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Determination of winter barley yield by the aim of multiplicative successive approximation

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Abstract—The aim of our study was to analyze the climate-winter barley yield relationship by means of a model which took impact of successive periods into account. This approximation is a step from statistical models to dynamic models.

Study was based on data of an agroclimatological database, which contained daily values of meteorological elements during 1951–2000 measured by the Hungarian Meteorological Service and yearly county average values of winter barley yield published by Hungarian Central Statistical Office. In order to investigate the impact of meteorological factors on yield, we separated the influence of weather and technology. Impact of meteorological factors on yield was examined by regression equations during selected periods, but only time periods with significant influence on yield were taken into consideration. Applying this model, trend function was determined firstly, then relationship between trend ratio and meteorological element of first significant time period was calculated. This process was continued until the last function of meteorological impact had been determined.

Verification and validation of results were accomplished by studying of correlation between measured and calculated values and determination of frequency distribution of estimation errors.

The multiplicative successive model is suitable for estimating yields of winter barley, which grows in the cool and wet part of the year. It demonstrates how successive periods of growing season influence yield. This method is a better tool for studying the effects of climatic variability or a possible climate change than a simple statistical model.

Key-words: winter barley, yield, multiplicative successive model, water supply, temperature

1. Introduction

Winter barley is an important fodder grain crop in Hungary. This is a mesotherm plant which prefers cold spring weather. Its temperature demand and absorption of radiation are similar to those of winter wheat, but its cold hardening is worse. Mainly, cold weather without snow seems to be unfavorable for winter barley. Length of sowing-emergence phenophase is usually longer than that of winter wheat, because of higher water demand of barley (*Szakály*, 1968). Peak of water demand can be observed between shooting and heading, after heading water demand decreases (*Varga-Haszonits et al.*, 2000). This plant can be harvested first (in the second half of June) among grain crops; therefore, it is less affected by summer droughts. Winter barley is mainly used as fodder and its nutrition value is higher than that of winter wheat. It usually has the third biggest harvested area, which follows the area of winter wheat and maize. This harvested area of winter barley did not increase over the last some years, but a drying tendency can change that (*Varga-Haszonits et al.*, 2000, 2006).

2. Material and methods

Study was based on data of an agroclimatological database which had been built by Meteorological Group of Institute of Mathematics, Physics and Informatics of University of West Hungary. That database contains daily values of meteorological elements during 1951–2000 measured by Hungarian Meteorological Service and yearly county average values of winter barley yield published by Hungarian Central Statistical Office.

Yield of winter barley is mainly influenced by agrotechnical factors (variety, nutrient supply, plant protection) and meteorological elements. Weather is a key component, because in most cases high percentage of the variability of the yield (20% – 80%) is due to the variability in weather conditions (*Fageria*, 1992; *Porter* and *Semenov*, 2005). Agrotechnical factors change slowly year by year in a given area, that is why these factors show trend of change (*Fig. 1*). Variability of meteorological elements from year to year can be significant, this is the reason of the fluctuation around the trend. In order to investigate the impact of meteorological factors on yield, we have to separate the influence of weather and technology. This can be evaluated by the method of making ratio or difference between the trend and the actual yield or by the help of simulation using different model-calculations (*Andresen et al.*, 2001; *Thompson*, 1962, 1969, 1975, 1986).

Fig. 1 shows that course of barley yields in the second half of the 20th century can be expressed by means of a polynomial of the third degree. Relative position of single points to trend function indicates that variability of yield increases with rising yields. For this reason, meteorological effect is expressed by trend ratio instead of the trend anomalies. So it can be calculated as follows:

$$\frac{Y(t)}{f(t)} = f(m), \tag{1}$$

where $Y(t)$ is actual yield in the tth year, $f(t)$ is yield calculated by means of trend function in the tth year, and $f(m)$ is a function of meteorological impact.

In this manner, actual yield can be expressed as follows:

$$Y(t) = f(t)\, f(m). \tag{2}$$

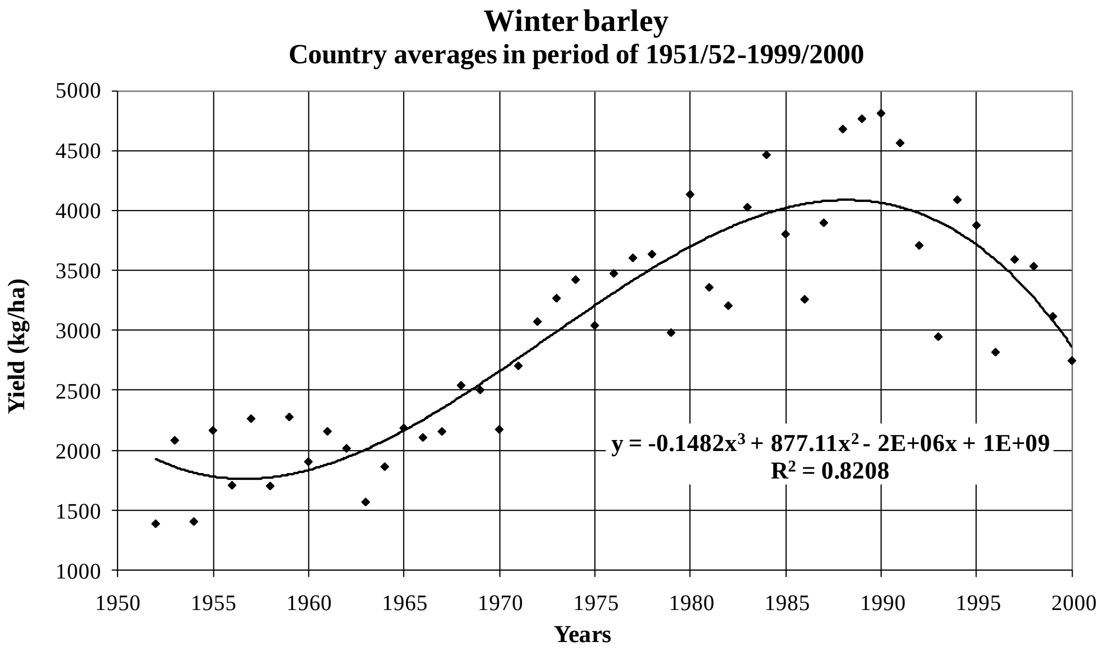

Fig. 1. Tendency of yearly variability in winter barley yield (kg/ha).

It seems to be practical to divide the growing season into different stages. These stages can be natural periods (phenological phases, intervals determined by threshold values) or calendar terms (seasons, months, ten or five days periods). Impact of meteorological factors on yield is examined by regression equations during selected periods, but only time periods with significant influence on yield are taken into consideration (*Szabó* and *Tóth*, 1989). These agrometeorologically important time periods are joined in a model based on multiplicative successive approximation. This dynamically estimating yield model makes possible to predict the crop yield before ripening (*Fuqin* and *Tian*, 1991; *Panofsky* and *Brier*, 1963; *Varga-Haszonits*, 1986, 1987, 1992).

Applying this model, trend function was determined firstly, then relationship between trend ratio and meteorological element (m_1) of first significant time period was calculated. First function of meteorological impact ($f_1(m_1)$) was determined this way:

$$\frac{Y(t)}{f(t)} = f_1(m_1)\,. \tag{3}$$

Then the ratio of $Y(t)$ actual yield and $f(t)\cdot f_1(m_1)$ estimating function is created, and this ratio has to be correlated with m_2 meteorological element of next significant time period for determining $f_2(m_2)$ function:

$$\frac{Y(t)}{f(t)\,f_1(m_1)} = f_2(m_2)\,. \tag{4}$$

This process is continued until the last function of meteorological impact has been determined. Herewith $Y^*(t)$ estimating function is worked out, and the model can be described as follows:

$$Y^*(t) = f(t)\,f_1(m_1)\,f_2(m_2)\ldots f_k(m_k)\,, \tag{5}$$

where $f_1(m_1)$, $f_2(m_2)$, …, $f_k(m_k)$ are functions of meteorological impact of significant time periods which are calculated by the aim of successive approximation.

Verification and validation of results (*Mavi* and *Tupper*, 2004) were accomplished by studying of correlation between measured and calculated values and determination of frequency distribution of errors.

Crop yield models are divided into three groups by *Ritchie* and *Alagarswamy* (2002). These are groups of statistical, mechanistic, and functional models. Statistical models are used to make large-area yield predictions. Nowadays, these models have been replaced by complex simulation models (*Abbaspour et al.*, 1992). Mechanistic models include mathematical descriptions of plant growth and development. Functional models contain simple equations or empirical relationship to describe the plant process and its environment (*Hoogenboom*, 2000).

This model belongs to the first (statistical) group, because it is based on dividing agrotechnical and meteorological impact and calculating meteorological impact as trend ratio. Calculation took into consideration ten-day periods with significant thermal effects, and it was accomplished by the aim of a multiplicative successive approximation.

3. Results and discussion

It is practical to start from the principle that – as we mentioned earlier – yields are influenced by agrotechnical factors and meteorological elements. Four production levels were distinguished (*Hoogenboom*, 2000; *Penning de Vries*, 1962) for these impacts. Yields would be determined by meteorological impact on first production level, if water and nutrient supply are basically favorable. Following this temporary water shortage, lack of nitrogen or phosphorus and potassium deficit can be observed on second, third, or fourth production level, respectively.

First and second levels can be interpreted as unchanged levels of meteorological elements in our study. In the case of third and fourth production levels, change of the yield was thought to be caused by change of nutrient supply and procedure of plant protection. Influences exerted on yield were examined agroclimatologically, and effects of nutrient supply and plant protection were took into account by means of trend in the case of third and fourth levels.

Yield of first two levels was essentially determined by meteorological elements. These meteorological factors can be divided into two groups: thermal (radiation and temperature) and humidity (relative humidity, precipitation, evapotranspiration, and soil moisture) factors. Water supply is influenced by humidity factors directly. That is the reason why humidity conditions of winter barley during growing season were analyzed (*Fig. 2*).

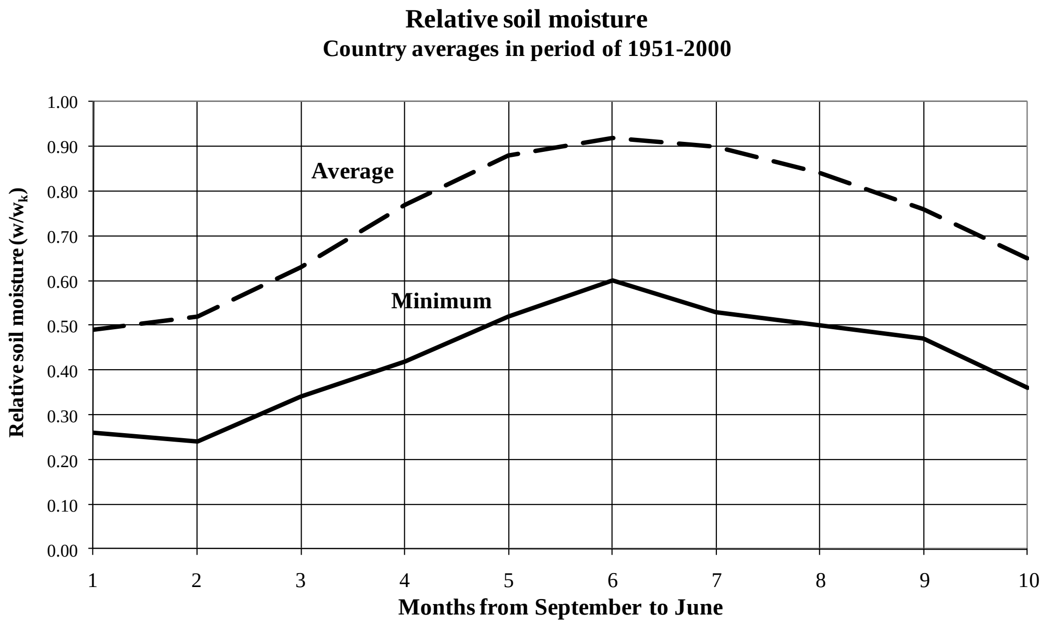

Fig. 2. Temporal changes in relative soil moisture (%) during the growing season of winter barley.

3.1. Water supply conditions of winter barley during growing season

Growing season of winter barley lasts from the second half of September to the second half of June. If survey is based on calendar terms, then months between September and June could be taken in account. Run of soil moisture during that period can be studied (*Fig. 2*). Soil moisture is expressed in the form of relative soil moisture in the first 1 meter depth of upper layer in soil:

$$w_r = \frac{w_a - WP}{FC - WP} = \frac{w}{w_k}, \tag{6}$$

where w_a is the actual soil water content (in mm), WP is the soil water content at wilting point (in mm), FC is the soil water content at field capacity (in mm), w is the available water content, and w_k is the available water capacity (in mm). All soil moisture values are related to 1 meter depth of upper layer in soil.

Lower limit of soil moisture demand of winter barley is 45% of available water according to *Szalóki* (1989, 1991). Soil moisture values above this threshold value are favorable for that crop. Higher limit of soil moisture demand is hard to be defined. Generally, high soil moisture values below field drained upper limit decrease air porosity causing oxygen shortage in pores and unfavorable water uptake.

Fig. 2 shows temporal changes in relative soil moisture during growing season of winter barley in Hungary (country average). It can be seen in *Fig. 2*, that mean values are above 45% of available water during the whole growing season. On the other hand, minimum values of relative soil moisture are below 45% between September and the middle of January and in the last month of the growing season. As we can see later, soil moisture conditions of autumn-early winter period have just a little effect on yields, and only May–June interval means a certain risk. The results were very similar in the case of other stations.

Hence, it can be presumed that water supply conditions are generally favorable for winter barley, but value of humidity factors can become critical in certain years. In this study, favorable water supply is assumed and impact of temperature on yield is analyzed.

3.2. Influence of temperature on yields of winter barley

Firstly, the growing season has to be divided into shorter periods. In this work a calendar term, namely ten-day period was chosen, because experience suggests that the same effect of meteorological conditions rarely extends for a longer interval, that meteorological impact of shorter periods varies, in turn, year by year.

Table 1a. Correlation coefficients of quadratic relationship between average temperature of ten-day periods and trend ratios of winter barley (from September to January)

Stations	Ten days periods in months														
	September			**October**			**November**			**December**			**January**		
	1	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Győr	0.28	0.30	0.03	0.16	0.10	0.38	0.11	0.30	0.25	0.29	0.37	0.45	0.18	0.11	0.20
Szombathely	0.17	0.27	0.08	0.31	0.10	0.40	0.21	0.35	0.31	0.38	0.36	0.42	0.30	0.28	0.25
Zalaegerszeg	0.18	0.31	0.12	0.26	0.11	0.20	0.16	0.50	0.41	0.46	0.30	0.30	0.11	0.20	0.16
Kaposvár	0.15	0.29	0.23	0.15	0.36	0.18	0.00	0.57	0.33	0.18	0.20	0.18	0.13	0.22	0.25
Pápa	0.20	0.22	0.16	0.12	0.07	0.34	0.09	0.43	0.23	0.24	0.26	0.31	0.15	0.12	0.30
Tatabánya	0.17	0.26	0.19	0.13	0.09	0.24	0.31	0.39	0.24	0.39	0.29	0.34	0.14	0.14	0.22
Martonvásár	0.28	0.25	0.16	0.17	0.22	0.30	0.09	0.39	0.15	0.21	0.35	0.28	0.26	0.11	0.27
Iregszemcse	0.19	0.28	0.25	0.11	0.34	0.23	0.18	0.51	0.20	0.12	0.18	0.19	0.15	0.14	0.22
Pécs	0.20	0.20	0.11	0.06	0.35	0.05	0.25	0.55	0.33	0.13	0.26	0.25	0.23	0.30	0.15
Kecskemét	0.10	0.27	0.16	0.16	0.24	0.25	0.17	0.49	0.30	0.16	0.30	0.22	0.19	0.19	0.24
Budapest	0.20	0.28	0.21	0.10	0.19	0.23	0.07	0.32	0.28	0.39	0.34	0.34	0.18	0.22	0.26
Szolnok	0.25	0.28	0.23	0.22	0.39	0.44	0.15	0.43	0.22	0.25	0.51	0.35	0.14	0.32	0.31
Szeged	0.10	0.17	0.21	0.09	0.28	0.35	0.14	0.31	0.21	0.07	0.46	0.37	0.33	0.19	0.30
Békéscsaba	0.19	0.35	0.27	0.43	0.34	0.34	0.14	0.31	0.18	0.00	0.52	0.45	0.26	0.15	0.33
Debrecen	0.18	0.36	0.06	0.35	0.31	0.38	0.18	0.29	0.33	0.23	0.57	0.42	0.09	0.03	0.23
Nyíregyháza	0.11	0.44	0.21	0.23	0.27	0.28	0.21	0.22	0.29	0.17	0.57	0.42	0.17	0.19	0.04
Miskolc	0.06	0.31	0.10	0.13	0.14	0.48	0.26	0.03	0.19	0.36	0.47	0.37	0.15	0.16	0.04
Kompolt	0.32	0.24	0.10	0.05	0.25	0.40	0.34	0.29	0.34	0.25	0.29	0.31	0.20	0.20	0.12
Balassagyarm.	0.30	0.15	0.04	0.18	0.03	0.29	0.43	0.11	0.25	0.07	0.23	0.42	0.40	0.20	0.33

Table 1b. Correlation coefficients of quadratic relationship between average temperature of ten-day periods and trend ratios of winter barley (from February to June)

Stations	Ten days periods in months														
	February			**March**			**April**			**May**			**June**		
	1	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Győr	0.39	0.36	0.15	0.15	0.21	0.08	0.12	0.30	0.32	0.25	0.32	0.34	0.48	0.25	0.25
Szombathely	0.34	0.37	0.05	0.18	0.08	0.12	0.13	0.13	0.33	0.36	0.35	0.37	0.32	0.27	0.13
Zalaegerszeg	0.42	0.43	0.15	0.22	0.13	0.23	0.13	0.06	0.37	0.18	0.29	0.21	0.26	0.19	0.13
Kaposvár	0.35	0.34	0.15	0.23	0.17	0.02	0.22	0.18	0.20	0.10	0.03	0.23	0.27	0.07	0.14
Pápa	0.35	0.36	0.01	0.02	0.06	0.14	0.23	0.18	0.28	0.18	0.31	0.45	0.39	0.28	0.21
Tatabánya	0.54	0.51	0.21	0.08	0.07	0.17	0.28	0.15	0.34	0.01	0.26	0.24	0.48	0.06	0.42
Martonvásár	0.35	0.27	0.10	0.14	0.09	0.13	0.22	0.26	0.26	0.19	0.33	0.37	0.35	0.16	0.26
Iregszemcse	0.35	0.31	0.17	0.18	0.17	0.19	0.15	0.37	0.32	0.32	0.07	0.15	0.30	0.15	0.17
Pécs	0.26	0.29	0.23	0.20	0.14	0.16	0.09	0.44	0.27	0.29	0.11	0.12	0.25	0.08	0.19
Kecskemét	0.38	0.41	0.24	0.21	0.15	0.09	0.27	0.42	0.25	0.23	0.23	0.29	0.26	0.15	0.24
Budapest	0.34	0.36	0.18	0.20	0.09	0.18	0.32	0.20	0.39	0.13	0.36	0.42	0.37	0.07	0.26
Szolnok	0.37	0.39	0.13	0.26	0.19	0.07	0.17	0.23	0.28	0.15	0.35	0.40	0.39	0.02	0.22
Szeged	0.36	0.20	0.29	0.30	0.28	0.13	0.26	0.37	0.39	0.30	0.31	0.33	0.39	0.05	0.11
Békéscsaba	0.31	0.24	0.24	0.45	0.12	0.29	0.16	0.30	0.46	0.22	0.26	0.27	0.40	0.06	0.08
Debrecen	0.41	0.37	0.11	0.37	0.07	0.23	0.10	0.31	0.48	0.20	0.29	0.28	0.37	0.05	0.18
Nyíregyháza	0.32	0.49	0.02	0.28	0.29	0.10	0.32	0.26	0.33	0.12	0.32	0.44	0.40	0.26	0.42
Miskolc	0.37	0.29	0.04	0.08	0.22	0.41	0.18	0.13	0.39	0.18	0.09	0.21	0.56	0.12	0.26
Kompolt	0.43	0.38	0.11	0.12	0.07	0.35	0.17	0.16	0.34	0.13	0.16	0.22	0.55	0.05	0.27
Balassagyarm.	0.49	0.47	0.18	0.09	0.16	0.06	0.49	0.24	0.38	0.26	0.15	0.31	0.40	0.15	0.52

Relationship between temperature and trend ratio was studied for all ten-day periods of growing season. *Table 1a* shows correlation coefficients of these relationships for September–January period and *Table 1b* demonstrates *r* values of January–June interval.

Temperature values of the third ten days period of October and the second ten-day period of November are in close correlation with yields as it can be seen in *Table 1a*. This is because of the relatively poor frost-tolerance of winter barley (*Varga-Haszonits et al*., 2006). In winter, mostly the third ten-day period of December (see *Table 1a*) and the first and second ten-day periods of February (see *Table 1b*) influence barley yield. It suggests that the success of barley production is basically influenced by permanent cold weather without snow-cover. Thus, significant influence of winter temperature values on yield are demonstrated also by investigations based on data of ten-day periods. In spring (and in early summer) mainly the third ten-day period of April, the third ten days period of May and the first ten-day period of June have great influence on productivity.

Selection of the most significant periods was done separately in the case of all stations, that is why these ten-day periods of our model can differ in different places. Data of *Tables 1a* and *1b* make it possible to choose appropriate intervals which can be used in the multiplicative successive model. Selected ten-day periods can be seen in *Table 2*.

Table 2. Ten-day periods chosen by means of sensitivity analysis

Stations	**Selected periods**			
	Period 1	**Period 2**	**Period 3**	**Period 4**
Győr	Nov 11–Nov 30	Dec 11–Dec 20	Feb 1–Feb 20	Apr 21–Jun 10
Szombathely	Nov 11–Nov 20	Dec 11–Dec 20	Feb 1–Feb 20	Apr 21–Jun 10
Zalaegerszeg	Nov 11–Nov 20	Dec 21–Dec 31	Apr 21–Apr 30	Apr 21–Apr 30
Kaposvár	Nov 11–Nov 20	Dec 11–Dec 31	Jan 1–Feb 20	Jan 1–Feb 20
Pápa	Nov 11–Nov 20	Dec 11–Dec 31	Feb 1–Feb 20	May 11–Jun 10
Tatabánya	Nov 11–Nov 20	Dec 11–Dec 31	Apr 21–Apr 30	Jun 1–Jun 10
Martonvásár	Nov 11–Nov 20	Dec 11–Dec 31	Jan 21–Feb 20	May 11–Jun 10
Iregszemcse	Oct 11–Oct 31	Nov 11–Nov 30	Feb 1–Feb 20	Apr 11–May 31
Pécs	Nov 11–Nov 20	Dec 11–Dec 20	Feb 1–Feb 20	Apr 11–May 10
Kecskemét	Nov 11–Nov 20	Dec 11–Dec 20	Feb 1–Feb 20	Mar 1–Jun 10
Budapest	Nov 11–Nov 20	Dec 1 –Dec 20	Feb 1–Feb 20	Mar 1–Jun 10
Szolnok	Nov 11–Nov 20	Dec 11–Dec 20	Feb 1–Feb 20	Mar 1–Jun 10
Szeged	Nov 11–Nov 20	Dec 11–Dec 20	Feb 1–Feb 20	Apr 1–Jun 10
Békéscsaba	Nov 11–Nov 20	Dec 11–Dec 20	Feb 1–Feb 20	Mar 1–Jun 10
Debrecen	Nov 11–Nov 20	Dec 11–Dec 20	Feb 1–Feb 20	Mar 1–Jun 10
Nyíregyháza	Nov 11–Nov 20	Dec 11–Dec 20	Feb 1–Feb 20	Mar 1–Jun 10
Miskolc	Nov 11–Nov 20	Dec 11–Dec 20	Feb 1–Feb 20	Mar 1–Jun 10
Kompolt	Oct 21–Feb 20	Apr 21–Apr 30	Jun 1–Jun 10	Jun 1–Jun 10
Balassagyarmat	Dec 21–Dec 31	Feb 1 –Feb 20	Apr 21–Apr 30	Jun 1–Jun 10

Calculations displayed in Section 2 can be done on the base of temperature data of those intervals. *Table 3* contains our results.

Table 3. Correlation coefficients of estimating functions for selected periods

Station	Trend	Correlation coefficients of estimating function			
	$f(t)$	Period 1 $f(t)\cdot f_1(m_1)$	Period 2 $f(t)f_1(m_1)f_2(m_2)$	Period 3 $f(t)f_1(m_1)$ $f_2(m_2)f_3(m_3)$	Period 4 $f(t)f_1(m_1)$ $f_2(m_2)f_3(m_3)f_4(m_4)$
Győr	0.9139	0.9319	0.9325	0.9405	0.9514
Szombathely	0.8627	0.8889	0.8903	0.9146	0.9275
Zalaegerszeg	0.9042	0.9241	0.9276	0.9252	0.9252
Kaposvár	0.9187	0.9460	0.9479	0.9588	0.9588
Pápa	0.9173	0.9451	0.9466	0.9504	0.9706
Tatabánya	0.8575	0.8955	0.8933	0.8922	0.9092
Martonvásár	0.8958	0.9288	0.9295	0.9429	0.9568
Iregszemcse	0.9207	0.9225	0.9499	0.9580	0.9630
Pécs	0.9054	0.9378	0.9381	0.9468	0.9524
Kecskemét	0.8139	0.8807	0.8921	0.8972	0.9233
Budapest	0.8545	0.8826	0.8859	0.8865	0.9014
Szolnok	0.8961	0.9290	0.9457	0.9523	0.9538
Szeged	0.8313	0.8511	0.8852	0.8932	0.9117
Békéscsaba	0.9162	0.9201	0.9409	0.9480	0.9519
Debrecen	0.8424	0.8647	0.9099	0.9314	0.9300
Nyíregyháza	0.8138	0.8315	0.8847	0.9282	0.9281
Miskolc	0.8430	0.8437	0.8809	0.9011	0.9197
Kompolt	0.8559	0.8939	0.8947	0.9075	0.9076
Balassagyarmat	0.8641	0.8873	0.9138	0.9125	0.9304

As it can be seen in *Table 3*, we have got better and better estimating functions by the aim of multiplicative successive approximation, and correlation coefficients came closer to the value of 1. According to our results it can be stated that if ten-day periods with no significant impact are used then the accuracy of estimation will essentially diminish.

The check-up of method was done by comparison of calculated and measured values. According to our results coefficient of determination (r^2 values) were higher than 0.9 at all stations. It means that correlation coefficients (r values) were close to 1. *Fig. 3* shows such a relationship.

The accuracy of estimation was checked by error of estimation – that is the difference between calculated and measured value – and then by studying the frequency of these errors. Results are indicated in *Table 4*.

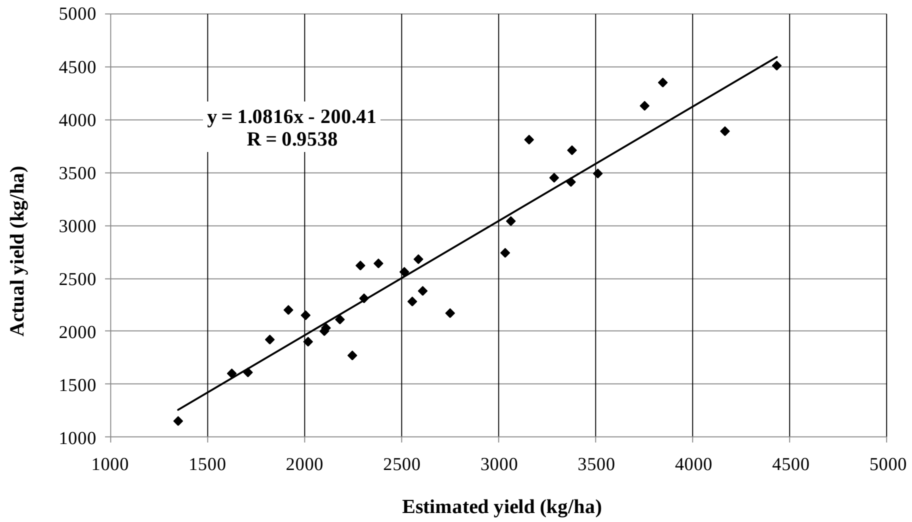

Fig. 3. Comparison of calculated and measured yield (kg/ha) values.

Table 4. Cumulative frequency of the difference between measured and calculated values

Stations	**Error of estimation (%) under**					
	5%	**10%**	**15%**	**20%**	**25%**	**30%**
Győr	47	77	87	93	93	97
Szombathely	33	77	80	90	97	97
Zalaegerszeg	27	73	83	90	97	100
Kaposvár	43	73	80	97	97	100
Pápa	37	77	97	97	97	100
Tatabánya	40	73	80	93	93	93
Martonvásár	37	77	90	93	97	100
Iregszemcse	37	73	83	93	100	100
Pécs	33	70	83	90	97	100
Kecskemét	60	70	83	90	93	93
Budapest	27	70	77	90	93	97
Szolnok	37	70	87	93	93	100
Szeged	37	70	87	87	97	97
Békéscsaba	27	73	87	90	90	100
Debrecen	20	70	90	93	97	97
Nyíregyháza	43	73	83	100	100	100
Miskolc	40	70	80	87	90	93
Kompolt	30	70	80	87	93	97
Balassagyarmat	33	77	83	87	93	97

The error of estimation was expressed in % of actual yield. As it can be seen in *Table 4*, our model gives acceptable results for yield estimation. When we used this method, the error of estimation was less than 5% in 30 – 40% of all cases and it was less than 10% in 70 –80% of all cases. It means that inaccuracy of estimation remained under 10% in two third of all studied cases.

4. Conclusions

Our results suggest that multiplicative successive model is suitable for estimating yields of winter barley which grows in the cool and wet part of the year in Hungary. Considering the fact that yield of cultivated plants is mainly influenced by meteorological conditions, water supply, nutrient supply and plant protection, yields can be accurately estimated if impact of agrotechnical factors (variety, nutrient supply, plant protection) is defined numerically by means of a trend function, and impact of meteorological factors is calculated as the fluctuation around trend values. This model becomes more simply if we suppose that water supply is favorable during the growing season of winter barley. Unfavorably dry spells usually occur only from July in Hungary.

Our model demonstrates how successive periods of growing season influence the yield. In this way, this method takes impact of successive periods into account, and it is a step from statistical models to dynamic models. Our results demonstrated that autumn frosts and permanent cold winter weather without snow-cover have great influence on productivity of winter barley.

This model is a better tool for studying the effects of climatic variability or a possible climate change, than a simple statistical model. The multiplicative successive model is a useful tool to estimate the effect of the possible climate change on the yield of winter barley and to feternime the past of the growing season in which the changes would occur.

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