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Agrometeorological research and its results in Hungary (1870–2010)

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Abstract—Agrometeorology is the branch of atmospheric sciences. Lately, modern agrometeorology has been based on exact principles and its findings are of interdisciplinary nature. The focal questions of agrometeorology are determined by the climate of large regions; therefore, its material division is specified by the local nature of the climate system and its methods are systematized by macro- and micrometeorology. Agrometeorology can be regarded as a group of determinant aspects of economic decisions. This publication summarizes the 150 years of development of agrometeorology in Hungary.

Key-words: history of agriculture in Hungary, agrometeorology, climatology, agroclimatology, productivity, weather sensitivity, hazards, water supply of crop canopy, evaporation, production, fertility, actual and potential production

1. Introduction

The ancient cultures had been continuously extending due to the knowledge created by the accumulation of observations. The specialization of this knowledge base created the fundamentals of specialized sciences as a result of the integration of sciences. Of these, the production activity dealing with the issues of human nourishment was developed, as well as the range of consumers which stems from human needs and these two were equally regulated by the climatic endowments of the environment whose risky significance has a global effect even nowadays. Through the centuries, agricultural production and social consumption, as well as the risk range of these two got into an increasingly close connection with each other which resulted in the forceful development of interests of connections towards each other and the deepening of these interests. During the modernization of agriculture, the climatic risk has been continuously increasing with the development of the consumer society. As a result, an increasingly complex connection has been developed between the agriculture and the climatic environment. The research area of agrometeorology arose from this field, as agrometeorology is meant to explain the causal chain of the biological consequences triggered by the physical effects of the atmosphere with the consideration of the causal order. It follows from this statement that the database of agrometeorology and the nature of its treatment methods is such a partial complex of the meteorological bases that concludes to the physical explanation and consequences of the effects elicited by the atmosphere.

2. Preliminaries of agrometeorological research in Hungary (1850-1950)

Temperate zone modern agriculture roots back into the 13th–16th century in England and the Netherlands. By this time, the history-forming period of great European migrations was over and a seemingly more permanent agriculture unfolded which rooted in the ancient fundamentals and which also provided the basis for modern agriculture that developed in the subsequent centuries. In the centuries after the millennium, there was no agriculture in a sense of that is called agriculture today. The increased population in the mentioned areas demanded an extremely intensive grazing animal husbandry whose environmental conditions were mainly provided by the favorable climatic endowments. This development resulted in severe natural consequences and they are regarded as the first revolution of agriculture in history. As a result of the heavy use, soils gradually lost their fertility. The soil degradation caused by soil use strongly deteriorated the ecological balance (*Overton* and *Campbell*, 1996; *Allen*, 1999; *Campbell*, 2010). The dilemma of losing the ecological balance resulted in an episode of developing agriculture which was regarded as an imperative condition in relation to the elimination of the crisis. Following the abolition of the aggravating circumstances, a more modern agriculture was developed in a few centuries, involving closed-loop animal husbandry, while crop rotations also became widely used and various methods of cultivation were also becoming increasingly widespread. This modernization became a general characteristic of agriculture inside the continent in a few centuries.

By the middle of the second millennium and the subsequent centuries, the production techniques applied for various climatic characteristics penetrated the Carpathian Basin. The production of western European, relatively more water demanding crops increased, the problems of water management regularly causing mediterranean droughts in the summer became more frequent, new plant species and varieties appeared, and these all contributed to the modernization of the Hungarian agriculture.

The region of Central European agriculture was the meeting point of the effects coming from these three directions, and the simultaneous benefits and complexity could be detected in the history of the past of Hungarian agriculture. *Fig. 1* shows the direction of the peculiarities characterizing the agriculture which evolved as a result of the mentioned climatic effects and the various large territorial differences.

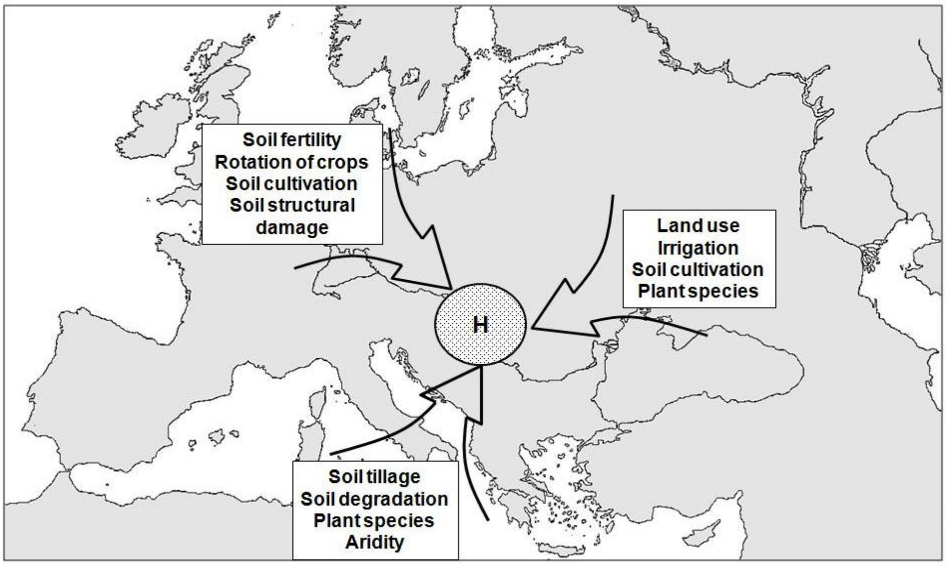


Fig. 1. Development dynamics of modern agriculture in Central Europe (1200-1600)

The conservative layer which is not adjusted to the given climate was struck by the extending cropping area of *newly produced plants* and the lack of *professional knowledge*. Simultaneously with the increasing change and modernization of the production structure, the processing industry was forcibly developed, resulting in what is called technical development.

The growth of agricultural production of this period was characterized by a less powerful prosperity and issues, in which the strong consequences of climatic effects were obvious developed and the dependence on these effects was also necessary. Since agriculture was based solely on natural resources at this time, the various soil characteristics and the consequence of the correlation between climate and soil also had an essential role in addition to climatic factors. The differences in the environment of the areas of the Carpathian Basin which are suitable for agricultural production played a very important role not only in the climate, but also in the soil characteristics. This role provided the basis for getting to know the empirical correlations and phenomena of subsequent agrometeorological knowledge.

There was limited receptiveness concerning development opportunities in the 18th century, mainly due to the social structure. The elements of production modernization were created almost only by the so-called allodial plot system. The smaller feudal farms represented the less favored social class.

In the 19th century, natural sciences developed sharply, resulting in the further intensification of agriculture. As a result of the increasing demand for new knowledge in the 1800s, agricultural higher education institutions were established which prepared professionals who constituted the intellectual basis of development. These were the institutions (Keszthely 1797, Magyaróvár 1850, Debrecen 1867) where agricultural climatology evolved in Hungary, as "Climatology" was an obligatory subject in the education program. Also, the outstanding teachers of these institutions provided the intellectual basis that was able to accept various forms of modernization. Simultaneously with the scientific basic education, field experiments were launched in a relatively narrow framework. In these trials, the determinant role of climatic effects which regulate yield were of chief importance in addition to cultivation and nutrient management. These issues necessitated the increasing range of research complexity.

The establishment of the National Meteorological and Earth Magnetic Science Institute (1870) was a significant event. Within this institution, an agrometeorological department was also established in addition to the more special data and knowledge collection activities, although it stopped working in the subsequent decades. The station network of the former meteorological institute published climatic data in various forms still used by educated agriculturalists and researchers with significant efficiency. The so-called agricultural experimental stations were also established in this period. In these stations, the climatic information was of significant scientific value.

Mention has to be made of the results of technical development launched in the second half of the 1800s. During the targeted planning processes, this development always considered the climatic parameters that provide information to build various constructions. Last but not least, it has to be noted that agrometeorology is a field of climatology which makes it possible to consider the efficiency of an agricultural technological system. From this viewpoint, Hungarian agrometeorological research left room for development for the succeeding generations.

In the first half of the 1900s, the agricultural use of meteorological information significantly served the research of climatic examination results which cannot be missing from agricultural development. Therefore, the publication of the standard time series of various weather elements was of primary importance. Based on these results, it was possible to launch agroclimatological research subsequently (*Smith*, 1915; *Cserháti*, 1905; *Gyárfás*, 1922; *Kreybig*, 1953; *Boncz*, 1992; *Nyíri*, 1993; *Kemenessy*, 1964; *Birkás*, 2006; *Györffy*, 1990).

The increasing development resulted in a production increase that created the basis of the economic crisis by the first half of the 1800s. As a result, the evaluation and thorough research of climatic effects was done rather slowly. In this period, the main tasks of the National Meteorological Institute were the gradual extension of climatic data collection, the improvement of its system, their collection in a few decades, the publication of the several year averages of the main elements, as well as the performance of technically limited forecasts.

The activity of the institute resulted in the simple information basis on which agrometeorology was built up.

In this period, no specific agrometeorological research was launched, but some researchers were already dealing with climate effect issues that affect agriculture, mainly with the aim to determine the extent of climate damages. The observation series performed between 1901–1930 made it possible to estimate the climate effects based on several decades, but these data were still mainly in connection with climatic extremities, and no more detailed statistical analysis was performed. The basis of examinations was the determination of the climatic differences between low and high yields concerning not more than a few smaller regions. In the subsequent decades of the millennium, there were yield series which provided an opportunity to analyze and explain the fluctuation of yields due to climatic reasons.

The reason for the late launching of agrometeorological research was not the lack of interest, but the simultaneous lack of knowledge about crop production and climate, although this issue arose as a problem independent of historical influences in an agriculturally significant country.

In the first decades of the 1900s, the preparation for war, the difficult economic circumstances caused by the First and Second World Wars, and the subsequent social change did not make it possible to further improve the related research. Despite the fact that the already traditional climatic observations coupled with the poor and significantly mutilated education system became incapable of functioning, tasks driven by new goals and the launching of these tasks became necessary.

3. Expansion of agrometeorological research (1950-2010)

In Hungary, the economic change after the Second World War took nearly ten years. The new fundamentals of the agricultural area and the change of farming methods root back to 1960. Also, this period marks the beginning of the modernization of agriculture. The reorganization of crop production was started, mainly by the replacement of crop species, partially the increasing use of *fertilizers* due to the lack of organic manure and further improvement of soil fertility. Within the *more modern agriculture*, the sensitivity to weather increased in crop production, also resulting in the growing production risk. This large change increased the demand for climatological information. This need was expressed in numerous forms, several different agricultural service research institutes were formed, some of which also performing various meteorological observations, measurements, and research activities that served agriculture directly (see later).

The manifold development elicited the fundamental change of the *agroecological approach* and a change of direction: research built on various natural science bases was becoming wider and the integrated system of knowledge was also extending. In the initial phase of development, the opportunities of intervention were gradually increasing with the extension of technological elements, but the long-term consequences of the interventions, their mechanisms, and the correlations of these remained unknown for the most part. Practically, the complex representation and mapping of the dynamics which can be observed in the field could not be done. The main question was posed: what could be the most important new method and system which can help in directly exploring the efficiency of interventions? It could be regarded as a historical point when the idea of launching complex *long-term experiments* was conceived.

The examinations covered not only the plant, but also the environmental factors which directly or indirectly affect the vital functions of the plant. These examinations are mainly built on biological, chemical, and physical rules. Only a narrow range of empirical methods can be observed in the basic concept of these examinations. Instead, the system of parameters which can be described in an exact way by explaining the causal conditions became more extended.

The agroecological systems have a specific energy and material flow. The factors governing the whole system are

- created by humans,
- driven by solar energy,
- maintained by the energy and material source and of the environment, as well as its flow,
- regulated by humans.

Therefore, the aim of natural science examinations is not to question the correctness of observations, but to get to know and describe exactly the assumed consequence. The dynamic approach built on the principle of causality lays the main emphasis on the importance of getting to know the processes. While the static approach is condition-focused, the dynamic approach focuses on the process. In addition to climate, soil can also be regarded as an environmental factor, although its characteristics are totally different than those of the atmosphere. Still, its conditions can greatly vary between crop years and the reason of this phenomenon is partly the climate effects, but also the use and effect of technological factors which are adjusted to the climatic conditions, too. Therefore, the effect of climate affects the physical condition of the air space close to the surface, and it has an indirect and altering effect through the soil as well. By doing so, the air, soil, and plants form a specific system in a physical sense, which is basically an ecological system of the nature (*Szász*, 1987; *Petrasovits* and *Balogh*, 1974).

The process-focused analysis of each question of modern crop production can only be performed if their basis is constituted by a scientific information system in which the criteria that meet the hierarchic principles are strictly met. This new approach set an ideal aim to perform the integrity role of cooperating branches of science; therefore, to be a cooperating research partner of meteorological research (*Monteith*, 1975; *Várallyay*, 2008).

As a matter of course, the development of the approach of agrometeorology cannot neglect climatological and meteorological measurements and the development of a database derived from their data, on which the narrowly interpreted agrometeorology is built. In other words, no agrometeorological examinations can be performed without climatological bases, since these areas of science systematize the effects which act on agriculture over time, and agrometeorology works out the explanation of the responses to these effects. Therefore, this is the reason why the main activity of agrometeorology cannot be observed without knowing the climatic examination of the country which is described by the section about the main characteristics of the climate of Hungary (*Várallyay et al*., 1980).

4. *Climatic description of the flat regions of the Carpathian Basin*

The climatological information on which agrometeorological examinations are built could be summarized as follows. It has to be emphasized that these data mainly refer to the relatively flat areas where the widely interpreted crop production has been carried out for centuries.

4.1. Radiation

The measurement of the energy of radiation was started after the 1900s, instruments were used to perform these measurements only on a few stations guided by the National Meteorological and Earth Magnetic Science Institute (OMFI) in the 1930s. Simultaneously with the network measurements, statistical analyses were also performed with the aim to determine the correlation between the measured sunshine duration and the daily duration of relative radiation. The aim was to get to know the average regional distribution of the radiation energy calculated on the basis of the sunshine duration measurements performed at 30-40 stations. In the 1950s, based on the research done by *Dobosi* and *Takács* (1959), the radiation balance could be determined on the basis of calculation. The first measurements aimed at determining the radiation balance were launched by the OMFI and the Agrometeorological Observatory of the former Agricultural Academy of Debrecen, which carried out regular measurements and energy flow examinations.

Radiation measurements were integrated into micrometeorological measurement programs (Berényi-Hesse, Hortobágy, 1962, OMFI-Balaton program 1958-1962, etc.), while some radiation measurements were carried out on demand at various agricultural research institutes (crop production, horticultural, agroecological research programs at Matronvásár MTA, University of Gödöllő, Debrecen, Keszthely, Szarvas, etc.)

The first step towards working out the method of estimating the photosynthetic proportion of radiation in Hungary was made by *Felméry* (1974).

By the millennium, the database of agrometeorological research needs was provided by a network which consisted of around 40 stations. This network helped to establish the research school whose leaders (*Takács*, 1972; *Dobosi*, 1972; *Major*, 1985) laid down the basis of the research and analysis of radiation measurements in Hungary. Furthermore, this network also provided other research locations (universities, research institutes, around 10 stations) with radiation data.

Based on the published measurement results related to the radiation energy supply of the agricultural area and the collected and organized measurements of the components of radiation flow, it can be stated that the energy supply of the Carpathian Basin significantly exceeds that of the agricultural areas at the same latitude.

Radiation is a meteorological element with two components, as the duration of radiation which is generally characterized by sunshine duration and the characteristics of the temporal and spatial features of radiation energy can be used both in theoretical and practical terms.

The temporal and spatial values of *sunshine duration* can be determined on the basis of the following important information:

– astronomic sunshine duration,
– temporal and spatial distribution of the quantity of radiation energy.

The *astronomic sunshine duration* is determined by the position of the Sun and the Earth to each other, and its value is referred to the solid angle of 180° if expressed in hours. The published possible sunshine duration values refer to the latitudinal degree of the country, whose monthly values are summarized in *Table 1*. The extreme values of the yearly solar cycle of the potential sunshine duration refer to the lowest and highest sun height days, expressed in hours/month and hours/day. The monthly and yearly sums (in geographical terms) of the potential sunshine duration slightly differ from each other due to the small range of the related surface. The yearly average sum of the potential sunshine duration is 4450 hours. The daily, monthly, and yearly sums of the actual sunshine duration are determined by geographical and climatological factors, of which the most important are the relief (due to the difference in the reference solid angle) and the clouds (due to climatological reasons). The monthly sums of the potential sunshine duration are shown in *Table 1*, where the actual monthly sunshine duration values are expressed in hours.

Despite the relatively small area of the country, there are average differences in the regional distribution of the sunshine duration mainly due to climatic reasons (clouds, fog). The regional difference of the average yearly sums exceeds 350 hours annually even in flat areas. According to the detailed examinations of *Takács*, the lowest yearly sums develop around the western and southwestern bordering areas of the Transdanubian region, where the yearly sum does not exceed 1700 hours. The area which is the richest in sunshine is the southern Danube-Tisza mid-region and the southern areas of the Trans-Tisza region, whose regional proportion is shown in *Fig. 2*.

Table 1. Monthly actual, possible and relative sunshine duration in Hungary

Month	**Actual**	**Possible**	**Relative**
	Sunshine duration		
Januar	2.0	8.9	0.22
February	3.0	10.2	0.29
March	4.5	11.8	0.38
April	6.1	13.5	0.45
May	7.8	15.0	0.52
Juny	8.5	15.7	0.54
July	9.2	15.4	0.60
August	8.5	14.2	0.60
September	6.4	12.6	0.51
October	4.3	10.9	0.39
November	2.3	9.3	0.25
December	1.5	8.3	0.18

Based on the research done by *Takács* and *Major*, as well as *Dobosi*, the temporal and spatial distribution of global solar radiation was processed by *Dávid et al.,* (1990), using the data of the period between 1951–1980 (*Distribution of the radiation balance in Hungary based on the data between 1951-1980, 1990.*). This work gives information concerning the monthly energy sums of the global radiation related to 44 polygons of the country, as well as the average values which determine the radiation balance.

4.2. Temperature

Air temperature values determined in accordance with climatological averages provide a wide range of information and they are published to a detailed extent. The agricultural consequences of the variability of temperature are commonly known. Nevertheless, the response reactions of the effect of different variability cannot be neglected either, as the reactive heat demand of the plants are constantly changing. It is one of the tasks of the modernization of agroecological research to analyze the climate sensitivity of various culture plants. While the determination of optimal heat demand was in focus in the past decades, manifold consequences of the effects of tolerance to extremities and heat stress had to be taken into consideration in the recent decades. The system of related agrometeorological knowledge is still incomplete. The traditional methods of temperature observations and the demand-focused information system of agriculture only partially satisfy this need (*Bacsó*, 1952, 1959).

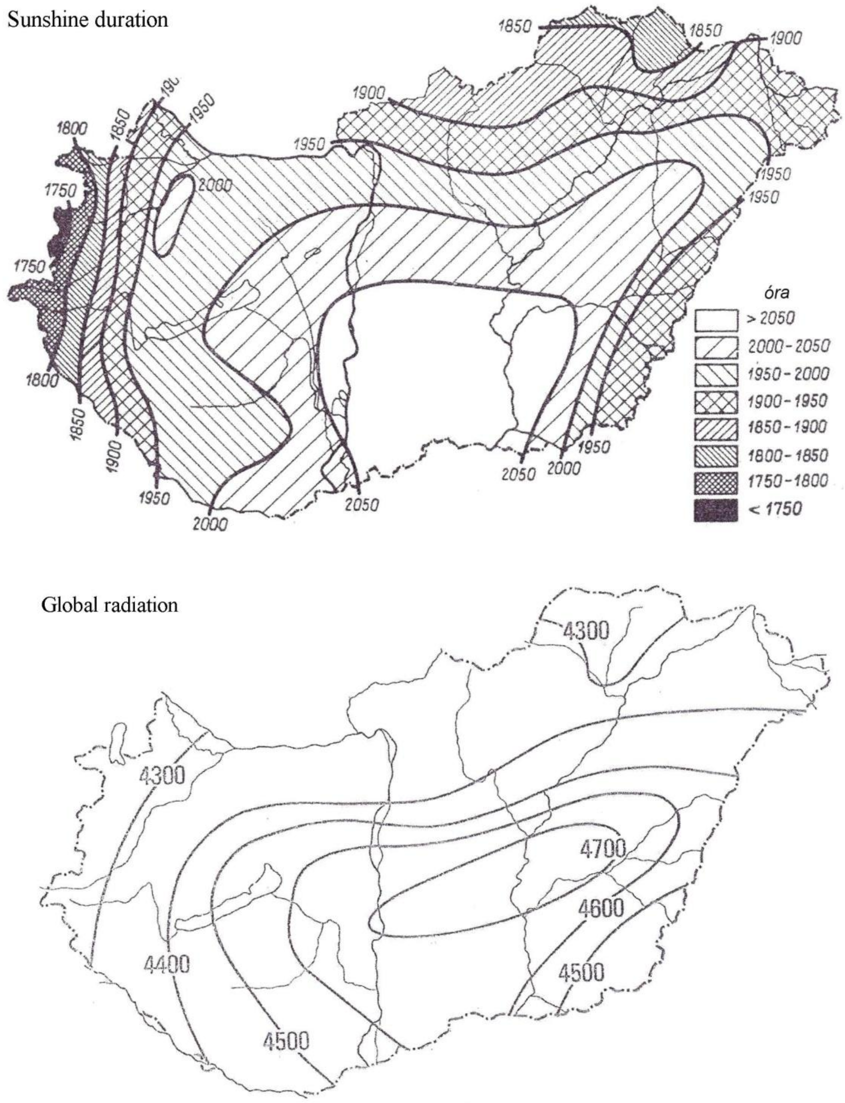


Fig. 2. Annual average of sunshine duration and the sum of global radiation (MJ m^{-2} $year^{-1}$) in Hungary (*Takács*, 1972; *Major*, 1985).

The agroclimatological characterization of temperature could be summarized on the basis of means, standard deviations, and the coefficient of variance. *Table 1* shows monthly mean temperatures of 100 years and the related statistical parameters of the 5 stations. Based on the multiple year mean values of this table, significant difference is shown between the various areas of the country. The yearly mean temperature is between 9–11 °C in Hungary. The yearly fluctuation is characterized by the difference between the mean temperature in July and January, and the extent of fluctuation continuously decreases from eastern Hungary to the west, whose value is around 20–21 °C. Typically, the interim seasons are long from agricultural aspect and this phenomenon lengthens the vegetation period (*Aujeszky et al*., 1951).

The 50–50 and 100-year monthly mean values shown in *Table 2* are rather close to each other, but it can only partially be accepted in view of the standard deviation values; therefore, longer periods need to be considered in order to determine the statistical probability of the variability. Nevertheless, these differences are significant from climate statistical aspect, and they do not have any fundamental importance from the viewpoint of agroclimatology. The referred values clearly show the great variability of the winter period. The lowest variability evolves in the second part of summer ($s < 1.5$). This statistical parameter is further increasing in the spring and autumn months ($s = 1.5$–2.5), which is then finally expressed in the value of coefficient variability (CV) (*Szász*, 1981, 2005).

In field crop production, the cumulated sum of daily mean temperature values is frequently used. This topic cannot be dealt with in detail in this study, since these values represent environmental physical effect and consequence for plants which have different heat demand.

The most perfect and detailed information about the variability of temperature and the probability of its values are provided by the distribution analyses. No such analyzed research results are available from agrometeorological measurements. In order to fill this gap, *Fig. 3* shows the distributions based on daily observations of 100 years in Debrecen, showing the daily mean temperature. The distribution curves of the three summer months make it possible to gain information mainly on the probability of the extremely high or low value ranges which cannot be related to any given day, but they serve the purpose of getting to know the lower and upper limits of the tolerance of plants' needs (*Fig. 4*).

The daily fluctuation of air temperature has a practical significance in agriculture, the extent of its value is shown below:

Season	**Winter**	**Spring**	**Summer**	**Autumn**
Daily average range (°C)	4,2–7,5	7.5–13.0	11.0–14.0	5.0–13.0

The minimum and maximum values of the daily fluctuations can cause irreversible damages to various extents. In the interim seasons, the critical extreme temperature is the minimum value, while it is the maximum value that could cause stress in the summer from the aspect of the heat demand of plants (*Kakas*, 1960).

Table 2. Monthly means, standard deviation, and coefficient variation of temperature (1901–1950, 1951–2000)

Mean temperature (°C)														
Station		**I.**	**II.**	**III.**	**IV.**	**V.**	**VI.**	**VII.**	**VIII.**	**IX.**	**X.**	**XI.**	**XII.**	**Year**
Zalaegerszeg	1901–1950	–1.2	0.7	5.8	10.8	15.8	18.9	20.9	19.9	15.8	10.4	5.0	1.0	10.3
	1951–2000	–1.2	0.7	4.9	9.9	14.6	18.0	19.5	19.1	15.2	9.9	4.6	0.4	9.6
Magyaróvár	1901–1950	–1.4	0.7	5.1	10.2	15.4	18.4	20.3	19.4	15.6	10.1	4.6	0.7	9.9
	1951–2000	–1.2	0.7	5.0	10.3	15.2	18.4	20.1	19.5	15.4	10.1	4.6	0.7	9.9
Túrkeve	1901–1950	–2.3	–0.3	5.3	10.9	16.6	19.7	22.0	21.1	16.7	10.8	4.8	0.3	10.5
	1951–2000	–1.8	0.4	5.3	11.1	16.4	19.9	21.6	21.1	16.7	10.9	4.9	0.5	10.6
Szeged	1901–1950	–1.0	0.8	6.5	11.7	17.2	20.4	22.7	21.7	17.7	12.1	6.1	1.6	11.5
	1951–2000	–1.3	0.8	5.4	11.1	16.2	19.6	21.2	20.8	16.6	11.0	5.2	0.8	10.6
Debrecen	1901–1950	–2.3	–0.5	4.9	10.8	16.4	19.5	21.5	20.5	16.1	10.4	4.7	0.3	10.2
	1951–2000	–2.1	0.0	4.9	10.7	15.9	19.1	20.8	20.2	16.0	10.5	4.7	0.1	10.1
Standard deviation (S)														
Station		**I.**	**II.**	**III.**	**IV.**	**V.**	**VI.**	**VII.**	**VIII.**	**IX.**	**X.**	**XI.**	**XII.**	
Zalaegerszeg	1901–1950	3.2	3.5	2.4	1.8	1.7	1.4	1.5	1.3	1.4	1.6	2.0	2.3	
	1951–2000	2.6	2.7	2.2	1.6	1.6	1.3	1.5	1.6	1.5	1.6	1.9	1.8	
Magyaróvár	1901–1950	3.1	3.4	2.2	1.7	1.7	1.5	1.2	1.2	1.5	1.6	1.9	2.3	
	1951–2000	2.7	2.6	2.2	1.4	1.6	1.4	1.4	1.5	1.5	1.7	1.8	1.8	
Túrkeve	1901–1950	3.5	3.4	2.3	1.9	1.8	1.4	1.3	1.5	1.6	1.8	2.2	2.6	
	1951–2000	2.7	3.0	2.4	1.6	1.6	1.4	1.4	1.7	1.7	1.5	2.0	2.3	
Szeged	1901–1950	3.5	3.5	2.5	1.9	1.8	1.5	1.5	1.7	1.7	1.7	2.0	2.5	
	1951–2000	2.6	3.0	2.2	1.6	1.5	1.3	1.4	1.5	1.6	1.6	2.1	2.3	
Debrecen	1901–1950	3.4	3.2	2.3	2.0	1.8	1.5	1.2	1.4	1.6	1.8	2.2	2.5	
	1951–2000	2.7	2.9	2.3	1.6	1.6	1.3	1.3	1.5	1.6	1.4	2.0	2.3	
Coefficient of variation (CV)														
Station		**I.**	**II.**	**III.**	**IV.**	**V.**	**VI.**	**VII.**	**VIII.**	**IX.**	**X.**	**XI.**	**XII.**	
Zalaegerszeg	1901–1950	–269.4	540.8	41.0	16.4	10.7	7.3	7.3	6.6	9.2	15.8	40.1	223.5	
	1951–2000	–217.9	381.9	44.5	15.7	11.0	7.5	7.5	8.4	10.1	16.4	41.2	415.2	
Magyaróvár	1901–1950	–221.3	520.4	43.9	16.6	10.7	8.0	5.8	6.4	9.7	15.5	40.7	343.0	
	1951–2000	–221.1	371.8	44.0	13.9	10.8	7.8	7.1	7.5	9.7	16.6	38.8	243.9	
Túrkeve	1901–1950	–153.4	–1031.5	43.5	17.4	10.9	7.4	5.9	7.0	9.7	16.8	44.7	877.7	
	1951–2000	–146.8	720.4	44.5	14.4	9.8	7.2	6.4	8.2	10.0	13.4	40.8	510.0	
Szeged	1901–1950	–336.6	448.1	38.6	16.1	10.5	7.6	6.6	7.8	9.7	14.0	33.5	156.1	
	1951–2000	–209.1	391.4	39.9	14.1	9.3	6.7	6.5	7.3	9.6	14.3	40.1	278.0	
Deebrecen	1901–1950	–150.3	–660.1	47.5	18.3	10.7	7.6	5.7	6.9	9.8	17.6	47.4	727.9	
	1951–2000	–133.5	6405.0	47.4	14.7	10.0	6.8	6.3	7.6	9.9	13.1	42.5	1679.5	

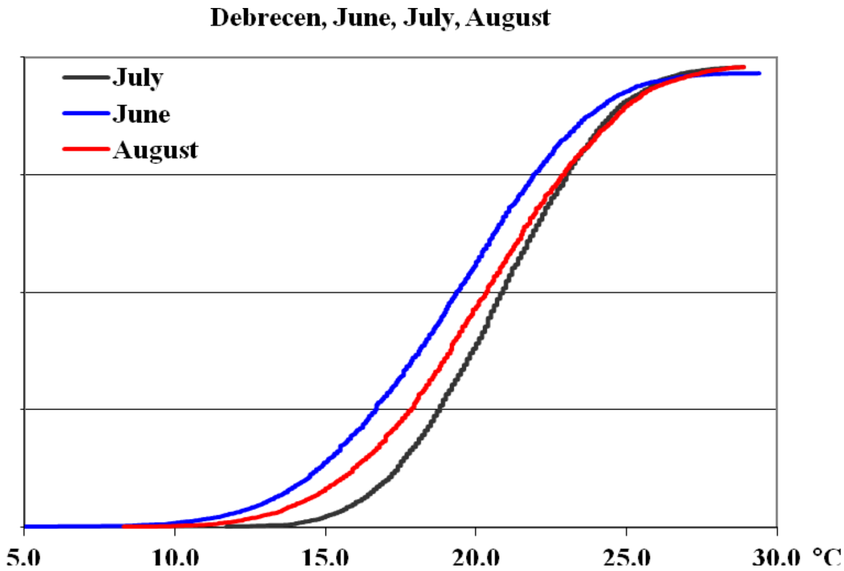


Fig. 3. Probable distribution of the daily average temperatures in summer months (Debrecen, 1901–2000).

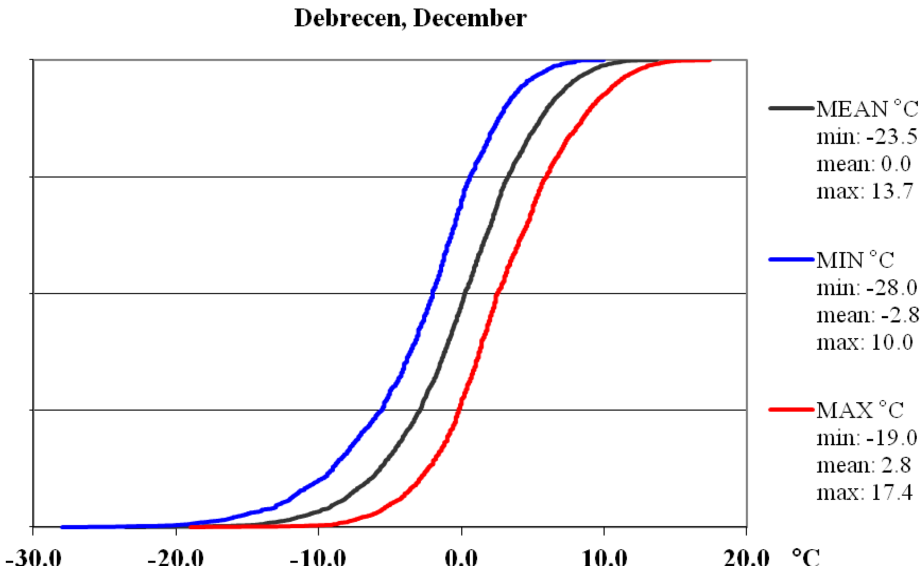


Fig. 4. Frequency distribution of the daily average and extreme temperatures in December with absolute maximun and minimum values (1901–2000).

The spring and partially the autumn temperature damages are mostly caused by radiation frosts which are developed in accordance with local conditions, such as micro relief, heat capacity of soils, etc.

There has been no frost statistical frequency analysis related to a short period of time which is based on several years of observations because of the spatial and temporal heterogeneity of frost sensitivity. *Table 3.* provides information about the frequency of frost of various strength in the region of Nyíregyháza and Kecskemét broken down to 5-day periods and expressed in a percentage which represents the duration of frost in days (*Szász*, 1988). This table shows the values calculated on the basis of the minimum temperatures measured at 200 cm height, which cannot be regarded as typical values in the lower soil layers.

Table 3. Frequency of five–day minimum temperature (Kecskemét, Nyíregyháza, 1931–1970)

Relativ frequency of different frosts, 1931–1970. Kecskemét											
	III.				**IV.**						**V.**
day	**12–16**	**17–21**	**22–26**	**27–31**	**1–5**	**6–10**	**11–15**	**16–20**	**21–25**	**26–30**	**1–5**
Frost days %	49.20	48.20	36.40	25.10	15.90	8.20	10.75	5.75	3.40	1.025	2.05
0 -(–0.9)	17.16	24.50	35.21	32.67	45.15	68.80	66.70	36.40	16.75	50.00	25.00
(–1)-(–1.9)	15.60	19.15	15.50	24.50	35.50	6.20	19.05	45.40	66.60		25.00
(–2)-(–2.9)	16.66	16.00	21.10	12.25	6.45	18.80	4.76	9.10	16.65	50.00	50.00
(–3)-(–3.9)	13.55	8.50	14.10	8.16	12.90	6.30	4.76				
(–4)-(–4.9)	11.45	11.70	5.64	16.30			4.73	9.10			
(–5)-(–5.9)	10.40	9.57	8.45	4.08							
(–6)-(–6.9)	5.21	5.32		2.04							
(–7)-(–7.9)	5.21	2.13									
(–8)-(–8.9)	3.12										
(–9)-(–9.9)	1.04	2.13									
(–10)-(–10.9)		1.00									

Relativ frequency of different frosts, 1931–1970, Nyíregyháza																
	III.				**IV.**						**V.**					
day	**11-15**	**16-20**	**21-25**	**26-31**	**1-5**	**6-10**	**11-15**	**16-20**	**21-25**	**26-30**	**1-5**	**6-10**	**11-15**	**16-20**	**21-25**	**26-31**
Frost days %	62.0	56.5	44.0	32.5	22.5	22.0	12.5	10.0	5.0	4.0	2.0	0.0	0.5	0.5	0.5	
0-(–0.9)	20.2	20.4	26.2	32.3	35.6	47.7	28.0	40.0	50.0	50.0	50.0		100.0		100.0	
(–1)-(–1.9)	22.6	23.0	25.0	30.8	22.2	31.8	40.0	10.0	30.0	25.0	50.0			100.0		
(–2)-(–2.9)	12.9	11.5	23.8	15.4	22.2	9.1	20.0	25.0	0.0							
(–3)-(–3.9)	13.7	11.5	10.2	6.2	15.6	6.8	4.0	15.0	10.0	25.0						
(–4)-(–4.9)	4.8	9.8	8.0	7.8	2.2	2.3		5.0	10.0							
(–5)-(–5.9)	10.5	5.2	6.8			2.3		5.0								
(–6)-(–6.9)	7.3	7.1		1.5			8.0									
(–7)-(–7.9)	4.0	3.5		1.5	2.2											
(–8)-(–8.9)	0.8	6.2		1.5												
(–9)-(–9.9)	0.8	0.9		1.5												
(-10)-(-10.9)	0.8	0.8														
(-11)-(-11.9)	0.8															
(-12)-(-12.9)				1.5												
(-13)-(-13.9)	0.7															

4.3. Precipitation

One of the main elements of agricultural production is precipitation, since the water supply of plants produced in Hungary is provided by natural precipitation with few exceptions. Precipitation is one of the most important aspects which determine yield. It has to be emphasized also because of the fact that the amount of precipitation in Hungary usually does not satisfy the demand posed by plants.

The level of precipitation supply is usually characterized by average sums. Temperate zone areas with continental climate usually have their maximum precipitation in the summer and the minimum precipitation in the winter. In mediterranean areas, this relation of precipitation during the year is the opposite. Since climate borders are rather variable, the different climatic characters are present in a mixed form in the Carpathian Basin (*Berényi*, 1943, 1945). From year to year, precipitation shows a rhapsodic yearly course in comparison with temperature that can be explained by the high variability of this element. Similarly to the description of temperature, the multiple-year mean values of precipitation, as well as its statistical parameters related to the 5 stations are summarized by *Table 4*. One of the most suitable statistical parameter of the variability of precipitation is the coefficient of variation (CV = standard deviation / mean). The coefficients of variation show a specific and strict yearly course in Hungary: the CV values reach their maximum (57–79%) at the beginning of spring – usually in March – and then they decrease until May and June. The minimum values fall around the time of precipitation maximum (44–63%), then they increase again until the end of summer or the first month of autumn to reach a secondary maximum (55–75%); by the winter months, the values will decrease again, but the monthly values will stay between 50 and 70%. CV values calculated for various points of the country are summarized in *Table 4*.

If the distribution of the precipitation sum of the growing season is shown on a similar scale, it can be seen that there is still a difference between the precipitation supply of the eastern and western part of the country. However, the difference between the yearly mean values of the driest and wettest areas is 300 mm per year, and the same difference in the growing season is still 300 mm, but this value refers to a significantly shorter period of time. As a consequence, the difference in the summer precipitation supply has a much stronger effect mainly on crop production, more specifically on the water balance of soils than before and after the vegetation period (*Bacsó,* 1952; *Szepesiné,* 1966).

As a matter of course, the extremes of the yearly precipitation sum take place in the southwestern areas of the Transdanubian region, which can be explained partially by relief-related reasons and partially by the current circulation status. In these areas, the range of fluctuation of the yearly sum significantly exceeds 900 mm, but the minimum amount is below 400 mm. The fluctuation range of the yearly sums of the Great Plain areas, where the usual amount of precipitation is low, is near 650 mm (*Hajósy*, 1952; *Kéri* and *Kulin*, 1953; *Szász,* 2005; *Goda*, 1966; *Péczely*, 1963, 1968).

Table 4. Sum, standard deviation, and variation coefficient of the monthly precipitation (1901–1950, 1951–2000)

Precipition (mm)														
Station		**I.**	**II.**	**III.**	**IV.**	**V.**	**VI.**	**VII.**	**VIII.**	**IX.**	**X.**	**XI.**	**XII.**	**Year**
Zalaegerszeg	1901–1950	39	38	43	62	74	81	87	81	70	65	59	49	748
	1951–2000	31	31	42	52	72	86	84	74	64	54	63	45	698
Magyaóvár	1901–1950	37	34	38	43	66	58	65	59	52	49	52	49	602
	1951–2000	33	33	36	43	54	66	69	57	45	43	53	44	576
Túrkeve	1901–1950	27	29	33	45	56	68	55	53	44	49	48	38	545
	1951–2000	33	32	30	41	60	71	55	49	41	32	48	46	536
Szeged	1901–1950	32	34	38	49	60	67	50	48	46	51	50	40	565
	1951–2000	28	27	28	40	52	66	53	51	37	31	43	43	497
Debrecen	1901–1950	32	32	34	45	59	69	61	60	46	53	51	41	583
	1951–2000	33	32	29	44	59	77	60	58	38	33	45	45	554
Standard deviation (S)														
Station		**I.**	**II.**	**III.**	**IV.**	**V.**	**VI.**	**VII.**	**VIII.**	**IX.**	**X.**	**XI.**	**XII.**	
Zalaegerszeg	1901–1950	23.0	28.6	30.5	33.3	42.6	35.7	53.7	49.3	42.0	42.6	40.9	29.2	
	1951–2000	20.2	21.5	22.1	29.8	32.6	45.3	43.5	42.1	34.7	41.9	34.4	26.4	
Magyaróvár	1901–1950	19.5	20.3	28.8	25.8	39.1	29.5	37.2	38.3	37.0	34.3	35.0	24.6	
	1951–2000	19.9	22.2	19.9	26.0	30.0	36.3	44.4	32.2	29.4	30.2	30.6	22.9	
Túrkeve	1901–1950	14.3	20.3	22.8	25.1	33.0	32.8	35.9	34.6	30.7	35.5	28.0	25.6	
	1951–2000	20.9	19.7	19.5	20.2	35.8	36.7	33.2	33.2	30.0	29.9	35.2	26.3	
Szeged	1901–1950	18.6	26.1	24.4	28.3	34.2	31.6	31.0	28.8	29.1	36.2	30.9	22.9	
	1951–2000	17.9	19.7	18.0	18.8	33.4	36.3	32.9	31.4	25.7	27.7	29.7	27.8	
Debrecen	1901–1950	19.0	21.6	25.5	27.4	29.8	33.3	38.1	38.5	30.5	33.7	29.8	27.6	
	1951–2000	18.4	19.0	18.5	19.4	34.9	40.0	33.5	37.8	28.9	30.0	27.5	22.9	
Coefficient of variation (CV)														
Station		**I.**	**II.**	**III.**	**IV.**	**V.**	**VI.**	**VII.**	**VIII.**	**IX.**	**X.**	**XI.**	**XII.**	
Zalaegerszeg	1901–1950	59	75	71	54	58	44	62	61	60	65	69	60	
	1951–2000	66	70	53	57	45	53	52	57	54	78	55	58	
Magyaróvár	1901–1950	53	60	76	60	59	51	57	65	71	70	67	50	
	1951–2000	60	68	55	61	56	55	64	56	65	71	58	52	
Túrkeve	1901–1950	53	70	69	56	59	48	65	65	70	72	58	67	
	1951–2000	64	63	65	49	60	52	61	67	72	94	73	58	
Szeged	1901–1950	58	77	64	58	57	47	62	60	63	71	62	47	
	1951–2000	64	72	65	47	64	55	63	62	70	90	69	65	
Debrecen	1901–1950	59	68	75	61	51	48	62	64	66	64	58	67	
	1951–2000	56	60	63	44	59	52	56	66	75	90	61	51	

Due to the variable nature of precipitation, exact precipitation maps can only be prepared with lots of imperfections, since the areas bordered by isohyets could also form patches of different variability. Apart from a few exceptions, a precipitation map is drawn on the basis of a *linear scale*, in accordance with the arbitrarily chosen value ranges of the so-called isohyets. Drawing up such a map is a relatively simple task, but the role of isohyets to function as borders is questionable. In reality, the difference in precipitation supply in the mentioned range has more or less similar variability. If high standard deviation is associated with the nearly identical mean values, it is possible to lose the reality of the map, since the difference between the areas limited by the isohyets which have the same values could show different probability. In order to prevent this error, the extent of distinction can be modified in accordance with the principles of statistical probability. If these principles are taken into consideration, a parting line can only be drawn between two stations if not only the mean, but also the standard deviation values of the related precipitation sums differ (*Szász*, 1968). If the standard deviations are considered, the *limit of the probability significance* can be calculated that will not necessarily be different from the averages, but the standard deviations from the mean values. The statistical precipitation map of Hungary shown in *Fig. 5* was prepared by *Szász* (1971). The precipitation sums of the areas delineated by the isohyets significantly differ from each other, while the sums did not significantly differ in the related period within the areas. Therefore, areas with homogeneous precipitation supply can be separated by using this principle. The advantage of this method can be reached by determining the number of precipitation measurement stations. Within the homogeneous fields, nearly exact precipitation sums can be determined at each optional point in the area delineated by the isohyets, even at the point where the standard deviation of the line, which is in accordance with the measurement location, is accepted. In other words, the mean values do not necessary mean identity or difference in themselves, but the standard deviation values of the two locations to be compared need to be considered in order make a decision. The determination of the difference in supply based on the statistical probabilities is necessary mainly in the areas where the mean precipitation and the related standard deviations are close to each other. The editing of homogeneous fields is by all means a complicated task, but the computerized processing removes this difficulty.

Considering the fact that the analysis of the precipitation in the country is rather manifold and numerous bibliographical sources were published in the last 50 years, we do not wish to describe any further matter of detail (*Péczely*, 1963, 1968; *Goda*, 1966; *Bacsó,* 1967; *Schirokné*, 1983).

4.4. Air humidity, evaporation

As a result of the radiation energy, significant amount of water gets into the air from wet surfaces by means of evaporation. Evaporation is a process which uses heat energy: its approximate value is 2500 kJ g^{-1}. Although the *quantity of water vapor in the air* is negligible in comparison with the mass of the atmosphere, its physical significance is rather great. The commonly known greenhouse gas effect is mostly created by water vapor. The highest possible quantity of water vapor in the air depends on temperature. The saturated vapor pressure (mbar) is the highest vapor pressure which is determined by temperature; the difference between the saturated and the actual vapor pressure is the saturation gap, a value very often used mainly during practical calculations. The ratio of the current and possible vapor pressure at a given temperature is the relative humidity, which serves the quantified expression of saturation. It has to be emphasized that the amount of water vapor present in the air space of the Carpathian Basin varies in a rather wide range (*Száva-Kováts,* 1937), which is mainly caused by the large differences in water vapor content of the air masses arriving from areas which have rather different climate.

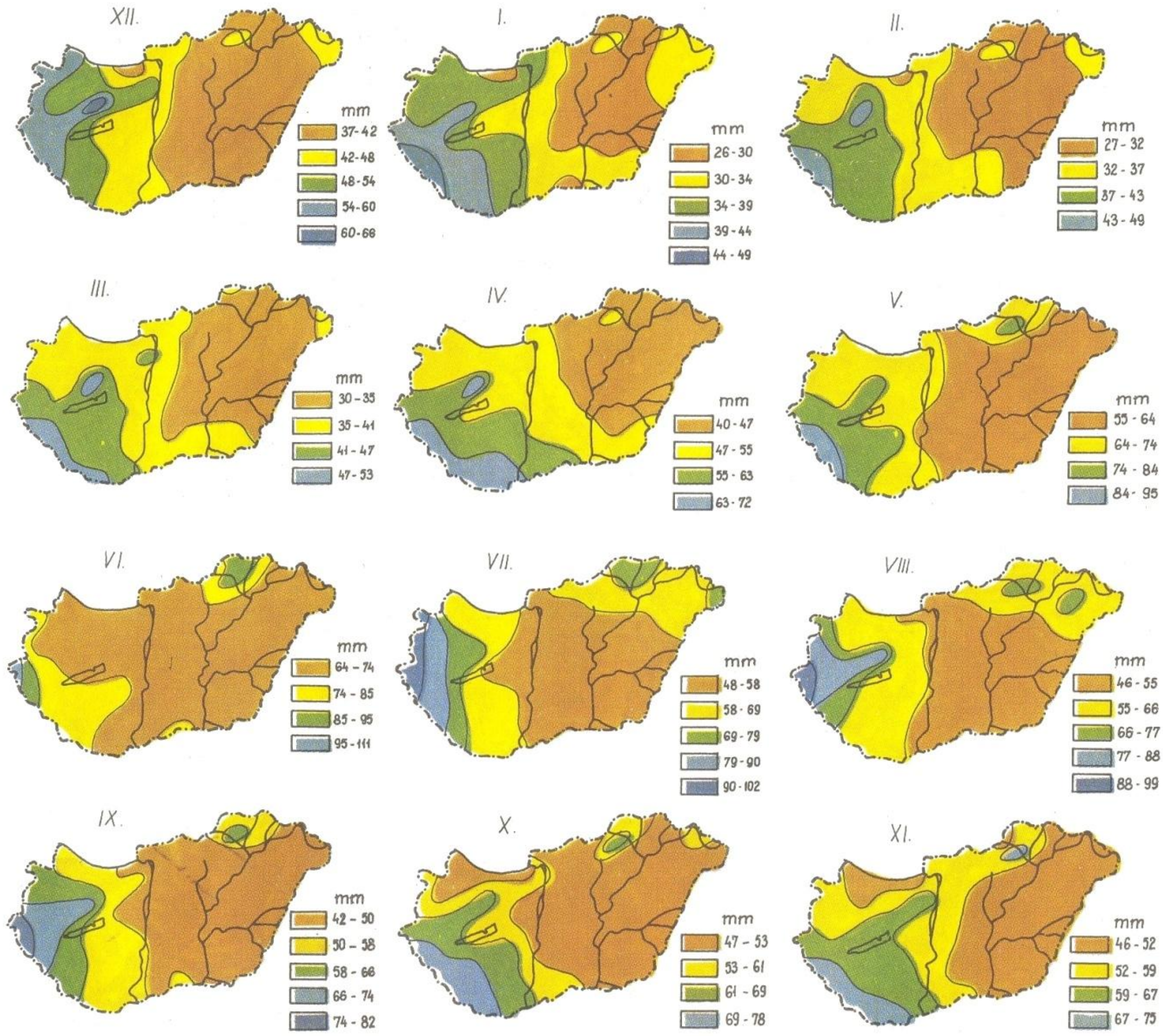


Fig. 5. Significant probable heterogeneity of monthly average precipitations in Hungary (1901–60) (*Szász*, 1971).

Nearly every meteorological element has a role in forming the conditions of *evaporation* to a different extent. The strongest regulatory factor is the incoming energy on the surface that is the absolute value of the radiation balance per unit of time. A high percentage of this energy can be used for evaporation above wet and water surfaces. The saturation deficit or the relative humidity define the intensity of the evaporation process, similarly to the increase of wind speed, which makes the *process of evaporation* more intensive with the increase of turbulence.

Evaporation is the meteorological element which cannot be measured directly; therefore, the mentioned significant factors determine the actual evaporation in a ratio which is in accordance with their importance. The actual evaporation can be estimated with various physical correlations. The amount of water which gets into the air in the form of water vapor in the case of the given physical condition of the atmosphere is called potential evaporation (P_0) (*Thornthwaite*, 1948). As a matter of fact, potential evaporation is a physical constraint, and it expresses the highest evaporation ability if the lack of water hinders evaporation. Measurements show that the evaporation of the open water surface is close to the potential evaporation. Instead of the rather complicated but reliable findings, various empirical formulae are used generally. The high number of these formulae makes it necessary to use them with precaution, because the weights of the various factors are different in areas with different climate. Theoretically, without the certification of the empirical formulae, the mentioned correlations cannot be appropriate and usable (*Fisher* and *Yates*, 1957).

Various formulae become popular in Hungary, of which the research considers the following to be worth mentioning:

Antal's method (1968): $P_0 = 0{,}74 \cdot (E - e)^{0{,}7} (1 + \alpha T)^{4{,}8} \quad \left[mm\ day^{-1} \right]$,

Szász' method (1973): $P_0 = \beta \left[0{,}0056 (T - 21)^2 (1 - RN_a)^{2/3} f(v) \right] \quad \left[mm\ day^{-1} \right]$,

Varga-Haszonits' method (1977): $P_0 = \dfrac{1 - RN_a}{1 + RN_a} \cdot T_k$,

where T_k is the temperature, *RN* is the relative humidity, *v* is the wind speed, (*E*–*e*) is the saturation deficit.

By using the empirical formulae, it is possible to determine the evaporation ability of the air (P_0), thereby providing the temporal and spatial change of the P_0 values in a wide range. Independently of climatic conditions, the extent of potential evaporation cannot exceed the equivalent of the radiation energy balance (expressed in mm) if rigorous physical criteria are considered. This form of evaporation is usually called balanced evaporation.

In order to determine the evaporation ability of the air, the evaporation-related water loss of different-sized, but standard water-filled tubs is determined.

Based on the water level differences measured in these tubs, the sum of evaporation in a day or in several days can be observed. For agricultural purposes, the evaporation loss of natural water surfaces is usually compared to this value. The examination of evaporation is almost indispensable from the practical aspect during the examination of the climatic characteristics of the country, since this is one of the strongest limiting factors in the development of crop production. In this relation, the climatic analysis of water supply problems have to be performed in order to work out the practical solutions (*Szász,* 1973a,b).

The Hungarian agrometeorological research has reached significant achievements in examining the potential evaporation in the country. Altogether, these results are suitable for the competent authorities to take the steps which are essential to implement developments such as water replenishment, irrigation, and drainage (*Kéri* and *Kulin,* 1953; *Péczely,* 1963; *Pálfai,* 2004).

The regional distribution of potential evaporation in Hungary is between 120–150 mm in the summer months. In the interim seasons, the monthly values range between 60–90 mm, while they are between 10–12 mm in the winter months. In the northern half of the Great Hungarian Plain, the value of P_0 ranges between 660 – 680 mm, while it reaches 800 mm in the southeastern areas of the Great Plain (*Antal*, 1968; *Szász,* 1973a,b).

The difference between the actual and potential evapotranspiration is the highest in the summer period, its regional distribution is shown in *Fig. 6*. Based on the curves in this figure, the lack of water and the difference between the actual and potential evaporation can be quantified (*Berkes,* 1946; *Antal,* 1966, 1987; *Füri* and *Kozma,* 1972, 1975, 1978; *Posza* and *Stollár*, 1983; *Dunkel et al.*, 1990; *Ács et al.,* 2007).

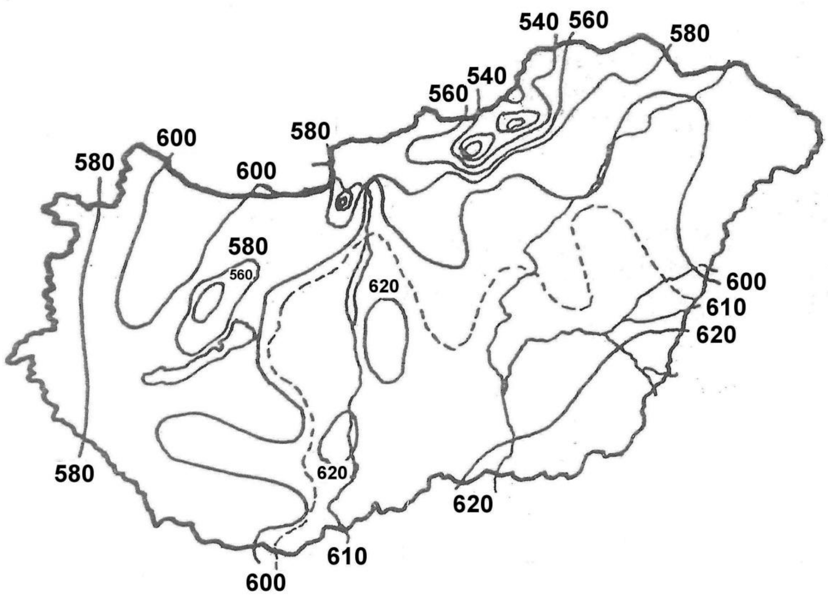


Fig. 6. Areal distribution of potential evapotranspiration in the summer half-year (1901–60).

Due to the high complexity of the problem to be solved, no numerical empirical formulae were prepared to estimate the actual evaporation, and the result of the estimation could contain non-negligible errors. The actual evaporation is significantly modified not only by the amount of available water, but also the speed differences between the water transfer of the soil and plants (*Szász,* 1988; *Ács,* 2004).

4.5. Wind

The interest of modern analyzing agrometeorology in wind speed became extraordinarily wide and deep in the last decades. The motion of air can have different direction and speed. As a matter of fact, wind is only one specific form of this motion system, representing the horizontal component of the motion of the air. The vertical movement is an especially important component of agrometeorology in the existing motion system. Wind speed increases with height, maintaining the process of energy and material transport which is directed towards the heights. The transport processes (sensible and latent heat, CO_2, pollutants, etc.) towards high levels are maintained by the air motion which has a turbulent structure, in which its vertical component plays a very important role.

In Hungary, high energy winds are relatively infrequent, the average wind speed is 2–3 m/s above flat regions. The maximum wind speed can be observed in one of the spring months and the minimum occurs usually in October. The highest wind speed values in the spring could reach 8–10 m/s and the rarely forming tornado-like speed is close to or even exceeds 20 m/s. The change of wind speed is characterized by strengthening during the day and lower values at dawn (1984).

High wind speed results in strong pressure of air. Wind pressure is proportional to the squared wind speed in reference to the surface perpendicular to the motion. These motions can cause significant mechanical damages mainly in forests or in large-leaved herbaceous plants (*Wágner* and *Papp,* 1984; *Papp,* 1974; *Tar,* 1991).

5. Climatic effects in crop production

The physical and dynamic effects on different branches of agriculture can be derived from the database of the climatological information system, and they could be either favorable or unfavorable in a differentiated way. Based on these effects, the responses or reactions whose theoretical and practical significance constitutes the basis of scientific advancement became known, and the system of effects and responses increases the concept range of agrometeorology.

We have a rather wide range of information about climate which provides the increase of knowledge with the accelerating technical development. Also, the increasing amount of information makes it more difficult to interpret research findings. Considering the fact that the information need is becoming increasingly manifold, a differentiated information system needs to be worked out. Crop production constitutes one component in the science which demands agricultural information. This means that crop production is not satisfied anymore by the traditionally processed climatic data, but it became necessary to get to know the consequences of their effects so that decisions can be made in relation to the introduction of yield-increasing technologies. The research of climate is the concern of meteorologists, but the effect of climate is a social concern. It is necessary to search for the opportunity for sciences dealing with the effect of climate to get to know the complex physical system of processes which is commonly known as agrometeorology.

The summarized findings in this area refer to the crop production-related framework of climate while looking for the opportunity of regional distinguishability in a geographical sense. These research projects could be regarded as agroecological examinations which cover the climatic factor group of the condition system of agriculture, more specifically crop production. This area of research restricts itself to the quantified determination of productivity also in relation to the approach to and the solution of modeling analyses while trying to explore the climatically potential production size in a quantified way for each region of the country based on the climatic *"constraint"* acting on various plants. The model which was worked out on the basis of this concept assumes certain simplified limit conditions, but this fact does not exclude the possibility of development. The most important objective is that the findings should well represent the role of climate in altering productivity; therefore, the climatically potential production expresses the size of climatic value (*Antal,* 1978; *Györffy*, 1976; *Hunkár*, 1990; *Jolánkai*, 1993).

For this reason, the following section provides the partial results which became commonly known as the findings of the main foreign and Hungarian research projects. All these results aimed at the quantified expression of climate as a factor which determines yield. The basis of the characterization of agrometeorology is the collection of climatic elements, which make it possible to describe the effects in an exact way in order to be able to quantify them. The brief overview of the climate of the examined area is done from this aspect.

5.1. Crop development and production

The quantified description of crop development is possible with using various models. Usually, an empirical correlation related to an impact factor in a certain form is used as a basis in an analytical form, which can be theoretically substantiated and it can be easily handled. The change of crop mass, height, its other organs over time describes the rate of development in which mass growth, development phases and the calendar dates of these phases can be determined in an exact way. The related field of science is called phenology, in which not only crop production but also genetics are significantly interested. Despite the fact that a non-linear process needs to be described, it still has to be expressed in the form of higher level functions in a mathematic form based on the temporal change of usually one climatic element (*Berzsenyi*, 2000). The use of non-recent formulae is significant and the most commonly used ones are worth mentioning here:

$$w/dt = k_1 \cdot m^{c_1} - k_2 \cdot m^{c_2} \qquad (Bertalanffy,\ 1941),$$

$$w = A\left(1 - b \cdot e^{-kt}\right) \qquad (Mitscherlich,\ 1909),$$

$$w = A\left(\frac{1}{1 + b \cdot e^{-kt}}\right) \qquad (Verhulst, 1838),$$

$$w = w_0 \cdot e^{kt} \qquad (Blackman,\ 1919),$$

$$w = w_0\ exp\left(\frac{\mu_0\left(1 - e^{Dt}\right)}{D}\right) \qquad (Gompertz,\ 1825),$$

$$w = w_0\ exp\left(a_1 t - a_2 t^2\right) \qquad (Richards),$$

$$\frac{dw}{dt} = \mu w\left(1 - \frac{w}{B}\right)e^{-Dt} \qquad (Chanter,\ 1976),$$

where w is the growth, k_x is a coefficient, t is the time, D is the coefficient of integration, μ is the coefficient of growth rate.

The number of optional functions is high, but the change of ontogenesis mass over time is different in the case of each species and crop year; therefore, the mentioned correlations and analyses provide a good opportunity to fulfil the target task (*Ábrányi*, 1978; *Berzsenyi*, 2000; *Szász*, 1988; etc.). According to Hungarian observations, growth curves can be effectively used in distinguishing crop year effects. Due to the changing distribution types of the parameters of multivariate functions, the extent of their usability is much lower. The growth curves are mainly realized with the use of continuous climatic elements, considering the fact that these functions describe a certain cumulative curve on various mathematical bases which necessitates the equidistant value series of the independent variable. The temporal distribution of the partial crop mass often becomes necessary to be used, e.g., stem mass, leaf mass, root mass, etc. Processing of the phenological and phenometric values in the mentioned form becomes valuable information, because the character of the curve describes the correlation between both the genetic and climatic effects. This latter question becomes useful information, because the parameters of these functions could be used to express the quantified values of the climatic reactions. For the sake of completeness, it has to be noted that the accumulation of the active temperature values above the basis temperature is a widespread method to classify the environmental conditions of several plants and also in phenological forecasts in other cases (*Berzsenyi*, 1993).

In the case of any functions which are used to describe growth, it has to be emphasized that the results do not refer to the whole vegetation period, but they mostly express the period between sprouting and flowering; therefore, they can be used for the vegetative development phase. The description of the generative phase is a more complex task, since the inner physiological processes regulate the yield increase and ripening instead of the environmental factors.

5.2. Correlation between weather and yield

This topic looks for an answer to the most important question of meteorology and crop production: in what way and to what extent do different elements regulate yield and yield quality in a separated form or together? This question is rather complex, and although we do not have universal and general equations, it is still worth summing up the currently reliable correlations, which were developed into what they are now.

The simplest correlation is the empirical one which usually verbally refers to the correlation between precipitation, temperature, and yield. Their time-enduring character is questioned and it is only rarely proven. *Bauman* (1949) worked out an empirical correlation used in crop production research by separating the crop years of high and low yields after classifying yields based on their extent. Bauman had the assumption that the best and most unfavorable weather type prevailed in these two categories. This procedure was also used in Hungary by *Berényi* in 1952 (*Berényi* 1945, 1954; *Berényi et al.*, 1959) who also analyzed the significance of the statistical difference of results. Later it was proved that Bauman's method can only be used if the weather effect is parabolic. In these cases, the optimal condition (temperature and precipitation) can be found at the intersection of two lines and its direct statistical surrounding (*Bocz* and *Szász*, 1962).

In the 1900s, correlation and regression analysis became widely used in agricultural research based on the method of *Smith* (1915). This method became common in the first half of the past century in Europe (*Holdefleiss,* 1930; *Smith,* 1915). In parallel with this, the method based on the examination of standard deviation was most commonly used in England (*Fischer* and *Yates,* 1957).

In the Hungarian agrometeorological research, the correlation methods were used in uni- and multivariate forms in order to determine the temperature and precipitation need of the main produced plants as well as their role in regulating yield (*Aujeszky, et.al.,* 1951). With this work, Berényi laid the foundations of one of the most important agrometeorological topic; therefore, several followers used this method within the framework of the yield analysis of plants (*Kerék,* 1934; *Szász,* 1955; *Justyák,* 1989; *Erdős* and *Lambert,* 1987; etc.). The correlation analysis was further developed, and the path analysis became widespread for the purpose of expressing the modification of the weight of different variables during the plant development process (*Botos* and *Varga-Haszonits*, 1974).

In the last 50 years, standard deviation analysis was used as a multifactor analytical method which can be applied to several purposes as a result of the extraordinary mathematical advancement. Its mathematical-statistical one-sidedness is shown by the fact that it is mainly widespread in the field of technical development. One of its main products is factor analysis which is only used by high-level mathematical analysts, and it is only applied in computerized model-based examinations.

Apart from these, further modern methods became very widely used which can be applied in the form of procedures built into complex systems based on probability-focused principles.

The analytical form of the correlation between weather elements and yield built on physical bases was first used in the 1950s with the following physical concept: the development of the organism of plants happens by taking up organic and inorganic substances from the soil in a chemical way, as well as by absorbing solar energy through plant vital processes and by incorporating this energy in the presence of water. This recognition immediately shows that the atmosphere has an almost exclusive role in this process, since the solar and soil surface sources of energy and water get to plants in the form of precipitation by means of meteorological processes. If the active role of solar energy is clarified, we can conclude that, through CO_2 and water – the constituents of the atmosphere –, plant life is not possible without development, growth, energy, water, and nutrients taken up from the soil. In other words, this means that the maximum mass of plant organism developed through vital processes is clearly determined by energy and water supply; that is the generator of production is energy and the fuels are CO_2 and water. The task of agriculture is to achieve the highest genetically possible vegetable production in a given place using the energy, and material stock provided by nature. The physical condition of nature is constant, while the genetic potential is changing and it can be altered by humans; therefore, only these two climatic factors form the basis upon which the mentioned criterion is expected to be realized in the form of organic matter in the future.

Temporal characterization of growth and development can be done with biophysical and chemical methods by describing photosynthesis in detail. The dry matter to be formed can be estimated on the basis of the rules of gross net assimilation and carbohydrate production. From the agrometeorological aspect, it is a fundamental question how actual and potential photosynthesis is going on and what is the ratio of the dry matter which was formed. The answer for this question is known in agrometeorology, although this ratio also involves the effect of other, non-meteorological roles of the production site, i.e., nutrient supply, soil effect, etc. This explains why the potential production can be estimated in the mentioned form since the 1950s (*de Wit*, 1954). Although the first analyses were done mainly in a global or climatic zone-focused relation

(*Lieth*, 1976), the aim of these examinations was primarily vegetation research. Also, one of the energetic research projects was launched by the author (*Szász*, 1981), who determined the energetically potential production size on the basis of the water analogue of Penman and the PAR values with 0.03 energy efficiency. In the following decades, the further developed form of this work also incorporated the effect of temperature and water supply, and an attempt was made to analyze the typical climatic potential of production sites by considering the proportion of the role of the level of plants' nutrient supply. It has to be noted that *Antal* (1978) and *Varga-Haszonits* (1987b) defined the size of climatic potential, but they used the proportion of the energy balance and water balance to characterize the climatic potential of various regions, that is the size of the dry matter mass which was approximated from the values of energy and water balance that were incorporated in the examination. *Szász* (1981) wished to determine the size of the actual production from the value of climatic potential. The basic correlations of this method could be summarized as follows:

$$EP_0 = \varepsilon(1-a)\,PAR/\eta,$$
$$KP_k = \varepsilon[(1-a)PAR/\eta]\,f(T,W)^{-1},$$
$$KP_{k\cdot N} = \varepsilon[(1-a)PAR/\eta]\,f(T,W)^{-1},$$
$$KP_{k\cdot N}\,/\,EP_0,\ PAR = G/2,$$

where η is the coefficient of conversion (15.7 MJ/kg), KP_{kN} is the plant factor referring to productivity, W is the humidity, G is the global radiation, KP_k is the sensitivity factor referring to temperature and humidity.

Based on these latter, the method was used on the yield series from 23 regions of the county with typically different climatic and soil endowments. As a result of the analyses, the following parameters were arrived at:

energetic potential	≈	EP_0	(t/ha),
climatic potential	≈	KP_k	(t/ha),
genetic potential	≈	$KP_{k\cdot N}$	(t/ha),
proportion	≈	$KP_{k.N}/KP_0$.	

The correlation system shown above constituted the basis of examinations whose database was the 30-year average yields from 23 production regions and the related meteorological database. The author used the method for agricultural purposes by means of estimating the role of genetic potential for various plant species as a parameter of determination. As a matter of fact, the genetic potential, i.e., productivity is a mobilizing factor which could be made usable to express maximum climate effects. A part of this correlation is shown in *Fig. 7* which demonstrates the energetically and climatically potential average yields, as well as the actual average yield and the level of production which can be achieved from the genetic aspect. These results were used in Hungarian and also in foreign research.

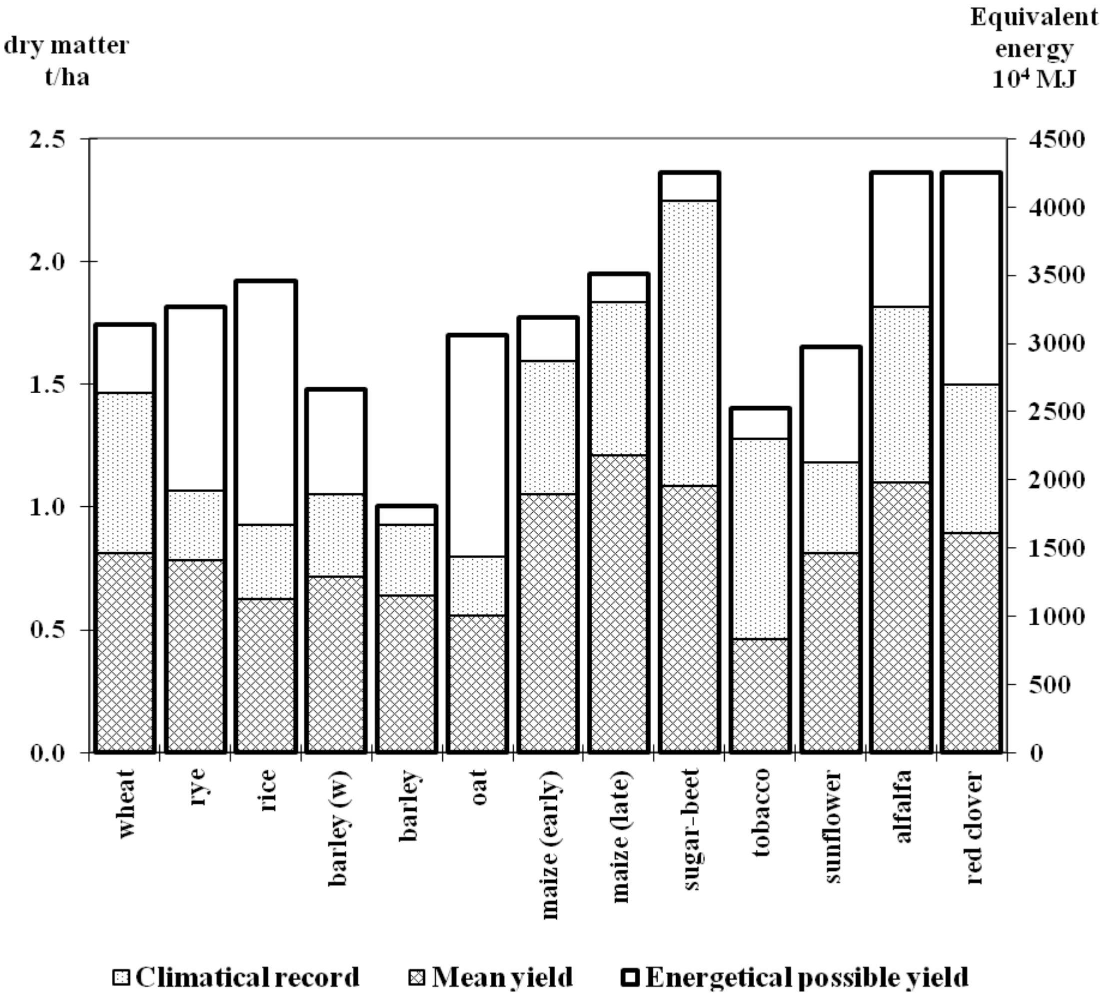


Fig. 7. Climatic records, energetically possible and mean yields of different plants.

It has to be emphasized that significant analyses were performed by the National Meteorological Service in the last 50 years in order to get to know the climate sensitivity of the main produced plants. Of these, the weather dependence findings of wheat (*Varga-Haszonits*, 1974), maize, and potato (*Berényi*, 1943, 1945, 1948*;, Szász*, 1961*; Ajtay*, 1979; *Hunkár*, 1990), paprika (*Erdős* and *Lambert*, 1987), barley (*Varga-Haszonits*, 1974), and various vegetable (*Cselőtei*, 1987) and fruit species are worth mentioning. Detailed and programmed examinations were performed in forests (*Justyák*, 1987). It also has to be mentioned that various governing authorities and ministries, such as the employees of the Agrometeorology and Forecast Department of the National Meteorological Service, cooperated in solving numerous agrometeorological problems by participating in various research programs directed by the government and professional departments.

The agrometeorological research turned into and have been going on in a rather manifold direction for decades, but two factors have especially important role due to the climatic endowments of the country. These are a) the natural water supply of agriculture and irrigation and b) the climatic effects of nutrient management. Details of these two topics still represent a current problem in guiding and developing agriculture on a country level.

5.3. The importance of water supply in crop production

The water cycle has one of the most important roles in the meeting point of the soil-plant-atmosphere system as the activity of all three spheres is peculiar at all times. The water cycle and the broadly meant balance-like record of water in the soil, i.e., *water balance* is an important natural phenomenon whose quantity can be detected by the form of the distinguished processes of the various production sites. The concept of *water cycle* can be approached in any possible ways, as it becomes clear that it refers to a specific motion system that is perpetuated by solar energy, and the transported material is water itself which is the main element of the material flow in plants. The limits of interpreting field crop production can be defined in physical terms; therefore, the limits of the atmospheric part and space of the water balance of various plant communities can be set, where certain physical parameters of the frictional boundary layer of the surface do not significantly change at a given distance from the surface. The lower boundary layer is located in the soil layer where the plant's root mass and the capillary boundary layer below the root mass meet.

The soil of the continent is a vast water reservoir also in global terms. Its upper layer contains all moisture, while its rhythmical change is regulated by the climate. The change is regulated by the simultaneous course of evaporation and precipitation. These two phenomena establish the water need of the plant cover in an optimal or – incidentally – extreme way. One of the main tasks of agrometeorology is to track the temporal change of soil moisture which originates from precipitation and to determine evaporation or evapotranspiration.

Nearly from the beginnings of the agrometeorological research, they tried to get to know the relative value of the available water stock. The numerical value of this stock is the water demand of plants which is the same as the measureable extent of the soil moisture content at all times (accessible soil moisture). The amount of precipitation only refers to the amount of water on the surface, while the water stock that can be stored is 30–40% of precipitation. This is the reason why the total amounts of precipitation and soil moisture are not in balance in the Carpathian Basin, depending on climate. In fact, their correlation is quite the opposite. Considering the physical characteristics of the most valuable soils from the agricultural aspects, the actual stored water stock and the monthly values of the balance components were the following:

- precipitation,
- stored water stock,
- evaporation.

These few data represent the yearly change of the cycle, the moisture content of the soil, and the values of the balance. As a matter of course, the variability of these values may greatly depend on the physical structure of the soil, the temporal distribution of precipitation, as well as the evaporation ability.

One of the most important ecological parameters of crop production is the water stock which can be taken up by plants, as well as its regional homogeneity. Since the physical heterogeneity of the soil is rather different along the profile, the change of the extent of moisture can hardly be determined from the quantities of the balance components. If the physical reality of the water balance equation is not harmed, it is possible to simplify the correlations of which several forms are known. There are no available long series (in climatic terms) of the soil moisture content, but *Varga-Haszonits* (1987a) estimated county mean values by means of calculation for the whole country. As a matter of course, this method has all those errors which could come from the inaccuracy of the equation used during the calculation. Based on a database which contains more than 30 years of measurement data, these components of the balance provided an opportunity to express the relative values of the water stock of the root zone related to a culture which has an average water need (grass). The relative value of crop water supply (*CWS*) can be estimated by using the following, seemingly simple equation:

$$CWS = \left[\frac{1}{F} \cdot R\left(XII - V\right) \cdot \frac{10 \cdot \sum R\left(VI - VIII\right)}{0.2 \cdot \sum T_d\left(VI - VIII\right)} \right] \cdot \frac{\left(e/E\right)_a}{\left(e/E\right)_m},$$

where (R) in the numerator is the amount of precipitation, the value in the denominator is the potential evapotranspiration, while $(e/E)_a$ represents the actual ratio of vapor pressure and saturation vapor pressure, and $(e/E)_m$ means the average ratio of vapor pressure and saturation vapor pressure for the same period, and T_d is the mean air temperature. The first member of the equation on the right is the value which depends on the physical condition of the soil, and it can be used to express the after-effect of soil moisture before the period of examination. Therefore, the equation expresses a recursive estimation. The value of water supply can be used to characterize the soil endowments, while it can also be interpreted from the climatic aspect; therefore, it can be regarded as a pedoclimatic correlation.

The regional distribution of the water supply (CWS) value – if the summer period is considered to be determinant – is the following: If the CWS value is <20, the region can be considered dry, CWS = 20–40 shows favorable water supply, while CWS > 40 is abundant and overabundant water supply. Due to the simplicity of the map, no extra explanation is needed.

5.4. Correlation between weather and agrotechnical effects

So far, the main characteristics of the range of findings were covered by the correlation between the climate and plants. With the advancement of agriculture, more specifically, modern crop production, the interest in various agrotechnical procedures got into focus. The main reasons for this phenomenon are the increase of soil fertility, the substantial unfolding of genetic potentials, and the protection of the physical condition and the living resources of the soil.

The organic medium of the soil and its health status makes it possible for plant nutrients to form continuously as a result of microbial activity. While the physical structure of the soil is a constant characteristic, the microbial processes in the soil greatly depend on its physical and chemical conditions. Significant research was carried out on the dependence of the nitrogen supply ability of soils on weather (*Szász* and *Lakatos*, 1991; *Nagy*, 2007). The nutrient stock of soil is an important component of the mentioned factor, since the dimension of the conceptual level of soil fertility mainly depends on this aspect. The determination of actual fertility is even more difficult, because the yield of plants cannot be increased without changing the actual fertility. Also, *Kreybig* (1953), *Sipos* (1979), and *Nagy* (1995, 2007) had a similar viewpoint as they emphasized that soil fertility is a dynamic characteristic and it significantly changes even within one crop year. Atmospheric effects play an important role in the change of soil fertility between seasons. The extent of soil fertility can be expressed by the collective of the chemical elements (e.g., mass fraction, etc.) that regulate the nutrient content of plants. In these series of factors, the available nitrogen forms develop in the phases of the C and N cycles. The activity of the microbial system which maintains this process depends on the quantity of bacteria at a given pH value, as well as the temperature and moisture content of the soil. The microbial activity, therefore, the dependence of the nitrate-nitrogen development on temperature is regulated by the Arrhenius equation concerning the value of the daily temperature fluctuation of soil:

$$v_M = K\left(\Delta T_{min}\right) exp\left(-E / RT\right),$$

where K is the dimensionless adjusting factor of living resources (currently referring to the bacteria sustaining nitrification) and T_{min} is the environmental temperature at which production is zero. This temperature can be considered to be nearly linear in the T_{min}–T_{max} range.

In addition to the theoretical statements, it is also necessary to talk about its significant role in practice. The amount of NO_3-N in 100 g soil (mg) is determined by soil temperature and its water content simultaneously: it is rapidly increasing with temperature in the case of average spring moisture, reaching its maximum at 15–20 mg/100 g in May at the time of the maximum precipitation. By the end of summer and in the early spring, the extent of forming drops back to a low level as a result of dried out soil, and then a secondary maximum develops by the end of autumn after the increase of moisture when the frequency of NO_3 decreases to about half of its highest possible value.

The dependence of the mentioned nitrification process on weather can be increased with favorable cultivation; therefore, it is worth maintaining a proper soil moisture content (water preservation, irrigation) and developing adequate soil moisture by loosening and compacting to be able to regulate the temperature. Most importantly, these tasks call for different cultivation methods on different soils in order to increase or maintain the level of soil fertility.

The natural soil fertility is not enough for the abundant nutrient supply of plants; therefore, its artificial increase became necessary by adding organic and mineral fertilizers into the soil. In relation to this procedure, the previously mentioned rule is applied again, since sustaining of the power of the soil is nothing else than the increase of the intensity of nitrification processes which is the consequence of microbial activity. The regulation of the extent of nitrification is done in an experimental way by artificially applied fertilizers. Usually, the yearly dose of nitrogen replenishment of soils with high fertility amounts to 120–150 kg/ha nitrogen fertilizers that are applied together with potassium and phosphorus (NPK) in order to increase efficiency. The effectiveness of fertilizers can be assured mainly by keeping the moisture content of the soil on the proper level. In other words, this means that the efficiency of fertilization is low in drought, and this effect reaches its maximum with maintaining around 70% of the relative moisture content of soils. Water abundance reduces efficiency in the form of leaching. Since each crop year has different characteristics, the efficiency is always different, too. *Fig. 8* shows the change of yield against different precipitation supplies depending on different NPK fertilizer doses in maize (*Rácz* and *Nagy*, 2011; Nagy, 2007). Providing fertilizer has an extraordinary importance in modern crop production, as if adequate soil moisture and fertilizer quantity is provided, 10–15% or even higher yield surplus can be reached in the case of water-demanding crops, while the lack of precipitation or the overdose of fertilizers could result in yield depression. In addition to the above, it has to be emphasised that the theoretical basis and the practical implementation of yield regulation in the mentioned form of fertilization calls for wide climatological knowledge, since economical yield increase with high efficiency can only be reached this way or by knowing how to conform to the climatic conditions.

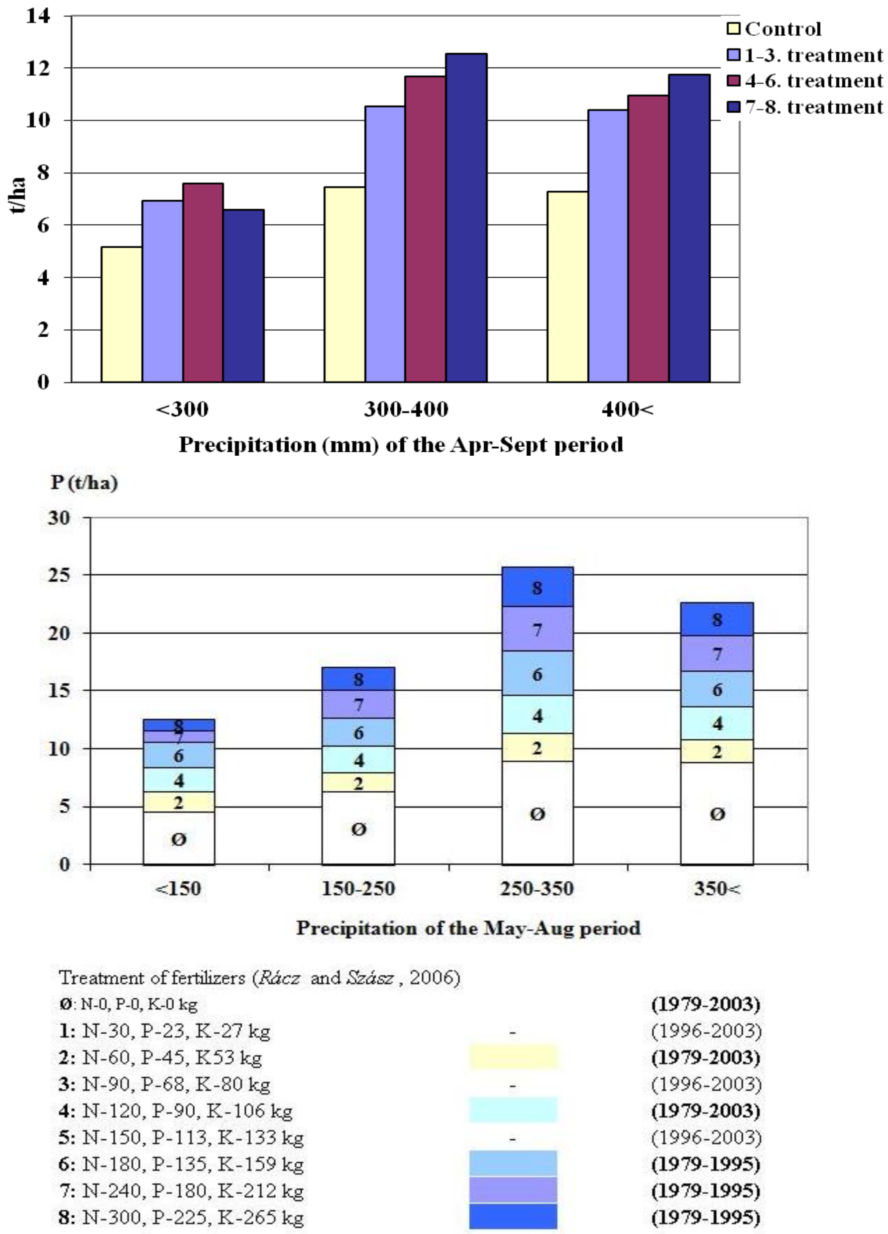


Fig. 8. Effects of mineral-fertility on corn yield by different natural water supply.

Fig. 8 shows the time series of the average yield of maize with different fertilization. On the horizontal axis the amount of precipitation are shown for the given period. Based on these time series, it can be established that the same fertilizer quantity provides significant yield surplus in the case of better precipitation supply. This statement shows that the nutrient effect will only unfold if the increased water demand is satisfied. These data were taken from a long-term field experiment carried out at the Hajdúság loess ridge (*Nagy*, 2007).

The effect of nutrient supply on water need was a generally researched topic. This issue was analyzed within the framework of numerous agrometeorological experiments (Keszthely, Szarvas, National Meteorological Service). As a general observation, it is known that if the average amount of precipitation is supplemented with around 50 mm irrigation water, the efficiency of fertilization increases significantly (*Antal,* 1968; *Posza* and *Tóth*, 1975; *Antal et al.,* 1977; *Tóth,* 1978; *Dávid,* 1981).

The two mentioned agrotechnical interventions: irrigation + fertilizer effects are the most influential factors concerning the efficiency of crop production; therefore, the research of these factors is among the most important topics even today. One should not neglect the fact that these two agrotechnical effects amount to 30−40% of the prime production costs in crop production. This high amount of costs makes it important to explore the correlations of this topic to an even deeper extent, since they could contribute to the reduction of production risk.

In addition to field experiments, the joint examination of water and nutrient supply is also carried out in so-called evapotranspiration model experiments in a rather manifold way in two locations (Szarvas, Keszthely). The model experiments clearly show that this bifactoral experiment makes it possible to determine the optimal ratio of interaction between water and nutrients which can have a significant role from the aspect of producing crops with average and high water needs. Solving this problem would not only have professional significance, but it could also satisfy an economic requirement.

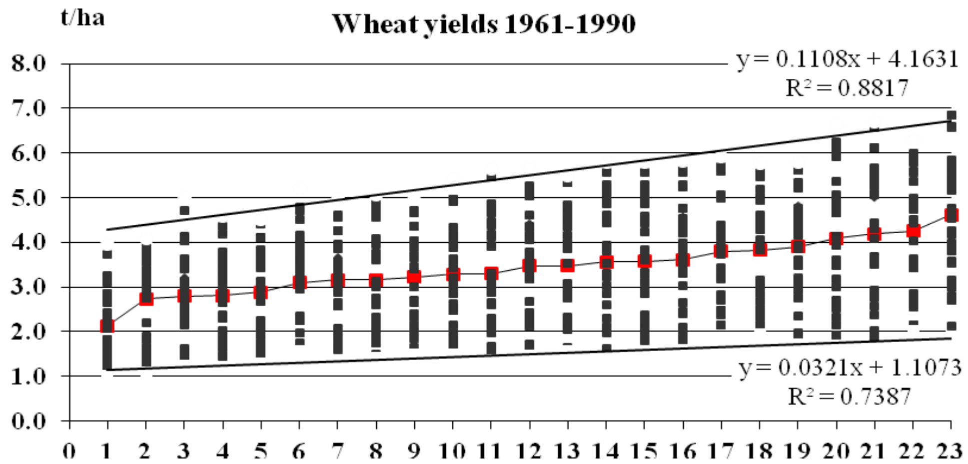
In addition to the above, it has to be emphasized that these sections summarize only the historical framework of the Hungarian agrometeorological research. There were numerous research results in various topics – mainly in relation to issues close to agriculture – which constitute the problems of various long-term experiments. As a matter of fact, these and similar cooperations should be regarded praiseworthy, due to their successfulness (*Dávid*, 1981, *Berényi*, 1945).

In the agricultural crop production in Hungary, there was a significant change in the modernization of the nutrient management of soils in the 1950s in addition to numerous other processes. In the early fifties, the once traditional organic manure use was switched by the widespread use of mineral fertilizers. The new technology raised new problems, one of which is the determination of the quantity and proportion of mineral fertilizer supply in the case of crops with various nutrient needs. As a matter of fact, Hungarian soils have rather heterogeneous structure and this characteristic is also shown by their nutrient supply. By properly building up the nutrient balance of soils, the specific fertility of soils can be improved which can mainly be expressed in yields. There are numerous well known approaches which say that increasing nutrient supply could moderate yield reduction (*Bocz* and *Szász*, 1962). According to other examinations, the yield fluctuation of different crops is still significant, even though it has changed – some decreased, others increased – for other reasons not mentioned here. From this aspect, the reason of fluctuation is mainly the climatic endowments. In order to clarify this issue, there was a wide survey in the eighties in Hungary to find an explanation to this phenomenon. Although the ratio of the variability of yield and each weather element did not change substantially, the dependence of plants on weather; therefore, their climate sensitivity still existed as shown by standard deviation analyses. It seems that this question is still not fully answered, as further examinations are necessary to explore the causal correlation between weather variability and the standard deviation of yield. *Table 5* shows the 30-year-long time series of wheat and maize which are the two main crops in Hungary. During the analysis of these series, it was established that the correlations between the two phenomena did not change substantially – $r = 0.6 - 0.8$ – which shows that there was no significant change in the ratio of standard deviations, only the yield level increased. In other words, the relative yield fluctuation really decreased with the increase of yields, but its absolute value did not increase. Based on this, it can be stated that the average yield of crops moderately increase as a result of yield level increase in the case of the same climatic effect. This issue is one of the fundamental points of the modernization of crop production.

Table 5. Average corn and wheat yield, standard deviation (S) and coefficient of variation (CV)

Soil region	Corn yields (t/ha)			Wheat yields (t/ha)		
	Mean 1961-90	S	CV	Mean 1961-90	S	CV
Szeghalom	3.04	0.79	25.80	2.13	0.78	36.52
Edelény+Encs	3.19	1.25	39.15	2.73	1.01	36.94
Kiskőrös	3.19	1.25	39.31	2.79	0.95	34.20
Fehérgyarmat	3.26	1.03	31.57	2.81	0.94	33.46
Nyírbátor	3.38	1.06	31.29	2.88	1.03	35.76
Gyöngyös	3.64	1.37	37.56	3.10	1.06	34.34
Gödöllő	4.05	1.48	36.64	3.16	1.03	32.63
Pápa	4.08	1.26	30.93	3.16	1.15	36.43
Barcs	4.17	1.23	29.45	3.22	1.06	33.04
Vas	4.19	1.44	34.33	3.29	1.08	32.86
Zalaegerszeg	4.22	1.40	33.04	3.30	1.24	37.69
Siófok	4.28	1.29	30.14	3.47	1.20	34.73
Kunszentmárton+Szentes	4.56	1.58	34.63	3.47	1.27	36.52
Siklós	4.57	1.52	33.30	3.57	1.35	37.94
Csorna	4.60	1.40	30.52	3.58	1.33	37.28
Komárom	4.66	1.66	35.74	3.62	1.32	36.57
Szolnok	4.73	1.70	35.89	3.80	1.26	33.21
Baja	4.86	1.48	30.39	3.83	1.22	31.92
Sárbogárd	5.04	1.69	33.56	3.90	1.22	31.29
Hódmezővásárhely	5.31	1.94	36.57	4.08	1.51	36.88
Szekszárd	5.35	1.78	33.27	4.19	1.63	38.84
Mezőkovácsháza	5.54	1.56	28.14	4.25	1.35	31.75
Hajdúhát	6.49	1.98	30.49	4.62	1.45	31.47

Fig. 9 shows yearly yield of wheat and corn in different growing regions between 1961–90 in Hungary. The increase of nutrient supply results in the increasing water demand of crops. Since the variability of precipitation supply did not decrease, the increased yields could react more powerfully to the extent of water supply. The reaction to water supply is increased by the increased water need, although the amount of precipitation showed a decreasing tendency over the past decade. As a result, drought periods and crop years are becoming more frequent. (*Ruzsányi,* 1974, 1992)



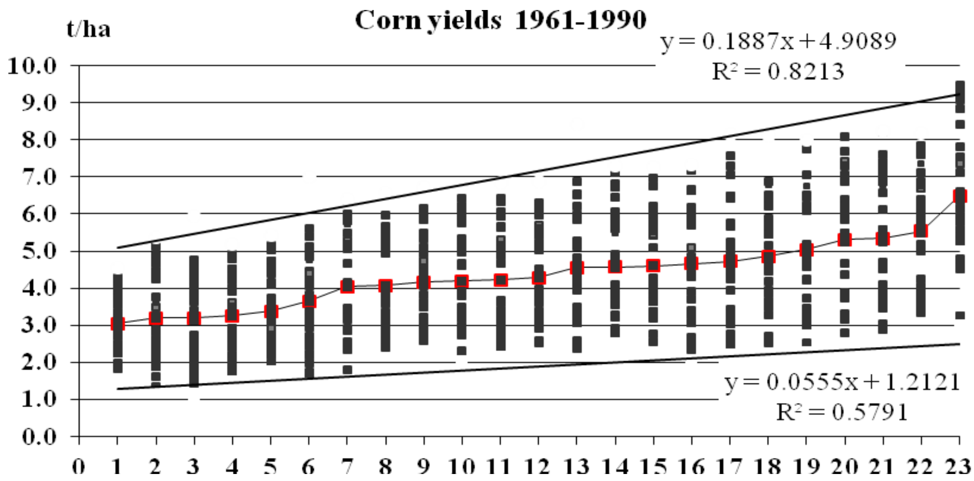


Fig. 9. Yearly yield of wheat and corn indifferent growing region between 1961–90 in Hungary.

Explanation of numbers on horizontal axis is given below in details.

Soil type	**Nr.**
Low-fertility soils (skeletal soils, bog soils, salt-affected soils)	1, 3-5
Brown forest soils	2, 6-11
Meadow soils, alluvial and sedimentary soils	13, 17, 22
Chernozem soils	15, 18-21, 23

The increase of nutrients and the associated yield increase reach its maximum if the nutrient effect unfolds in the case of favorable water supply. It is an undisputed fact that the extent natural water utilization became more favorable with the increase of yield, while this phenomenon is further intensified by the modest natural water supply level. This latter is favorable until a certain critical value, but the stronger unfolding of water shortage reduces the extent of water utilisation and develops disorders in crop growth, finally resulting in yield decrease.

5.5. Micrometeorology in agrometeorology

Within the framework of complex meteorological research, the physical problems of meteorology are often raised from theoretical and practical aspects in various areas of meteorological practice. As a matter of fact, this phenomenon is ordinary, since it represents two sides of a problem. The predecessor of agrometeorology is the complex and complication of empiricism, physics, micrometeorology, and energetic and aerodynamic processes in the frictional space of the surface. Agrometeorology gets increasingly involved in the interpretation of various parts of agriculture, but its methods are based on physical principles, and it mainly uses the direct physical findings of the surface boundary layer while interpreting biological processes. Today, this phenomenon is clearly shown by the fact that well known international journals feature lots of practically usable findings of agrometeorological research which are based on physical principles among studies that show the aims of nearly sterile meteorological examinations. Despite the fact that agrometeorology and micrometeorology are only narrow branches of science, neither of them can exist without the other concerning the issues they are dealing with; therefore, disciplinarity can be clearly recognized from both sides. In Hungary, agrometeorology originated from empiricism and it also took elements from climatology in order to survey meteorological impacts. From this position, agrometeorology builds a more detailed physical basis while gradually leaving climatology behind in order to provide solution to various problems. Based on this path, it can be established that agrometeorology was not separated from meteorology. On the contrary, it increasingly utilizes the new physical knowledge that formed in the field of micrometeorology. However, agrometeorology attempts to show them “in different clothes” in the area of a more practical science. This process was clearly expressed in the past 50 years in Hungary.

At the beginning, the process described above was shown in the instructions of the former German “Geiger” school, which described the phenomena in the air space close to the surface in a descriptive way under the summarizing name of microclimate and it also attached a speculative explanation to the description of these phenomena, assuming the causal aspect of their background. Microclimatology was widespread mostly in European countries; therefore, there is a large number of related case studies among Hungarian micrometeorological publications, especially from the previous decades.

Agricultural microclimatology observes the yearly and daily cyclic condition changes triggered by plants, the change of temperature and moisture profiles in plant populations and the difference from the profiles above the flat surface and grasslands free from plants. In Hungary, agricultural microclimatology was known as “population climate” both in agriculture and meteorology. At the beginning, the research dealing with this branch of science did not aim at finding the physical explanation for the development of profiles. Instead, the goal was to explore the relationship between the developed profile and some physiological processes of the plant. Therefore, the population climate, or, in other words, vegetable microclimate did not consider the difference between the profiles to be the production of a dynamic process, but mainly of its biological consequence (*Endrődi,* 1967, 1974; *Hunkár,* 1985; *Justyák,* 1989). According to this point of view, the plant population does not intend to explain the quantified evaluation of the physical processes going on in the air space. Instead, the primary subject of interest was the impact of the air condition on plants in high detail. It is not a coincidence that the erroneous nature of this approach did not provide the importance of the new knowledge from the physical aspect from which it could have been the initiator of various biophysical conclusions. It is an undoubted fact that the correlation between the air space of the canopy and the physiological processes of the plant can be considered an especially important knowledge, but the new observations provided usable scientific information mostly in the field of plant biophysics (*Dunkel,* 1984; *Cselőtei,* 1987; *Varga-Haszonits,* 1987b; *Anda* and *Lőke,* 2005).

Canopy climate research was launched in the decades after the turn of the century in Hungary and abroad. In Hungary, *Kálmán Kerpely* performed various population climate-related examinations with the aim to determine the resulting impact between temperature, moisture and evaporation ability in various grown crop populations. The mentioned examinations were carried out in the field experiments established at the Debrecen Agricultural Academy with notable results. The main findings of these examinations referred to the exploration of the joint efficiency of the nutrient and water supply. The work performed in the mentioned field is still significant today.

Later, German researcher *Geiger* organized highly detailed canopy climate research projects in the populations of field crops and forests. The aim of this research was to emphasize the population climate modification role of water supply. *Berényi* extended the population climate research while also considering the microclimate modification impact of the relief in addition to the biological need of plants (*Berényi,* 1954, 1958; *Justyák,* 1960; *Borhidi* and *Dobosi,* 1967; *Szász,* 1973a,b, 1988).

While we acknowledge the agrometeorological significance of population climate research findings, it can be established that the static-focused work needs to be renewed, which was first recognized in foreign research stations. The meteorological use of the physical examination results of the boundary layer – Prandtl's layer – provided an extensive space for evolving new directions while accepting the findings of the previous population climatological research. The modernization was founded by the general use of energetic measurements, as well as the detailed exploration of the aerodynamic rules of energy and material transfer, further extending the possibilities of complex agro- and biophysical research which justified and explained the previously observed change of conditions with proper physical reality. The simpler energy balances and the implementation of the quantified analysis of turbulent sensible and latent heat transfer provided new bases for a significant part of agrometeorology both in macro- and microclimatic senses. This way, agrometeorology became an interdisciplinary science which made use of atmospheric physical and agricultural knowledge jointly. The theoretical cognition and methodical use of turbulent transport processes made it possible to describe the processes with mathematical correlations based on physical principles – an opportunity that had only been a desire until this point. Furthermore, based on these correlations, a phase of processes can be built up bases on which model-based research findings can be obtained.

Today, modeling can be considered a reachable goal in agrometeorology, despite the fact that gathering and arranging theoretical knowledge still calls for numerous tasks to be done. It is possible to describe the processes which will serve the purpose of the basic model of scientific life by building together separate processes later, based on the results of measurement systems built on digital bases. It has to be emphasized that the most critical point of this problem is the development of the right algorithms that could be regarded as bricks in the building of science (*Ábrányi,* 1978; *Hunkár,* 1984, 1986, 1990; *Szász*, 1987; *Dunkel et al*., 1987, 1989; *Szabó,* 1988, 1989; *Justyák,* 1989; *Ács,* 2004).

From this viewpoint, the Hungarian agrometeorological research is successful, since numerous research findings were obtained which provided model-based results in order to make progress. The modeling activity that is becoming increasingly accurate is a hopeful tendency that has enormous progress today in international relations. It has to be emphasized that the professional representatives of this tendency do not only increase the values of the agrometeorological research in a narrow sense, but they have high significance in developing practical agriculture both from theoretical and practical points of view. The high level economic utilization of the model system of agricultural activities is recognized in a definite form today, but it can only be hoped to become more extensive if the branches of science associated with agriculture, e.g., agrometeorology will contribute actively to this joint activity. In this field, the Hungarian agrometeorological research calls for further development in order to carry out joint development. The sum and collective of partial potentials represent the level of total active potential concerning all areas. In other words, this means that without the cooperation of the related branches of knowledge, it could become doubtful to reach the potential borders; therefore, the performance level of the scientific society stays under the potential borders.

In addition to the above, it has to be emphasized that these sections summarize only the historical framework of the Hungarian agrometeorological research. There were numerous research results in various topics – mainly in relation to issues close to agriculture – which constitute the problems of various long-term experiments. As a matter of fact, these and similar cooperations should be regarded praiseworthy, due to their successfulness.

6. Conclusions and results

The Hungarian events and findings of the more than one and half-century-long history of agrometeorology could be summarized as follows:

1. Modernization of agriculture in Hungary was extended in the second half of the 1800s, mostly due to Western European impacts.
2. Around the middle of that century, agricultural higher education institutions were established, providing a professionally educated expert basis for the subsequent periods.
3. In the years between 1850–2000, research institutes were established which helped Hungary becoming increasingly effective in launching international agricultural research.
4. The National Institute of Meteorology and Geomagnetics started to work in 1870 and launched organized and controlled climatological observations at its stations while connected to the international network.
5. At the beginning of the 20th century, the first standard climate elements appeared in the form of 30-year averages (1870–1900).
6. Empirical climate-based agrometeorological research was launched, dealing mostly with the issues of successful prevention of damages caused by weather (e.g., frost, drought, water logging, wind).
7. There was a restructuring in the Hungarian climate network at the time of the World War II.
8. Effect functions, indexes and statistical indexes in accordance with the empirical or physical correlations serving the characterization of the climate and the temporal and spatial change of agrometeorological processes were worked out.
9. By the middle of the 20th century, a national climatic database was established as a result of the joint work of the Hungarian Meteorological Service and the main research institutes. This database made it possible to

establish an agrometeorological information system.

10. The research order of agrometeorological research started to unfold characteristically in the 1960s:
    a. statistical agrometeorology,
    b. agrometeorology built on biophysical bases,
    c. model-based agrometeorology.

    The interpretation range of all specialized branches was continuously becoming increasingly widespread, thereby establishing theoretical bases in a way that they could finally be clustered into a complex research system.
11. For today, the findings of this branch of science which is built on climatic and micrometeorological bases contribute to the development of agriculture in a manifold way. Therefore, the requirements of increasing the natural energies by man also increased.
12. The need for the cooperation between meteorology and agriculture resulted in the further increase and efficiency growth of both fields of science.

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