Scientific Papers. Series D. Animal Science. Vol. LXVI, No. 2, 2023
ISSN 2285-5750; ISSN CD-ROM 2285-5769; ISSN Online 2393-2260; ISSN-L 2285-5750

CLIMATIC CHANGES OF ATMOSPHERIC PRECIPITATION AND THE VITAL ACTIVITY OF BEES

Valentina CEBOTARI, Ion BUZU

Institute of Zoology of Science Academy from Moldova, 1 Academiei Street, MD 2028, Chisinau, Republic of Moldova

Corresponding author email: valentinaceb@yahoo.com

Abstract

The aim of the present work was to reveal the impact of climate changes of atmospheric precipitation on the vital activity of bee colonies. To elucidate this impact, Pearson's linear correlation coefficients were calculated between monthly atmospheric precipitation and the average annual value of each of the 6 main morpho-productive characters of bee families, such as: queen prolificacy, winter resistance, strength and colony resistance to disease, brood viability and honey production. The scientific research was carried out on the families of Apis mellifera bees from the Carpathian race at the "Apibio Regina Mierii" experimental apiary. For the research, the average monthly and annual atmospheric precipitation data for the last 11 years (2010-2020) from the nearest hydrometeorological station, located at a distance of 27 km from the apiary, were used. The results of the research demonstrated that the winter resistance of bee families has an obvious tendency to be positively influenced by atmospheric precipitation in March ($r_{xy} = 0.461 \pm 0.237$; $t_r = 1.95$; $P < 0.1$). The prolificacy of queens is influenced negatively - by atmospheric precipitation in June ($r_{xy} = -0.582 \pm 0.199$; $t_r = 2.92$; $P < 0.01$) and positively - by atmospheric precipitation in July ($r_{xy} = 0.579 \pm 0.200$; $t_r = 2.89$; $P < 0.01$). The strength of bee colonies is positively influenced by atmospheric precipitation in December of the previous year ($r_{xy} = 0.571 \pm 0.213$; $t_r = 2.68$; $P < 0.05$), as well as in March ($r_{xy} = 0.561 \pm 0.206$; $t_r = 2.72$; $P < 0.05$) and July ($r_{xy} = 0.482 \pm 0.231$; $t_r = 2.09$; $P < 0.05$) of the current year. The viability of the bee brood is negatively influenced by atmospheric precipitation in the months of January ($r_{xy} = -0.469 \pm 0.235$; $t_r = 2.00$; $P < 0.05$) and May ($r_{xy} = -0.577 \pm 0.201$; $t_r = 2.87$; $P < 0.01$) of the current year, and positive - from the atmospheric precipitation in March of the current year ($r_{xy} = 0.504 \pm 0.225$; $t_r = 2.24$; $P < 0.05$) and October of the previous year ($r_{xy} = 0.599 \pm 0.203$; $t_r = 2.95$; $P < 0.01$). Disease resistance of bee families is influenced negatively - by atmospheric precipitation in January of the current year ($r_{xy} = -0.497 \pm 0.227$; $t_r = 2.19$; $P < 0.05$) and positively - by atmospheric precipitation in August of the previous year ($r_{xy} = 0.565 \pm 0.215$; $t_r = 2.63$; $P < 0.05$), as well as the annual atmospheric precipitation of the previous year ($r_{xy} = 0.560 \pm 0.217$; $t_r = 2.58$; $P < 0.05$). Honey production of bee families is positively influenced - by atmospheric precipitation in the months of September ($r_{xy} = 0.711 \pm 0.156$; $t_r = 4.56$; $P < 0.001$), November ($r_{xy} = 0.599 \pm 0.203$; $t_r = 2.95$; $P < 0.01$) and annual ($r_{xy} = 0.560 \pm 0.217$; $t_r = 2.58$; $P < 0.05$) of the previous year, and negatively - by atmospheric precipitation in February ($r_{xy} = -0.706 \pm 0.151$; $t_r = 4.68$; $P < 0.001$) and June ($r_{xy} = -0.511 \pm 0.223$; $t_r = 2.29$; $P < 0.05$) of the current year.

Key words: *atmospheric precipitation, bees, climate changes, vital activity.*

INTRODUCTION

Apiculture, in the Republic of Moldova, presents a branch of agriculture of particular importance for the national economy, due to the value and quality of the products offered by it, the fact of creating jobs among the vulnerable layers of the population in rural areas, as well as for maintaining through pollination homeostasis and biodiversity of natural ecosystems.

In total, there are approximately 180 thousand bee families in the country, from which approximately 4.5 - 5.0 thousand tons of honey are obtained annually, of which approximately 4000 tons are exported to different countries (Program National, 2020). Other bee products, quite important, are obtained from bees, such as: wax, pollen, propolis, royal jelly, venom, which are used in various fields of the national economy (food industry, medicine, pharmaceuticals, cosmetics, plastic arts, etc.).

One of the most important benefits brought to man by bees, is the additional product obtained from increasing the productivity of entomophilous plants from cultivated and spontaneous flora, as a result of their pollination, thus ensuring the perpetuation of nature's biodiversity.

In the Republic of Moldova, bees pollinate about 600,000 ha of agricultural land, from which an additional 20-30% of the annual

harvest is obtained, worth more than 3.6-4.0 billion lei. (Statistical Yearbook, 2021).
The honey bee, being the main pollinator of entomophilous crops, is currently facing the impact of climate change and its weather on the world map. In the last decades of the 20th century and the beginning of the 21st century, human society exerts an increasing influence on the climate, in particular, on the Earth's temperature, through the burning of fossil fuels, the cutting of forests and the intensive breeding of animals. These activities generate emissions of enormous quantity of greenhouse gases, which add to those already naturally present in the atmosphere, thus contributing to the greenhouse effect, global warming and hydrological regime change, which have an impact on flora and fauna ecosystems , especially on pollinators, including *Apis mellifera* bees (Ambjerg-Nielsen, 2012; Climate change, 2012; Causes of climate change, 2018; SSC-Raport, 2009; Bojariu et al., 2015; Kremen et al., 2007; Memmott et al., 2007).
Climate change includes changes, in the complex, of air temperature, atmospheric precipitation regime and extreme or more irregular meteorological phenomena, such as: drought, storms, tornadoes, hail, floods, etc. (Bee Decline, 2013; Consequences of climate change, 2018; Econews Infomediu Europe, 2018; Marin et al., 2014). Climate change leads to: an increase in the average global temperature with significant variations at the regional level, a decrease in fresh water resources for the population, a reduction in the volume of the ice caps and an increase in the level of the oceans, a change in the hydrological cycle, an increase in arid surfaces, anomalies in the unfolding of the seasons, an increase in frequency and intensity extreme climate phenomena (Barbu et al., 2011; Themes biodiversity, 2017; Sandu et al., 2010).
Despite the existence of the Paris Agreement - the United Nations Framework Convention on Climate Change (Acordul de la Paris, 2016), greenhouse gas emissions and global warming continue to increase. Thus, in an official publication of the European Environment Agency (EEA), it is shown that the total emissions of greenhouse gases in the European Union (EU) increased by 0.7% in 2017, compared to 2016. The increase of greenhouse gas emissions in the EU was recorded for the fourth consecutive year (Small increase, 2019).
Along with global warming, climate change in atmospheric precipitation is also of major concern. Clouds, which are the more condensed form of tiny water molecules suspended in the air, are the main source of atmospheric precipitation. Tiny water particles play an important role in how and how long clouds form, the amount of solar radiation that clouds can reflect, and determine the type of precipitation generated. The concentrations and composition of water particles determine climate changes, the time and place where precipitation occurs (Busuioc et al., 2006).
Climate changes related to the frequency and volume of atmospheric precipitation have attracted the attention of many specialists and researchers in the field (Busuioc et al., 1999; Ștefan et al., 2004; Ștefănescu et al., 2014; Tomozeu et al., 2007), because they cause real economic and social costs, affecting food production and prices globally.
A report by the European Environment Agency "Climate change, impacts and vulnerability in Europe 2012" reveals rather pessimistic forecasts of climate change, in which Europe will be gripped by higher temperatures, in combination with a decrease in precipitation in the southern regions and increase in precipitation in Northern Europe. In addition, ice sheets and glaciers are melting and sea levels are rising. All these trends are expected to continue (Climate change, 2012). According to the same Report, climate changes in atmospheric precipitation have a direct impact on the physiology, phenology and distributions of biodiversity of fauna and flora, as well as on human society as a whole.
Pessimistic climate change predictions are complemented by other researchers (Birsan et al., 2014; Bojariu et al., 2015), which states that, in the months of the warm season, there is a tendency to decrease precipitation, which will generally increase towards the end of the 21st century. Under these conditions, the trend of predictions is associated with the signal of climate change determined by the increase in the concentration of greenhouse gases in the atmosphere, at a global level, with the regional signal of decreasing precipitation in the area, as

well as with the negative impact on agriculture, natural ecosystems and society human as a whole.
A Greenpeace Research Labs Report (Bee Decline, 2013) states that “climate change, such as rising temperatures, changing precipitation patterns and extreme or more irregular weather events, are impacting pollinator populations. Some of these changes may affect them individually, ultimately affecting their communities, which is reflected in the increased rate of extinction of pollinator species”.
According to the data of some of our previous researches, it was demonstrated that excessively high temperatures in the spring-summer of a dry year caused a drastic decrease in the morpho-productive performance of bee colonies by 20-46% (Cebotari et al., 2013).
In our other research, it was found that climatic changes in air temperature in different months of the year have different impact on the vital activity of bee families depending on the time of year and air temperature values (Cebotari et al., 2019).
Positively appreciating the results of the multiple above-mentioned researches, we can report that they have brought useful information regarding the impact of climate change on ecosystems in general and on pollinators in particular. At the same time, with the exception of our research, in the bibliographic sources accessible to us, there is a lack of information regarding: the concrete influence of climatic changes of atmospheric precipitation on the vital activity of bee families; the evolution of the value of the morpho-productive characters of the bee families according to the monthly and annual atmospheric precipitation; the correlative links between atmospheric precipitation parameters and the level of morpho-productive performances of bee families. Therefore, determining the correlations between the average monthly atmospheric precipitation parameters in different periods of the year and the evolution of the value of the morpho-productive characters of the bee families, presents a scientific and practical interest for mitigating the impact of climate change weather.
In this context, the aim of the present paper was to elucidate the impact of climate changes of atmospheric precipitation on the vital activity of *Apis mellifera* bee families.

MATERIALS AND METHODS

The scientific researches were carried out on the families of *Apis mellifera* bees from the *Carpathian* race at the experimental apiary "Apibio Regina Mierii", located in the Center area of Codrilor Moldovei, Ocolul Silvic Ghidighici, Canton no. 8, Forest sector no. 21. There were a total of 50 bee families in the apiary. During the years 2010-2020, annually, in each family of bees in the apiary, the resistance to wintering was evaluated individually, in the month of March, and in the month of July, the main morpho-productive characters of reproduction and development (prolificity of the queen, strength of the family), of resistance to diseases, viability of the brood, as well as productivity of the quantity of honey accumulated in the nest, according to the methods developed by us (Cebotari et al., 2010) for the Zootechnical Norm regarding the certification of bee families, the raising and certification of bee brood material, approved by the Decision of the Government of the Republic of Moldova no. 306 of 28.04.2011 (Zootechnical norm, 2011). Afterwards, the average value for the entire hive of each of the morpho-productive characters evaluated was calculated.
In order to research the impact of climate change on the vital activity of bee colonies, monthly and annual atmospheric precipitation data were collected for the last 11 years (2010-2020) from the nearest hydrometeorological station, located in Bravicea town, Călăraş district, at a distance of 27 km from the apiary. During this period, for each individual month, Pearson's linear correlation coefficients were calculated between the quantity of atmospheric precipitation and the average value per hive of each of the 6 main morpho-productive characters of the bee families, such as: the prolificacy of the queens, the power bee colonies, colony overwintering resistance, colony resistance to diseases, brood viability and honey production of bee colonies. For the months of the first period of the year (January -

July), the correlation coefficients were calculated between the quantity of atmospheric precipitation and the values of the morpho-productive characters of the bee families, evaluated in the same year at the end of July, with the exception of winter resistance, which was evaluated in March. Given the fact that the climatic factors from the second period of the year (August - December) no longer influence the morpho-productive characters already evaluated in July of the current year, the atmospheric precipitation variable from the months of August-December was calculated in correlation with the value of the morpho-productive of bee families from the following year.

The same correlation coefficients were also calculated for the variable of the annual quantity of atmospheric precipitation and the average values per apiary of the above-mentioned 6 morpho-productive characters.

Pearson's linear correlation coefficient (r_{xy}) was calculated on the electronic computer in the Files/StatSoft/STATISTICA 12 program. For each correlation coefficient separately, the correlation certainty criterion (t_r) and the certainty threshold (P) were calculated according to Student.

The data obtained in the research were statistically processed and their certainty assessed, according to variational biometric statistics, according to the methods of Plokhinsky (1989).

RESULTS AND DISCUSSIONS

The results of the research demonstrated that the climate changes, which took place between 2010 and 2020 in the area where the experimental apiary is located, caused a fairly wide variability in the amount of atmospheric precipitation (Table 1).

Table 1. Monthly and annual atmospheric precipitation recorded at the Station Hydrometeorological "Bravicea", Călărași district, during the years 2010-2020, mm

Month of the year	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
January	87.3	19.6	18.1	31.4	51.1	26.5	32.8	29.5	50.5	63.2	4.2
February	40.8	45.7	78.1	33.8	5.9	21.3	27.4	22.5	53.2	29.7	29.1
March	18.7	24.8	15.0	65.1	12.9	57.7	25.7	30.8	88.5	11.2	16.3
April	41.4	27.6	84.2	29.1	55.1	41.8	39.8	112.5	5.0	34.5	14.4
May	97.0	22.9	44.1	62.1	88.3	12.6	64.5	42.9	24.1	177.7	68.6
June	147.2	119.8	64.3	142.8	27.4	34.8	188.0	89.7	77.1	81.0	101.3
July	64.0	64.6	44.1	9.5	91.7	83.2	19.6	85.5	70.5	30.3	28.3
August	43.4	50.5	39.7	78.2	18.9	38.0	120.7	33.9	45.9	33.9	1.3
September	49.7	12.2	6.3	114.6	10.3	20.2	9.0	29.7	43.5	36.3	33.7
October	51.7	24.2	36.5	4.9	44.3	42.8	134.5	62.3	4.7	32.9	71.1
November	37.1	4,9	23.3	60.7	91.8	56.6	36.5	31.7	61.4	11.7	25.5
December	56.6	20.2	99.2	6.6	41.3	2.7	11.2	81.2	37.4	28.3	43.7
Annual total	**734.9**	**437.0**	**552.9**	**638.8**	**539.0**	**438.2**	**709.7**	**651.6**	**561.8**	**570.7**	**437.5**

The annual amount of atmospheric precipitation, during this period, varied from a minimum of 437.0 mm in 2011 to a maximum of 734.9 mm in 2010 or by 68.2%. The average annual amount of atmospheric precipitation in the period 2010-2020 was 570.2 mm. The lowest atmospheric precipitation fell in the years 2011 (437.0 mm), 2015 (438.2 mm) and 2020 (437.5 mm). The decrease in atmospheric precipitation, in these years, caused three terrible droughts, which affected not only the harvests of agricultural crops, but had a negative impact on the flora and fauna of the intact ecosystems, especially on the honey flora and, as a result, on the vital activity of bees.

The data show that the monthly amount of atmospheric precipitation varies over the years in quite significant amounts. In the analyzed period (2010-2020), the greatest variability (contrast) of the monthly amount of atmospheric precipitation was recorded in August, oscillating from 1.3 mm in 2020 to 120.7 mm in 2016, the variation constituting 92.8 times (92.80%). The lowest variability in the amount of atmospheric precipitation was recorded in June, oscillating from 27.4 mm in 2014 to 188.0 mm in 2016, the variation being 6.9 times. A fairly large variability in the amount of monthly atmospheric precipitation, during this period, was also found in the months: October, from 4.7 mm in 2018 to 134.5 mm in 2016, with the variation index of 28.6 times; April, from 5.0 mm in 2018 to 112.5 mm in 2017, with a variation of 22.5 times; January, from 4.2 mm in the year 2020 to 87.3 mm in the year 2010, with a variation of 20.8 times, and in November, from 4.9 mm in the year 2011 to 91.8 mm in the year 2014, with a variation of 18.7 times. In the other months of the year, the variability of the amount of atmospheric precipitation, during this period, oscillated from 7.9 times in March to 18.2 times in September.

During the monitored period, four severe droughts were recorded, which started in the years when the amount of annual precipitation was relatively lower compared to other years, but not the lowest. The analysis of the data demonstrates that the terrible droughts manifested in those years, in which the lowest amounts of precipitation were recorded in the warm period (May - August). Despite the fact that in 2011 the lowest annual amount of precipitation was recorded (437.0 mm), the drought did not occur, because during the warm period of this year, sufficient amounts of precipitation fell (257.8 mm). At the same time, the terrible drought was triggered in the years 2012, 2015, 2018 and 2020, in which the amount of atmospheric precipitation in the warm period constituted, respectively, 192.2 mm, 168.6 mm, 217.6 mm and 199.5 mm, being the lower than all the years of the monitored period.

Climatic changes in the amount of atmospheric precipitation, as well as extreme phenomena triggered in the area where the experimental apiary is located, caused a variability, in some cases significant, of the vital activity of bee families, expressed in different levels of development of morpho-productive characters (Table 2).

From the data presented, we observe that the average prolificity of queens per hive varied, during this period, from 1252 eggs/24 hours in 2020, to 1806 eggs/24 hours in 2011. The variability of this character in bee families was 44, 2%.

Table 2. Average morpho-productive indices of families of bees at the Experimental Apiary "Apibio Regina Mierii" during the years 2010-2020

The year	Queens prolifi-cacy, eggs/ 24 hour	Family power, kg	Winter resis-tance, %	Brood viabi-lity, %	Disea-se resis-tance, %	Honey produc-tion, kg
2010	1583	2.83	80.1	85.1	76.8	38.8
2011	1806	2.97	82.5	91.0	89.4	32.8
2012	1740	2.37	86.2	88.6	87.4	23.9
2013	1661	3.03	91.1	91.0	90.5	35.5
2014	1781	3.13	93.3	92.3	91.6	57.4
2015	1711	3.04	88.6	95.8	86.3	44.2
2016	1371	2.20	84.1	95.7	89.2	31.0
2017	1678	2.36	86.8	95.5	92.6	34.2
2018	1781	3.14	88.4	95.4	91.7	39.7
2019	1716	2.38	71.3	88.1	91.6	49.9
2020	1252	2.05	83.4	92.1	91.0	38.8

The strength of the family, expressed by the amount of bees in the nest, fluctuated from 2.05 kg in 2020 to 3.14 kg in 2018, the variability constituting 53.2%. Winter hardiness varied, albeit to a lesser extent, from 71.3 percentage points in 2019 to 93.3 percentage points in 2014, the variability being 30.8%. The lowest variability among the researched morpho-productive characters, in this period, was found in the viability of the brood, fluctuating from 85.1 percentage points in 2010, to 95.8 percentage points in 2015, with a variability of 11 ,2%. The disease resistance (hygienic instinct) of bee families fluctuated, during the nominated period, from 76.8 percentage points in 2010 to 92.6 percentage points in 2017, the variability being 17.1%. Overall, we observe that the climate changes, during this period, caused a fairly obvious variability in the honey production accumulated in the nest, from a minimum of 23.9 kg in 2012, to a maximum of 57.4 kg in 2014, the variability being 58.4%.

In order to elucidate the concrete relationships of climate change impact of atmospheric precipitation on the vital activity of bee families, for each individual month, the linear correlation coefficients (rxy) were calculated between the monthly amount of atmospheric precipitation and the average value per apiary of the morpho characters - productive of bee families (Table 3).

Table 3. The correlation coefficient (r_{xy}) between the monthly quantity of atmospheric precipitation in the first period of the year and the average value of the morpho-productive characters of bee families (N = 11)

Morpho-productive characters	$r_{xy} \pm m_r$	t_r	**P**
January precipitation			
Winter resistance	-0.321 ± 0.270	1.19	>0.1
Queens prolificacy	0.226 ± 0.286	0.79	>0.1
Family power	0.335 ± 0.267	1.25	>0.1
Disease resistance	-0.497 ± 0.227	2.19	<0.05
Brood viability	-0.469 ± 0.235	2.00	<0.05
Honey production	0.452 ± 0.240	1.88	<0.1
February precipitation			
Winter resistance	-0.152 ± 0.294	0.52	>0.1
Queens prolificacy	-0.150 ± 0.295	0.51	>0.1
Family power	-0.083 ± 0.299	0.28	>0.1
Disease resistance	-0.233 ± 0.285	0.82	>0.1
Brood viability	-0.360 ± 0.262	1.37	>0.1
Honey production	-0.706 ± 0.151	4.68	<0.001
March precipitation			
Winter resistance	0.461 ± 0.237	1.95	<0.1
Queens prolificacy	0.302 ± 0.274	1.10	>0.1
Family power	0.561 ± 0.206	2.72	<0.05
Disease resistance	0.158 ± 0.294	0.54	>0.1
Brood viability	0.504 ± 0.225	2.24	<0.05
Honey production	0.065 ± 0.300	0.21	>0.1
April precipitation			
Queens prolificacy	0.200 ± 0.289	0.69	>0.1
Family power	-0.277 ± 0.278	0.99	>0.1
Disease resistance	0.022 ± 0.301	0.07	>0.1
Brood viability	0.030 ± 0.301	0.10	>0.1
Honey production	-0.240 ± 0.284	0.84	>0.1
May precipitation			
Queens prolificacy	-0.186 ± 0.291	0.64	>0.1
Family power	-0.305 ± 0.273	1.12	>0.1
Disease resistance	-0.032 ± 0.301	0.11	>0.1
Brood viability	-0.577 ± 0.201	2.87	<0.01
Honey production	0.479 ± 0.232	2.06	<0.05
Iune precipitation			
Queens prolificacy	-0.582 ± 0.199	2.92	<0.01
Family power	-0.308 ± 0.273	1.13	>0.1
Disease resistance	-0.270 ± 0.279	0.97	>0.1
Brood viability	-0.426 ± 0.247	1.72	<0.1
Honey production	-0.511 ± 0.223	2.29	<0.05
Iuly precipitation			
Queens prolificacy	0.579 ± 0.200	2.89	<0.01
Family power	0.482 ± 0.231	2.09	<0.05
Disease resistance	-0.087 ± 0.299	0.29	>0.1
Brood viability	0.243 ± 0.284	0.85	>0.1
Honey production	0.363 ± 0.261	1.40	>0.1

The results of the research demonstrated that the atmospheric precipitation in January had a significant negative impact on the resistance to diseases and the viability of the brood. Thus, the coefficient of the linear correlation of the quantity of atmospheric precipitation this month with disease resistance is negative of medium level, having a significance of one certainty threshold according to Student (r_{xy}= -0.497 ± 0.227; t_r = 2.19; P < 0.05) (Figure 1).
The correlation between the quantity of atmospheric precipitation in this month of the year and the viability of the brood is also negative of medium level with the significance of the threshold one according to Student (r_{xy} = -0.469±0.235; t_r = 2.00; P<0.05). In addition, the atmospheric precipitation in January has a tendency of positive influence on honey production (r_{xy} = 0.452±0.240; t_r = 1.88; P<0.1).
Although, the correlation coefficient (r_{xy}) is of medium level, this correlation shows only a tendency, because the certainty criterion (t_r) has a significance, only by the zero threshold according to Student (P<0.1).

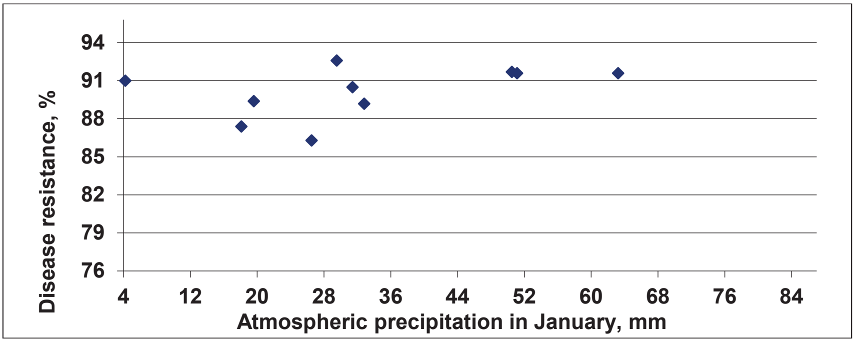

Figure 1. Point correlation between atmospheric precipitation in January and disease resistance

Atmospheric precipitation in February, which usually falls in the form of snow, does not have any significant influence on most of the morpho-productive characters of the bee families, with the exception of honey production. Although the theoretical mechanism is not known, how atmospheric precipitation in February could influence the future honey production evaluated in June-July, but in our research, it was found that they have a significant negative impact on honey production (Figure 2).

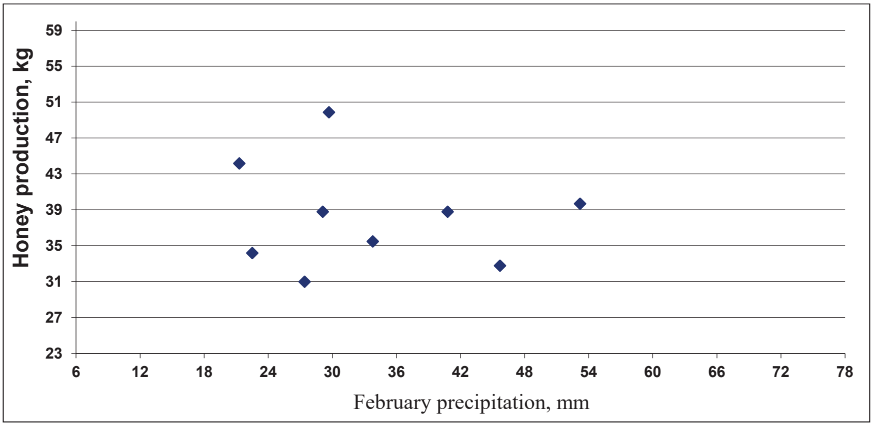

Figure 2. Point correlation between atmospheric precipitation in February and honey production

Thus, the correlation coefficient between these two variables (February atmospheric precipitation and honey production) is significantly negative at a high level (r_{xy} = -0.706 ± 0.151; t_r = 4.68; P<0.001), with the highest threshold of certainty according to the probability theory of prognostications without error according to Student. According to us, the negative impact of these precipitations is an indirect consequence of the increased humidity in the nest of bee families, which has negative influences on the main morpho-productive characters, such as: queen prolificacy, family resistance to wintering, brood viability, disease resistance and family power. The correlation of atmospheric precipitation with these characters is negative, although it is insignificant.

Atmospheric precipitation in March has a general positive influence on the vital activity of bee families. This is confirmed by the existence of positive correlations of different levels with all the research morpho-productive characters, especially on winter resistance, family strength and brood viability.

Thus, the correlation coefficient between atmospheric precipitation in March and wintering resistance is positive at a medium level, with an obvious tendency towards significance close to the threshold of one according to Student (r_{xy} = 0.461±0.237; t_r = 1.95; P<0.1). At the same time, the correlation coefficient between atmospheric precipitation this month and the strength of the bee family is positive above average level and quite significant, falling within the threshold of certainty according to the probability theory of prognoses without error according to Student (r_{xy}= 0.561 ± 0.206; t_r = 2.72; P<0.05) (Figure 3).

The same atmospheric precipitation in March had a significant positive impact on brood viability. Thus, Pearson's linear correlation coefficient between the atmospheric precipitation in March and the viability of the brood is of an above-average level, with the significance of the one certainty threshold according to the probability theory of prognoses without error according to Student (r_{xy} = 0.504±0.225; t_r = 2.24; P<0.05).

The research demonstrated that the atmospheric precipitation in the month of April does not exert any negative or positive influence on the vital activity of the bee families, because the linear correlation coefficients between the amount of precipitation in this month and the morpho-productive characters of the bee families had no values significant (P>0.1).

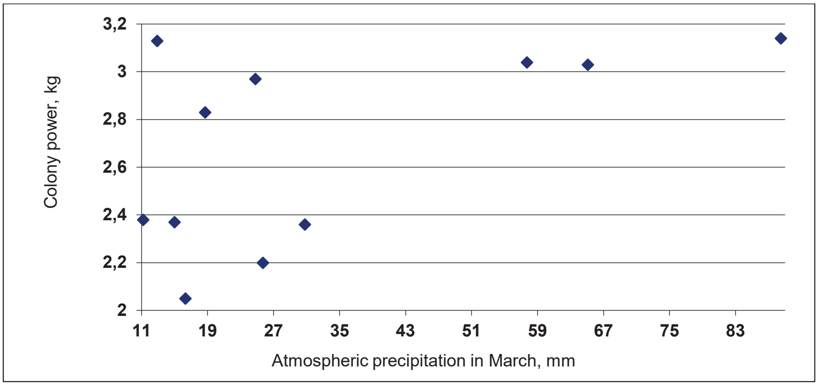

Figure 3. Point correlation curve between atmospheric precipitation in March and colony power

Atmospheric precipitation in May has an ambiguous influence on the vital activity of bee families. On the one hand, the atmospheric precipitation in this month negatively influences the viability of the brood. Between these two variables, an above-average level negative correlation was found (r_{xy} = -0.577 ± 0.201; t_r = 2.87; P<0.01), with the significance of the second certainty threshold according to the probability theory of error-free prognoses according to Student.

On the other hand, it is important to note that the atmospheric precipitation in May had a positive influence on honey production (Figure 4).

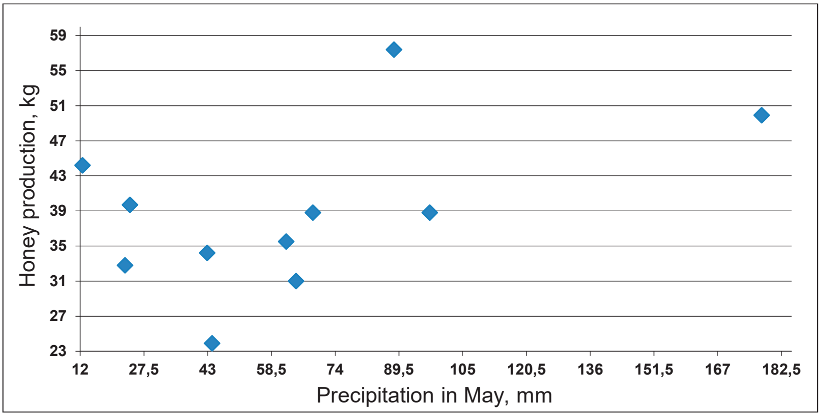

Figure 4. Point correlation between atmospheric precipitation in May and honey production

Thus, Pearson's linear correlation coefficient between atmospheric precipitation in May and honey production is of medium level, with the significance of the first certainty threshold according to the probability theory of prognoses without error according to Student (r_{xy} = 0.479 ± 0.232; t_r = 2.06; P<0.05).

According to us, the positive impact of atmospheric precipitation in May is explained by their stimulating influence on the process of circulation of the sap of honey plants and abundant accumulation of the nectar of their flowers, which directly contributes to the significant increase in the amount of honey accumulated in the nest.

Research has shown that the atmospheric precipitation in June has a negative influence on the development of the main morpho-productive characters. The negative impact of these precipitations is manifested significantly on the prolificacy of queens and honey production (Figure 5).

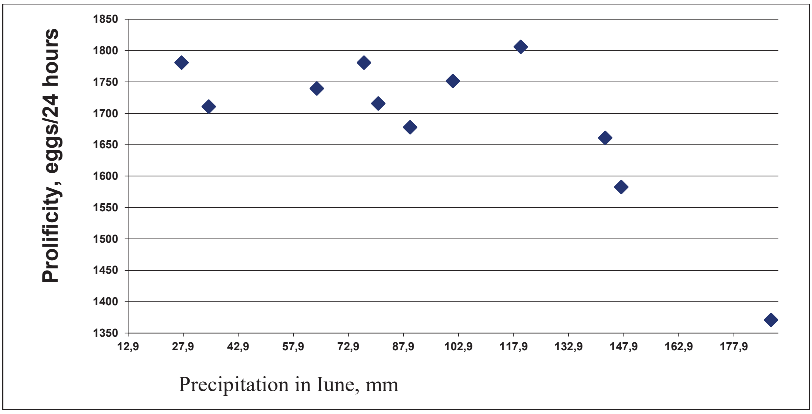

Figure 5. Point correlation between atmospheric precipitation in Iune and the prolificacy of queens

Thus, Pearson's linear correlation coefficient between the quantity of atmospheric precipitation in June and the prolificacy of queens is negative above average level, with the significance of the second threshold according to the probability theory of prognoses without error according to Student (r_{xy} = -0.582±0.199; t_r= 2.92; P<0.01). Between the quantity of atmospheric precipitation in this month and the production of honey, a negative correlation was recorded, also above average, with the significance of threshold one according to the probability theory of prognoses without error according to Student (r_{xy} = -0.511 ± 0.223; t_r = 2.29; P<0.05). At the same time, between the quantity of atmospheric precipitation in Iune and the viability of the young, a medium-level negative correlation trend with zero-threshold significance can be seen (r_{xy} = -0.426 ± 0.247; t_r = 1.72; P<0.1).

Research has shown that atmospheric precipitation in July has a mostly positive influence on the main morpho-productive characters of bee families, especially with significant influence on the prolificacy of queens and the power of bee colonies (Figure 6).

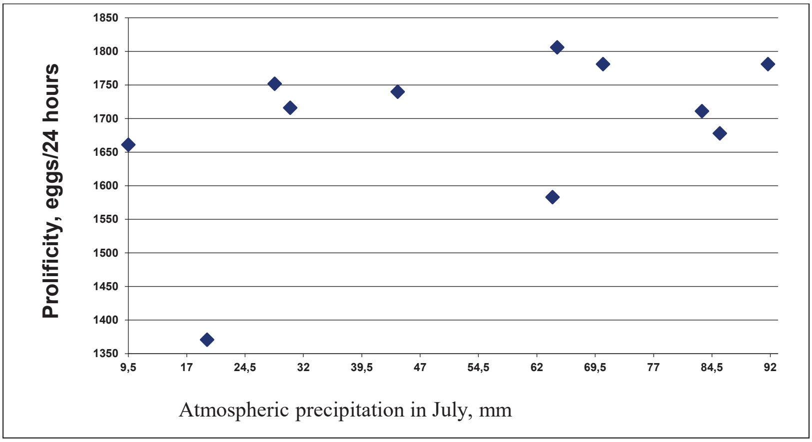

Figure 6. Point correlation between atmospheric precipitation in July and the prolificacy of queens

Thus, Pearson's linear correlation coefficient between the quantity of atmospheric precipitation in July and the prolificacy of queens is positive above average level, with the significance of the second threshold according to the probability theory of prognoses without error according to Student (r_{xy} = 0.579 ± 0.200; t_r = 2.89; P < 0.01). Between the quantity of atmospheric precipitation in this month and the strength of the family, there was a positive correlation of medium level, with the significance of the threshold of one according to the probability theory of prognoses without error according to Student (r_{xy} = 0.482 ± 0.231; t_r = 2.09; P<0.05).

Precipitation in this month has a weak tendency to have a positive influence on honey production.

However, the linear correlation coefficient between these two variables is not significant (r_{xy} = 0.363 ± 0.261; t_r = 1.40; P>0.1).

Generalizing the climate change impact of atmospheric precipitation in the first period of the year, we can deduce that the large amounts of precipitation in this period, especially in February and June, have a negative impact on the vital activity of bee families by reducing the level of development of the main morpho-productive characters. The negative impact is directly caused primarily on queen fertility, brood viability and honey production. Under the action of atmospheric precipitation during this period, the humidity in the nest increases excessively, inhibiting the development of most of the morpho-productive characters of bee families. At the same time, the atmospheric precipitation in the months of January, March, May and July has a mostly positive influence on the main morpho-productive characters, especially on the prolificacy of the queens, the power of the family and the production of honey.

Starting with the second half of the year, the atmospheric precipitation from July - December can no longer have an impact on the morpho-productive characters previously evaluated (in July), but they can have a direct impact on the vital activity of the bee families related to the consolidation of the power of the colonies and their preparation for winter, as well as indirectly on the evolution of the value of morpho-productive characters in the next year (Table 4).

Research has shown that atmospheric precipitation in August has no significant influence on the main morpho-productive characters, except for the resistance of bee families to diseases. It was found that the atmospheric precipitation in this month has a significant positive impact on the disease resistance of bee colonies, evaluated in the following year (Figure 7).

Table 4. The correlation coefficient between the quantity of monthly atmospheric precipitation in the second half of the preceding year and the value of the morpho-productive characters of bee families in the following year

Morpho-productive characters	$r_{xy} \pm m_r$	t_r	**P**
August precipitation			
Queens prolificacy	0.138 ± 0.310	0.44	>0.1
Family power	-0.158 ± 0.308	0.51	>0.1
Winter resistance	0.152 ± 0.309	0.49	>0.1
Brood viability	0.087 ± 0.314	0.28	>0.1
Disease resistance	0.565 ± 0.215	2.63	<0.05
Honey production	0.052 ± 0.315	0.16	>0.1
September precipitation			
Queens prolificacy	0.166 ± 0.307	0.54	>0.1
Family power	0.299 ± 0.288	1.04	>0.1
Winter resistance	0.098 ± 0.313	0.31	>0.1
Brood viability	-0.192 ± 0.305	0.63	>0.1
Disease resistance	0.349 ± 0.278	1.25	>0.1
Honey production	0.711 ± 0.156	4.56	<0.001
October precipitation			
Queens prolificacy	0.021 ± 0.316	0.07	>0.1
Family power	-0.091 ± 0.314	0.29	>0.1
Winter resistance	0.185 ± 0.305	0.61	>0.1
Brood viability	0.599 ± 0.203	2.95	<0.01
Disease resistance	0.256 ± 0.295	0.87	<0.1
Honey production	-0.397 ± 0.266	1.49	>0.1
November precipitation			
Queens prolificacy	0.307 ± 0.286	1.07	>0.1
Family power	0.325 ± 0.283	1.15	>0.1
Winter resistance	-0.059 ± 0.315	0.19	>0.1
Brood viability	0.385 ± 0.269	1.43	>0.1
Disease resistance	-0.221 ± 0.301	0.73	>0.1
Honey production	0.599 ± 0.203	2.95	<0.01
December precipitation			
Queens prolificacy	0.304 ± 0.287	1.06	>0.1
Family power	0.571 ± 0.215	2.68	<0.05
Winter resistance	0.119 ± 0.311	0.38	>0.1
Brood viability	-0.111 ± 0.312	0.35	>0.1
Disease resistance	0.041 ± 0.316	0.13	>0.1
Honey production	-0.065 ± 0.315	0.21	>0.1
Annual total precipitation			
Queens prolificacy	0.380 ± 0.270	1.41	>0.1
Family power	0.414 ± 0.262	1.58	>0.1
Winter resistance	0.084 ± 0.315	0.27	>0.1
Brood viability	0.165 ± 0.308	0.53	>0.1
Disease resistance	0.560 ± 0.217	2.58	<0.05
Honey production	0.286 ± 0.290	0.99	>0.1

The Pearson's linear correlation coefficient between the quantity of atmospheric precipitation in August and the disease resistance of bee families in the following year is positive above average, with the significance of threshold one according to the probability theory of prognoses without error according to Student (r_{xy} = 0.565 ± 0.215; t_r = 2.63; P<0.05).

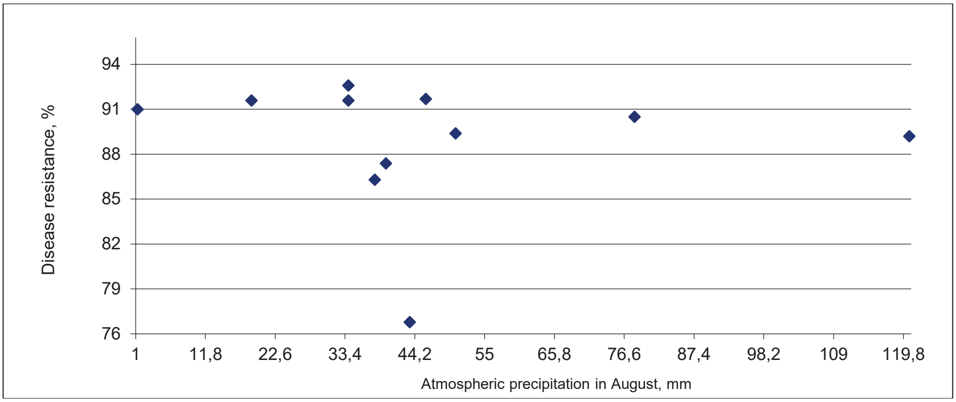

Figure 7. Point correlation between August atmospheric precipitation and disease resistance

Atmospheric precipitation in September tends to have a positive influence on most of the morpho-productive characters of bee colonies in the following year. The positive impact of atmospheric precipitation in September manifests itself significantly on honey production (Figure 8).

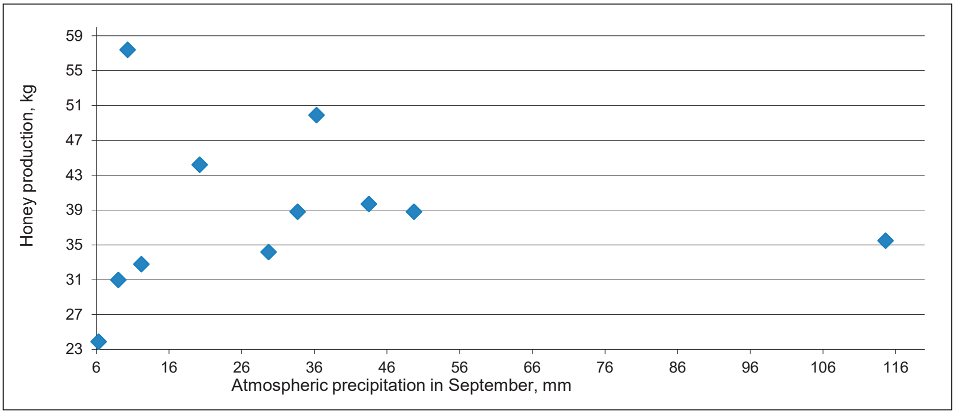

Figure 8. Point correlation between atmospheric precipitation in September and next year's honey production

Thus, Pearson's linear correlation coefficient between the quantity of atmospheric precipitation in September and the honey production of the bee colonies in the following year is obviously high-level positive, with the significance of the third threshold according to Student's theory of the probability of forecasts without error (r_{xy} = 0.711 ± 0.156; t_r = 4.56; P<0.001).

According to us, this influence is indirect and is explained by the fact that the atmospheric precipitation in September favors the process of plant sap circulation, ensuring the successful wintering of honey plants and the production of a considerable quantity of nectar in spring honey flowers.

Atmospheric precipitation in October has a tendency to have a positive indirect influence on most of the morpho-productive characters of bee families in the next year.

In particular, the positive influence is significantly manifested on the viability of the brood. Pearson's linear correlation coefficient between the quantity of atmospheric precipitation in October and the viability of the brood of bee colonies in the year next is above-average level positive, with threshold two significance according to Student's error-free prediction probability theory (r_{xy} = 0.599 ± 0.203; t_r = 2.95; P<0.01).

Atmospheric precipitation in November also tends to have a positive indirect influence on most of the morpho-productive characters of bee colonies in the next year. In particular, the trend of positive influence is more evident on queen prolificacy, bee colony strength and brood viability. Moreover, atmospheric precipitation in November has a significant positive influence on honey production the following year (Figure 9).

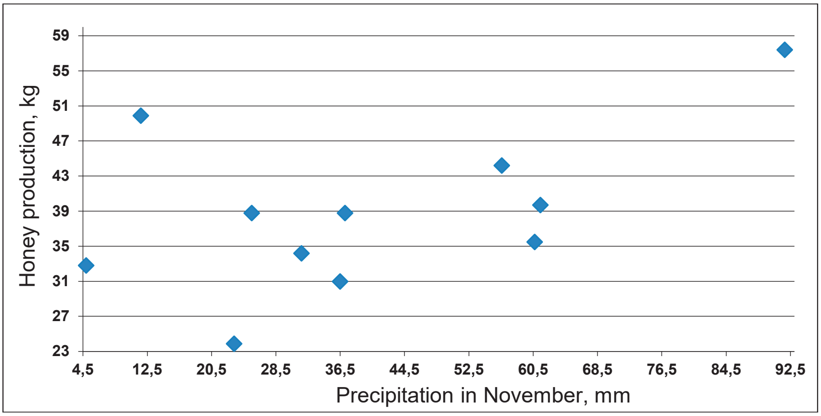

Figure 9. Point correlation between atmospheric precipitation in November and next year's honey production

The Pearson's linear correlation coefficient between the quantity of atmospheric precipitation in November and the honey production of bee colonies in the following year is obviously positive above the average level, with the significance of the second threshold according to the probability theory of Student's error-free forecasts (r_{xy} = 0.599 ± 0.203; t_r = 2.95; P<0.01).

Atmospheric precipitation in December also tends to have a positive indirect influence on most of the morpho-productive characters of bee families in the next year. In particular, the trend of positive influence is more evident on the prolificacy of queens, the strength of the bee colony and the resistance to wintering. Through this, the positive impact of atmospheric precipitation in December is significantly manifested on the strength of bee families. Thus, Pearson's linear correlation coefficient between the quantity of atmospheric precipitation in December and the strength of bee colonies in the following year is obviously positive above average level, with the significance of threshold one according to Student's probability theory of forecasts without error (r_{xy} = 0.571 ± 0.213; t_r = 2.68; P<0.05).

Generalizing the results of the research of climatic changes of atmospheric precipitation on the vital activity of bee families, we can conclude that the total annual quantity of atmospheric precipitation has a tendency to have a positive influence on the main morpho-productive characters, such as: the prolificacy of queens, the strength of the bee colony, brood viability, disease resistance and honey production. In particular, the positive impact of annual atmospheric precipitation is manifested on the resistance of bee families to diseases (Figure 10).

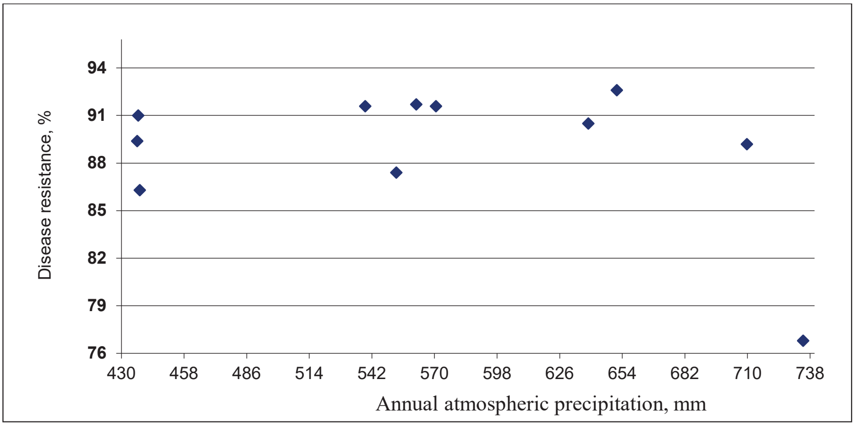

Figure 10. Point correlation between annual atmospheric precipitation and disease resistance of bee families the following year

Thus, the Pearson's linear correlation coefficient between the total annual quantity of atmospheric precipitation and the disease resistance of the bee colonies in the following year is significantly positive above average level, with the significance of the threshold of one according to the probability theory of Student's error-free forecasts (r_{xy} = 0.560 ± 0.217; t_r = 2.58; P<0.05). According to us, atmospheric precipitation, having a general positive impact on honey flora, contributes to the quantitative and qualitative increase of nectar-pollen resources and the strengthening of the immune system of bees, expressed by increasing the resistance of bee colonies to diseases.

CONCLUSIONS

The resistance of bee families to wintering has an obvious tendency to be positively influenced by atmospheric precipitation in March (r_{xy} = 0.461 ± 0.237; t_r = 1.95; P<0.1).

The prolificacy of the queens is negatively influenced by atmospheric precipitation in June (r_{xy} = -0.582 ± 0.199; t_r = 2.92; P<0.01) and positively by atmospheric precipitation in July (r_{xy} = 0.579 ± 0.200; t_r = 2.89; P<0.01).

The strength of bee colonies is positively influenced by atmospheric precipitation in December of the previous year (r_{xy} = 0.571 ± 0.213; t_r = 2.68; P<0.05), as well the ones in March (r_{xy} = 0.561 ± 0.206; t_r = 2.72; P<0.05) and July (r_{xy} = 0.482 ± 0.231; t_r = 2.09; P<0.05) of the current year.

The viability of the bee brood is negatively influenced by atmospheric precipitation in the months of January (r_{xy} = -0.469 ± 0.235; t_r = 2.00; P<0.05) and May (r_{xy} = -0.577 ± 0.201; t_r = 2.87; P<0.01) of the current year, and positive - by the atmospheric precipitation in March of the current year (r_{xy} = 0.504 ± 0.225; t_r = 2.24; P<0.05) and October of the previous year (r_{xy} = 0.599 ± 0.203; t_r = 2.95; P<0.01).

Disease resistance of bee families is influenced negatively - by atmospheric precipitation in January of the current year (r_{xy} = -0.497 ± 0.227; t_r = 2.19; P<0.05) and positively - by atmospheric precipitation in August of the previous year (r_{xy} = 0.565 ± 0.215; t_r = 2.63; P<0.05), as well as the annual atmospheric precipitation of the previous year (r_{xy} = 0.560 ± 0.217; t_r = 2.58; P<0.05).

Honey production of bee families is positively influenced - by atmospheric precipitation in the months of September (r_{xy} = 0.711 ± 0.156; t_r = 4.56; P<0.001), November (r_{xy} = 0.599 ± 0.203; t_r = 2.95; P<0.01) and annual totals (r_{xy} = 0.560 ± 0.217; t_r = 2.58; P<0.05) of the previous year, and negatively - by atmospheric precipitation in February (r_{xy} = -0.706 ± 0.151; t_r = 4.68; P<0.001) and June (r_{xy} = -0.511 ± 0.223; t_r = 2.29; P<0.05) of the current year.

ASKNOWLEDGEMENTS

This work was carried out as part of the Fundamental Scientific Research Project of the Institute of Zoology within the State Program (2020-2023) - Code 20.80009.7007.12

"Diversity of hematophagous arthropods, zoo and phytohelminths, vulnerability, strategies to tolerate climatic factors and the development of innovative procedures for the integrated control of species of socio-economic interest".

REFERENCES

Arnbjerg-Nielsen, K. (2012). Quantification of climate change effects on extreme precipitation used for high resolution hydrologic design. *Urban Water Journal*, 9 (2), 57-65, doi: 10.1080/ 1573062X. 2011.630091.

Barbu, I., & Popa, I. (2011). Monitoring the risk of drought in Romanian forests. *Bucovina Forestieră*, IX (1-2), 37-51.

Bee Decline (2013). Greenpeace Research Labs Technical Report, 48 p. http://www.greenpeace. org.

Birsan, M.V., & Dumitrescu, A. (2014). Snow variability in Romania in connection to large-scale atmospheric circulation. *International Journal of Climatology*, 34, 134-144. doi: 10.1002/joc.3671.

Bojariu, O. et al. (2015). *Climate change – from physical bases to risks and adaptation*. Bucharest, RO: Printech Publishing House.

Busuioc, A., Giorgi, F., Bi, X., & Ionita, M. (2006). Comparison of regional climate model and statistical downscaling simulations of different winter precipitation change scenarios over Romania. *Theor. Appl. Climatol.*, 86, 101−124.

Busuioc, A., Storch, H., & Schnur, R. (1999). Verification of GCM generated regional seasonal precipitation for current climate and of statistical downscaling estimates under changing climate conditions. *J. Clim*., 12, 258−272.

Causes of climate change (2018). https://ec.europa.eu/ clima/ change/causes_ro

Cebotari, V., & Buzu I. (2010). Zootechnical norms regarding the honeybee colonies evaluation, breeding and certification of genetic material in beekeeping. *Contemporary Science Association. Proceedings of the 1st International Animal Health Science Conference: The Beekeeping Conference*, Addleton Academic Publishers, New York, Library of Congress Control Number, p. 26-30.

Cebotari, V., Buzu, I., & Postolachi, O. (2019). Impact of climate cange of air temperature on vital activity of the bee families. *Scientific papers. Series D. Animal Science*, LXII(1), 249-255.

Cebotari, V., Buzu, I., Postolachi, O. et al. (2013). Impact of drought morpho-productive features of Apis mellifera Carpatica bee colonies. *Scientific Papers. Animal Science*, 60(18), 155-159.

Climate change, impacts and vulnerability in Europe (2012). EEA (European Environment Agency), Report 12/2012. http://www.eea.europa.eu.

Consequences of climate change (2018). https://ec.europa. eu/ clima/change/consequences_ro.

Econews Infomediu Europe (2018). http:// www.infomediu. eu/eco-news/9059.

Kremen, C., Williams, N., Aizen, M. et al. (2007). Pollination and other ecosystem services produced by mobile organisms: a conceptual framework for the effects of land-use change. *Ecology Letters*, 10, 299-314.

Marin, L., Birsan, M.V., Bojariu, R., Dumitrescu, A., Micu, D.M., & Manea, A. (2014). An overview of annual climatic changes in Romania: trends in air temperature, precipitation, sunshine hours, cloud cover, relative humidity and wind speed during the 1961–2013 period. *Carpath. J. Earth. Env*., 9(4), 253-258.

Memmott, J., Craze, P., Waser, N. et al. (2007). Global waming and the disruption of plant-pollinator interactions. *Ecology Letters*, 10, 710-717.

Paris Agreement – United Nations Framework Convention on Climate Change (2016). https://eur-lex.europa.eu/ content/paris-agreement/ htlm? locale=ro.

Plokhinsky, N.A. (1989). A Guide to Biometrics for Animal Scientists. Moscow, RU: Kolos Publishing House, 256 p. [in Russian]

Sandu, I., Mateescu, E., & Vătămanu, V.V. (2010). *Climate changes in Romania and the effects on agriculture*. Craiova, RO: Sitech Publishing House.

Small increase in EU total gas emissions in 2017, with transport emissions up for the fourth consecutive year (2019). Annual European Union greenhouse gas inventory 1990-2017 and inventory report 2019. https://www.eea.europa.eu./highlights/small-increase-in-eus-total-ghg.

SSC - Report on the state of the environment (2009). https://www.anpm.ro/anpm_resources/migrated content/uploads.

Statistical Yearbook of Moldova 2016-2020 (2021). www.statistica. gov. md/ pageview. php.

Stefan, S., Ghioca, M., Rimbu, N., & Boroneant, C. (2004). Study of meteorological and hydrological drought in southern Romania from observational data. *Int. J. Climatol*., 24, 871−881.

Stefanescu, V., Stefan, S., & Georgescu, F. (2014). Spatial distribution of heavy precipitation in Romania between 1980 and 2009. *Meteorol. Appl*., 21, 684-694. doi:10.1002/met.1391.

The national program (2020) for the development of beekeeping in the Republic of Moldova for the years 2021-2025, approved by the Decision of the Government of the Republic of Moldova no. 768/2020. *Monitorul Oficial* nr. 293-303, art. 933.

Themes biodiversity (2017). https:// www.eea.europa.eu/ ro/themes/ biodiversity.

Tomozeiu, R., Stefan, S., & Busuioc, A. (2007). Spatial and temporal variability of the winter precipitation in Romania in connection with the large-scale circulation patterns. *Theoretical and Applied Climatology*, 81, 193-201. doi: 10.1007/ s00704-004-0082-3.

Zootechnical norm (2011) regarding the certification of bee families, the raising and certification of beekeeping broodstock approved by Government Decision no. 306 of 28.04.2011. *M.O. of MD* nr. 78-81 of 13.05.2011, art. 366).