TECHNOLOGICAL DEVELOPMENT AND THE STABILITY OF TECHNOLOGY IN CROP PRODUCTION
TECHNOLÓGIAI FEJLŐDÉS ÉS A TECHNOLÓGIA STABILITÁSA A NÖVÉNYTERMESZTÉSBEN

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ÖSSZEFOGLALÁS

Számos növény területegységre vetített terméshozamát vizsgálva, a legtöbb ország hosszútávú idősorainak alakulása meglehetősen jelentős ingadozásokat mutat. Az ilyen ingadozások fő oka az időjárás változékonysága, és a folyamatosan változó gazdasági, piaci helyzet.

Véleményünk szerint a technológia akkor tekinthető megoldottnak egy adott növény esetében, ha a termesztés ökológiai adottságainak megfelel, azaz az adott területen gyakran előforduló időjárási anomáliákat jól tűri, ezek nem csökkentik számottevően a terméseredményeket. A természeti erőforrások eltérő volta, és az időjárás változékonysága okozta termésingadozások mérése nem egyértelmű. Kérdés, hogy a trend körüli ingadozás mikor tekinthető elfogadhatóan kicsinek a biztonságos, kockázatmentes termeléshez, és mi az a nagyságrend, amely mellett már elfogadhatatlanul bizonytalan, hiszen a termelők szempontjából mind a kiugróan alacsony, mind pedig a kiugróan magas hozamok nagy kockázatot jelentenek.

A termésingadozás becslésére a szokásos relatív vagy abszolút szórás, illetve variancia számítását nem tartottuk kielégítőnek. Azonos szórást ugyanis különböző tulajdonságú idősorokban is tapasztalhatunk, így például olyankor, ha az adatsor elemei körülbelül azonos nagyságú, közepes mértékű ingadozásokat mutatnak az átlaghoz képest; de akkor is kaphatunk ugyanekkora szórásértéket, ha az adatok többségénél az átlagtól való nagyon kicsi, ugyanakkor néhány adat esetében az átlagtól való nagyon nagy eltérés a jellemző.

A termelő számára az első variáció, azaz a sok közepes mértékű eltérés a hozam vonatkozásában elfogadható, kezelhető helyzetet teremt, azonban az alkalomszerűen bekövetkező szélsőséges hozamok jelentősen növelik a gazdálkodás kockázatát A fentiek miatt a jelen cikkben egy olyan statisztikai mutató kidolgozására teszünk kísérletet, mely hosszútávú idősorokban a trendtől való kiugró eltérések előfordulását méri. A cikkben a FAO 1961-2000 időszakra vonatkozó adatbázisa segítségével a világon legnagyobb volumenben termesztett 18 gazdasági növény 40 éves hozam-idősorain mutatjuk be a kidolgozott mutató alkalmazását 10 országra, és értékeljük a technológiának a hozamok stabilitására gyakorolt hatását. Meghatározzuk, hogy a vizsgált országokban mely növények tekinthetők a fenti értelemben "jól technologizáltnak", és melyek azok, amelyek esetében még technológiai áttörésre van szükség.

KULCSSZAVAK: hozam idősorok, fluktuáció, stabilitás, variabilitás, kockázat

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ABSTRACT

The long term time series of the yields of various crops in many countries show wide fluctuations around an increasing trend, the main reasons of them may be variability of weather and the continuously changing economic environment.

Technology can be considered suitable for the production, if it agrees with the ecological features of the area, that is, it can compensate for the weather anomalies typical for the region, so that yields do not vary to a great extent. The measurement of yield variations caused by different natural resources and changing weather is not straightforward, and it is not easy to say what amount of variability can be considered reasonably small for the safe, riskless production, and what is the extend at which risk is unacceptably high.

The application of absolute or relative standard deviations, or variances to measure yield variability do not seem satisfactory for the assessment of yield stability. For this reason the present paper introduces an indicator, which measures the extreme variations around the trend in long term time series. The objective of the analysis is to assess the main agricultural crops of the world by the yield time series of the last 40 years, and evaluate the impacts of technology on yield stability. An attempt is made to distinguish crops and countries for which production may be considered "well technologised" and those for which there is reason to expect crucial technological change. Yield time series of 10 countries and 18 crops were collected from the FAO database for the time period of 1961-2000, to demonstrate the advantages of the applied method.

KEY WORDS: yield time series, fluctuation, stability, variability, risk

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DETAILED ABSTRACT

The long term time series of the yields of various crops in many countries show wide fluctuations around an increasing trend, the main reasons of them may be variability of weather and the continuously changing economic environment. The impacts of technological development will lead to more efficient crop production better suited to the climatic characteristics of the area. This is indicated by an increasing trend in the yield time series, but these series still show fluctuations, to a varying extent. Technology can be considered suitable for the production, if it agrees with the ecological features of the area, that is, it can compensate for the weather anomalies typical for the region, so that yields do not vary to a great extent. The measurement of yield variations caused by different natural resources and changing weather is not straightforward, and it is not easy to say what amount of variability can be considered reasonably small for the safe, riskless production, and what is the extend at which risk is unacceptably high.

The application of absolute or relative standard deviations, or variances to measure yield variability do not seem satisfactory for the assessment of yield stability. The same standard deviation value can be found for time series with frequent medium size variations as well as for time series with most of the data being very close to the average but a few of them very far from it. The first situation may be acceptable for the farmer, as it can be incorporated into the business plans, but the second case, that is, the occassional extreme yields will add unacceptable risk to farming. For this reason the present paper introduces an indicator, which measures the extreme variations around the trend in long term time series. The objective of the analysis is to assess the main agricultural crops of the world by the yield time series of the last 40 years, and evaluate the impacts of technology on yield stability. An attempt is made to distinguish crops and countries for which production may be considered "well technologised" and those for which there is reason to expect crucial technological change.

Yield time series of 10 countries and 18 crops were collected from the FAO database for the time period of 1961-2000. A risk-index was computed for each crop and country, which measures whether the yield series showed more large fluctuations around the increased trend than what would be acceptable for average situations measured by the normal distribution. Results led to different conslusions than what was expected from the classical statistical averages and standard deviations. The same analysis was also carried out for shorter time series of 1961-1989 to see whether the economic transition in Eastern Europe had serious implications on the technological trends in the last ten years.

INTRODUCTION

The long term time series of the yields of various crops in many countries show wide fluctuations around an increasing trend. The reasons for these fluctuations may be attributed to two main factors. One of them is obviously the variability of weather and climatic conditions, the other may be the continuously changing economic environment, market situation. When assessing long term time series of 35-40 years a clearly visible increasing trend may be observed, which can be explained by the impacts of technological development resulting in increased yield potentials of new crop varieties and improved farming practices leading to more efficient crop production (e.g. mechanisation, fertilisers, herbicides and pesticides, varieties better suited to the climatic characteristics of the area). However, besides the increasing trend time series for nearly every country show fluctuations, to a varying extent.

Technology can be considered suitable for the production, if it agrees with the ecological features of the area, that is, it can compensate for the weather anomalies typical for the region, so that yields do not vary to a great extent. In agriculture two technologies of two regions cannot be simply compared as the climate and other natural conditions always differ *[2,5]*. Yields cannot be expected to be absolutely stable either.

The measurement of yield variations caused by different natural resources and changing weather is not straightforward. The impacts of alternative technologies cannot be simply distinguished from impacts of weather, so the assessment of the stability and reliability of the chosen technology is a complicated matter. One practical approach may be to quantify the impacts of the deterministic influencing factors, and to attribute the remaining variation to the stochastic impacts of weather and natural environment. The impact of the deterministic factors is taken to be the trend observable in the yield time series, while the variation around the trend can be considered the direct impact of the stochastic environment.

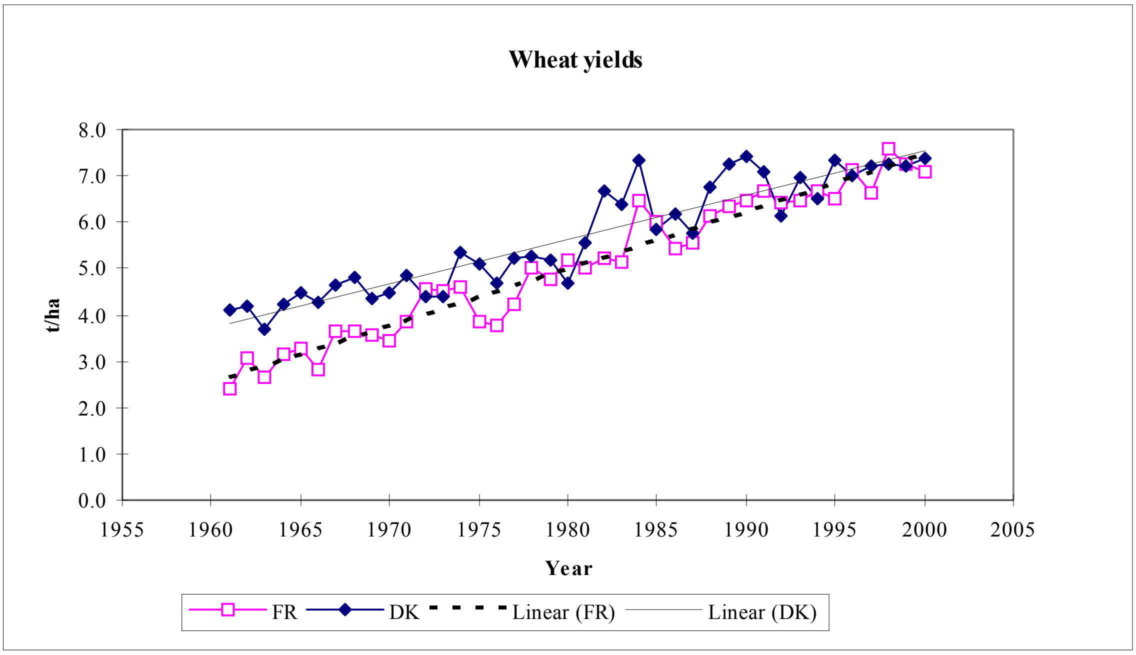
If the above approach is accepted as a starting point, then the question still remains, what amount of variability can be considered reasonably small for the safe, riskless production, and what is the extend at which risk is unacceptably high. From the viewpoint of farmers both too high and too low yields may cause serious problems. In the former case there is no sufficient amount to sell in the market, so the profit is insufficient, and the survival of the farm would necessitate the utilisation of savings from earlier years - which is not often possible. In the years with exceptionally high yields the balance of supply and demand would result in low market prices, which, in spite of the large amounts sold, also result in low total profit *[6]*.

The application of absolute or relative standard deviations, or variances to measure yield variability do not seem satisfactory for the assessment of yield stability. The same standard deviation value can be found for time series with frequent medium size variations as well as for time series with most of the data being very close to the average but a few of them very far from it. The first situation may be acceptable for the farmer, as it can be incorporated into the business plans, but the second case, that is, the occassional extreme yields will add unacceptable risk to farming (Table 1 and Figure 1).

Table 1: Statistical indicators for the wheat yield series of France and Denmark

Country	Denmark	France
Average	5.7	5.1
Standard deviation	1.2	1.5
Coefficient of variation CV%)	21.2	29.2
Trend	y=0.0953x-183.03	y=0.1228x-238.17
R2	0.8565	0.9467

Figure 1: Wheat yield series for France and Denmark



For this reason the present paper introduces an indicator, which measures the extreme variations around the trend in long term time series. The objective of the analysis is to assess the main agricultural crops of the world by the yield time series of the last 40 years, and evaluate the impacts of technology on yield stability. An attempt is made to distinguish crops and countries for which production may be considered "well technologised" and those for which there is reason to expect crucial technological change.

MATERIALS AND METHODS

The analysis was based on the Agricultural Database of FAO where crop yields were available for the years1961-2000 *[3]*. The following crops and countries were used in the research:

Crops: barley, wheat, maize, rice, rye, oats, sunflower, rapeseed, potatoes, sugarbeet, hops, green peas, onions, cabbages, spinach, carrots, cucumbers and soybean (the total world production of these crops is significant).

Countries were chosen where the above crops are grown in large amounts (Hungary was always included for the sake of comparison): Canada (CA), Denmark (DK), France (FR), Hungary (HU), Italy (IT), The Netherlands (NL), Turkey (TU), United Kingdom (UK) and the United States of America (US). For some crops not all the countries had time series for the above period, and for a few crops (e.g. soybeans and rice) Japan (JP) was also included in the analysis for its importance in the world production.

The mathematical model uses the following notations:

x_{ijt} denotes the average yield for crop *j,* country *i* and year *t,* as in the FAO database. Indices are: $i= 1, ..,10$ in the above order of countries, (i=1 Canada, i=9 USA, i=10 Japan); $j= 1,..,18$ in the above order of crops (j=1 barley, j=18 soybeans); $t=1,...,40$ where t=1 is the year1961, t=40 is the year 2000.

As the magnitude of data differ by crop, data of each time series were divided by the time series average, so that the resulting "normalised" time series became of similar magnitudes. Then linear trends were fitted to these normalised series. Ordinary least squares estimates were used to compute the z_{ijt} residual series for all i,j values. This means, that the sum of squares for the z_{ijt} series is small, and the mean of it by t (time) is around 0. The slope of the fitted linear trend can be interpreted as the speed of the yield increase in the studied period. The constant of the fitted line can be considered as a baseline natural potential production for the given country, to which the impacts of technology can be added. Then the stability of technology means that the z_{ijt} , ($t=1...40$) series remains in the neighbourhood of *0*. In other words, the crop is capable of producing reliable yields under occassional extreme weather conditions.

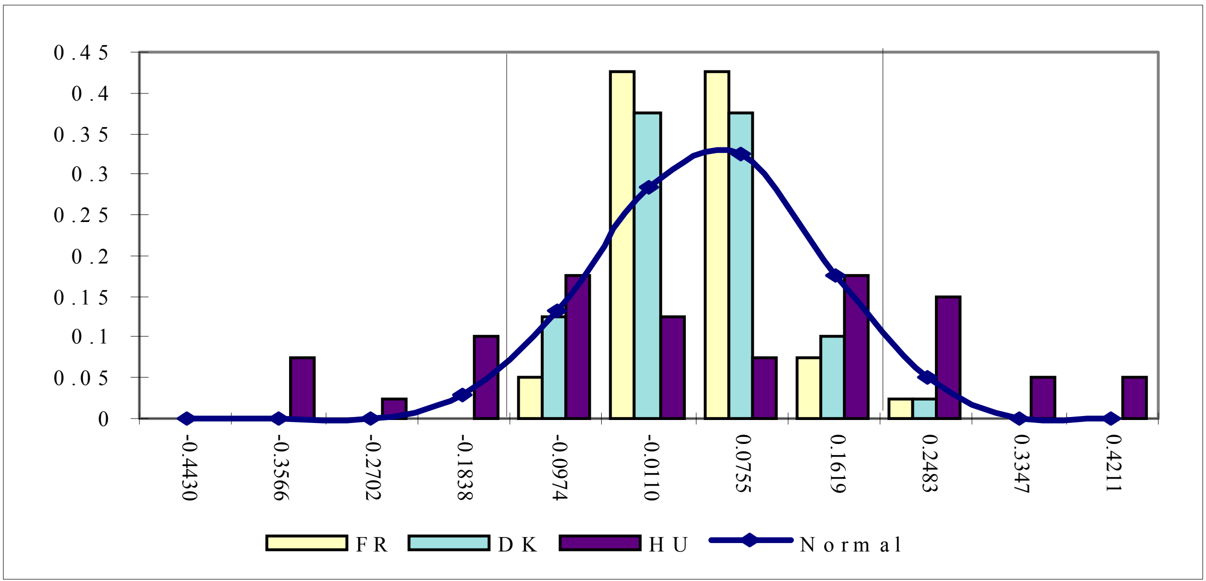
Then the z_{ijt} time series are analysed further in the following way. The index of the crop, *j* is fixed (that is, a particular crop is chosen for the analysis) and then the histogram of the z_{ijt} values is computed. The range of the values (the interval between the smallest and the largest value) is divided to 10 equal parts. Let v_{jn} denote the upper boundary of the *n*th subinterval for crop *j*, *(n=0,..10)*, v_{j0} being the smallest, v_{j10} the largest value in the interval. For country *i* let h_{ijn} denote the number of z_{ijt} values falling between v_{jn-1} and v_{jn} , that is, into the *n*th sub-interval.

Then a country and crop is considered technologically stable, if the frequency of the z_{ijt} values is high around 0 and low elsewhere. As a comparison the normal distribution with expected value of 0 and standard deviation of σ_j was taken where σ_j equals the countrywise average of the σ_{ij} empirical standard deviations of the z_{ijt} series for fixed *i,j* indices. $F_j(x)$ denotes the distribution function of this $N(0, \sigma_j)$ normal distribution. Taking a random sample of *N* items from such a distribution, let m_{jn} *(n=0.10)* denote the number of elements being not larger than v_{jn} (the upper boundary of the *n*th sub-interval), then $m_{jn} = N \cdot F_j(v_{jn})$, if $v_{jn} \geq 0$, and $m_{jn} = N \cdot [1 - F_j(|v_{jn}|)]$, if $v_{jn} < 0$ [4].

Technology will be considered stable if among the z_{ijt} values not less falls into the sub-intervals near 0 as it would happen with a random sample of the same size taken from the above $N(0,\sigma_j)$ normal distribution. Typically the sub-intervals of $[-2\sigma_j, 0]$ $[-\sigma_j, 0]$ $[0, +\sigma_j]$ and $[0, +2\sigma_j]$ are assessed in the empirical analyses of variability, and here the same approach is followed.

The difference of $h_{ijn} - m_{jn}$ was computed for each crop *j*, and $n= n(j)-2, n(j)-1, n(j)+1, n(j)+2,$ where $n(j)$ is the index of the sub-interval containing 0. Technological stability then means, that the above difference is negative for the first two, and positive for the last two intervals (see Figure 2).

Figure 2: Distribution for the residual series computed from the linear trend of wheat yields, compared to the normal distribution (FR: France, DK: Denmark, HU: Hungary)



As a result of the analysis the following matrix was computed:

$p_{ij}=m_{j,\ n(j)-2} - h_{ij,n(j)-2} + h_{ij,\ n(j)+2} - m_{j,\ n(j)+2}$, and $P = [\ p_{ij}\ ,\ i=1..10,\ j=1..18\ ]$

The technology for a country and a crop is then said to be reasonably stable if the elements of the above matrix *P* are positive, and as high as possible (Table 2).

Table 2. : Matrix P for years 1961-2000

	Country i=	1	2	3	4	5	6	7	8	9	10
j=	Crop	CA	DK	FR	HU	IT	NL	TU	UK	US	JP
1	barley	3.22	0.22	3.22	-9.78	0.22	2.22	1.22	3.22	3.22	
2	wheat	-1.12	1.88	4.88	-12.12	2.88	1.88	-3.12	2.88	2.88	
3	maize	3.11		3.11	0.11	3.11	-2.89	3.11	-11.89	-6.87	
4	rice			-3.50	-11.50	0.50		3.50		4.50	3.50
5	rye	-0.15	1.85	4.85	-5.15	3.85	1.85	0.85	1.85	-1.15	
6	oats	3.68	-3.33	2.68	-17.33	-0.33	-0.33	3.67	3.68	2.68	
7	sunflower	5.63		8.63	1.63	8.63		9.63		6.63	
8	rapeseed	1.97	-0.04	0.97	0.97	-2.03	1.96	-3.04	0.97		
9	potatoes	4.09	-0.91	-0.91	-7.91	4.09	-0.91	0.09	2.09	4.09	
10	sugarbeet	2.96	1.96	3.97	-4.04	1.96	-0.04	-4.04	-4.04	5.96	
11	hops	1.16		-0.84	4.16				8.16	-5.84	
12	green peas	1.67	-0.33	1.66	-3.33	-4.33	1.67	0.67	0.67	-1.33	
13	onions	0.34	-4.66	-1.66	-12.66	7.34	-4.66	6.34	0.34	7.34	
14	cabbages	-2.69	-8.69	4.31	-9.69	3.31	4.31	3.31	-12.69	4.31	
15	spinach	4.47	0.47	2.47	-0.53	6.47	-1.53	0.47		-9.53	-2.53
16	carrots	3.59	-1.41	4.59	-4.41	4.59	-6.41	-10.41	-1.41	6.59	
17	cucumbers	-1.93	-16.93	-0.93	-5.93	3.07	-6.93	3.07	3.07	3.07	
18	soybean	3.52		-10.48	-4.48	3.52		-3.48		3.52	2.52

Table 3: Matrix P for years 1961-1989

	Country i=	1	2	3	4	5	6	7	8	9	10
j=	Crop	CA	DK	FR	HU	IT	NL	TU	UK	US	JP
1	barley	3.78	3.78	3.78	0.78	3.78	-3.22	-3.22	-3.22	4.78	
2	wheat	-6.99	2.01	3.01	-0.99	4.01	0.01	-0.99	0.01	2.01	
3	maize	-3.37		-3.37	-3.37	-3.37	-3.37	-3.37	3.63	1.63	
4	rice			-3.67	-7.67	2.33		3.33		4.33	4.33
5	rye	-4.41	4.59	1.59	-0.41	6.59	1.59	-1.41	0.59	1.59	
6	oats	3.17	2.17	2.17	-5.83	-2.83	-4.83	5.17	4.17	3.17	
7	sunflower	-6.32		2.68	0.68	1.68		5.68		-0.32	
8	rapeseed	3.82	2.82	1.82	-0.19	2.82	2.82	-5.19	0.82		
9	potatoes	1.89	-5.11	-2.11	-0.11	0.89	-2.11	0.89	-3.11	7.89	
10	sugarbeet	1.00	2.00	2.00	-1.00	2.00	1.00	-6.00	-1.00	4.00	
11	hops	-5.44		4.57	4.57				4.57	-4.44	
12	green peas	1.61	-0.39	3.61	0.61	2.61	2.61	2.61	2.61	0.61	
13	onions	-0.75	-3.75	-2.75	-8.75	4.25	0.25	1.25	-0.75	4.25	
14	cabbages	0.99	-2.01	2.99	-4.01	1.99	0.99	0.99	-7.01	1.99	
15	spinach	3.40	-4.60	3.40	0.40	3.40	0.40	-1.60		-5.60	-1.60
16	carrots	1.76	2.76	2.76	-4.24	1.76	-2.24	-7.24	-1.24	4.76	
17	cucumbers	5.84	-14.16	-1.16	-2.16	6.84	-0.16	6.84	3.84	6.84	
18	soybean	2.96		-7.05	-1.05	2.96		-4.05		2.96	2.96

At the beginning of the nineties the transition of the economic and political system had serious consequences for agriculture in Hungary. The total transformation of the property structure resulted in the emergence of private farms, of which a considerable proportion suffered from lack of capital. These farms could not afford to use the most up-to-date farming technology. As a result, the yields of many crops decreased considerably, especially those which had been grown in large scale cooperative and state farms formerly. This fact can be observed in the yield time series, the increasing trend breaks around 1990, which distorts the analysis for the whole time range. For this reason matrix P was also computed for a shorter time scale, from 1961 to 1989. Results are shown in Table 3.

DISCUSSION

The results show a large variation among crops and countries. There are no crops which would have safe positive values for all the countries, nor countries where all the crops would have positive *p*-values in the matrix. Positive values may be interpreted as indicators for the particular crop and country showing that the applied technology in that country is well suited to the ecological characteristics of the environment - and this includes not only mechanisation and fertilisation but also choosing the crop variety well adapted to the climatic and soil conditions and the weather variations.

For Hungary it is always the shorter time series - that is, the series for 1961 to 1989 - which have the better *p*-values, though the negative values of the longer time series are still negative for the shorter one. This means, that the last ten years seriously increased the instability in the crop yields in Hungary, which may be the indicator of a certain decrease in the level of farming technology. The only exceptions are the maize and the rapeseed series, and for them the *p*-values in the matrix turned to positive as a result of the performance in the last ten years.

The same feature may be observed for several other countries, which suggests that a slight decline in the technological level is not a unique characteristics of Hungary.

Considering crops with negative values in matrix P weakly technologised crops Table 4 summarises the number of these crops for the analysed countries for the shorter time scale of 1961-1989 as well as the longer time scale of 1961-2000. The table shows that only three countries, Canada, the UK and Turkey may have experienced a general technological improvement in the last decade.

Table 4: Number of weakly technologised crops

time series	CA	DK	FR	HU	IT	NL	TU	UK	US	JP
Long (1961-2000)	4	8	6	14	3	8	5	4	5	1
Short (1961-1989)	6	6	6	13	2	6	9	6	3	1
Total number of crops	17	13	18	18	17	14	17	14	18	3

The question naturally arises whether the presented computation gives additional information in comparison to the generally used statistical indicators of variation. Bacsi and Vizvári (2002) gives a detailed comparison between the *p*-values of the above matrix and the commonly used coefficient of variation (CV), which is computed as the standard deviation divided by the average of the analysed series. Results often showed that crops and countries seemingly stable by the CV value were valued as highly risky by the computation of matrix P. Another important advantage of the *p*-values is that by this not only the same crop of various countries, but several crops of the same country may be compared for their risk. Here again the application of the CV statistics often leads to opposite conclusions as the assessment by *p*-values. As it was shown by Figure 1 the classical method of standard deviations and averages does not always agree with the intuitive assessment of the stability of a particular time series, and the present approach may be a reasonable alternative. Another advantage of the present method is that it does not require too detailed data - yield series are generally easily available - and the required computation needs are simply carried out by any spreadsheet. This makes it a possible tool for decision making, as it clearly indicates which crops may be relatively safely grown under the present technological conditions, and which are those which need greater caution if stable yields and stable incomes are an important concern of the grower.

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