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Impact of agricultural landscape structure on energy flow and water cycling[1]

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Abstract

In long term studies the following climatological characteristics were measured or calculated: air and soil temperature, sunshine, wind speed, vapor pressure, saturation deficit, precipitation, humidity, incoming and reflected solar energy, energy emitted by active surfaces and primary production. Taking into account the relationships between climatological characteristics, the growth stages of vegetation, and relations between heat balance components, the fluxes of energy used for evapotranspiration, air, and soil heating were estimated in various ecosystems composing the agricultural landscape. The energy contained in biomass production of various crops was estimated also. Aggregate estimates of energy flow connected with evapotranspiration, and soil and air heating were calculated for eight model landscapes which differed by the plant cover structure. A higher variability of energy fluxes was observed for individual ecosystems than for agricultural landscapes. It was shown that the structure of the plant cover has an important bearing on energy flow and water cycling both by direct and indirect influences. Shelterbelts are especially important in their influence on energy flow and water cycling.

Introduction

The Institute of Agrobiology and Forestry in Poznań, Poland has coordinated, for the past twenty years, interdisciplinary studies on energy and matter flux of an arable landscape. The landscape is located about 40 km south of Poznań in the area of the West Polish Lowland which is a ground moraine formed during the Baltic glaciation, terminating about 10,000 years ago. The Field Station of the Institute of Agrobiology and Forestry is situated in the middle of the study area near a small village called Turew. Therefore, Turew is used to identify the landscape. The terrain consists of a rolling plain made up of a slightly undulating ground moraine, with many drainage valleys. The differences in elevation, between higher and lower parts of the area, do not exceed a few meters. Light soil, with favorable water infiltration conditions, is found on higher parts of the terrain. Peat soils, having a relatively high water retention value, occur in small depressions. The depth of the ground water table is related to elevation and ranges from 0.5 to 4.0 m below the soil surface. Its depth also fluctuates during the year depending on the annual water regime.

The climate of the area is one of the warmest in Poland, with a mean annual air temperature of

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8°C. The plant growth season, with an air temperature above 2.5°C, lasts 225 days. On the average, it begins on March 21 and ends on October 30. Average mean annual precipitation, for the years 1881–1985, is 527 mm (Madany *et al.* 1972). Although the amount of precipitation in the spring–summer period is more than twice that in winter, a shortage of water takes place during the growing season.

The landscape is composed of 69% arable field ecosystems, 14% shelterbelts, and small forests, and 12% meadows, and pastures, with the remainder villages, roads, small lakes, channels, and water logged areas.

Generally the crop structure of arable fields consists of 50% cereals (rye, wheat, barley, and oats), about 25% row crops (beet, potato, and rapeseed), 10% perennial fodder crops, and 15% others. This crop rotation is similar to the Norfolk rotation (Russell 1973) which assures maintenance of soil fertility.

Shelterbelts are characteristic components of the Turew landscape. They were planted on the initiative of Dezydery Chłapowski, in the twenties of the previous century. Chłapowski understood the usefulness of shelterbelts as field enclosures, in changing the microclimate for cultivated plants, for wood production and for their esthetic and protective values. Shelterbelts consist of false acacia (*Robinia pseudo-acacia*), poplars (*Populus* spp.), oaks (*Quercus* spp.), pines (*Pinus* spp.), spruces (*Picea* spp.) and a small number of other tree species.

Methods

Energy flow and water cycling within the landscape was studied by variety of climatological, hydrological and ecological methods. Climatological characteristics such as air and soil temperatures, sunshine, wind speed, vapor pressure, saturation deficit, precipitation and humidity, were measured by standard methods under field conditions. Incoming and reflected solar radiation were measured under field conditions by use of a Kipp-Zonnen solarimeter. Also, net radiation (R_n), was measured directly by the use of a 'Sontag' net-radiometer produced by the Democratic Republic of Germany, as well as being calculated empirically in equation 1.

The energy flux of ecosystems in the landscape was determined by the relationships between the climatological characteristics of the region, the growth stage of vegetation, and the heat balance components (LE – latent heat used for evaporation, A – sensible heat used for heating air and S – soil heat) (Kędziora and Olejnik, in press, Kędziora and Olejnik 1984, Tamulewicz and Woś, in press). The relationships used in the paper consist of the following site-specific, empirical equations (Kędziora *et al.* 1987):

$$R_n = (1-a) \cdot R \cdot (0.22+0.54 \cdot u) - 5.67 \cdot 10^{-8} \cdot (t+273)^4 \cdot (0.56-0.08 \cdot e^{0.5}) \cdot (0.1+0.9 \cdot u) \quad (1)$$

$$W = \frac{100 \cdot (d \cdot v^{0.5})^{atn\left(\frac{\pi}{2} \cdot f\right)}}{t \cdot (0.4+u)} \quad (2)$$

$$LE/Rn = \frac{7.58}{W + 7.00} - 1.02 \quad (3)$$

$$A/R_n = 0.09 - \frac{8.58}{W + 7.47} \quad (4)$$

$$S = -2 + 2 \cdot (t_i - t_{i+1}) \quad (5)$$

where:

all fluxes are expressed in watts per square meter.

R_n – net radiation

W – agrometeorological index showing the relationship between plant growth and meteorological conditions and the proportion of energy used for evapotranspiration and air heating in the radiation balance. The higher the index value, the greater the part of net radiation used for evapotranspiration.

R – the theoretical amount of solar radiation reaching the earth in the absence of an atmosphere.

LE – latent heat used for evaporation.

A – sensible heat used to heat the air.

S – soil heat.

u – relative sunshine, dimensionless.

t – air temperature in degrees Celsius

e – vapor pressure in millibars;
d – saturation vapor pressure deficit in millibars;
v – wind speed in meters per second;
f – stage of plant development, dimensionless, changing from 0 to 1;
a – albedo (ratio of reflected to incoming radiation);
t_i – soil temperature at a depth of 10 cm at the beginning of the month;
t_{i+1} – soil temperature at a depth of 10 cm at the end of the month.

The data for the above equations (except that for net radiation) were obtained from micrometeorological measurements carried out in the Turew landscape (Kędziora and Olejnik (in press), Kędziora *et al.* 1987). The method of mean profiles was used to obtained latent and sensible heat fluxes (Oke 1978, Monteith 1975). For measuring soil heat flux the heat transducer method (direct method) was used, as well as heat capacity method (indirect method, Taylor and Ashcroft 1972).

Primary production was evaluated by various methods (Ryszkowski 1984). The most frequently used method was the summation of biomass increases of above and below-ground parts of plants, including fall of above-ground parts of plants beween sampling dates. Both the production of cultivated plants, as well as weeds and the regrowth of plants, were included in estimates of primary production in agro-ecosystems.

Table 1. Albedo of various surfaces in the landscape of Turew. (Tamulewicz and Woś, in press)

Ecosystem	Albedo
Winter wheat	
Sprouting	0.15
Growing	0.17
Full developed	0.23
Rape seed	
Growing	0.17
Before harvest	0.26
Alfalfa	
Growing	0.19
Full developed	0.22
Meadow	
Green	0.23
After cutting	0.15
Shelterbelt	
Leafless	0.10
Green	0.15
Bare soil	
Light	0.19
Dark	0.15

Albedo – the first control mechanism of energy flux at the landscape level

Incoming solar energy to the landscape is determined by the 24-h pattern of earth rotation, sun elevation above the horizon during the year, and cloudiness. These are the factors which are beyond the interplay of ecological processes operating at the landscape level. Incoming solar radiation is intercepted by the ecosystem or is reflected. Reflection, which is estimated by the albedo value, is lower when the intercepting surface has high moisture, a rough surface and dark colors. The albedo phenomena is the first control mechanism of energy flow in the landscape, where the ecosystem properties of the landscape influence the amount of intercepted solar energy of the whole system.

Measurements of albedo in the Turew landscape have shown that albedo increases with crop growth in wheat and rapeseed, and with dense, green growth in meadows and shelterbelts (Table 1). For example, fields with growing rapeseed reflect about 9% less energy than rapeseed fields just before harvest (Table 1). In daily rates of energy flux this difference amounts to 20 joules per sec. Rapeseed fields just before harvest reflect about 11% more energy than the adjoining shelterbelt. These data show that the structure of plant cover is very important for energy interception in the landscape, both for its influence on surface roughness, as well as its color.

The difference, for the vegetation season, in reflected solar energy of agro-ecosystems, is as much as 23% (Table 2). The highest amount of reflected energy is observed in the meadow landscape (632 mJ m^{-2}), and the lowest amount is in

Table 2. Albedo and total amount of solar energy reflected from different landscapes of the Turew region during the vegetation season.

Parameter	Landscapes			
	Cereals only	Cereals and row crops	Meadows	Mosaic of cereals, row crop, and shelterbelts
Albedo	0.22	0.22	0.23	0.21
Reflected energy in mJ m^{-2}	590	604	632	577

Table 3. Heat balance structure in different ecosystems of the Turew landscape. (Mean for total vegetation season).

Parameter mJ m^{-2}	Ecosystems					
	Shelterbelt	Meadow	Rape seed	Beets	Wheat	Bare soil
Rn	1730	1494	1551	1536	1536	1575
LE	1522	1250	1163	1136	1090	866
A	121	215	327	339	385	651
S	87	29	61	61	61	47
A/LE	0.08	0.17	0.28	0.30	0.35	0.76

the mosaic landscape (577 mJ m^{-2}) (Table 2). However, differences in albedo among the landscape is very minor.

Landscape energy interception is determined not only by radiation reflection, but also by reradiation of heat in long-wave radiation. Long wave radiation is determined by the temperature of the radiating surface (usually approximated by the air temperature), its emissivity, and air humidity. Within the range of field temperatures of the Turew landscape, the heat reradiation changes by a factor of 1.14, according to the Stefan Baltzman Law (Rosenberg 1974). Also, there are small variations in emissivity between ecosystems of the Turew landscape (Oke 1978). A change of 0.05 in the albedo means a change in the interception value of 4 joules per second per square meter in spring and of 10 joules per second per square meter in summer. This is quite a substantial difference. The latter value is equal to the energy needed to evaporate 10 mm of water per month. One can conclude that plant cover, which is the main factor controlling the albedo in the Turew region, is the most important factor controlling interception of solar energy at the landscape level.

Heat balance of the ecosystems of the Turew landscape

The balance between all sources of incoming and reflected radiation, as well as energy emitted by the active surface, defines the amount of energy intercepted by the landscape. This balance is called the net radiation, (R_n) and it determines the amount of energy used for the internal workings of ecosystems.

The values of net radiation in ecosystems of the Turew landscape range from 1494–1730 mJ m^{-2} for the vegetation season (Table 3). The lowest net radiation was observed in the meadow ecosystem, while the highest was in the shelterbelt (Table 3). Crops of rapeseed, beets, and wheat have practically the same values of net radiation. The net radiation of meadows is slightly 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 3). The range of energy values used for evapotranspiration (LE) is from 866 mJ m^{-2} (bare soil) to 1522 mJ m^{-2} (shelterbelt);

Table 4. Precipitation (PPT), evapotranspiration (ETR) and its ratios for different ecosystems during the growing season.

Parameter	Ecosystems					
	Shelterbelt	Meadow	Rapeseed	Beets	Wheat	Bare soil
Precipitation in mm	375	375	375	375	375	375
Evapotranspiration in mm	609	500	465	454	436	346
ETR/PPT	1.62	1.33	1.24	1.21	1.16	0.92

the shelterbelt uses nearly 5.5 times less energy, for heating air (A) than does bare soil. Evapotranspiration energy for crops and meadows also differs. Wheat has the lowest evapotranspiration value and meadow the highest (Table 3). Energy used for heating soil (S) is the smallest part of net radiation and ranges from 29 mJ m^{-2} 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 (47 joules per second per square meter) 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 (Kapuściński 1986).

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 3). 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 3) has shown that shelterbelts increase evapotranspiration much more than meadows and at the same time exert a cooling effect on the air. However, shelterbelts heat the soil to a greater extent than grasslands. During the vegetation season, water evaporated by shelterbelts surpasses the precipitation of this period by 62% (Table 4) which has a drying effect on surrounding fields. The cultivated fields have lower evapotranspiration rates than shelterbelts and meadows (Table 4) but still these rates are greater than growing season precipitation. The water deficit in the Turew landscape is counterbalanced by late autumn and winter precipitation.

The role of plant structure in partitioning solar energy increases the diversity and variability of energy fluxes within the various ecosystems of the landscape. However, stabilizing effects on the 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.

Table 5. Heat balance components, their ratios, potential (ETP) and real (ETR) evapotranspiration, and ratios of real to potential evapotranspiration and to precipitation (PPT) for different landscapes of the Turew region for the vegetation season (March 20 to October 31).

Type of landscape	R_n MJ m^{-2}	LE MJ m^{-2}	A MJ m^{-2}	S MJ m^{-2}	LE/R_n	A/R	ETP mm	ETR mm	$\frac{ETR}{ETP}$	$\frac{ETR}{PPT}$
K1	1542	−1035	−495	−12	−0.67	−0.32	650	414	0.64	1.10
K2	1586	−1078	−496	−12	−0.68	−0.31	586	431	0.74	1.15
K3	1567	−1010	−546	−11	−0.64	−0.35	581	404	0.70	1.08
K4	1529	−1130	−386	−13	−0.74	−0.25	644	452	0.70	1.20
K5	1587	−1140	−434	−13	−0.72	−0.27	586	456	0.78	1.20
K6	1494	−1250	−230	−14	−0.84	−0.15	618	500	0.81	1.33
K7	1586	−1258	−315	−13	−0.79	−0.20	898	503	0.56	1.34
K8	1586	−1161	−412	−13	−0.73	−0.26	592	464	0.78	1.24

For description of landscapes see text.

Heat balance of the landscape

To analyse the impact of landscape structure on the heat balance structure eight model landscapes (Table 5) were studied. Their structures are as follows:

1. Whole landscape is composed of cereals only (Type K1). Plant germination starts at the beginning of September and harvest comes at the end of July the following year.
2. The landscape is composed of cereals but with the addition of shelterbelts (Type K2) which are permeable, 15 m high, 21 m wide and spaced 300 m apart. Shelterbelts cover about 10% of the landscape area.
3. The third landscape (Type K3) is structured as K1 but with shelterbelts providing only mechanical control of wind speed (windbreaks) but do not evaporate water itself. This means that climatic conditions in K3 are the same as in K2 but the albedo and development stage of the plants are the same as in K1.
4. The fourth landscape (Type K4) is composed of cereals, row crops and perennial crops in the proportion: 50%, 25% and 15% respectively. The remaining 10% of the area is occupied by villages, roads and other terrain not under cultivation.
5. The fifth landscape (Type K5) has structure as K4 but with shelterbelts covering about 10% of the total area.
6. Meadow (Type K6).
7. The seventh landscape (Type K7) is as K1 but is situated in a region where strong advection (horizontal inflow of dry and hot air) occurs. This type of landscape does not exist in the Turew region.
8. Landscape same as K7, but with shelterbelts (Type K8).

In order to estimate energy fluxes in the model landscapes the following assumptions were made (Jansz 1959, Rosenberg 1974): the shelterbelts reduced wind speed by a factor of 0.6, increased the air temperature by a factor of 1.1, and increased the vapor pressure by a factor of 1.15.

The values used in the analysis resemble the microclimatic conditions characteristic of the Turew landscape (Ryszkowski 1975, Ryszkowski and Karg 1976). The shelterbelts in the humid climatic conditions of the Turew region, change the heat balance structure only slightly (Table 5 compare K1 and K2). They cause a small increase in net radiation due to the lower albedo of shelterbelts. Also, latent heat flux, used for evapotranspiration, is higher in the landscape with shelterbelts than in the open landscape. This means that there is more water evaporation from the landscape with shelterbelts. Although shelterbelts cause a distinct decrease of potential evapotranspiration from (650–586), they also cause an increase in real evapotranspiration because of the decrease in stomatal resistance of trees and an increase in turbulence in the shelterbelt canopy.

The same results are obtained when landscapes

K4 and K5 are compared. But if air turbulance conditions are only changed by artificial windbreaks (landscape K3), which do not stimulate evapotranspiration, real evapotranspiration decreases slightly.

A quite different situation can be observed when strong advection occurs (Table 5, landscapes K7 and K8). The landscape with shelterbelts evaporates about 40 mm less water per season than the open landscape. Thus, in a landscape which is under the impact of strong advection a real saving of water occurs in landscapes with shelterbelts.

Comparison of the ratios of latent and sensible heat to the net radiation (LE/R_n and A/R_n) shows that ecosystems use from 64% (landscapes with mechanical windbreaks) to 84% (meadows) of the net radiation for evapotranspiration and only from 15% (meadows) to 35% (landscapes with mechanical windbreaks) for the heating of the air.

The ratio of real to potential evapotranspiration (ETR/ETP Table 5) shows that the more arid climatic conditions of the landscape, the lower real evapotranspiration in relation to the atmospheric evaporative demand. This means that under such conditions intensive irrigation can be applied with good benefit in yield.

Because the ratio of runoff to precipitation in the Turew region during the vegetation season is very small (approximately 0.1) and total precipitation for the vegetation season amounts to 375 mm, evapotranspiration exceeds incoming water to the ecosystem by as much as 70–160 mm (Table 5). The ratio of real evapotranspiration to precipitation (ETR/PPT Table 5) always exceeds unity. This means that plants must depend upon stored water in the soil. Stored water in soil decreases during the vegetation growing season, and a reduction in the depth of the ground water table is observed in the Turew region by as much as one to two meters.

On the basis of some of the results presented above one might conclude that shelterbelts enhance the water deficit of the Turew landscape. This conclusion is confirmed if only the evapotranspiration rate is considered. However, in early spring a landscape area with shelterbelts can collect about 20–80 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. Thus, in open landscapes water tends to be lost more rapidly (Ruellan 1976).

Energy flow into plant biomass production

Solar energy intercepted in photosynthesis and stored in plant biomass as primary production provides the energy supplies which drive the life processes in all heterotrophs (humans, animals, and microbes). Agricultural activity focuses on yield, which is that part of the primary production useful to humans. The annual net primary production of a field consists of the increase of biomass of above- and below-ground parts of cultivated plants, including those parts shed during growth. In addition to the production of the main crop one has to include production of weeds, self-sown plants (*e.g.*, rye), sprouting from discarded seeds during harvest, as well as production of catch crops if they are raised in addition to the main crops.

Long term studies carried on in the Turew agricultural landscape provided information on the variability of annual primary production rates (Ryszkowski 1984, Ryszkowski in press, French *et al.* 1979, Kukielska 1973a, 1973b, 1975, Wójcik 1973, 1979). The average annual net primary production in agro-ecosystems of the Turew landscape was estimated to be 1494 gdw m^{-2} (Ryszkowski in press). The lowest detected value was 906 gdw m^{-2} in potatoes, when no forecrops were cultivated and the field lay fallow in the early spring. In the summer an intensive development of the potato pest, Colorado beetle (*Leptinotarsa decemlineata*), took place, and caused the destruction of many plants and the exceptionally low annual primary production of the field. The highest annual primary production of 2938 gdw m^{-2} was in a field of rapeseed, during exceptionally favorable conditions of soil moisture and insolation.

High values of primary production are observed when there are favorable conditions for plant growth. However, such favorable conditions do not last long in nature and primary production of the ecosystem eventually returns to modal value. The

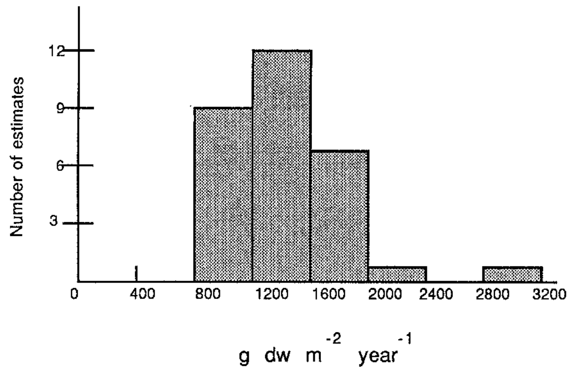

Fig. 1. Distribution of annual primary production rates in the Turew landscape (after Ryszkowski, in press).

modal value of primary production represents the most probable primary production under the prevailing climatological conditions. The modal value for the Turew landscape was calculated from 30 estimates of primary production obtained during 15 years of study (Fig. 1) (Ryszkowski 1984, in press) and was between 1200 and 1600 gdw m^{-2}

Photosynthetically active radiation (PAR), according to estimates of Tamulewicz and Woś (in press) for five consecutive vegetation periods (1981–1985), averaged 1263 MJ m^{-2}. The ratio of photosynthetically active radiation to global radiation changes from 0.49–0.51 during the vegetation season, but considering the whole vegetation season the ratio is 0.50, which means that global radiation amounts to 2526 MJ m^{-2} (Tamulewicz and Woś in press). The energetic value of the primary production, assuming an energy value of plant tissue of 16.7 kJ/g dry weight (Lieth 1975), is 24.6 MJ m^{-2}. Photosynthetic efficiency, which is a ratio of the energy stored in biomass production to the input of solar energy, is 0.02 during the vegetation season (from March 21 until October 31). If it is recalculated for the whole year, photosynthetic efficiency is about 0.01. The variability of photosynthetic efficiency for the vegetation season ranges from 0.012–0.038, if one considers the lowest and the highest production rates during the 15-year period.

One of the factors causing variability of production rates at the level of the landscape is the length of the plant growth period. Cultivated plants usually grow in shorter spans of time in comparison to the entire vegetation season, because of crop rotation, harvest pattern, agrotechnology and other factors which control the existence of the plants in the field. Growth of cultivated plants is simultaneous and the sequence of development stages is highly synchronized, which is in striking contrast to grasslands or forests. One could expect lower values of primary production when the presence of the plant cover in the field is over a time span shorter than the vegetation season. For example, when potatoes or rye only are cultivated, plants exist in the field about four months for potatoes and nine months for rye and during the rest of the year the field is fallow, or the soil is covered by weeds. In these cases the primary production is much lower than when a fore-crop of rye for cattle forage and a main crop of potatoes are cultivated in one year and plant cover exists in the field over 11 months (Table 6).

The second in the rank of factors influencing net primary production is probably the water regime, especially the timing of rainfall with plant growth periods, as well as the ability of the soil to store moisture (Ryszkowski 1984). Thus, rotation of crops influences the spatial pattern of variability of primary production rates, while the water regime influences the temporal variability of production rates at the landscape level.

Conclusions

The impact of the landscape structure on energy flow and water cycling can be noted first at the point where the solar radiation is intercepted and partially reflected by the active surface of the ecosystems making up the landscape. The albedo of individual ecosystems in the Turew landscape varies by a factor of 2.6. The lowest value of albedo was found for leafless shelterbelts and the highest for rapeseed fields before harvest (Table 1). But the aggregate estimates of albedo in various types of landscape in Turew region (Table 2) gives a much smaller range of estimates. The smallest aggregated estimate was found in landscape composed of cultivated field and shelterbelts (0.21) and the highest in a grassland landscape (0.23). The smaller range of albedo values between landscapes is caused mainly

Table 6. Influence of the length of the growth period on primary production.

Crop	Growth period (months)	Number of estimates	Average production gdw m^{-2} $year^{-1}$	Author
Potato	4	4	1128	Kukielska 1973a, 1973b, 1975
Rye	9	10	1328	Kukielska 1973a, 1973b Wójcik 1973, 1979
Rye as forecrop and potatoes as main crop	11	6	1637	Kukielska 1975

Table 7. Variability of energy fluxes (MJ m^{-2} per vegetation season) in agricultural ecosystems and in the landscape.

Parameter	Range of values in basic ecosystems		Range of values in landscape	
Albedo dimension less	0.15 shelterbelt	0.26 rapeseed before	0.21 cultivated fields + shelterbelts	0.23 grassland
Intercepted radiation R_n	1494 meadow	1730 shelterbelt	1494 grassland	1587 cultivated fields
Energy used for evaporation	866 bare soil	1522 shelterbelt	1035 cereals only	1250 grassland
Energy used for air heating	121 shelterbelt	661 bare soil	230 grassland	495 cereals only
Energy assimilated in primary production	15 potato	49 rapeseed	convergence to 25	

by the fact that the soils in the Turew landscape have an albedo similar to green plant cover (0.19 and 0.23 respectively) and that estimates of albedo for the landscape is weighted by the areal contributions of individual ecosystems. The extreme values of albedo are not as important at the level of the landscape, so that the range between albedo values (*e.g.*, in grassland versus cultivated fields with shelterbelts) is smaller than the values for individual ecosystems.

The shelterbelts use the largest amount of energy for evapotranspiration and bare soil uses the least (Table 3). The difference between these habitats amounts to 76%. Again, the range of values is smaller (ca. 20%) when various types of landscapes are compared. The lowest amount of energy used for evapotranspiration is characteristic of a landscape composed of cereals only, while the highest value is observed in a meadow landscape (Tables 3 and 5). If a forest landscape existed in the Turew region, it would probably use the largest amount of energy for evapotranspiration. *E.g.*, Calder (1986) found that forests in the humid conditions of England use more energy for evapotranspiration than they gain as net radiation (R_n). Surplus energy is supplied from ecosystems in the neigborhood and from air flowing over forest canopy.

The plant communities which are existing under the relatively most luxurious moisture conditions for growth in the Turew landscape are grasslands located in terrain depressions usually lying along draining ditches. Although trees in shelterbelts use more water, they are located on a small part of the landscape and therefore the landscape of cultivated field with shelterbelts uses less energy for evapotranspiration than meadow landscapes (Table 5).

Very high variability in energy used for air heating is observed between ecosystems (Table 3), while at the landscape level much less variation is observed (Table 5).

Comparison of the variation of energy flows (Table 7) leads to the conclusion that there is much higher variability at the ecosystem level than at the landscape level. One reason is that in the Turew landscape there are no large areas covered by forests with constant good supplies of water. The second reason is that energy gradients occur between ecosystems composing a landscape and energy is transported from one ecosystem to another which partially ameliorates the differences between them. For example, air movement induced by thermal gradients can transport surplus heat from one ecosystem to another. Thus, the reaction of the entire landscape will not be the simple sum of heat balances of individual ecosystem. One can conclude that the structure of vegetation cover is a very important factor controlling energy fluxes within the landscape.

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