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Analysis of the interrelation between the heat balance structure, type of plant cover and weather conditions

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A b s t r a c t. There are many ways of micrometeorological description of the environment. One of them is the analysis of heat balance of an active surface which characterizes very well areas with different plant cover. In literature, the heat balance of an active surface is described as: *Rn+LE+S+G*=0. In the paper there are analyses of results of the measurements of the heat balance structure carried out in the vegetation season of 2000, during 43 days of July and August, over three agricultural ecosystems: maize, alfalfa and spring wheat. The daily dynamics of the heat balance structure as well as the influence of factors such as: radiation, precipitation and wind speed on the heat balance structure of the ecosystems and the landscape are examined in the paper.

K e y w o r d s: heat balance, evapotranspiration, latent heat, sensible heat, Bowen ratio

INTRODUCTION

One of the ways of the micrometeorological description of our environment is the presentation of the heat balance structure of the active surface. In literature it is usually described as an equation (Paszyński, 1972; Kędziora, 1999; Monteith, 1977; Oke, 1978):

$$Rn+LE+S+G=0$$

where: *Rn* is net radiation, *LE* is latent heat flux density, *S* is sensible heat flux density, and *G* is soil heat flux density; all the values are expressed in W m^{-2}.

It is assumed that the fluxes coming to the surface have positive values and the outgoing have negative values. The values of particular components depend mainly on the type of plant cover, plant development stage and their conditions (which belong to biotic parameters), as well as on the meteorological conditions and the soil moisture (which belong to abiotic parameters) (Olejnik, 1996). As a result, the structure of the heat balance, mainly due to biotic parameters, characterizes areas with different plant covers very well.

In the vegetation season of 2000, long term examinations of the heat balance structure were carried out by the Bowen ratio-energy balance method with the application of the measurement systems described by Leśny *et al*. (2001). The Bowen method has often been used to describe water and energy exchange between the atmosphere and active surface (Cargnel *et al*., 1996; Alves *et al*., 1996; Todd *et al*., 1996; Todd *et al*., 2000; Lee *et al*., 2004). By the use of the Bowen method, it is important to locate the measurement system in the field under examination concerning adequate fetch conditions (Schuepp *et al*., 1990; Schmid, 1997). In this paper were analyzed the results of measurements carried out during of 43 days of July and August, on three agricultural ecosystems: corn, alfalfa and spring wheat. The daily dynamics of the heat balance structure as well as the influence of factors such as: radiation, precipitation and wind speed on the heat balance structure of the ecosystems and the whole landscape are examined in the paper.

AREA OF RESEARCH AND WEATHER CONDITIONS

From the aforementioned crops under examination, maize and alfalfa were at their full vegetative development stage during the time of the research. At the beginning of the research, spring wheat was still green, but it started to ripen, so it can be assumed that by the end of July its vegetation practically ceased. Thus, during most of the measurement period, wheat, not vegetatively active, insulated the soil

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from the atmosphere, making difficult the transfer of water vapour to the atmosphere.

General characteristics of the weather conditions during the entire measurement period were as follows: average air temperature 17.9°C, average water vapour pressure 12.8 hPa, average wind speed 1.6 m s^{-1}, sum of precipitation 138.6 mm (Table 1).

During the initial stage of measurements, from 13th July to 23rd July, it was rather cold, with high cloudiness and little precipitation. Thereafter followed days with changeable weather but the temperature tended to increase and the cloudiness tended to change. The warmest period was the week from 14th to 21st August.

RESULTS

The weather condition changes were clearly manifested by modifications in average daily values of the heat balance components, the course of which is shown in Figs 1 and 2. In the course of the average daily values of the net radiation Rn and soil heat flux *G* (Fig. 1), substantial several-day fluctuations are noticeable, particularly in the first half of the measurement period. However, differences between the ecosystems, although distinctive, are not substantial (except for a few days). On the other hand, in the course of the turbulent fluxes (Fig. 2) the differences are clear and substantial. The latent heat flux over the wheat field fluctuates little and reaches small values, almost never exceeding -40 W m^{-2}, whereas over the fields of maize and alfalfa the fluctuations are very high and average daily values reach even those of -127 W m^{-2}. Quite reverse is the course of the sensible heat flux. For maize and alfalfa the values are very low, in the range of -20 W m^{-2} and subtly variable, whereas for wheat they exceed -140 Wm^{-2}. However, the difference between the structure of heat balance of the examined ecosystems is best illustrated by the courses shown in Fig. 3, presenting the variability of alpha (*LE/Rn*) and beta (*S/LE*) indexes. Index alpha for alfalfa and maize oscillates near the value of –0.8. For wheat, however, the index oscillates very substantially, from the value of -0.10 to -0.70. The Bowen ratio – beta index (*S*/*LE*) is, for active ecosystems, not much above zero, ranging from 0 to 0.4, while for vegetatively inactive fields, it reaches values exceeding 10 (the Y axis of on the graph was limited to 6 in order to emphasize variability at low v alues of the indexes).

T a b l e 1. Daily average of heat balance components, meteorological parameters and alfa and beta ratios for chosen days, as well as average values for the whole measurement period for three plant cover types: maize, alfalfa, spring wheat

Parameter	Calm wind, low radiation 25.07.2000			Strong wind, high radiation 30.07.2000			Strong wind, low radiation 15.07.2000			Calm wind, high radiation 24.07.2000		
	Maize	Alfalfa	Wheat	Maize	Alfalfa	Wheat	Maize	Alfalfa	Wheat	Maize	Alfalfa	Wheat
t		17.5			17.1			14.3			18.3	
e		14.4			12.5			12.2			12.9	
v		0.2			3.0			2.7			1.0	
Rn	33	38	43	144	148	162	54	53	63	148	157	172
G	-4	-3	-2	-6	-8	-8	-3	-4	-3	-14	-10	-10
LE	-26	-31	-25	-110	-118	-24	-44	-36	-34	-119	-118	-37
S	-3	-5	-16	-28	-21	-130	-7	-14	-26	-15	-30	-125
alfa	-0.79	-0.80	-0.58	-0.77	-0.80	-0.15	-0.82	-0.67	-0.54	-0.81	-0.75	-0.22
beta	0.12	0.15	0.63	0.25	0.18	5.47	0.15	0.39	0.76	0.12	0.25	3.35

	Days after rainfall (7 mm at 29.07.200)											
	Sunny days						Cloudy days			**Average values for the whole measurement period**		
	1 day after rainfall 30.07.2000			3 days after rainfall 1.08.2000			2 days after rainfall 31.07.2000					
	Maize	Alfalfa	Wheat	Maize	Alfalfa	Wheat	Maize	Alfalfa	Wheat	Maize	Alfalfa	Wheat
t		17.3			18.4			16.4			17.9	
e		12.5			12.2			12.3			12.8	
v		3.7			2.9			2.0			1.6	
Rn	144	148	162	156	162	167	55	57	62	96	101	105
G	-6	-8	-8	-10	-9	-9	1	-1	1	-4	-5	-4
LE	-110	-118	-24	-127	-117	-16	-46	-62	-9	-75	-81	-26
S	-28	-21	-130	-20	-36	-141	-10	7	-53	-17	-16	-74
alfa	-0.77	-0.80	-0.15	-0.81	-0.72	-0.10	-0.84	-1.10	-0.15	-0.78	-0.80	-0.25
beta	0.25	0.18	5.47	0.16	0.31	8.91	0.21	-0.10	5.62	0.23	0.20	2.83

t is air temperature (°C), *e* is water vapour pressure (hPa), *v* is wind speed (m s^{-1}).

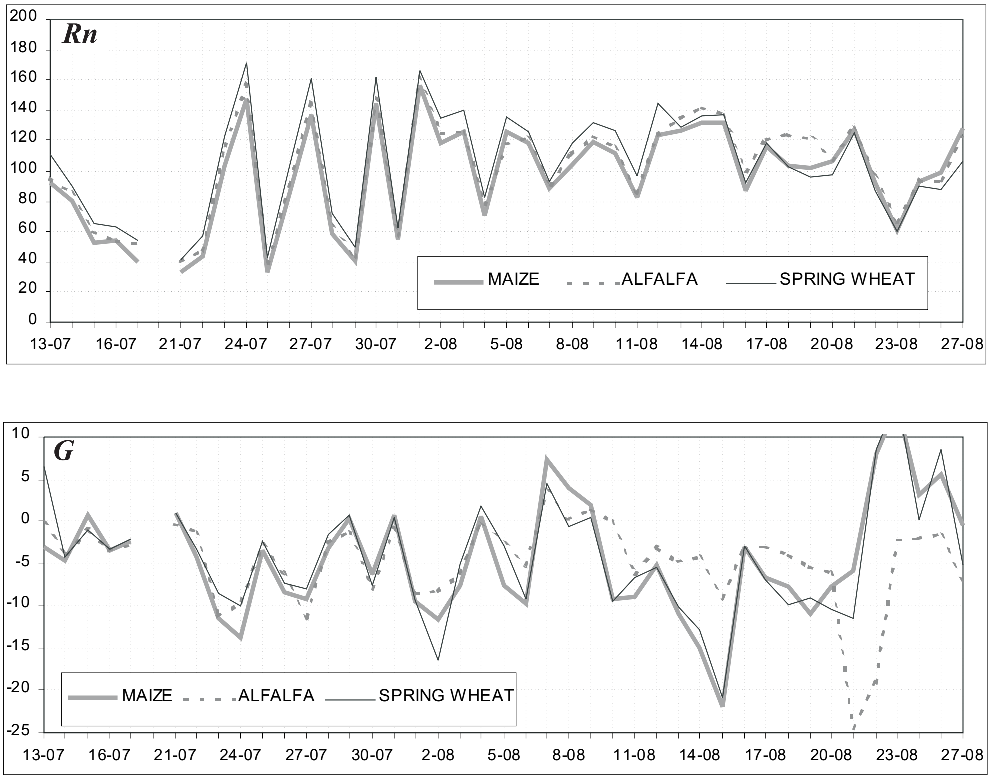

Fig. 1. Course of mean daily values of net radiation *Rn* and soil heat flux *G*.

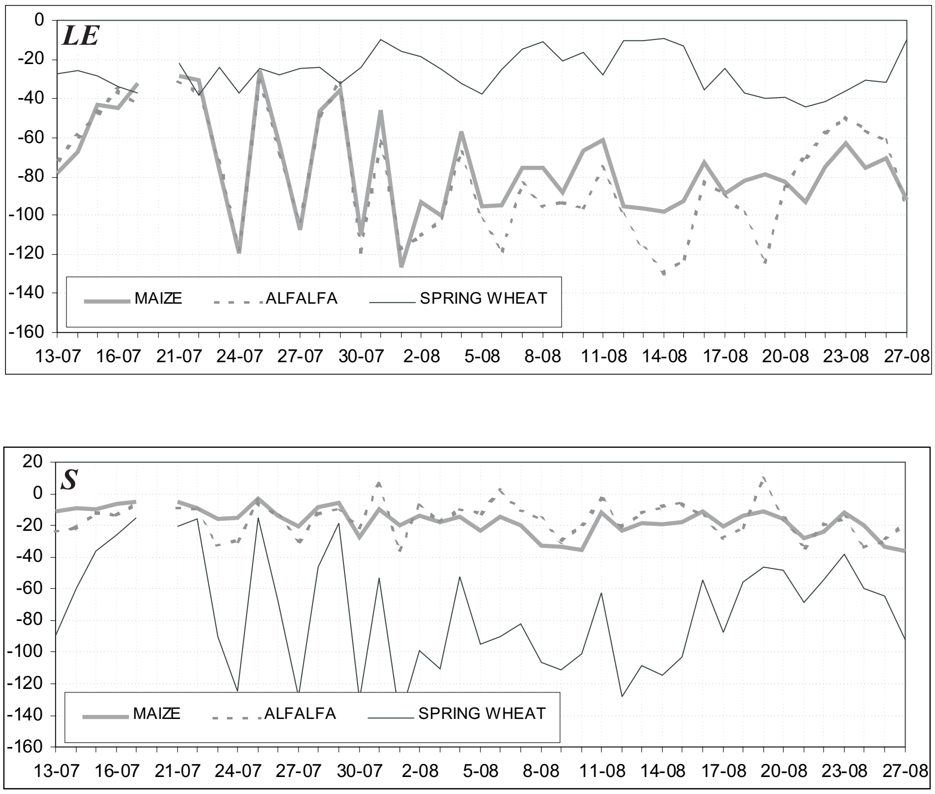

Fig. 2. Course of mean daily values daily of latent *LE* and sensible *S* heat fluxes from 13th July to 27th August, 2000, over three agroecosystems.

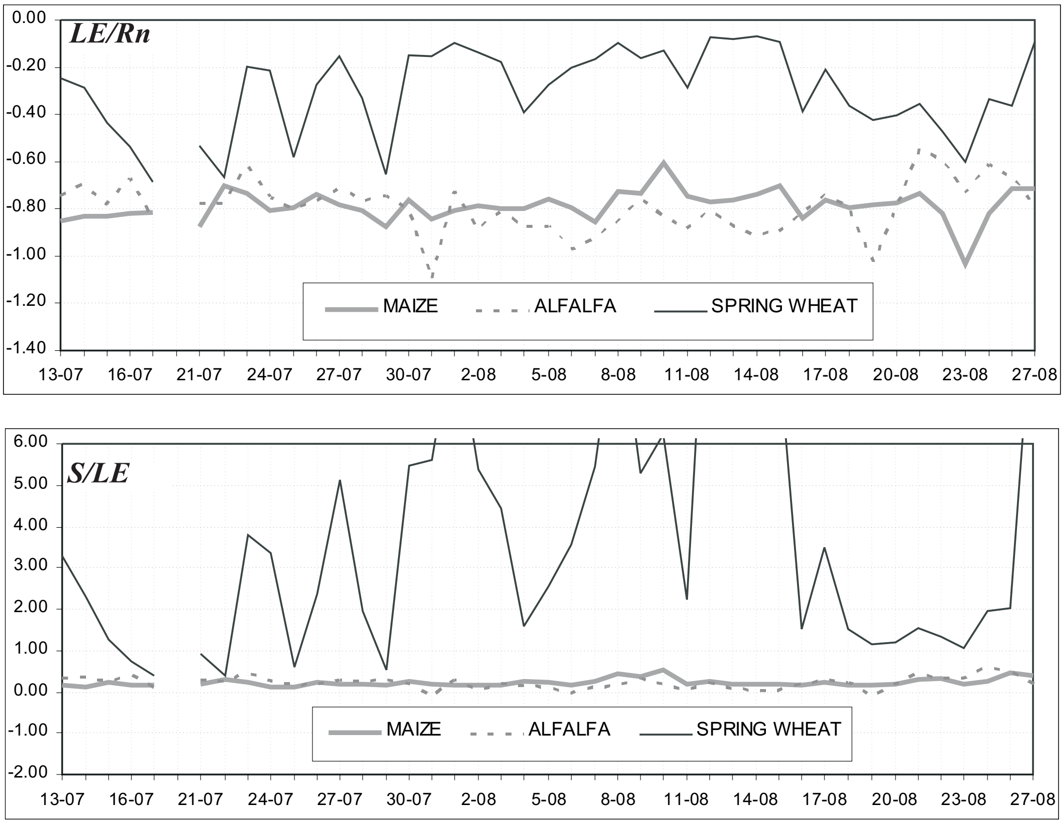

Fig. 3. Course of mean daily values of ratios *LE/Rn* and *S/LE* from 13th July to 27th August, 2000, over three agroecosystems.

The daily courses of the heat balance components over the vegetatively active and inactive surfaces differ substantially. The largest outgoing flux over the inactive surface is the sensible heat flux, used for heating the air. Over the active surfaces (evaporating areas), the largest outgoing flux is always the latent heat flux. This leads to the conclusion that the plant cover and its plant development stage plays a double role in the process of shaping the structure of heat balance of ecosystems. Growing plants intensify the transpiration process, which consumes the larger part of energy from net radiation, the energy which could potentially heat air or soil. On the other hand, when plants are fully developed and ripened, they fulfil an entirely different function. By insulating the influx of heat to soil and reducing evaporation from the surface of the soil (they do not transpire themselves), they become the least evaporating element of the landscape and, at the same time, an element which devotes most of its accumulated heat for the sensible heat flux and consequently for heating the air.

From the entire period of 43 days, several days were chosen which are characterized by the most interesting meteorological combinations and, on their example, the influence of the weather on the structure of heat balance was analyzed. Table 1 presents average daily values of the heat balance components as well as indexes of the heat balance structure (alpha = *LE*/*Rn*, beta = *S*/*LE*) for a day with a weak wind and low radiation intensity and for a day with a strong wind and strong radiation. Although the higrothermic conditions (air temperature and water vapour pressure) were similar, the heat balance structure is strongly modified by the net radiation. Index alpha, which defines the efficiency of using the solar energy in the process of evapotranspiration, for both active surfaces (maize and alfalfa) does not differ in the two respective days. However, weakly transpiring surfaces show the decrease of the alpha index by several times. This, consequently, causes a high increase of the Bowen ratio (beta index) which grows by several times in the case of inactive surfaces. This is confirmed by the conclusion drawn up in the previous paragraph. If, however, the wind is weaker (weaker turbulence), the differences between the ecosystems, although clear, are smaller (Table 1). The cloudiness works contrarily to the wind. Strong wind increased differences in the structure of the heat balance of various ecosystems, but the increase of cloudiness decreases them. For instance, on 1st August, during strong sun radiation, the maize field used for heating the air less than 1/6 of the energy which it used for evapotranspiration (the value of Bowen ratio equals to 0.16), Table 1. On the same day the biologically inactive spring wheat field used for heating the air 9 times more energy than for evaporation (the Bowen ratio equals to 8.91). During a cloudy day, on 31st July, the differences are much lower. The Bowen ratio for maize field equals to 0.21 and for wheat 5.62.

Precipitation is also of major importance. With the passage of time, after the precipitation, the differences get bigger (Table 1). One day after precipitation on a sunny day the Bowen ratios over inactive surfaces were respectively 5.47, but already three days after precipitation they increased respectively to 8.91. In the case of active surfaces, the Bowen ratios were low all the time.

DISCUSSION AND CONCLUSIONS

The applied measurement systems based on the Bowen's method proved to be very useful and reliable during constant measurements of energy fluxes and vapour over several ecosystems. Constant measurements of the four components of the heat balance over four fields simultaneously during the vegetative season of 2000 allowed to conduct an analysis of the dependence of type and condition of the plant cover and meteorological conditions on the structure of the heat balance components. It was proved that the heat balance structure over vegetative active and inactive surfaces differs substantially. In the case of physiologically inactive surface, the largest outgoing flux is sensible heat flux, energy used for heating the air (convective areas), whereas in the case of vegetatively active surfaces, the largest outgoing flux is the flux of latent heat used in the process of transpiration (evaporating areas). Thus, the type and condition of the plant cover of the active surface had a crucial influence on the heat balance structure. It manifested itself in very high differences between the values of the turbulent fluxes of sensible and latent heat. Under the same weather conditions, in extreme cases, the daily average flux of the latent heat over the vegetative active surfaces was over four times bigger than that over the mature plants. In such circumstances, about 80% of the heat balance energy was used for the transpiration process over strongly evaporative surfaces, whereas over the surfaces with mature plants the respective value was only 25%.

Thus, the areas covered by alive and active plant covers, which transpired strongly, are the 'evaporating areas' that modify the influence on the thermal air currents and on the dynamics of the atmosphere. The areas devoid of the active plant cover are 'convective areas', generating turbulent movements of the atmosphere. Consequently, mechanisms controlling excessive convection are observable in a mosaic landscape, whereas monotonous landscape (*eg* a large area covered by cereal crops), can, in the period of full maturity of the plants, generate a strong instability of the atmosphere.

The influence of the weather conditions on the heat balance structure is vital but has only a modifying role. However, it can be stated that the stronger net radiation, the stronger the wind, the less cloudiness, and the drier the environment, the bigger the difference in the heat balance structure between biologically active and inactive surfaces. To sum up the above analysis, it can be stated that the role of the agricultural landscape in shaping the heat balance structure of the earth surface and consequently in shaping the dynamics of the earth's atmosphere appears to be a factor of fundamental importance.

Thereby, the role of the agricultural landscape structure in shaping the heat balance structure of the earth's surface and consequently in shaping the whole dynamics of the atmosphere seems to be the most important factor. On the basis of the results presented, one can state that in a mosaic structure of the landscape, also the wind direction can play an important role in shaping the heat balance structure of the ecosystem and at the same time the landscape. The wind transports a certain amount of energy from above the inactive ecosystems to over the active ones (advection), where these additional portions of energy can increase evaporation from vegetatively active ecosystems. Consequently, large heat reserves are not cumulated locally, so the mosaic structured landscape never reaches the degree of convection of the monotonous landscape.

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