Thermodynamic approach to assessing the productivity of phytocenoses - a way to predict their protection in a changing climate

E P Kvachantiradze
Russian State Agrarian University - Moscow Timiryazev Agricultural Academy, Moscow, Russia
eteri.kr@yandex.ru

Abstract. In the scientific literature, the prognostic equations of the productivity of phytocenoses have a local nature – this fact can be explained by the absence of a single unit of measure for all variables composing the equation. The result of this approach is the refusal to find one model that describes the general regularity of changes in the physiological processes of plants due to climatic changes. The productivity of phytocenoses is the result of the “soil-plant-climate” relationship. In the previous studies, the author presented a thermodynamic approach to climate analysis; a methodology has been developed for determining the volumetric heat content of soils, and the thermodynamic approach to assessing plant productivity is proved in the current study. For this purpose, the concepts of the heat content of phytomass and the heat content of the aerotope (unit of measure - kJ / kg of dry air) were introduced, and from this point of view the dependence of physiological parameters is based not on various combinations of external meteorological parameters, but on the corresponding integral indicators of the heat content of the leaf and aerotope for conditions of different density and plant height. The heat content of the phytomass was taken as the heat content of the air space bordering the lamina. Introduction of these concepts simplified the analysis of the multifactorial effect of meteorological elements on plant productivity. The capability of a thermodynamic approach to assess the productivity of phytocenoses as a result of the relationship of plants with the environment is demonstrated, as evidenced by the high degree of correlation dependence of the studied parameters. The possibility for describing the “soil-plant-climate” system in a single energy system is substantiated, provided that an assessment of the productivity of phytocenoses is introduced from the point of view of net primary productivity, measured in energy units (Joule).

1. Introduction
The world we live in is a complex system of relationships. For example, the flora and, accordingly, the animal kingdom are determined by the soil-climatic conditions of existence. And since climate change is now an indisputable fact, it becomes necessary to predict the direction of changes in the plant world.

It is possible to describe the “soil-plant-climate” system from the point of view of plant productivity as a result of interconnection with environmental conditions, like any interconnection system, but subject to a unified measurement approach in the system of units to all components of the system. Moreover, this unit should be a physical, not an empirical measure.

Currently, all mathematical models for predicting plant productivity include parameters of different units of measurement [1], [2], [3], [4], [5], [6], which makes it impossible to find the general regularity
of changes in the physiological processes of plants from climatic changes for any geographical point. As a result, the model describes a particular case. Only a single approach to the measurement system, even using the statistical analysis method, will make it possible to model the pattern of changes in physiological processes of plants depending on climatic changes, to read the possible course of changes in productivity processes for any considered hydrometeorological situation.

In previous studies of the author, it was proved that for hydrometeorological indicators, such a unit of measure is the heat content, as an integral indicator of growing conditions: temperature and air humidity. A thermodynamic approach to climate analysis was demonstrated in the study [7], and a technique for determining the volumetric heat content of soils was given in the study [8]. The methodology for predicting soil moisture content is presented in the articles [9], [10].

There is no thermodynamic characteristic of the productivity of phytocenoses, which could describe the system “soil-plant-climate” in a single system of units.

The transition of the description of the “soil-plant-climate” system to a single system of units of measurement will allow us to find the regularity of the relationships in this system, as well as to predict the stability or direction of changes in phytocenoses in a changing climate for any geographical point.

Purpose of the study: to show the capability of a thermodynamic approach to assess the productivity of phytocenoses, as the resulting relationship with the external environment.

2. Theory and research methodology
It is commonly known that the main climatic parameters affecting the formation and productivity of cenoses are air temperature, air and soil humidity, and also the influx of solar radiation. But temperature is a measure of the degree of heating of the body, determined by the human senses, and therefore, as an empirical value, it will not be able to physically characterize the system of the relationship between plant productivity and the environment.

The amount of heat is a physical quantity, which is a measure of the amount of energy of motion of the molecules of the studied object. In our case, the studied object is air.

The heat content of air quantitatively characterizes the amount of heat contained in the mixture of dry air and water vapor, which is the surrounding air (kJ / kg of dry air). In addition, a thermodynamic complex indicator of air temperature – the heat content of air, is directly related to the volumetric heat content of the soil and the radiation regime (light intensity).

According to the definition:
1) heat content or enthalpy is the amount of energy that is available for conversion to heat at a certain temperature and pressure;
2) with mixing, or convection of two gases having a different temperature, the gas with a higher temperature is cooled, and the gas with a lower temperature is heated, i.e. heat exchange will take place between them – the process of energy transfer from a more heated gas to a less heated one, accompanied by changes in a number of physical parameters.

Let us use this definition in our subsequent discussion.

It is commonly known that in the ecosystem there is a constant exchange of substances and energy between the biocenosis and the biotope (habitat), and homeostasis (constancy of the internal environment) is the key to the constancy of the system. Let us consider which biotope factors affect homeostasis or, in other words, which environmental factors can disrupt the formed biocenosis.

To assess the productivity of phytocenoses as a result of interconnection with the external environment, we introduce the concepts of “heat content of phytomass” and “heat content of the internal air deciduous medium (aerotope)”, and from this point of view we consider the fundamental study of O. D. Sirotenko [1] in a different interpretation: the dependence of physiological parameters is based not on various combinations of external meteorological parameters (as Sirotenko suggests), but on the corresponding integral indicators of the heat content of the leaf and aerotope for conditions of different density and height of plants.

For the heat content of phytomass, we take the heat content at the surface of the leaf surface – in the air space adjacent to the lamina.
The introduction of the concept of heat content of phytomass and heat content of the air internal interfoliaceous environment (aerotope) will simplify the analysis of the multifactorial effect of meteorological elements on plant productivity. The analysis will be limited to finding the result of heat transfer process. Heat transfer is the process of energy transfer from a warmer to a less heated space with moist air, and this process is accompanied by changes in a number of physiological parameters of plants. In our case, the result of heat transfer process is the intensity of physiological parameters of photosynthesis and transpiration of plants.

3. The discussion of the results
In the study [1] on pages 48–65, the initial data and the results of a numerical experiment in the “soil-plant-climate” system are given.

Three variants of agrocenosis $L = 1; L = 2; L = 3$ of equal height but different density were considered: rare $S = 0.01$; average $S = 0.05$; thick $S = 0.10$ with a relative leaf density $L = SH$.

The hydrometeorological parameters under consideration are: temperature, humidity and air velocity of the aerotope and air space bordering the lamina.

Investigated physiological parameters: photosynthesis and transpiration of plants.

Due to the large amount of experimental material, the author [1] demonstrates selectively the most interesting data – these are only 10 interconnected points of the “soil-plant-atmosphere” system. Moreover, each point is the averaged data of a large number of experiments, which ensures the reliability of the data.

As mentioned above, the purpose of this study is to describe the “soil-plant-climate” system in a single system of units. Let us demonstrate the capability of a thermodynamic approach to assess the productivity of phytocenoses as a result of interconnection with the external environment.

For each studied point, temperature and air humidity were expressed as an integral indicator – the heat content of the air space bordering the lamina $W_l$ and aerotope ($W_a$). The unit of measure is kJ / kg of dry air.
Figure 1. Intensity of photosynthesis (F) and transpiration (T) depending on the heat content of the leaf (W) and the difference in heat contents (ΔW) under various conditions of agrocenosis (L).

where x - intensity of photosynthesis F, mgCO₂cm⁻²day⁻¹; v - intensity of transpiration T, mmcm⁻²day⁻¹; W - heat content of the leaf, kJ/kg of dry air; ΔW - difference in heat contents, kJ/kg of dry air; L = 1; L = 2; L = 3 - levels of density of agrocenosis.

Air movement was not taken into account, because the atmosphere is considered from the position of a fixed state, that is, as a closed thermodynamic system consisting of dry air and water vapor with constant atmospheric pressure and constant heat inflow (averaged over the corresponding time period). It is known from thermodynamics that in this case the heat content of the system is a constant value, depending on temperature and moisture content.

The figure shows the course of photosynthesis and transpiration intensity for specific cases depending on Wl – the heat content of the leaf and ΔW - the difference in the heat content of the leaf (Wl) and the internal air environment (Wa).

For each variant of agrocenosis, the intensity of photosynthesis is closely dependent on Wl, and the transpiration rate depends on ΔW = Wl - Wa. The correlation coefficient for the first case is 0.98, and for the second it is 0.96.

Units of measurement:
- for physiological indicators of photosynthesis intensity (F) and transpiration (T): mgCO₂cm⁻²day⁻¹; mmcmday⁻¹, respectively;
- for the heat content of air bordering the surface of the leaf (Wl) and aerotope (ΔW), energy characteristic: kJ/kg of dry air.

The high correlation dependence indicates on the capability of a thermodynamic approach to assess the productivity of phytocenoses as a result of interconnection with the external environment, and the admissibility of describing the “soil-plant-climate” system in a single energy system of units.

However, as a characteristic of the productivity of phytocenoses, it is necessary to use not the considered parameters, but the parameters of the net primary productivity (NPP):
- the accumulation of organic matter by plants minus the flow rate for respiration and photorespiration, i.e. the result of the relationship between the phytocenosis and the environment, expressed in energy units (Joule).

Undoubtedly, for each phytocenosis there is a range of tolerance to heat content, within which productivity will also depend on the heat content of the aerotope and the lamina. In the natural phytocenoses, the preservation of homeostasis is ensured provided that these parameters are constant. A transition to the description of the “soil-plant-climate” system in a single system of units of measurement will make it possible to predict the direction of these changes for a specific phytocenosis at any geographical point, and, therefore, will predetermine their protection in a changing climate.

4. Conclusions
The capability of a thermodynamic approach to assess the productivity of phytocenoses as a result of interconnection with the environment has been demonstrated.

A description of the “soil-plant-climate” system in a single energy system of units is possible, provided that an assessment of the productivity of phytocenoses is introduced from the position of net primary productivity (NPP), measured in energy units (Joule).

The introduction of the thermodynamic principle of assessing the productivity of phytocenoses, as an integral characteristic of the living conditions of a living organism, will allow:
- to establish the direction of changes in productivity for a particular phytocenosis at any geographical point, and therefore, predetermines their protection in a changing climate;
- to determine the optimal values of heat content at which maximum yields are achieved;
- to establish the boundaries of the rational distribution of zones of cultivation of specific crops;
- to identify economic and government measures that increase the efficiency of the use of climate resources.
References

[1] Sirotenko O D 1981 Mathematical modeling of the water-thermal regime and productivity of agroecosystems (Leningrad, Gidrometeoizdat) p 167

[2] Sirotenko O D and Pavlova V N 2010 A new approach to identifying the weather-crop yield functionals for assessing climate change consequences Russian Meteorology and Hydrology 35(2) 142-48

[3] Gill K, Kiran R and Paul S 2014 Meteorological model for rice yield forecasting in Ludhiana region Indian Journal of Ecology 41(2) 257- 61

[4] Ghosh K, Balasubramanian R, Bandopadhyay S, Chattopadhyay N, Singh K K and Rathore L S 2014 Development of crop yield forecast models under FASAL- A case study of kharif rice in West Bengal Journal of Agrometeorology 16(1) 1-8

[5] Esfandiary F, Aghale G and Mehr A D 2009 Wheat yield prediction through Agro Meteorological Indices for Ardebil District, Int. J Biol. Life Sci. 1(2) 48-51

[6] Bhatt T A, Ahmed L and Kotru R 2015 Relation between Agrometeorological indices, crop phenology and yield of rice genotypes as influenced by real time N management J. Agrometeorol 17(1) 90-97

[7] Kvachantiradze E P 2016 Basic Climate Forcing Factors from the Thermodynamic Point of View GEOMED 2016. 4th International Geography Symposium. May 23 – 26 Kemer (Antalya, TURKEY) 52-61

[8] Kvachantiradze E P 2019 IOP Conf. Ser.: Earth Environ. 302 012023

[9] Kvachantiradze E P 2011 Theoretical calculation of the water supply in the soil Bulletin of the Federal State Educational Establishment of Higher Professional Education Moscow State Agroengineering University V P Goryachkina 2(47) 34-37

[10] Kvachantiradze E P 2014 A theoretical model of soil moisture reserves reconstruction based on mean multiyear values of air temperature and humidity, as well as soil porosity International Technical and Economic Journal 3 85-88