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The Influence of the Weather Conditions on Biological Soil Activity and Maize Productivity

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A B S T R A C T

Article presents the results of studies of the influence of weather conditions on the activity of maize microbiocenosis, plant green mass productivity, grain yield, the spread and development of diseases in agrocenosis. Methods. Field experiment, rehydration, adsorption, phytopathological assessment of plants. Results. Weather conditions during the research period were characterized by an increased temperature regime, insufficient and uneven distribution of precipitation during the growing season, which significantly affected the growth, development and maize productivity. The increase of the grain yield of maize (by 3-4 %) compared with the best year due to weather conditions, with a clearly reduced amount (by 3.5-13.7 %) of the formed green mass through the lack of moisture was noted. In conditions of overwetting (precipitation is more than 48 mm than the average annual and an increased average monthly air temperature of 3-5°C) compared with similar hot and dry (arid) periods (rainfall is 15-45 mm lower average annual), in gray forest loamy soil an increase in total microbial biomass by 12-108 % and carbon dioxide emission by 9-12 % increased the synthesis of humic substances by 15-39 % was noted. The decrease by 1.5 time in the development of root rot in maize plants and by 6-13 % of their spread was noted. Conclusions. Thus, changes in weather conditions (increase in average monthly temperatures by 3-5°C and increase i*n precipitation by 48 mm / decrease in precipitation by 15-45 mm) did not have a clear* effect on the functioning and activity of microbiocenosis and soil fertility.

Keywords: Zea mays L., Carbon dioxide emission, Development of diseases, Biomass of microorganisms, Sspread of diseases, Hydrothermal regime.

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Introduction

Ukraine is one of the five largest exporters of maize in the world. The area under maize crops increased by 3.7 times from 1990 to 2018. Such a significant increase in cultivated areas of the crop caused gross disturbances in crop rotation, an increase in the number of pathogenic microorganisms, harmful insects and weeds in agrophytocenoses, and an increase in the biological and chemical pollution of agroecosystems due to an increase in the use of plant protection chemicals [1]. Irrational and irresponsible use of arable land leads to the loss of organic matter, which in turn turns the agroecosystem into a powerful source of greenhouse gas (CO_2) [2, 3]. A sensitive indicator of changes in the state of biotic and abiotic components of the soil, which are caused by natural and anthropogenic factors, is the activity of microbiocenosis.

Changes in climatic parameters (temperature, precipitation, increase CO_2 concentration, etc.) have both direct and indirect effects on soil microorganisms through changes in physiological and biochemical processes in plant organisms, which initially causes changes in the trophic chains of microorganisms, and further in the structural and functional organization of the entire microbiocenosis.

During various studies [4-7] the most frequently used indicators of the rate of production of CO_2 and microbial biomass, which allow us to assess the state of microbiocenosis of the soil and agroecosystem as a whole. It is known that an increase in the concentration of CO_2 in the atmosphere usually stimulates the influx of organic carbon into the soil system, increasing the activity of the root system and exudation, while the quality of the exudates produced by the plant decreases. It is known that an increase in CO_2 concentration reduces the nitrate content in the soil, while the spread of mycorrhizal organisms increases by 47%, and the number of nitrogen-fixing bacteria also increases [8]. It is proved that higher plants are the main factor determining the composition, abundance and activity of microorganisms in the soil [9]. It should be noted that carbon cycle reactions are highly sensitive to the temperature factor. Minor changes, which can contribute to significant emissions of carbon from the soil back into the atmosphere. The indirect effect of climate change on microorganisms, i.e indirectly through plants, it can be stronger than with the direct action of the temperature factor on the formation of the composition, bioecological properties and microbial community functions [10-12]. Naturally, climate change also poses a new problem for maize producers and requires a rethinking and improvement of each element of agricultural technology. Since in different years the amount of moisture and the distribution of precipitation during the growing season significantly affect the yield and quality of maize grain [13,14].

Based on the foregoing, the aim of our work was to study the influence of weather conditions (air temperature, rainfall) on the change in the main indicators of soil microbiocenosis activity, the phytopathological situation in agrocenosis and maize productivity.

Objects and Methods

The studies were conducted on the experimental fields of the Institute of Forage and Agriculture of Podillya of National Academy of Agrarian Sciences of Ukraine during 2011-2013. Soil sampling was carried out by the standard method [15] in long-term field experiments, the characteristics of which are shown in Table 1. Soil samples from maize agroecosystems were taken from the plant layer 0-20 cm from May to September, when the microbiocenosis reached its stable, balanced state. All samples were prepared by a single method: they were dried in air and crushed to a size of < 3 mm; visible plant debris and mesofauna were removed. The experiments were carried out in five repetitions.

To characterize the hydrothermal regime during the study, the average values of monthly air temperatures and precipitation for the field test area were used. For a more complete analysis of heat resources and precipitation, we calculated the hydro-thermal coefficient of Selyaninov (HTC), which is adequate to the ratio of precipitation to 0.1 sum of temperatures for the study period with values over 10°C [16,17]. To assess hydrothermal conditions by the HTC parameter, the following gradation of parameters was adopted: HTC below 0.5 – a sharp deficit of precipitation (severe drought); 0.6–0.7 – insufficient humidity (very dry) 0.8–0.9 – drought (drought is not intense), 1.0–1.2 – insufficient humidity, 1.3–1.6 – moderate humidity, > 1.7 – excess humidity, HTC > 2.0 – strong excess humidity [18]. In experiments, a hybrid of maize Krasilov 327 MB FAO 350 was grown with a sowing rate of 5.5 million viable seeds per hectare. The experimental area was 30 m^2 with a row spacing of 0.7 m. Field trials included three blocks. Plant growing practice was standard for the conditions of the Right Bank Forest-Steppe Zone of Ukraine. In each year of research, maize was sown in the last ten days of April and harvested in the first ten days of October. The agrochemical parameters of the soil were determined according to standard methods [19], the research results are shown in Table 1.

Table 1. *Agrochemical characteristics of the soil of the experimental fields, 0–20 cm*

Soil type	pH	Humus %	Concentration, mg/kg soil		
			Nitrogen easily hydrolyzed compounds	Mobile phosphorus	Exchange potassium
Gray forest medium loamy	4,2	2,06	74,2	174	115

The activity of microbiological processes occurring in the soil of the maize root zone was determined three times during the growing season in the phase of 2–3 leaves, tillering and wax ripeness. The carbon content of microbial biomass (Smik) in the soil was determined by the rehydration method, by gently drying the samples at a temperature of 65–70°C for 24 hours with further extraction with a 0.5 M solution K_2SO_4 [20-22]. The intensity of carbon dioxide (CO_2) emission from the soil was carried out under controlled conditions (temperature, humidity) by the adsorption method after alkaline adsorption was determined by titration and conversion to the amount of CO_2 released from the soil [15,20,22]. To determine the complex damage of plants by root rot (average intensity of damage to plants,%), we used the four-point VIZR scale modified by V. Peresypkin and V. Pidoplichko [19]. As a result of the experiment, a visual assessment of the damage to plants by root rot was carried out, where: 0 points – there were no signs of damage; 0.1 points – damages were noted in the form of separate brown or black dots on the roots, the underground internodes and the basal part of the stems; 0.5 points – dot damages of half of the underground internodes or roots; 1 point – slight browning or blackening of the underground internodes, the base of the stem and root system in the form of separate strokes; 2 points – a strong browning of the underground internodes and roots on the basis of the stem brown or black stripes; 3 points – strong and continuous browning of the base of the stem and the underground internode, more than half of the roots have died out; 4 points – the plants died. The spread of diseases is the number of affected plants or their individual organs as a percentage of the total number examined on the area or field, was determined by calculation [19], according to the formula:

$$P = \frac{n \cdot 100}{N} ,$$

where P is the spread of diseases,%; n is the number of affected plants (plant organs) in the sample; N is the total number of examined plants (organs) in the sample. The direction of microbiological processes in the soil (mineralization coefficient, humus accumulation coefficient) was determined by E. Andreeyuk and G. Iutinskaya [23]. Statistical processing of experimental results was performed in Microsoft Excel. The mean values (x) and their standard deviations (SD) were determined. The significance level selected for the study was P < 0.05.

Results and Discussion

During three years of field research, the temperature regime of the first half of the maize vegetation was characterized by an excess of long-term average values of 1–5°C, especially in June–July (Fig. 1).

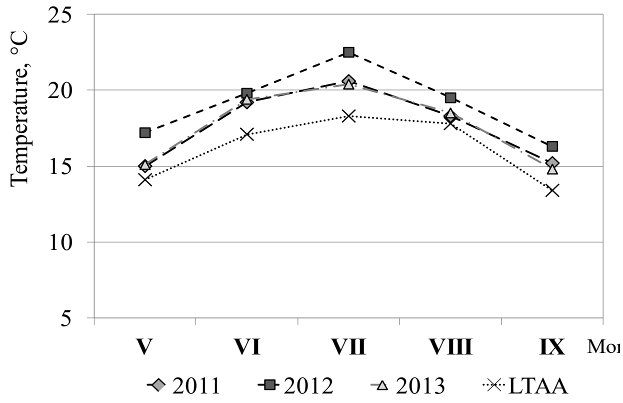

Fig. 1. *Dynamics of average monthly temperature during the maize growing season*

Monthly temperatures exceeding 3–5°C continued throughout the growing season – from May to September 2012. These months in 2011 and 2013 were characterized by significant amount of precipitation, whereas the entire vegetation period of 2012 was observed to be drought (Fig. 2).

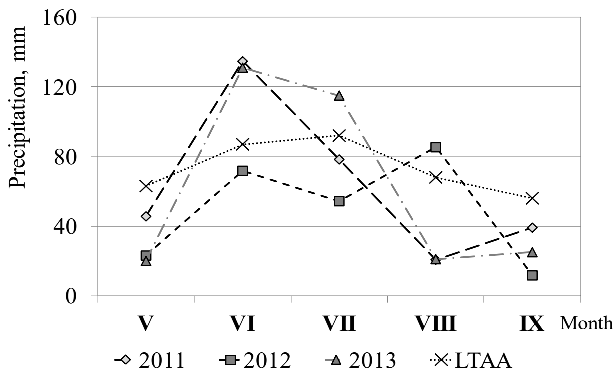

Fig. 2. *Dynamics of monthly precipitation during the maize growing season*

Maize is a heat loving and drought tolerant crop, which requires an average daily temperature of + 25°C for growth and development. This culture tolerates drought well until the tube exit phase. From the throwing panicles moment its moisture need is the most significant [24]. A lack of moisture during this critical period causes withering of the plants, drying of the leaves, decreased photosynthetic activity and pollen viability, and this leads to impaired fertilization and subsequent formation of grain [25].

Thus, comparing the values of the hydro-thermal coefficient (HTC) of each year of research and the average long-term indicators (ALTI), it follows that the weather conditions of 2013 were close to optimal for the development of plants and the formation of a maize crop (Fig. 3). ALTI data for 2013 have an advantage over others and characterizes not only the incoming part of the water balance (precipitation), but also the unproductive discharge of moisture (evaporation) from the surface of the soil or plants and allows to evaluate the influence of two abiotic factors at the same time [6].

The first half of the 2011 year vegetation season was favorable for the level of HTC, and since August there was a lack of precipitation and drought, which negatively affected the formation of ears of corn and grain. In 2012, the level of HTC during the entire growing season was very low, which indicates the extreme conditions for the development of plants and the accumulation of green mass of maize, because the long period (May–July) with abnormal heat and drought was observed.

Comparison of agrometeorological indicators in the researched years with the obtained crop showed that the range of differences in weather conditions during the growing season of maize significantly influenced the biological activity of microbiocenosis (Table 2), the yield of green mass and grain (Fig. 4).

The lack of precipitation in August leveled out favorable weather conditions for plants of the first half of the maize vegetation, which did not allow the plants to form a high yield due to the use of nutrient reserves accumulated in the green mass. The initial phases of maize ontogenesis (May) were characterized by an insufficient amount of precipitation, respectively, and moisture in the soil, which most likely restrained the development diseases of young plants` roots. According to the results of phytopathological evaluation, the distribution of root rot of maize was 56 % (Table. 2). Confirmation of the average level of disease development is the content of microbial biomass at the level of 112.3 μg C / g of soil and carbon dioxide emissions in the range of 32.8 mg of CO_2 / kg of soil. Thus, it can be argued that the bacterial component, rather than the

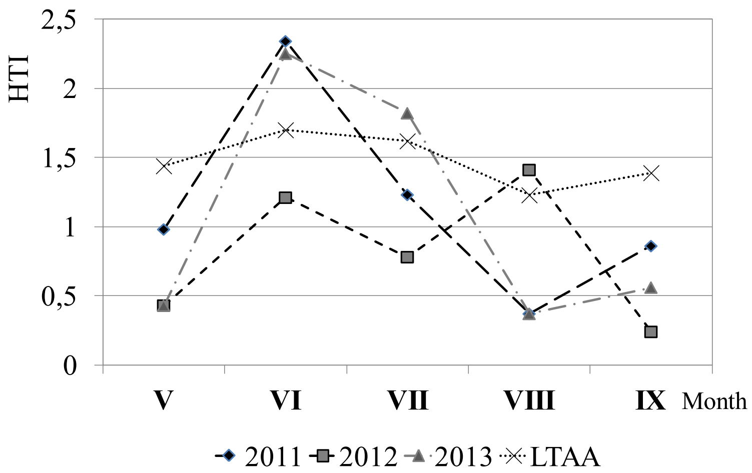

Fig. 3. *Dynamics of HTC during the maize growing season*

Table 2. *Indicators of the biological activity of microbiocenosis and phytopathological evaluation of maize plants*

Test indicator	Researches period, year		
	2011	2012	2013
Microorganisms biomass, μg C / g of soil	112,3±5,17	100,6±3,82	208,3±8,75
CO_2 emission, mg CO_2 / kg of soil	32,8±0,95	29,2±1,02	32,0±1,06
The spread of root rot, %	56,0±4,2	62±2,3	49±3,1
The development of diseases, %	2,1±0,5	3,3±0,4	2,0±0,5

fungal one, dominated in the microbial community of the soil [26], as the fungal component forms a significant part of the biomass of soil microbiocenosis [27; 28]. The activity of synthesis processes in the soil was positively affected by conditions of elevated temperatures and humidity, typical for the period May–July 2011, as evidenced by the values of the mineralization and humus accumulation coefficients (1.32 and 1.28 respectively).

Moisture deficiency and increased temperature regime during May–July 2012 caused a significant decrease in the formation of green mass of maize (Fig. 4).

As a result, the productivity indicators of the green mass of plants amounted to 57.9 t ha^{-1}, which are 7.3–9.2 t ha^{-1} less than in other years. At the same time, the grain maize yield was at a level close to the crop with optimal weather conditions – 6.37 t ha^{-1}. This effect is due to the drought tolerance of the culture. It also contributed to obtaining a relatively high grain yield in a dry year and an increased average monthly temperature, because under such conditions, plants of type C4 increase the efficiency of nitrogen use in photosynthetic structures, to which this crop belongs [5]. Another physiological feature of maize plants provides its resistance to drought – it has a very low transpiration coefficient, because plants use carbon dioxide more economically with minimal water losses [29]. However, a high level of solar insolation and a significant precipitation deficit during certain interphase periods of the vegetation affected plant incidence with diseases. The prevalence of root rot in agrophytocenosis was fixed at the level of 62 %, and the development of diseases was 3.3 %, which was 1.6 times higher than in other researched periods (Table 2). It is known that the defeat of maize (fusarium root and stem rot) contributes to the weakening of plants due to violations of the soil water regime and other weather stresses [30]. Therefore, it can be assumed that the unstable distribution of precipitation during the growing season and the excess rainfall in April before sowing contributed to the development of the disease.

It is known that temperature is more significant influencing factor of the functional structure of soil microbiocenosis. Scientific research [24] proved that temperature affects the population density of bacteria with an eutrophic type of nutrition and is 86.2 %, streptomycetes – 22.1 %, micromycetes – 18.5 %. The simultaneous combination of temperature and soil moisture factors contributes to growth in the influence of the latter on the number of streptomycetes by 3 times, soil micromycetes and oligotrophic bacteria – by 4 times, bacteria immobilizing nitrogen of mineral compounds – by 8 times.

Abnormal weather conditions in 2012 (exceeding average monthly temperatures by 3–5°C and a reduced amount of precipitation by 15–45 mm depending on the study period) also affected the biological activity of the soil. The content of microbial biomass in maize agrocenosis was 100.6 µg C / g of soil, which is 2 times lower than the data for the optimal weather year (2013). Also the anal-

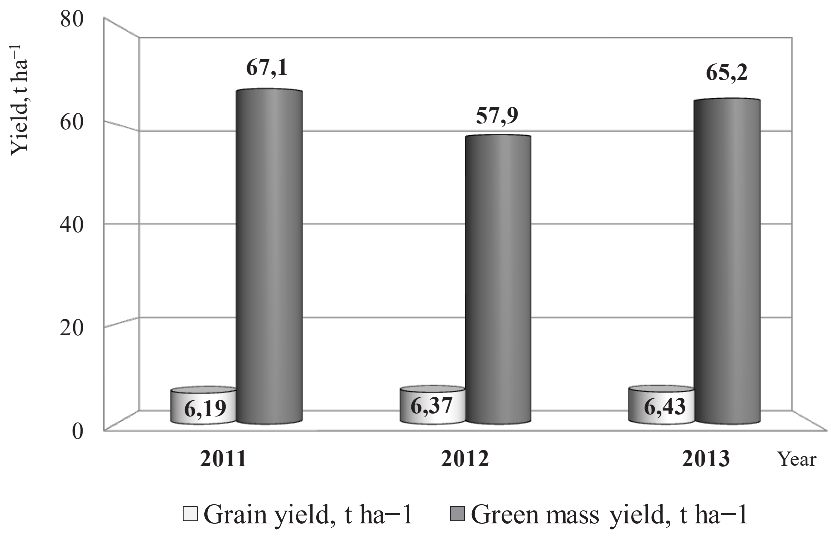

Fig. 3. *Maize yield, t ha^{-1}*

* Yield t ha^{-1}, SSD$_{2011\text{-}2013}$:0,08; green mass t ha^{-1}, SSD$_{2011\text{-}2013}$: 1,5

ysis of the indicators of biological activity of the soil showed that an increase in temperature and the reduction amount of precipitation negatively affects the processes of humus accumulation in the soil (K_{hum} = 0.92).

If the initial stage of the growing season was characterized by low rainfall, the temperature regime was optimal for the development of maize plants and the accumulation of phytomass, which promotes the development of the powerful root system that permetes deep into the substrates of the soil. This, in its turn, favorably influence the formation of a high yield in conditions of insufficient moisture supply. That is why in 2013, despite a very low rainfall in May and August, a high yield of green mass and maize grain was obtained, respectively 65.2 and 6.43 t ha^{-1} (Fig. 4). Maize plants at the end of the growing season show a high need for nutrients for grain formation.

In 2013 the phytosanitary condition of maize crops was the best. Diseases affected up to 49 % of crops with its development in only 2 % of plants. It should be noted that there were no objective reasons for the development of fungal diseases associated with weather conditions, since during the period of sowing and the initial growth and development of maize plants, an increase in air temperature and a small amount of precipitation was observed. Probably, the main sources of infection of maize plants were root rot pathogens located in the soil or on the seed surface. Indicators of microbial biomass and carbon dioxide emissions were 208.6 µg C / g of soil and 32.0 mg CO_2 / kg of soil, respectively (Table 2). For hydrothermal conditions 2013 approached to the long-term average data; during this period the balance of the processes of humus accumulation was noted (K_{hum} = 1.06). Thus, the obtained results indicate that in 2013 there were optimal conditions for the functioning of the soil microbiocenosis in maize crops.

The influence of the weather on yield and grain quality is also confirmed by researching [13, 31]. For example, the maize crop under optimal weather conditions (HTC 1.01) amounted to 1.05 t ha^{-1} with the maximum efficiency of the plant protection system. Under conditions of heat and moisture deficit (HTC 0.56), 0.43 t ha^{-1} of maize was harvested and a low level of chemical protection of plants was recorded [31]. Accordingly, contrasting weather conditions during the researched period had a significant impact on the effectiveness of the herbicides and the number of weeds, and became a determining factor in the maize yield.

Conclusion

It has been established that in years with an extremely high temperature and arid conditions (exceeding average monthly temperatures by 3–5°C and a reduced amount of precipitation by 15–45 mm, depending on the month of research), it is possible to obtain a quite high yield of maize grain at the level of 6.37 t ha^{-1}, but with losses in green mass productivity (in the range of 7–9.5 t ha^{-1}). It should be noted that the uneven distribution of precipitation during the growing season and the excessive amount of precipitation before sowing (exceeding the norm by 48 mm) contributed to the development of plant diseases by 1.6 times and an increase in the spread of diseases by 26 % compared to favorable weather conditions. Consequently, during the critical temperature regime, but with excess humidity in the first half of the growing season, high rates of root rot prevalence (56 %), which caused the decrease in the grain yield to the level of 6.1 t ha^{-1} were observed. However, a high level of humidity has contributed to the accumulation of the large amount of green mass for plants (67.1 t ha^{-1}), which is 9.2 t ha^{-1} more than in adverse year conditions. On the other hand, during extreme periods (excessive humidity and a monthly average temperature increase of 2–5°C) in comparison with the same hot but arid periods, the amount of total microbial biomass in the soil increases (by 12–108 %) and the synthesis processes increase humic substances (by 15–39 %) and carbon dioxide emission is activated (by 9–12 %). Therefore, such weather conditions contribute not only the increasing of the yield of maize green mass but also preservation of soil fertility.

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