THESES OF DOCTORAL (PhD) DISSERTATION

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THE EFFECT OF CLIMATIC VARIABILITY ON WINTER BARLEY PRODUCTION

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1. THE AIM OF THE RESEARCH

The aim of the research is to provide a comprehensive picture of the agroclimatological conditions of winter barley, an important fodder grain crop in Hungary, as any study of that nature has not been published in our country yet. The research involves investigation aimed to discover the scope of compliance of the climate in Hungary with the climatic demand of winter barley along with the impact of climatic conditions on the development of the plant and its crop yield. The study seeks to reveal

- how meteorological elements influence the content of the phenophase and the phase of developing, as well as the nature of the growing season
- whether the multiplicative successive approximation model worked out to determine the impact of climatic factors on winter barley yields is suitable for estimating yields
- As in lives of plants – especially in the size of actual crop yields – such factors as water supply and radiation are of vital importance, the present study intends to investigate the water demand, water supply, water and radiation use efficiency of winter barley. This was essential to define the climatic potential and to work out (agro)climatic classification for agriculture.

2. MATERIAL AND METHODS

Databank as basis to the research

Meteorological data. Meteorological data can be classified in two major groups: measured and derived (calculated) data. Data measured in compliance with the relevant rules and regulations at representative observation stations by instruments developed for meteorological purposes derive from the observation network of the Hungarian Meteorological Service (OMSZ): Balassagyarmat, Kaposvár, Kecskemét, Pápa, Martonvásár (1951-1990); Békéscssaba, Budapest, Debrecen, Győr, Iregszemcse, Kecskemét, Kompolt, Miskolc, Mosonmagyaróvár, Nyiregyháza, Pécs, Szeged, Szolnok, Szombathely, Zalaegerszeg (1951-2000).

Derivative data (photosynthetically active radiation, evaporation, soil moisture) were determined on the basis of available measured data with the help of methods worked out within former agroclimatic research.

Phenological data. This databank contains data measured by the observation network of the Hungarian Meteorological Service and the phenological observation network of the National Food Chain Safety Office (it is the successor of former Central Agricultural Office): Eszterág, Debrecen, Tordas (1967-94); Kompolt, (1967-97); Debrecen, Iregszemcse, Kompolt, Mosonmagyaróvár, Székkutas, Eszterág, Villány, Cserkút, Gyulatanya, Nyíregyháza, Karcag, Füzesabony, Tordas, Agárd (1984-97).

Agroclimatological characterization of the growing season of winter barley

In order to be able to analyse the growing season of winter barley, above all, we should get acquainted with the spatial and temporal changes the plant goes through from the sowing to the ripening, including the trend of changes during each phenophase of the plant.

During phonological investigations we studied not only the timing of the phenophases but the content of those as well. We examined the yearly fluctuation between phenological dates and the duration of phenophases.

The effect of climatic variability on the phenophases of winter barley

Clarifying the nature of relationship between the various phenophases and the entire growing season is also important since we need to have a comprehensive knowledge of how the change of the lengths of the phenophases might influence that of the growing season, as it is obvious that meteorological effects occurring during phenophases more closely related to the growing season are even more significant. Therefore we are to determine which phenophases have the most influence on the length of the growning season, since climatic impact might prevail mostly through these periods.

The effect of climatic variability on the crop yields of winter barley

Separating agrotechnical and meteorological effects. As in our country – in the case of rising winter barley crop yields – an increasing yield fluctuation can be seen around agrotechnical levels, a multiplicative relationship of effects should be assumed. If the agrotechnical effect described with a trend function is Yo(t), and the function expressing the joint effects of meteorological factors is f(M), the value of crop yield Y(t) can be calculated as follows:

$$Y(t) = Yo(t) \cdot f(M). \quad (1)$$

From this, on the basis of trend ratio, the function of meteorological impact can be defined:

$$\frac{Y(t)}{Y_o(t)} = f(M) \quad (2)$$

Carrying out the aforementioned calculation for each meteorological element (m_1, m_2,...,m_k) by using different natural and calendar periods of the growing season both meteorological elements with significant influence on crop yield and the period when they occur can be selected. During the research, the function describing the impact of meteorological factors can be estimated by using of multiple regression methods. In this manner meteorological impact function, that is, the estimation function (Y(t)*), can be written as follows:

$$Y(t)^* = Yo(t) \cdot f(m_1) \cdot f(m_2) \cdots f(m_k) \quad (3)$$

Yield estimation by the residual method. One of the possible methods for defining equation (3) is the residuum analysis-based multiplicative successive approximation procedure (successive approximation), through which the effects of meteorological factors can be estimated; hence trend ratio and crop yield can also be predicted. Considering m_1, m_2,...,m_k meteorological factors included in the study, the multiplicative function of meteorological effects in successive periods can be calculated by means of the residual method-based multiplicative successive approximation, involving the different variables consecutively. With the help of this method, the elements that influence winter barley yield can be selected and the strength of their impact determined. Furthermore, estimated and actual crop yields can also be compared.

Verification and validation of results. Results are assessed in two steps. On the one hand correlation between calculated and measured values is defined on the other hand, the frequency distribution of different errors during the estimation processes is investigated. The error of estimation, which is the difference between the measured and calculated values, was expressed as a percentage of actual crop yields.

Analysis based on monthly and seasonal periods. The study reported analyses first the impact of temperature values on crop yields, individually applying simple regression functions. There are two periods during the growing season in which temperature exerts a significant influence on yield, namely the mean temperature of winter months (December, January, February) which is important because it has an effect on overwintering of barley, and mean May temperature (a short period before and after the flowering phenophase). By means of the residual approach (multiplicative successive approximation process), analysis targeting the joint effect of the selected periods can also be accomplished.

Analysis based on ten day period related data. The present study determines the periods with significant temperature impact based on dataseries of 30, then 40 and finally 50 years. Correlation with trend ratio was investigated concerning each ten day period. By implementing the selection of the most significant periods concerning winter barley yield separately in the case of all observation stations, phases of the model may differ at different observation stations.

Radiation use efficiency of winter barley

In case we would like to determine radiation use efficiency referring to economic crop, it can be calculated as follows:

$$\varepsilon = \frac{Y \cdot Q_0}{FAKS} \qquad (4)$$

When calculating the coefficient of radiation use efficiency including the total volume of biomass, the aforementioned economic crop is to be divided by HI. The HI (harvest index) value of barley is 0.39; the energy demand (Q_0) of producing one single unit of biomass is 17000 kJ for 1 kg of organic substance.

If Y_{GAZD} is given in kg/ha, Q_0 kJ in kg, then the value of FAKS has to be converted into $KJ \cdot ha^{-1}$. The results obtained are normally expressed in %.

Water use efficiency of winter barley

When characterizing the water use efficiency of plants we define the quantity of crop that the plant produces by evaporating one single unit of water content, that is, the water use efficiency (WUE = water use efficiency) is:

$$WUE = \frac{Y}{E} \qquad (5)$$

where Y is the value of economic crop (grain) expressed in g/ha, E indicates the actual evapotranspiration within the entire length of the growing season (expressed in kg/ha).

3. RESULTS

3.1. An agroclimatic description of the growing season of winter barley

3.1.1. Statistical characteristics of winter barley phenophases

In the period of the phonological chronology between the years of 1967-1982 the length of growing season fluctuated between 260 and 280 days and by the late 1970s it approximated the length of 260 days, that is, it showed a slightly decreasing tendency. After 1982 the length of the growing season – except one or two years – became shorter than 260 days, thus, the trend of change reflects a significant shortening of the growing season. This phenomenon can be explained by the fact that there was a bigger change in temperature after the 80s.

3.1.2 The system of climatic conditions of winter barley production

Thermal characteristics of the growing season of winter barley. The research findings conclude that the growing season of winter barley – compared to the period of other annual plants – is cooler and wetter. Thus, the most frequently predicted tendency of up warming as a result of climate change is assumed to generate less extreme conditions for winter barley than for other annual grain crops, provided that the tendency of change is present over the whole year.

Hygrical characteristics of the growing season of winter barley. As for all meteorological factors, hygrical elements display a higher level of variability in general, therefore the study reported investigated the water supply conditions of winter barley in terms of soil moisture and evaporation demand. The research findings underlie that the growing season of winter barley is characterized by relatively favourable water supply conditions.

3.1.3 Natural periods

In the autumn term between the time of sowing and the date of mean temperature values falling beyond 5 degrees centigrade the plant has 40-50 days on average to develop strong enough for the resting period (**Table 1.**).

Table 1. Statistics of phenophases of winter barley and the beginnings of natural phases (1984-1997)

Observation station	The sequence numbers of different phases								
	Length of sowing - $D_{Ő5}$ period			Lenghts of period between $D_{Ő5}$ - D_{T5}			Length of ripening D_{T5} - period		
	min.	av.	max.	min.	av.	max.	min.	av.	max.
Miskolc	23	37	51	109	132	145	59	83	102
Kaposvár	21	40	55	110	130	148	70	98	154
Kecskemét	22	45	73	98	124	138	70	82	95
Mosonmagyar-óvár	15	43	60	99	125	138	76	86	102
Nyíregyháza	25	36	49	106	129	143	72	92	111
Békéscsaba	33	44	60	94	121	136	77	90	104
Szolnok	36	47	60	96	122	135	72	84	110

In the overwintering phase, when daily mean temperature values are beyond 5 degrees, the plant is in the resting phase, which lasts from the middle of November till mid-March. The spring term lasts from the time temperature rises above 5 degrees (D_{T5}), which is mid-March, till the ripening phase in mid-June.

3.2. Climatic impact on winter barley phenophases

3.2.1. Meteorological conditions and plant development

Climatic variability and the duration of phases. The present research concludes that the sowing-emergence phase in the autumn term appears to be longer, since the date of emergence showed a three-day-delay. The trend of changes of length of the emergence-shooting phase which also involves the overwintering period – due to its complex nature – can hardly be generalised. Spring term phenophase durations were basically characterised by shortening of durations of phases. The rising tendency of temperature change after the 1980s provides an explanation to this phenomenon.

Thermal elements and plant development index. As it is well- known in plant physiology, temperature and solar radiation are in correlation, they jointly effect plant development, which can be properly demonstrated by the radiothermal index. In our country, the length of phenophase can be defined in a nearly deterministic way by applying the radiothermal index.

The close linear relationships between the sum of thermal elements and lengths of phenophases make it possible to create a plant development index based on the sums of thermal-meteorological elements. With the help of this index, the development of the plant can be monitored on a daily basis. Calculation results can be verified by clarifying the relationship between calculated and the actual values. These calculations prove that, in our country, primary the sum of photosynhetically active radiation and the sum of temperature values can be applied for calculating the plant development index. A closer correlation of the results could only be expected in case the determination of the potential amount hallmarking particular periods could be refined.

3.2.2. Date of ripening of winter barley

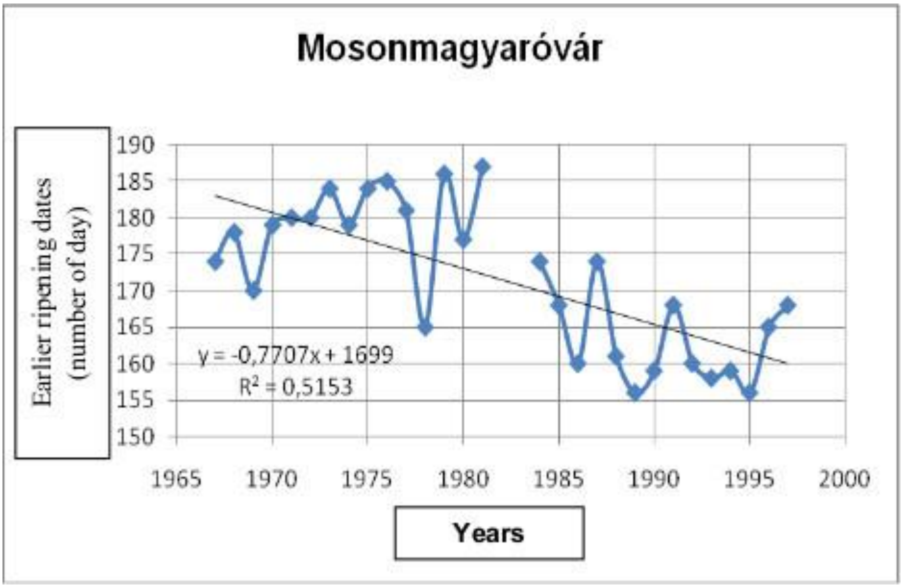

Figure 1. Yearly fluctuation of earlier ripening dates of winter barley

The ripening phase of winter barley tended to shift towards a bit later dates during 1967-1981, whereas between the years 1982-97 there is a significant shift towards much earlier ripening dates (**Figure 1)**. As a result of recent climate changes, a definite trend of earlier ripening dates can be seen. If we describe the trend of this change on a linear scale, we can conclude that the ripening phase of winter barley gets shorter with 0,77 day per year, consequently it means 7,7 days in every 10 years, that is, it has shifted to an approximately one week earlier ripening date in our country.

When examining discrepancies between values calculated on the basis of the date of emergence and observed values it can be concluded that after 1980 the error of estimating the ripening date of barley based on the date of emergence is within ± 4-6 days with around 70% feasibility. Since the forecast embodies more than 7 months (200 days) it can be considered an appropriate interval estimation.

3.3. The impact of climatic variability on winter barley crop yield

3.3.1. Studying sensitivity

Determination of meteorological impact functions. The effect of agrotechnical factors (variety, nutrient supply, plant protection) can be demonstrated by a trend function of the third degree (**Figure 2)**.

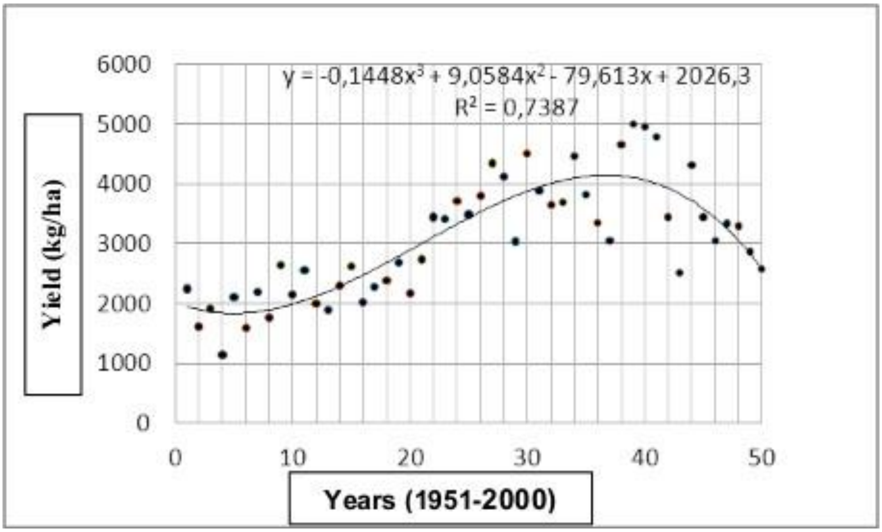

Figure 2. Trend function calculated on the basis of actual grain crop yields in Jász-Nagykun-Szolnok County between 1951-2000

Trend ratio values ($Y(t)/Y_0(t)$) can be calculated on the basis of trend function values, which expresses the rate of change between actual crop yields and trend values.

3.3.2. Analysis based on seasonal and monthly data

Investigating the effects of winter and May mean temperatures. The effect of winter and May mean temperatures was described by a polynomial of the second degree (**Table 2)**.

Table 2. The effect of mean temperatures on trend ratio. Values of quadratic correlation coefficients of winter barley (1951-2000)

Effect of mean temperature on trend ratio			
County	**Town**	r_{winter}	r_{May}
Győr-Moson-Sopron	Győr	0.51	0.36
Vas	Szombathely	0.55	0.34
Zala	Zalaegerszeg	0.42	0.30
Tolna	Iregszemcse	0.40	0.20
Baranya	Pécs	0.38	0.13
Bács-Kiskun	Kecskemét	0.34	0.41
Pest	Budapest	0.43	0.50
Jász-Nagykun-Szolnok	Szolnok	0.49	0.43
Csongrád	Szeged	0.34	0.36
Békés	Békéscsaba	0.43	0.25
Hajdú-Bihar	Debrecen	0.60	0.35
Szabolcs-Szatmár-Bereg	Nyíregyháza	0.47	0.28
Borsod-Abaúj-Zemplén	Miskolc	0.54	0.42
Heves	Kompolt	0.48	0.48

Temperature of both the overwintering period and May can significantly influence the actual winter barley crop yields. The estimation error remained under 5% in nearly 20% of the cases, considering the total amount of cases estimation error occurred in less than 10% in 50% of all cases. A bit more than two thirds of all cases proved to encounter estimation errors in less than 15%.

Analysis of successive effects via residual method. The examination of successive effects of mean winter and May temperatures applying the residual approach confirms a close linear relationship and its correlation coefficient is r = 0.9197, that is, its coefficient of determination is r^2 = 0.8458 in Jász-Nagykun-Szolnok county (**Figure 3**).

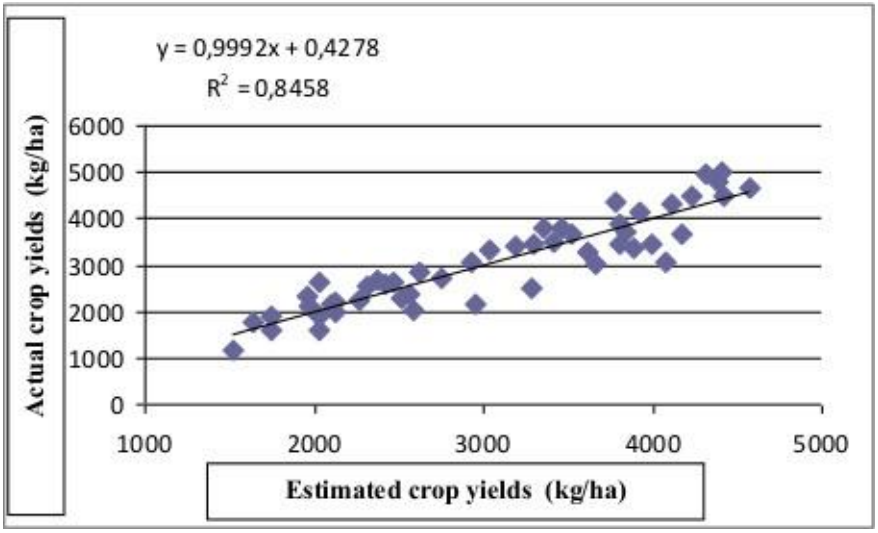

Figure 3. Comparison of estimated and actual crop yields in Jász-Nagykun-Szolnok County (1951-2000)

Temperature imposes a strong effect on winter barley yields in this county. This effect is especially significant in the winter months and in May which is the phase of heading-flowering. Similar results were obtained in the other counties. Therefore it can be concluded that a possible climate change would effect winter barley production significantly. Hence, the application of the method will lead to results proper for estimation purposes.

3.3.4. Analysis based on ten day period data

Temperatures of the third ten day period of October and the second ten day period of November in the autumn term reflect a closer relationship to crop yield. As for winter months, thermal conditions of the third ten day period of December and the first and second ten day periods of February bear a major impact on crop yields (it might be related to vernalization, however, further research is needed to prove this).

Thus, a ten day period-based research also underpins the importance of winter thermal effects. Concerning springtime, the third ten day period of April, the third ten day period of May and the first ten day period of June have a major effect on crop yields. The coefficients of determination (r^2 values) were higher than 0,9 at all observation stations, which means that correlation coefficients (r values) were close to 1.

Verification and validation of results. It can be assumed that during the estimation processes carried out by applying the method 30-50% of estimations will differ less than 5% from the actual values, whereas 70-80% will contain estimation errors less than 10%. Hence, with this method we are able to estimate yield in approximately three quarter of the cases with errors less than 10%.

Research findings underpin that the multiplicative successive approximation model is suitable for estimating the crop yields of winter barley which grows in the cool and wet part of the year. Furthermore, the model can even be simplified by presuming that water supply will remain favorable during the growing season of winter barley from year to year. Rarely should we expect drier periods, as those occurred in our country mainly from July on.

As for research based on the period of ten day periods, the method is accurate in terms of practical aspect and is suitable for promptly estimating crop yields latest in the first ten day period of June. Winter barley is harvested at the end of June or at the beginning of July, therefore information gained one month before harvest can be useful as well (e.g. regarding storage, market positions etc.).

The model applied is able to consider the impact of subsequent periods and represents a major step from purely statistical models towards dynamic models. The model can be employed to investigate in which stages of the growing season the aforementioned changes occur. On the other hand, effects caused by these changes can be monitored numerically through crop yield values.

3.4. Climatic potential of winter barley

3.4.1. The radiation use efficiency of winter barley

Compared to the theoretically possible maximal radiation use efficieny data, values of radiation use efficiency gained during our research and referring to the economic crop yields of winter barley are relatively low: they are 0,2 %-0,5 %. It would be expedient to increase the value of radiation use efficiency coefficients of some important economic crops, because in this case we would achieve proportionally bigger yields. This aim can be realized through the selection of species that utilize radiation in a more effective way and the application of practical processes that enhance radiation use efficiency.

3.4.2. Water use efficiency of winter barley

Assuming favorable water supply conditions and the insurances of suitable nutrient levels and plant protection, under the climatic conditions of our country the potential of actual maximum crop yields determined by water use efficiency remain under 10 t/ha in the cooler northern and western regions, while they are over 10 t/ha in the other parts of the country.

4. NEW OR NOVEL SCIENTIFIC ACHIEVEMENTS (THESES)

1) Within the investigation of the impact of meteorological elements on winter barley phenophases – with the help of the radiothermic index – we succeeded in detecting a much closer, nearly deterministic correlation than any domestic research achieved before.
2) Our research findings indicate a close relationship (with a correlation coefficient over 0,9) between the date of emergence and the length of the emergence-ripening phase, which supports the estimation of the date of ripening and harvest of the plant.
3) We numerically determined how the plant utilizes the radiation available during the growing season. The national average values of radiation use efficiency of winter barley referring to economic crops increased from below 0,25% in the early 1950s to over 0,5% by the end of the 1980s. In the last ten day period of the millennium this value shows significant decrease because of agrotechnical reasons.
4) We quantified how the water content evaporated of winter barley is utilized for the actual crop yield of the plant. Average values reflect that the evaporation of each kg of water produces 0,85-1,10 grams of grain crop. Maximal values fluctuate between 1,40 and 2,15 grams. It is remarkable that in counties located in the northern part of the Great Plain (Jász-Nagykun-Szolnok, Hajdú-Bihar and Szabolcs-Szatmár–Bereg County) maximum values exceed the quantity of 2 grams. Minimum values fluctuate between 0,29 and 0,54 grams.
5) The multiplicative successive approximation model, which is based on the determination of residuum, enabled to define a close correlation

between the meteorological elements during the growing season of winter barley and the actual grain crop. Thus, it was possible to select the most significant periods of the growing season from the aspect of meteorological factors. Furthermore, the research also identified the meteorological factors which influence crop yields the utmost, which proved as a proper tool in estimating crop yields with less than 10% of estimation error in more than 70% of the cases, which can be considered a very good outcome.

6) We worked out a climate-yield model based of the production levels defined by de Wit, in which we determined

- the 3rd and 4th levels of agrotechnical factors (variant, nutrient supply, plant protection) by applying a trend function,
- the 2nd level of water supply by the agroclimatologial analysis of both soil moisture and evaporation demand
- the 1st production level of meteorological effects by the multiplicative successive approximation method based on the analysis of residuum. Previous model of this kind concerning winter barley has not been worked out before, moreover, it also cannot be found in literature published in English.

5. PUBLICATIONS

Monographs and notes:

1. VARGA-HASZONITS Z. - VARGA Z. - LANTOS ZS. – **ENZSÖLNÉ GERENCSÉR E.** (2006): Az éghajlati változékonyság és az agroökoszisztémák. Monográfia. Monocopy, Mosonmagyaróvár. 410 oldal.

Scientific studies published in Hungarian language

1. VARGA-HASZONITS Z. - VARGA Z. - LANTOS ZS. – **ENZSÖLNÉ GERENCSÉR E.** (2005): Az 1951-2000 közötti időszak hőmérsékleti minimum értékeinek agroklimatológiai elemzése. „Agro-21" Füzetek. 40. szám, 94-105.
2. VARGA-HASZONITS Z. – VARGA Z. - LANTOS ZS. – **ENZSÖLNÉ GERENCSÉR E.** (2005): Az éghajlatingadozás hatása a vegetációs periódusra. Acta Agronomica Óváriensis. 47 (2), 3-20.
3. VARGA-HASZONITS Z. – VARGA Z. - LANTOS ZS. – **ENZSÖLNÉ GERENCSÉR E.** (2005): Az 1951-2000 közötti időszak szélsőséges nedvességi értékeinek agroklimatológiai elemzése. „Agro-21" Füzetek. 46. szám, 26-37.
4. VARGA-HASZONITS Z. – VARGA Z. - LANTOS ZS. – **ENZSÖLNÉ GERENCSÉR E.** (2006): Az 1951-2000 közötti időszak hőmérsékleti maximum értékeinek agroklimatológiai elemzése. „Agro-21" Füzetek. 47. szám, 55-69.
5. **ENZSÖLNÉ GERENCSÉR E.** (2007): A termikus meteorológiai elemek hatása az őszi árpa (Hordeum vulgare L.) fejlődésére. Acta Agronomica Óváriensis. 49 (2) 281-286. o.

6. VARGA-HASZONITS Z. – VARGA Z. - LANTOS ZS. – **ENZSÖLNÉ GERENCSÉR E.** – MILICS G. (2008): A talajok vízellátottságának hatása a gazdasági növények vízigényének alakulására. Agrokémia és Talajtan. 57 (1), 7-20. o.

7. **ENZSÖLNÉ GERENCSÉR E.** (2009): Az őszi árpa termesztésének agroklimatológiai jellemzői hazánkban. Acta Agronomica Óváriensis. 51 (2). 3-20.

8. LANTOS ZS. - VARGA Z. – VARGA-HASZONITS Z. – **ENZSÖLNÉ GERENCSÉR E.** (2010): Gazdasági növények sugárzáshasznosításának agroklimatológiai elemzése. „Klíma-21" Füzetek. 59. szám, 66-73. o.

Scientific studies published in English

1. **ENZSÖLNÉ GERENCSÉR E.** - LANTOS ZS. – VARGA-HASZONITS Z. – VARGA Z. (2011): Determination of winter barley yield by the aim of multiplicative successive approximation. Időjárás. Vol. 115. No. 3. 167-178. **(IF 0,364)**

2. VARGA-HASZONITS Z. – **ENZSÖLNÉ GERENCSÉR E.** - LANTOS ZS. - VARGA Z. (2011): Water demand and water use efficiency of winter barley in Hungary. Acta Agronomica Hungarica. 59 (1). 59 (1). 13-22. o.

3. VARGA-HASZONITS Z. - VARGA Z. – **ENZSÖLNÉ GERENCSÉR E.** – LANTOS ZS. (2010): Estimation of winter barley yield by means of a multiplicative successive procedure based on the residual method. Acta Agronomica Óváriensis. 52 (2). , 9-18.

4. VARGA-HASZONITS Z. - VARGA Z. – LANTOS ZS. – **ENZSÖLNÉ GERENCSÉR E.** – MILICS G. (2010): Effect of soil

watet supply ont he water demand of crops. AGROKÉMIA ÉS TALAJTAN 60 (Különszám), 75.

Lectures:

1. **ENZSÖLNÉ GERENCSÉR E.** (2007): A termikus meteorológiai elemek hatása az őszi árpa (Hordeum vulgare L.) fejlődésére. MTA IV. Növénytermesztési Tudományos Nap 2007. március 29-31. Mosonmagyaróvár.