 2: Share of ground water in evapotranspiration related to weather conditions and depth of ground water level (A - warm weather and shallow ground water level, B - cold weather and deep ground water level)

Foto 3: Very strong wind erosion in spring in Turew landscape

Controlling of water and wind erosion

Gross water erosion as well as wind erosion is not very frequent in Turew landscape, mainly due to rather flat terrain and weak winds. But sometime and in some places the so called microerosion is serious problem causing degradation of surface ploughed soil layers. Also the wind erosion can be substantial threat for ploughed soil layers (Foto 3). Such occurrence is observed in the early spring under special weather conditions. At this time there are many bare fields in the agricultural landscape. When under such conditions the cold weather is accompanied by very intensive solar radiation and very high wind speed the very high water vapor saturation deficit in the near surface air layer is observed. It is generated by intensive heating of soil aggregates surface and very low concentration of water vapor in the cold air. It, in turn, brings to extremely intensive evapotranspiration from the soil aggregated. In such condition the hydraulic conductivity within soil aggregates is to low to ensure enough water flux density from inside of aggregates to its surface to cover the needs of evapotranspiration. This process leads to drying up the surface of the aggregates and its crumbling. These small mineral particles as well as organic matter is intensively blown away bring to real silt-storm.

In Turew landscape the wind erosion can starts when wind speed measured at 2 m above ground exceeds 4 $m \cdot s^{-1}$ (Borówka 1980). Although in process of blowing away the particles of find and medium sand are firstly set in motion, finally the silt and organic matter is blown away. It consists 47 to 88% of total blown away when weak wind is blowing, 52 to 73% during medium wind speed and 32 to 47% during strong wind (Uggla i Nożyński 1962).

One of the best measures to counteract the wind and water erosion is introduction of net of shelterbelt into uniform landscape. Suitable dens of shelterbelt net can reduce the wind speed up to 60% of this in open landscape (Jansz 1959) and reduce runoff up to 10% in comparison with open landscape (Kędziora and Olejnik 2002). The reduction of wind up to 60% brings to reduction of wind erosion eleven fold (Borówka 1980).

Biodiversity protection and enhance

Conversion of pristine ecosystems into cultivated fields and intensification of agricultural production brought an impoverishment of biological diversity which was recognized not only by scientists (e.g. Wilson 1992; Karg and Ryszkowski 1996; Reaka-Kudla et al. 1997; Collins and Qualset 1999; Bourdeau 2001; Loreau et al. 2002) but also by politicians (Convention on Biological Diversity opened in 1992 at the Earth Summit in Rio de Janeiro for endorsing; COM 1999 and many other documents). Increasing human population and intensification of agricultural production have profound impact on the ecological carrying capacity of agricultural landscapes for biodiversity. Those concerns are aggravated by increasing water shortages. Some countries already suffer water deficits and it is foreseen that by 2050 water shortages will become a critical worldwide problem (Brown 2001; Swaminathan 2001).

The possibilities that agriculture could be integrated with biodiversity protection are related to change of cultivation technologies (Srivastava et al. 1996; Hudson 2001) and to management of agricultural landscape structure in order to provide survival refuges for biota (Baldock et al. 1993, Ryszkowski 1994, 2000).

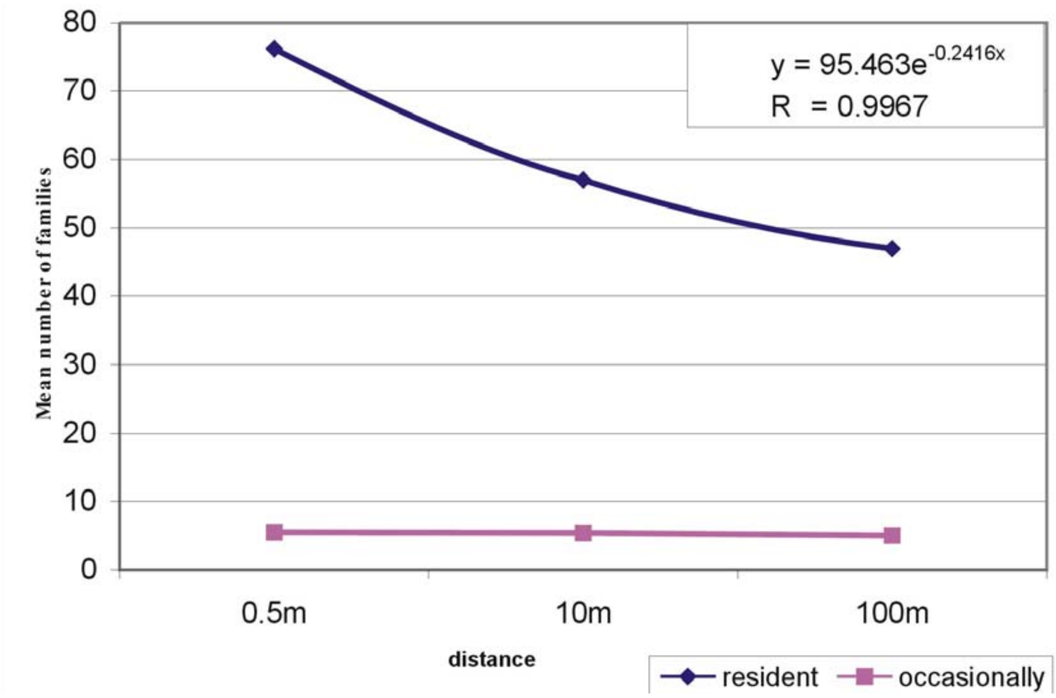

Figure 3: Number of resident and occasionally appearing families in different distances from shelterbelt (after Ryszkowski et al. 2006)

The recent review of relationships between biodiversity and landscape structural characteristics showed the importance of composition, heterogeneity and fragmentation of habitats, their connectivity and scale dimension for biodiversity protection (Waldhardt 2003). Two kinds of habitat diversity can be distinguished in agricultural landscape. The first one is diversity of crops which form the matrix of agricultural landscape and second one is diversity of permanent landscape structures that is diversity of seminatural or perennial patches of vegetation such as shelterbelts, small forests, stretches of grassy vegetation, small mid-field water reservoirs or wetlands and so on. The studies on insect communities carried out during the 16 years in two type of agricultural landscape (uniform and mosaic) show significant impact of landscape structure diversity on number of insect families appearing in these landscapes. These two landscapes were similar as regards to crops diversity but differ essentially in share of permanent landscape elements such us shelterbelts, small forests, stretches of meadows, small mid-field ponds and wetlands (Ryszkowski et all. 2006). During 15 years of study in 11 cases the number of insect families was higher in mosaic landscape. It was found, that number of families and diversification of the residual families depend on distance from the shelterbelts, but such relation for occasionally families were not found (Fig. 3.) The mean number of families found in wheat field at the 100m distance shelterbelt was equal to 52.0 and was higher than their number recorded in wheat fields of the uniform landscape which amounted to 40.9. This result indicate that even at the distance of 100 m to the nearest shelterbelt the diversity of insect communities was influenced by specimens coming from a refuge site. This finding supports the conclusion obtained in comparisons of annual estimates of mean number of families recorded in the mosaic and uniform landscape that diversity of landscape stimulates diversity of insect community. One can conclude, therefore, that the more compact network of refuge sites is the higher the diversity of insects can be observed in fields located between shelterbelts.

The Turew agricultural landscape is reach in rare and protected vascular plants (45 threatened species and 23 protected species). More than 22 rare and very rare insect species were identified. The communities of invertebrate as well as vertebrate are very rich in Turew Landscape (Table 5). The very rich breeding bird communities (86 species) exist in the Turew landscape. Such high density of protected and rare species is caused by introduction of shelterbelt network. Within the area is located landscape park, which protect and stimulate ecologically sound landscape management.

The results of those analysis document that negative effects of agriculture intensification on biota can be mitigated by the introduction permanent vegetation structure. It seems that shelterbelts are especially suited for these landscape services. The presence of refuges and their distribution should match the requirements for breeding, food acquisition, dispersion abilities and other needs of the organisms in question. Introduction of a mosaic landscape should enhance landscape services and help to protect biodiversity more than biodiversity friendly attempts of farming only within cultivated fields.

Table 5: Number of animal species in the Turew agricultural landscape

Number of invertebrate species		**Number of vertebrate species**	
Enchytraeidae	25	Fishes	15
Nematoda	40	Amphibia	12
Lumbricidae	7	Reptilia	4
Araneae	28	Nesting birds	86
Thysanoptera	47	Mammals	48
Coleoptera	about 700		
Heteroptera	about 130		
Homoptera	145		
Apoidaea	258		
Daylight Lepidoptera	47		
Night Lepidoptera	350		
Microlepidoptera	150		

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