Acta Agrophysica, 2001, 53, 189–200

SOIL MOISTURE AND THERMAL PROPERTIES STATE UNDER PLANT CROPS[1]

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Summary. Soil moisture and thermal properties in the surface layer on the fields with different crops were analysed. The distribution of topsoil moisture and thermal properties changed depending on rainfall amount and a type of plant crop. The soil moisture differentiation between the fields with different crops have been affected by a different precipitation interception (depending on type and stage of canopies and amount and intensity of rain), as well as the different course of evaporation from soil surface and transpiration by plants. It was clearly visible comparing the data from wheat field (with the dense and closed plant canopy) where the soil moisture and their changes were smaller than at the fields with incomplete plant cover (sugar beet, maize). Besides, the level of soil compaction determined by method and term of cultivation on particular fields had a great weight. The effect of plant cover on soil thermal properties observed in cultivated fields was indirect as it results from the soil moisture changes.

Keywords: water content, thermal conductivity, heat capacity, bulk density, plants canopy.

INTRODUCTION

The state of moisture, thermal and other physical properties of soil in the cultivated fields showed a great differentiation in space and great changes over time [1, 14, 15, 17]. Spatial variability of the soil physical properties resulted mainly from different treatments and crops on neighbouring fields, whereas its temporal

[1] This paper was partly financed by the State Committee for Scientific Research under the grant No. 6 P06H 029 20 in the years 2001-2003 and Slovak Scientific Grant Agency VEGA, project No. 2/7064/20

changes are related to amount and temporal distributions of precipitation together with evapotranspiration intensity during a given period. It is worthily to add, that evapotranspiration is closely dependent on other components of surface heat balance, i.e. radiant energy, sensible heat flux to atmosphere and heat exchange with soil. The plant canopy existence modifies all these energy exchange and transfer processes and creates specific microclimatic conditions in relation to a type and vegetation growth stage [4, 5, 7, 9, 10].

The objective of the present paper was to examine the changes of moisture and thermal properties in the surface layer of soil affected by a plant cover type. In this layer the greatest and quickest variations of the mentioned properties are observed due to atmospheric conditions and, at the same time, the greatest spatial variability within individual cultivated field, as well as the complex of fields with different crops.

OBJECT AND METHOD

The data used in the paper were obtained from the investigations carried out during two vegetation seasons in Felin near Lublin, Poland. The study object consisted of adjacent fields of cabbage (seedlings), sugar beet, winter wheat, maize and potato in season 1992, and maize and spring wheat in 1993 season. Loess-like, silty soil (Orthic Luvisol developed from silt formations) was a typical mineral soil, homogeneous within all study objects.

Topsoil (1–6 cm) water content and bulk density were measured at 10 m spacing along parallel transects across the fields (five transects in 1992 and ten transects in 1993 season). The reflectometric method and a TDR meter manufactured by Easy Test Ltd., Lublin, Poland [8] was used to determine soil moisture during given days (at midday). At the same points the soil was sampled for bulk density determination using 100 cm^3 volume and 5 cm height cylinders.

Volumetric heat capacity of soil (C_v) was calculated using the formula of de Vries [16], based on volumetric fraction of minerals, organic matter and water in the soil. Soil thermal conductivity (λ) was derived using the statistical – physical model [12, 13] and thermal diffusivity of soil (α) as the ratio of these thermal properties.

Statistical characteristics of soil moisture, bulk density and individual thermal properties have been determined for a given cultivated field over several days.

The meteorological data used for analyses come from the Agrometeorological Observatory of Agricultural University in Lublin, located near the examined fields.

RESULTS AND DISCUSSION

The subject of analyses were the mean values and dispersion (standard deviation) of moisture and several thermal properties of soil stated within measurement points located in transects across the adjacent fields with different crops. Recognition of soil moisture differences between the fields, as well as within individual field and on borders from field to field and also comparison of courses (transects) of soil thermal properties with the same courses of soil moisture and bulk density come to be possible in this way. All the data were inquired regarding meteorological conditions during a period preceding each the measurement days.

First examined day in 1992 season, 17 June, was the third day after the last of a few rainy and cloudy days. The sum of precipitation during these days was 4.7 mm, however on individual day less than 1.7 mm. Earlier, an eight-day period without rainfall and great sunshine duration was noted (Fig. 1a). These meteorological conditions were favourable to differentiate soil moisture state in the cultivated fields. As shown in the next graph (Fig. 1b), the values of topsoil moisture in transects through examined fields were considerable diverse on this day. The second measurement day in 1992 season was fixed on 26 June, two days after rainfall of 28.2 mm. This precipitation caused an increase of moisture of soil at all the fields and at the same time, diminution of the differences (equalisation) between the fields.

The graphs in Fig.3 concern the data from a season 1993. The first of the measurement days, 6 July, followed a sixty-day period without precipitation, while the other one (9 July) was the second day after 4.4 mm precipitation. On both mentioned days moisture of soil occurred to be higher at a maize field as compared to spring wheat one and the values were almost the same (despite precipitation occurrence between the days).

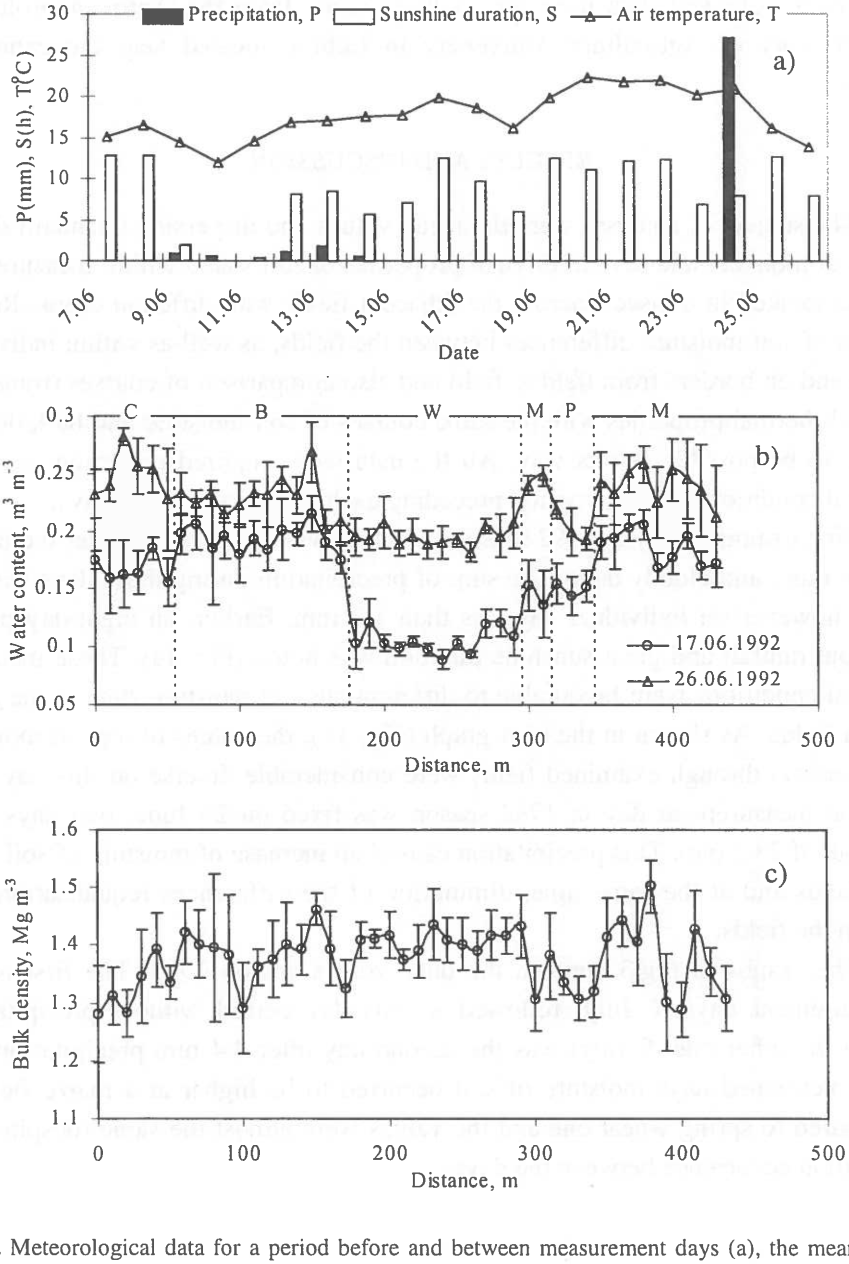

Fig. 1. Meteorological data for a period before and between measurement days (a), the mean and standard deviation values of soil moisture (b) and soil bulk density (c) in transects across the cultivated fields on 17 and 26 June 1992 (every point represents five measurement data). Explanation: C – cabbage (seedlings), B – sugar beet, W – winter wheat, P – potatoes and M – maize field.

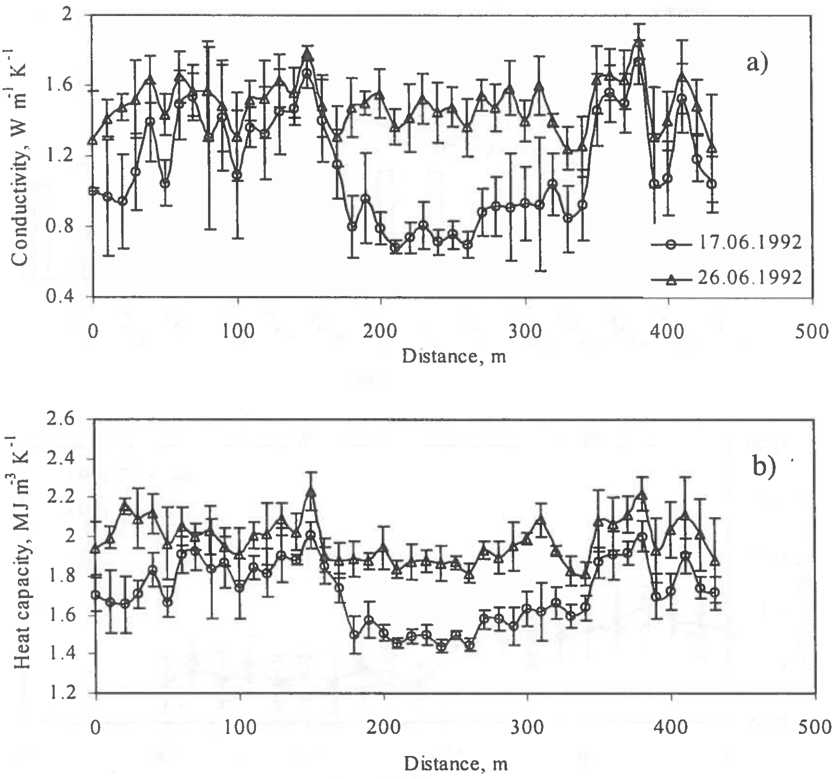

Fig. 2. The mean and standard deviation of soil thermal conductivity (a), and volumetric heat capacity (b) in transects across the cultivated fields on 17 and 26 June 1992 (every point represents five measurement data).

Analysing the soil moisture data in a more detailed way, we draw attention to the differentiation between wheat and maize fields in both seasons, as well as between wheat field and these of maize and sugar beet in a season 1992. Those were the fields of a differentiated character of plant cover resulting from both, a plant species and cultivating method (wheat with dense crop canopy, the rest fields with row planting seeds and incomplete plant cover of soil). Moreover, the different time of soil cultivation in the particular fields should be taken into consideration. Together with cultivation type they influenced soil moisture and level of compaction and, as a consequence, the soil moisture state and dispersion during analysed days.

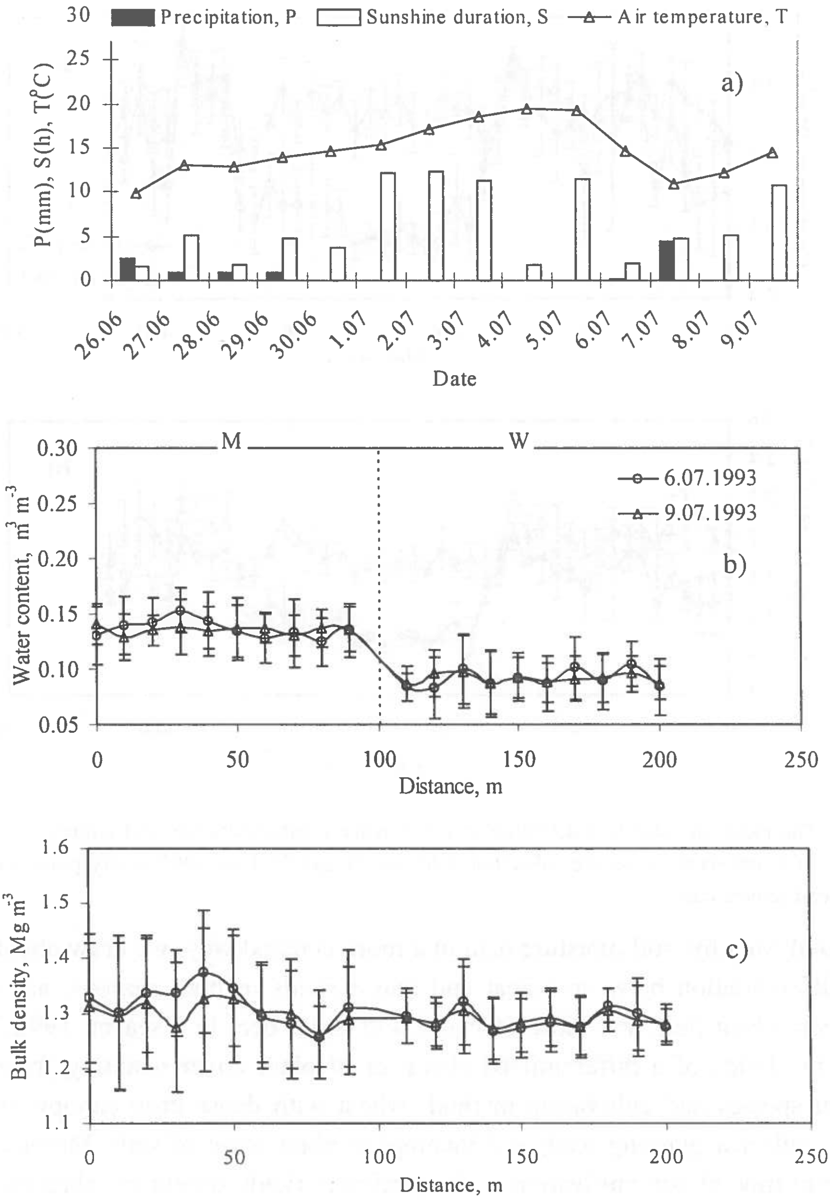

Fig. 3. Meteorological data for a period before and between measurement days (a), the mean and standard deviation values of soil moisture (b) and soil bulk density (c) in transects across the maize (M) and spring wheat (W) fields on 6 and 9 July 1993 (every point represents ten measurement data).

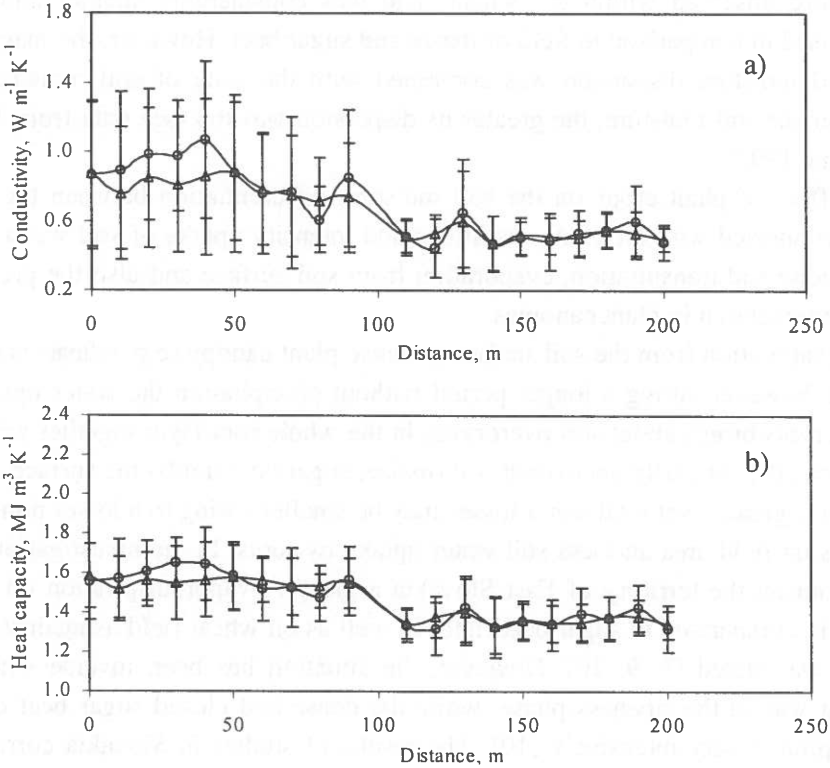

Fig. 4. The mean and standard deviation of soil thermal conductivity (a), and volumetric heat capacity (b) in transects across the cultivated fields on 6 and 9 July 1993 (every point represents ten measurement data).

In the winter wheat field due to autumn term of cultivation and sowing, the soil bulk density was stabilised and showed a small dispersion, whereas in the maize and sugar beet fields (cultivation in the spring) was differentiated within a field area and its dispersion was much greater in comparison to the wheat field (see Fig. 1c). From the data presented in Fig. 3c it can be seen that similar mean values of soil bulk density in the maize and spring wheat fields were noted (alike method and term of cultivation) while the value dispersion was considerably different. It can be connected with another spatial distribution of planting seeds in these fields. The data presented in Fig. 1b and 3b show that soil moisture on the field covered with the dense and closed plant canopy (wheat) was smaller than the fields with incomplete plant cover (sugar beet, maize). Also the dispersion of soil moisture observed within the wheat field was considerably smaller and more equalised in comparison to field of maize and sugar beet. However, the magnitude of soil moisture dispersion was combined with the state of soil moisture: the greater the soil moisture, the greater its dispersion was too (see data from 17 and 26 June 1992).

Effect of plant crops on the soil moisture differentiation between the fields was connected with different conditions and intensity uptake of soil water in the root zone and transpiration, evaporation from soil surface and also the precipitation interception in plant canopies.

Evaporation from the soil surface at dense plant canopy (e.g. wheat) is diminished, however during a longer period without precipitation the water uptake by plant roots brings about soil overdrying in the whole root layer together with surface one [9]. At partly uncovered soil (maize, sugar beet fields) the surface evaporation is greater, yet total water losses may be smaller owing to a lower number of plants on field area and less soil water uptake by roots. In the investigations carried out on the territory of East Slovakia a greater evapotranspiration on wheat field in comparison to sugar beet field, as well as on wheat field as against maize field was stated [3, 9, 10]. However, the situation has been inverse when the wheat was in the ripeness phase, while the dense and closed sugar beet canopy transpirated very intensively [10]. The results of studies in Slovakia correspond well to the data presented in this paper and explained the soil moisture differentiation on the fields on 26 June.

Different changes of soil moisture recorded after rainfall occurrence resulting from precipitation interception and its dependence on amount and intensity of rainfall for a given type and stage of plant crop. At low precipitation increase of soil moisture may be unnoticeable due to great precipitation interception in high and dense plant canopies. The researches carried out in Felin [2, 6] showed that precipitation interception on wheat canopy in the heading stage and successive ones reached right up to 70–80% when amount of precipitation was lower than 2 mm, whereas at precipitation over 10 mm it was mostly less than 40%. In other investigations [11] there was stated a greater effective precipitation (i.e. amount of rainwater reaching the soil surface) in the sugar beet plots with incomplete plant cover in comparison to dense canopy of spring barley. This effects correspond to the data obtained from the measurements on 9 July 1993 and 17 June 1992 (after relatively small rainfall), as well as to data from 26 June 1992 when after heavy rainfall a soil moisture increase was visible on all the cultivated fields (wheat as well).

From the data presented in Fig. 2 and 4, it can be seen that the values of soil thermal properties along transects through the fields for each days correspond generally to soil moisture along the same transects. As a result of the physical dependence of a given thermal property upon soil water content and bulk density, the changes of topsoil moisture caused by rainfall and transpiration must be reflected in changes of the thermal properties. Thus, alike the case of soil moisture, soil thermal properties are also affected by a type and growth stage of plants in a significant way.

The mean values of soil heat capacity stated in transects across the sugar beet field (from 1.74 to 2.01 MJ m^{-3} K^{-1}) and the maize field (from 1.70 to 2.00 MJ m^{-3} K^{-1}) on 17 June 1992 were considerably higher in comparison to these observed in the winter wheat field (from 1.44 to 1.58 MJ m^{-3} K^{-1}). In the day after rainfall, 26 June 1992, an increase and equalisation of the soil heat capacity values on examined fields was noted, but simultaneously a greater interval of the extreme values in the sugar beet and maize field occurred (from 1.91 to 2.23 MJ m^{-3} $K^{-1}$and from 1.88 to 2.22 MJ m^{-3} K^{-1}, respectively). The mean values of soil thermal conductivity in transects across these fields during the same days had similar arrangement and changes to soil heat capacity values, i.e. on the sugar beet and maize fields they were higher than the winter wheat field. However, on the contrary to change tendency of soil heat capacity values after rainfall, the smaller interval of extreme values of soil thermal conductivity were noted on all fields. Within the sugar beet field on the day 17 June 1992 the values were contained between 1.09 – 1.66 W $m^{-1}K^{-1}$ while on 26 June from 1.31 to 1.78 W $m^{-1}K^{-1}$, in the maize field – respectively – between 1.04 – 1.74 W $m^{-1}K^{-1}$ and 1.25 – 1.85 W $m^{-1}K^{-1}$ and in the winter wheat field between 0.69 – 0.96 W $m^{-1}K^{-1}$ on the first day and 1.36 – 1.59 W $m^{-1}K^{-1}$ on the second day.

Distribution of the soil thermal properties mean values in transects across the fields during examined two days in 1993 season was close (especially in the spring wheat field) because of a small change of soil moisture. During both days, higher values of soil heat capacity and thermal conductivity occurred on the maize than spring wheat field (alike as soil moisture). It is worthy to notice that also the interval of the extreme values of these thermal properties were greater in the maize than wheat field. For example, on day 6 July 1993, the mean values of soil thermal conductivity in transects across the maize field ranged from 0.61 to 1.07 W $m^{-1}K^{-1}$ and in the spring wheat field from 0.44 to 0.65 W $m^{-1}K^{-1}$ and in the case of soil heat capacity there were between 1.47 – 1.66 MJ m^{-3} K^{-1} and 1.32 – 1.42 MJ m^{-3} K^{-1}, respectively.

Generally it can be confirmed, that dispersion values of soil heat capacity was connected mainly with soil moisture dispersion and to lover degree with dispersion of soil bulk density. In the case of soil thermal conductivity the dispersion values was determined by both the dispersion of soil moisture and bulk density. Actual soil moisture conditioned which soil property (moisture or bulk density) influenced dispersion of thermal conductivity values stronger (at lower soil moisture the dispersion of soil thermal conductivity was greater everywhere and its character was similar to dispersion of soil bulk density).

CONCLUSIONS

In the paper the state of moisture and thermal properties in the surface layer of soil affected by a plant crops type was examined. Distribution values of these soil properties in transects across adjacent fields with different plant cover was studied for several days taking into consideration the meteorological conditions, as well as the times and methods of soil cultivation and planting seeds.

From the analysis of soil moisture on particular cultivated fields it appears that its distribution in space (i.e. mean values and dispersion) was determined by a type and growth stage of vegetation, then meteorological conditions (mainly occurrence and amount rainfall, as well as sunshine duration over a given period). The differentiation of soil moisture between examined fields have been influenced by different precipitation interception and different intensity of evaporation from soil surface and transpiration by plants. In the wheat field, because of greater rainwater retention by dense plant canopy and evapotranspiration, the soil moisture and their changes were lower in comparison to these in the fields with incomplete plant cover (sugar beet, maize). Simultaneously, considerable role has been played by the level of soil compaction determined by a method and term of soil cultivation on particular fields.

The effect of plant cover on soil thermal properties state observed on cultivated fields is of an indirect character, i.e. it emerges through the soil moisture changes, in turn conditioned by type and growth stage of plant canopy.

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STOSUNKI WILGOTNOŚCIOWE I CIEPLNE GLEBY POD RÓŻNYMI ROŚLINAMI

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S t r e s z c z e n i e. Celem pracy było określenie wpływu zróżnicowanej pokrywy roślinnej na stosunki wilgotnościowe i cieple gleby. Rozpatrywano przestrzenne rozkłady wilgotności i właściwości cieplnych gleby biorąc pod uwagę warunki meteorologiczne, sposób uprawy gleby i siewu oraz czas wykonania zabiegów uprawowych.

Rozkład wilgotności gleby na polach z uprawą różnych roślin uwarunkowany był z jednej strony przez rodzaj i stan pokrywy roślinnej, a z drugiej strony – przez warunki pogodowe, głównie wystąpienie i wielkość opadów atmosferycznych oraz usłonecznienie. Na zróżnicowanie rozkładu wilgotności między polami miała wpływ zróżnicowana intercepcja opadowa (ograniczenie dopływu wody opadowej do powierzchni gleby), jak również różna wielkość parowania z powierzchni gleby oraz transpiracji roślin. Jak wykazała analiza danych, na polu o gęstej i zwartej pokrywie roślinnej (pszenica) wilgotność gleby i jej zmiany po opadach były mniejsze niż na polach o niepełnym pokryciu gleby przez rośliny (buraki cukrowe, kukurydza). Określone znaczenie miał przy tym stan zagęszczenia gleby, zdeterminowany przez rodzaj zabiegów uprawowych i czas ich przeprowadzenia.

Wpływ pokrywy roślinnej na właściwości cieplne gleby ma charakter pośredni, tj. dokonuje się poprzez zmiany wilgotności gleby, uwarunkowane z kolei rodzajem i stanem łanu.

S ł o w a k l u c z o w e: wilgotność gleby, cieplne właściwości, gęstość, pokrywa roślina.

Translated by: authors