Acta Agronomica Óváriensis Vol. 52. No. 2.

Estimation of winter barley yield by means of a multiplicative successive procedure based on the residual method

ZOLTÁN VARGA-HASZONITS – ZOLTÁN VARGA –
ERZSÉBET ENZSÖLNÉ GERENCSÉR – ZSUZSANNA LANTOS

University of West Hungary
Faculty of Agricultural and Food Sciences
Mosonmagyaróvár

Summary

The relationship between climate and winter barley yield in the period of 1951 to 2000 was studied using two different methods. Firstly meteorological elements and periods – that had significant influence on yield – were selected by means of the simple regression function. Then complex impact of the selected elements on productivity of barley was determined by multiple regression functions.

In the latter case functions of meteorological effect in successive periods were estimated by means of a multiplicative successive procedure based on the residual method. For this reason the impact of meteorological elements in successive periods was correlated with the residuum (remainder) of the function of meteorological impact in the former period. In this manner the complex effect of successive periods on yields was defined numerically. Our results suggest that winter barley yields are mainly determined by the mean temperatures of winter and May if soil moisture conditions are favourable. The impact of milder winters and cooler May months on barley productivity seems to be advantageous. A possible climate warming tendency would be favourable for this grain crop only in the winter period of year. Warmer May temperatures would reduce productivity.

Keywords: winter barley, yield, climate, temperature, multiplicative model, successive approximation, residual method.

Introduction

The effect of weather on winter barley yield in the period of 1951 to 2000 was studied using two different methods. Firstly meteorological elements and periods – that had significant influence on yield – were selected by means of the simple regression function. Then complex impact of the selected elements on productivity of barley was determined by multiple regression functions.

In the latter case functions of meteorological effect in successive periods were estimated by means of a multiplicative successive procedure based on the residual method. For this reason the impact of meteorological elements in successive periods was correlated with the residuum (remainder) of the function of meteorological impact in the former period. In this manner the complex effect of successive periods on yields was defined numerically. Validation of the method was done by comparison of actual and calculated values of yield.

Material and methods

Database

Agroclimatological studies are based on the simultaneous observation of meteorological and phenological events. Parallel agroclimatological data for our investigations derive from the Agroclimatological Database of the Faculty of Agricultural and Food Sciences of the University of West Hungary. This database contains daily values of meteorological elements measured by the Hungarian Meteorological Service and phenological data originally observed by the Central Agricultural Office (data observed before 1980) and the Hungarian Meteorological Service (data observed after 1980) and finally yearly average values of winter barley yield in counties, published by the Hungarian Central Statistical Office.

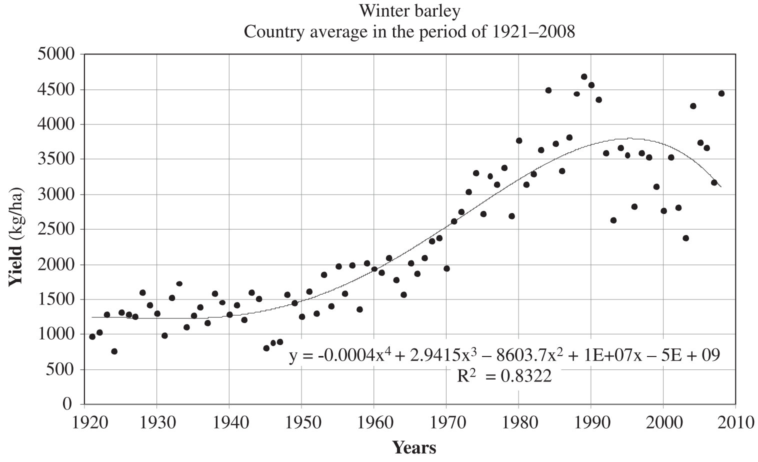
Applied methods

Plant-environment relationship can be described from an agrometeorological point of view as follows (*Varga-Haszonits* 1992):

$$Y(t) = f(A, M) \qquad (1)$$

where Y(t) is actual yield in a given t time period, A is the impact of agrotechnological factors (variety, nutrient supply, plant protection), and M is the impact of meteorological elements in the same t time period.

Figure 1. Course and trend of winter barley yield



The influence of agrotechnological factors can be calculated as a trend function (*Thompson* 1975). Agrotechnological factors change slowly year by year in a given area; therefore these factors show the trend of change (*Figure 1.*). The impact of meteorological elements can significantly vary from year to year, thus these impacts can be determined by fluctuations around the trend. *Figure 1.* shows that the course of barley yield values in the 20th century can be expressed by means of a polynomial curve of the fourth degree. Position of single yield values compared to the trend function indicates that variability of yield increases with rising yields. Accordingly meteorological factors influence yield not additively, but in a multiplicative manner. For this reason meteorological effect is expressed by trend ratio instead of trend anomalies (*Varga-Haszonits* 1986). Thus yields can be calculated if agrotechnological effect is f(t) (trend function) and meteorological effect is f(m):

$$Y(t) = f(t) \cdot f(m) \qquad (2)$$

Using equation (2) the function of meteorological impact can be written as:

$$\frac{Y(t)}{f(t)} = f(m) \qquad (3)$$

Impact of meteorological factors on yield can be examined for each meteorological elements (m_1, m_2,....,m_k) by using different natural or calendar periods. In this way both meteorological elements and periods (phenological stages) with significant influence on yield can be selected.

In equation (3) the impact of meteorological factors was estimated by using of multiple regression functions. Values of the f(m_1, m_2,...,m_k) multivariate function can be used for the estimation of meteorological influences. Multiplying the values of the trend function f(t) with the values of the meteorological impact function f(m_1, m_2,...,m_k) the value of expectable yield (Y(t)*) can be estimated. Hence it is best termed as an estimation function:

$$Y(t)^* = f(t) \cdot f(m_1, m_2, ..., m_k) \qquad (4)$$

The second type of approximation is a multiplicative successive procedure based on the residual method (*Panofsky* and *Brier* 1963) by which the impact of meteorological factors (trend ratio) on yield can be determined (*Varga-Haszonits* 1987). Considering m_1, m_2,…,m_k meteorological factors, the multiplicative function of meteorological impact in successive periods can be calculated by means of discontinuous approximation based on the residual method. First, relationship between trend ratio and meteorological element of the earliest time period was analyzed by using a $f_1(m_1)$ quadratic function:

$$\frac{Y(t)}{f(t)} = f_1(m_1) \qquad (5)$$

If this $f_1(m_1)$ function had a high coefficient of correlation, $Y_1(t)$* the estimation function can be defined as:

$$Y_1(t) = f(t) \cdot f_1(m_1) \qquad (6)$$

Then yields calculated by means of the estimation function and actual yields can be compared. If the results are unsatisfactory, then analysis has to be continued.
Next, correlation between ratio of actual yield and calculated yield and the value of the following meteorological element (m_2) was examined. In this way we could determine the next function of meteorological impact ($f_2(m_2)$):

$$\frac{Y(t)}{f(t)\cdot f_1(m_1)} = f_2(m_2) \qquad (7)$$

If results were still unsatisfactory, investigation had to be continued by taking more successive meteorological elements into account. Yields were estimated by the following function:

$$Y(t)^* = f(t)\cdot f_1(m_1)\cdot f_2(m_2)...f_k(m_k) \qquad (8)$$

Estimated yield was calculated in a multiplicative form by using functions of successive meteorological influences and trend ratio which expressed agrotechnological impact.
This method can be used when actual yields are known. Impact of meteorological elements on winter barley yield can be determined by means of this model. Then estimated and actual yields can be compared.

Verification

Verification and validation are universally used terms in agrometeorological modelling. Verification is such a method by which we can certify that the functional relationships used in the model are correct or not. If the model does not give output values close to the observed values then some correction of functional relationships may be necessary (*Mavi* and *Tupper* 2004). Comparison is usually made by using a linear relationship ($y = a + bx$), the cofficient of correlation of which shows the accuracy of the estimation.

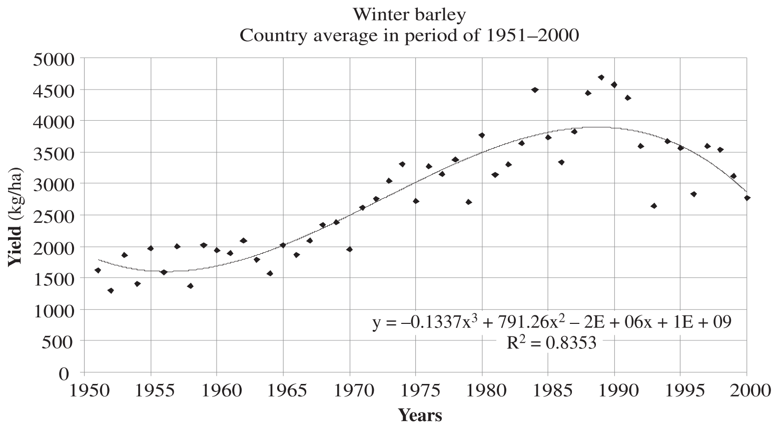
Validation

Validation is a comparison of values calculated by the model and actual values in independent observations (*Mavi* and *Tupper* 2004). In this case reliability of estimation can be studied. Models can be considered useful when the difference between outputs of models and observed data (error of estimation) are less than a threshold value determined from a practical point of view. The higher the frequency of small errors of estimation the more accurate the model is.
Both verification and validation are methods for comparison of calculated and measured values, that is why these terms sometimes are used as synonyms.

Results and conclusions

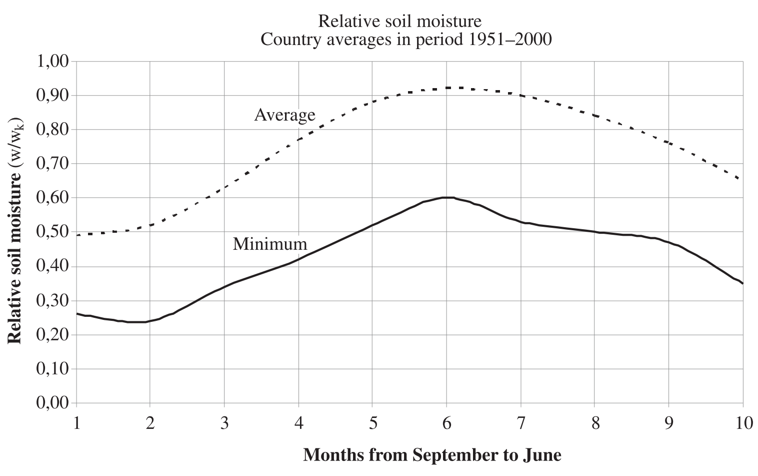
Trend of winter barley yields (Y(t)) was analyzed on the basis of a fifty year long (1951–2000) data series. *Figure 2.* shows that the course of barley yields in the second half of the 20th century can be expressed by means of a polynomial of the third degree. The trend function embodies agrotechnological (variety, nutrient supply, plant protection) influence. Ratio of actual yield and trend value (Y(t)/f(t)) expresses meteorological impact (f(M)). Above all, these effects have to be determined.

Figure 2. Function which describes tendency of yearly variations of winter barley yields



Selection of influencing factors. Meteorological factors are the most variable ones among the environmental factors. There are two groups of meteorological factors of great importance: thermal and humidity factors. In Hungary, growing season of winter barley coincides with the wet period (period of October–June) of the year. Soil moisture demand (static water demand) of winter barley is a water content in soil over 45% of available water (*Szalóky* 1991).

Figure 3. Monthly country average and minimum values of relative soil moisture during growing season of winter barley (1951–2000)



Ratio of actual (w) and maximum available (w_k) water content of soil (in root zone) is called relative soil moisture. It can be seen in *Figure 3.,* that average values of relative soil moisture are above the earlier mentioned threshold value in the whole growing season, except for September on the basis of the country average data between 1951 and 2000. Although soil moisture can vary significantly in certain years, average soil moisture conditions during the growing season of winter barley seem to remain favourable. This is the reason why we analyzed first of all the impact of a thermal element (namely temperature).

However, it is evident, there may be years when relative soil moisture values less than average can be occurred during the growing season of winter barley. It can be seen in *Figure 3.* that the minimum values of relative soil moisture remain over 0.45 threshold values only in the period of January–May. Therefore, in autumn months and in months May and June time periods can occur when the soil moisture becomes unfavourable for winter barley.

Since soil moisture conditions are basically favourable for winter barley during its growing season, we supposed that humidity has no significant influence on yield – as a rough estimate – and our research work focused on thermal impact.

Influence of single meteorological elements on yield. Temperature is a thermal element that is generally necessary for life. For this reason impact of temperature values on trend ratio during different parts of growing season was analyzed. We found two periods during the growing season in which temperature exerts a significant influence on yield; these were the mean winter temperature (period from December to February) and the mean May temperature. Winter temperature is an important factor because it has an effect on overwintering of barley and May is the most (weather) sensitive period of the growing season just before and after flowering (heading).

Table 1. Correlation coefficients of mean winter temperature-yield and mean May temperature-yield relationships, respectively (1951–2000)

Places of observation	Relationship between mean winter temperature and yield	Relationship between mean May temperature and yield
Békéscsaba	0.4319	0.2462
Budapest	0.4281	0.4924
Debrecen	0.6009	0.3459
Győr	0.5119	0.3560
Iregszemcse	0.4021	0.2011
Kecskemét	0.3407	0.1161
Kompolt	0.4991	0.4777
Miskolc	0.5365	0.4197
Nyíregyháza	0.4677	0.2776
Pécs	0.3762	0.1332
Szeged	0.3442	0.3586
Szolnok	0.4933	0.4003
Szombathely	0.5540	0.3337
Zalaegerszeg	0.4162	0.2995

The effect of winter temperature on barley yield was determined by means of a polynomial function of the second degree. Our results are shown in the second column of *Table 1.* Coefficients of correlation confirm that temperature has significant influence on winter barley yield in the winter. Cold weather has a basically unfavourable effect and higher temperature values usually increase productivity of barley.
Results of the impact of May temperatures are shown in the third column of *Table 1.* It can be seen that May temperature has less influence on yield; coefficients of correlation are smaller than those of winter temperatures.
The May temperature during heading-flowering phenophase is also a yield influencing factor, but its influence is less importance. During the spring period which includes the flowering-heading phenophase, the May mean temperatures are also considered as factors influencing yield, but of less impact.
This study makes it possible to forecast winter barley yields on the basis of winter temperature and then we could estimate productivity by means of a multiplicative successive model based on winter and May temperature. Results of second column in *Table 2.* show that yield values calculated on the basis of winter temperature indicates close correlation with actual yield.

Table 2. Correlation coefficients of relationship between actual yields and estimated yields; estimations were based on mean winter temperature and mean winter and May temperature, respectively (1951–2000)

Places of observation	Relationship between actual yield and estimated yield	
	Winter period	Winter period and May
Békéscsaba	0.9380	0.9479
Budapest	0.8561	0.9100
Debrecen	0.9016	0.9234
Győr	0.9284	0.9451
Iregszemcse	0.9384	0.9436
Kecskemét	0.8982	0.9239
Kompolt	0.8428	0.8972
Miskolc	0.8518	0.8876
Nyíregyháza	0.8411	0.8603
Pécs	0.9468	0.9468
Szeged	0.8982	0.9188
Szolnok	0.8916	0.9197
Szombathely	0.9089	0.9327
Zalaegerszeg	0.9316	0.9391

Yield estimation by means of a successive model. Joint effect of winter and May mean temperatures was determined by using the multiplicative successive method (*Varga-Haszonits* 1987). This research was based on Equations (6), (7) and (8).
Results are shown in the third column of *Table 2*. It can be seen that correlation coefficients of the relationship between calculated and measured yields increased when the relationship includes both winter and May temperature.

As *Table 2.* demonstrates, the correlation coefficients indicate a close linear relationship between actual and estimated yields, the values of which are usually above 0.9. Thus the method produces acceptable results for estimation of winter barley yield, which means that, temperature strongly influences the productivity of winter barley. This impact increases during the winter months and in May when the heading-flowering phenophase occurs. Productivity of winter barley would be significantly affected by a long-term change of temperature (for example a climate change).

Table 3. Cumulative frequency of the differences between actual and estimated yields (estimatory errors) (1951–2000)

Places of observation	**Error of estimation** (in percent)					
	5%	**10%**	**15%**	**20%**	**25%**	**30%**
Békéscsaba	36	70	88	92	92	94
Budapest	38	62	78	84	92	96
Debrecen	34	64	80	88	94	98
Győr	36	66	78	88	96	100
Iregszemcse	42	62	80	88	92	94
Kecskemét	32	58	78	92	96	96
Kompolt	42	60	68	86	90	90
Miskolc	24	58	74	86	92	94
Nyíregyháza	30	50	78	86	88	92
Pécs	32	60	76	90	96	98
Szeged	40	74	82	90	92	94
Szolnok	30	66	80	86	88	94
Szombathely	44	60	78	84	92	98
Zalaegerszeg	36	64	88	92	94	94

Also frequency of errors of estimation – that is the difference between estimated and actual yields – was investigated (*Table 3.*). The error of estimation was expressed as a percentage of actual yield. When we used this method the error of estimation was less than 5% in 35–45% of all studied cases, it was less than 10% in 55–75% of all cases and it was less than 15% in 75–90% of all cases.

Our results suggest that winter barley yields are mainly determined by the mean winter and May temperature if soil moisture conditions are favourable. The impact of milder winters and cooler May months on barley productivity seems to be advantageous. A possible climate warming tendency would be favourable for this grain crop only in the winter period of year. Warmer May temperatures would reduce the barley productivity.

Az ôszi árpa terméshozamának becslése a reziduális módszeren alapuló fokozatos közelítésű multiplikatív modellel

VARGA-HASZONITS ZOLTÁN – VARGA ZOLTÁN –
ENZSÖLNÉ GERENCSÉR ERZSÉBET – LANTOS ZSUZSANNA

Nyugat-magyarországi Egyetem
Mezőgazdaság- és Élelmiszertudományi Kar
Mosonmagyaróvár

Összefoglalás

Az éghajlati elemek és az őszi árpa terméshozama közötti kapcsolatot az 1951-től 2000-ig terjedő időszakra kétféle módszerrel vizsgáltuk. Az első vizsgálat során először egyváltozós regresszióval választottuk ki az őszi árpa termését befolyásoló fontosabb meteorológiai elemeket, illetve azokat az időszakokat, amikor ezek a tényezők a legnagyobb hatással vannak a terméshozam alakulására. Ezután többváltozós regressziós módszerrel elemeztük a kiválasztott meteorológiai elemek együttes hatását az őszi árpa terméshozamára. A második esetben a reziduális módszeren alapuló szakaszos közelítésű multiplikatív modellel határoztuk meg az egymásra következő időszakok meteorológiai hatásainak függvényét. Ez azt jelenti, hogy az időben egymásra következő meteorológiai hatásokat a megelőző időszak hatásfüggvényeinek a reziduumával hozzuk összefüggésbe. E vizsgálat arra irányult, hogy az egymásra következő időszakok milyen kumulált hatással vannak a termés alakulására.

A vizsgálati eredmények azt mutatják, hogy kedvező nedvességi feltételek esetén a tél középhőmérséklete és május középhőmérséklete határozza meg elsősorban a terméshozamot. Azt mondhatjuk tehát, hogy az árpa termése szempontjából az lenne a kedvező, ha a telek enyhébbé, a májusok pedig inkább hűvösebbekké válnának. A globális éghajlatváltozás esetén tehát nálunk csak a téli hőmérséklet emelkedése lenne kedvező hatású. Ha a májusi hőmérséklet is növekedne, az viszont kedvezőtlen lenne a terméshozamok alakulása szempontjából.

Kulcsszavak: őszi árpa, terméshozam, éghajlat, hőmérséklet, multiplikatív modell, fokozatos közelítés, reziduális módszer.

References

Mavi,H. S. – Tupper, G. J. (2004): Agrometeorology. Principles and Applications of Climate Studies in Agriculture. Food Product Press, New York.

Panofsky, H. A. – Brier, G. W. (1963): Some Applications of Statistics to Meteorology. The Pennsylvania State University, Pennsylvania.

Szalóki S. (1991): A növények vízigénye és öntözésigényessége. Az öntözés a kisgazdaságokban. (Water demand and irrigation demand of crops. Irrigation in farms.) *Ed.: Lelkes J. – Ligetvári F.,* Folium Könyvkiadó Kft., Budapest, 21–42.

Thompson, L. M. (1975): Weather Variability, Climatic Change, and Grain Production. Science, Vol. 188: 535–541.

Varga-Haszonits Z. (1986): A multiplikatív időjárás-termés modellek elvi módszertani alapjai. (Principal-methodical basis of multiplicative crop-weather models.) Beszámolók az 1983-ben végzett tudományos kutatásokról. OMSZ, Budapest. 155–164.

Varga-Haszonits Z. (1987): Az őszi búza terméshozama és az időjárás közötti kapcsolat meghatározása szakaszosan közelítő multiplikatív modellel. (Relationship between winter wheat yield and weather determined by multiplicative model using successive approximation.) Beszámolók az 1985-ben végzett tudományos kutatásokról. OMSZ, Budapest, 184–196.

Varga-Haszonits Z. (1992): Komplex agroklimatológiai modell az őszi búza produktivitásának jellemzésére. (Complex agroclimatological model for characterizing the productivity of winter wheat.) MTA doktori értekezés (HAS Doctoral dissertation). Budapest.

Address of the authors – A szerzők levélcíme:

VARGA-HASZONITS Zoltán – VARGA Zoltán –
ENZSÖLNÉ GERENCSÉR Erzsébet – LANTOS Zsuzsanna
Nyugat-magyarországi Egyetem
Mezőgazdaság- és Élelmiszertudományi Kar
H–9200 Mosonmagyaróvár, Vár 2.
E-mail: varzol@mtk.nyme.hu