# The Yield Stability Index Reloaded – The Assessment of the Stability of Crop Production Technology

Zsuzsanna BACSI (✉)
Zsolt HOLLÓSY

**Summary**

The technology of crop production should provide high yields under varying environmental conditions typical for the geographical zone of production. However, crop yields may fluctuate from year to year. As long as these fluctuations are small, the technology reliably delivers yields close to the expectations, but occasional extreme low or high yields can cause serious concern for the farmers. Thus the fluctuations of yields should be kept within reasonable limits. The level of fluctuation is usually measured by statistical dispersion indicators, e.g. standard deviation, or coefficient of variation. Farmers may well tolerate small yield fluctuations as acceptable uncertainties of crop production, but a few extremely low or high yields may be disastrous for them. The present paper introduces an adjusted measure of a yield stability index and tests it for 10 countries and 18 crops. These crops include the main staple crops of the world, including cereals and vegetables. The countries selected are the main agricultural producers of the EU and a few large non-European countries. Results are compared for two time periods, 1961-2000 and 2004-2016, to show which crops are produced with the most reliable technologies in various countries. The adjusted Yield Stability Index was computed and compared for two time periods, 1961-2000 and 2004-2016. The results show that this index gives a meaningful measure of yield stability, which gives a more subtle indication of instability than the usual measures of dispersion. The positive values of the index can indicate a stable technology, i.e. one that can respond to the year-by-year variations of environmental conditions, and the suitability of the actual crop to the actual geographical environment, while the negative index shows that the crop may not be suitable, or the applied technology is not good enough. These considerations should be taken into account when deciding about cropping structures and R&D directions.

**Key words**

crop yield, fluctuation, risk, time series, yield stability

University of Pannonia, Georgikon Faculty, Department of Economics, Social Sciences and Rural Development, Hungary. Address: 8360-Keszthely, Deák F. u. 16.

✉ Corresponding author: bacsi-zs@georgikon.hu

Received: March 16, 2019 | Accepted: September 11, 2019

## Introduction

Climate change will have a substantial effect on agricultural production. Agriculture, and especially crop production, is very sensitive to weather and other environmental impacts. The changing patterns of precipitation and temperature, and the increased occurrence of extreme weather events make crop yields fluctuate between the years, which is a challenge for production technology to maintain stable food provisions (Molnár and Molnárné Barna, 2015).

Technological development is focused on achieving higher crop yields, while yields in each year fluctuate around the trend, due to the changes in environmental conditions. Yield fluctuations generate fluctuations in the revenues of farmers, and this provides considerable risk for them. Low yields mean a decrease in marketable quantities, while high yields may lead to excess market surplus and decrease sales prices. The negative correlation between crop yields and prices has been established by several studies, see for example Coble et al.(2000), Imai et al. (2008) or Sherrick (2012). Tóth- Kaszás et al. (2017) emphasize the importance of producer risk aversion as a typical characteristic of small-scale farmers. The crucial issue is a limited local market demand, with overproduction that makes profitability very uncertain. The association of high yields and lower producer prices was demonstrated by Kovářová et al. (2017) regarding sugarbeet production in the Czech Republic, and by Kovářová and Procházková (2017) for milk yield and milk price fluctuations as well as milk turnover changes for 2006-2011.

The current agricultural transfer payments in the EU provide a certain cushion against yield variability risks. In Hungary, for example, farmers largely depend on these direct subsidies for their economic survival (Takács-György and Takács, 2012). Therefore, if these subsidies disappear, or considerably decrease, then the efficiency of input use, i.e. profitability, and with that risk avoidance and the development of more stable technologies will become more important. As a result, the motivation for high, but stable yields will definitely increase (Mizik, 2019).

The question is how to define the "reasonably stable" yield, i.e. how to determine the maximum allowed cumulative deviation from the increasing yield trend so that production-related risks remain low.

High yields are often accompanied by higher yield variability (Khalili and Pour-Aboughadareh , 2016, Nielsen and Vigil 2018). Producers can usually better accept a high average yield with larger yield variance than lower yields and small yield variance. Therefore, yield stability assessments should consider both the mean yield and yield variance. Measuring the risk of a yield falling below a certain limit is more useful than measuring the general level of yield variance (Piepho, 1998).

Yield stability analyses are often aimed at finding the highest yielding varieties or cropping systems that are relatively stable under changing environmental conditions (Piepho 1998, Wang et al. 2012, Nielsen and Vigil 2018). Yield variability can be measured at the level of individual crop varieties, and also at the aggregate national level, i.e., at the level of the average yields of all varieties of a particular crop grown in a certain area.

A detailed analysis of yield stability for wheat and maize was completed by Gollin (2006) using aggregated crop yield data of 91 countries from the FAOSTAT database for 1961-2005. Khalili and Pour-Aboughadareh (2016) assessed the adaptability of various barley cultivars to specific natural conditions, stating that high adaptability requires high mean yield across environments, with little variability or deviation from the mean yield. Both mentioned studies use the coefficient of variation and the sum of squares of deviations around a regression line to measure variability. Grover et al. (2009) tested the yield stability of maize in four long-term cropping systems with the same tools, assuming that high coefficients of variation indicate high variability. Nielsen and Vigil (2018) compared the yield stability of winter wheat grown in various crop rotations systems in Akron (Colorado) for 1993-2016 measuring stability by range, standard deviation, and coefficient of variation (CV) and by the deviations of yields from regression lines fitted to annual yield data. The yield variability of paddy rice, maize, wheat and rapeseed were assessed over the period 1952-2009 in Yunnan, China by Wang et al. (2012). The trend of each yield series was determined, then the residual series were computed, and the proportion of residuals to the estimated trend values was taken. Negative residual proportions were considered as various levels of disaster, in the range of -0.05 to -0.35. However, none of the above studies considered positive residuals problematic in any sense.

As Bacsi and Vízvári (2002), and Vízvári and Bacsi (2002) point out, a high standard deviation may be due to a few very extreme fluctuations, but also to many small ones. The many small fluctuations are acceptable for the producer, while a few extremely low, or high yields may create serious economic risk. Bacsi and Vízvári (2002) developed a yield risk index to measure the occurrence of extremely high or low yields in a time series. The yield stability index (Vízvári and Bacsi, 2002) quantifies the level of stability for a yield series quantifying the proportion of annual yields being reasonably close to the yield trend within a given time period.

Bacsi and Vízvári (2002) and Vízvári and Bacsi (2002) tested these indices for 10 countries and 18 crops for the time period 1961-2000. The present paper makes an adjustment to the computation method and carries out the analysis of yield stability for the same crops and countries for the period 2004-2016. Our goal is to measure the changes in crop yield stability from 1961-2000 to 2004-2016 to assess improvements in crop production technology, in view of climate change and the changing agricultural policies of the EU. The other purpose is to demonstrate the applicability of the yield stability index for the agricultural policy of a country, as the Yield Stability Index can measure how a particular crop - or its current production technology – fits to the climatic conditions of a particular country. For this purpose, Bacsi and Vízvári (2002) introduced the term "weakly technologized crop" for crops producing large yield variability in a given time period.

## Materials and Methods

The fluctuations of time series around the trend are usually quantified by statistical measures of dispersion, e.g. the sum of the absolute errors (the absolute value of the difference between the actual value and the trend estimation), the sum of squares of error, or the standard deviation, or the coefficient of variation (Brink, 2010), although other methods are also used, e.g. the average percent deviation from a trend, either linear or non-linear (Cuddy and Della Valle, 1978).

The paper applies an adjustment to the methodology of computing the Yield Stability Index as was described in Vízvári and Bacsi (2002), and in Bacsi and Vízvári (2002). A brief summary of the calculations for the Yield Stability Index is given below, illustrated by the example of potato yields in the USA in 2004-2016.

Taking a country and a particular crop, annual yields are measured for a given period of years. The measure of fluctuations is computed as described below.

First, the magnitude of the fluctuations naturally depends on the magnitude of the whole time series, therefore we rescale the data, dividing them by the average of the yield series. Thus, our rescaled yield series represent yields relative to the average yield of the analyzed period. The advantage of this approach is that the rescaled yield series of various crops and various countries become comparable from the stability viewpoint, even if their yield levels differ due to the intensity of production or to climatic conditions.

Another possibility to make the yields of various countries and crops comparable is to normalize them by deducting the minimum value and then dividing the remainder by the difference between the maximum and the minimum value. However, using this method each yield series is transformed into the 0-1 interval, so all fluctuations would also be transformed into a 0-1 fluctuation. For example, a yield series of values 90%, 100% and 110% of the average value would be normalized into a series of 0, 0.5 and 1 respectively, as well as a series having values of 50%, 100% and 150% of the average. However, the first series obviously fluctuate much less than the second series, which the process of normalization fails to represent, while rescaling (i.e. division by the average) properly conveys – transforming the first series into 0.9, 1.0, 1.1 and the second series 0.5, 1.0 and 1.5 respectively. This is the reason why rescaling is used to transform the yield series into comparable values.

Then the trend line of the rescaled yield series is determined by fitting a linear regression line to the annual rescaled yield values – altogether 13 points in our example, for each year in 2004-2016. The residuals of the series are computed as the difference of the actual series minus the yield values estimated from the fitted line. These residual values are the actual fluctuations around the trend line and our aim is to evaluate whether these fluctuations are reasonably small, or large enough to create considerable risk.

The third step is to measure the magnitude of these residuals, whether they are small enough to consider the series stable, or large enough to judge them unstable. Let's take the range of the rescaled yield residuals, and divide this range to 10 equal segments. As residuals should follow a normal distribution with zero mean, we take a normal distribution with zero mean and the standard deviation of the residual series. When a group of countries are used for comparison, the minimum and maximum of the residual range are taken as the minimum and maximum of all the countries, and the standard deviation for the normal distribution is the average of all the residual standard deviations of the assessed countries for the crop. Thus the same normal distribution and the same residual range for the 10 segments are used for each country for a particular crop.

Then our task is to compare the normal distribution and our rescaled residual values, as it is explained below.

The measure of stability is defined to quantify the result of this comparison between the normal distribution and our rescaled residual series. The residual values are stable if many of them fall near zero, i.e. in the segments neighboring the segment that contains the value zero, which is one of the middle ones of the 10 segments. So we define the four middle segments favorable segments, and count the number of the rescaled residual values falling within these segments. The lower three and the upper three segments represent unfavorable values, as they are too low or too high values, indicating large fluctuations. We can compute the number of residual values falling to these unfavorable segments. The proportion of the rescaled residuals falling into the four middle segments is called favorable residual frequency (*FRF*), and the proportion of the values from the normal distribution falling into the middle four segments is called favorable normal frequency (*FNF*). Then favorable difference (*FD*) is defined as the difference of these: $FD = FRF - FNF$. A positive *FD* indicates that more of our residuals fall near zero than a series taken from a proper normal distribution. Then, the proportion of the rest of the rescaled residuals (i.e. the ones not falling into the four middle segments) is called unfavorable residual frequency (*URF*). Similarly, the proportion of the values from the normal distribution not falling into the four middle segments is called unfavorable normal frequency (*UNF*), and unfavorable differences are computed as the difference of these: $UD = URF - UNF$. A positive *UD* means that more points of the residual series are far from zero (i.e. large in absolute value), which would be expected from a proper normal distribution.

Stability requires a large *FD* and a small *UD*. Thus the Yield Stability Index (*YSI*) is defined as $YSI = FD - UD$. As $URF = 1 - FRF$ and $UNF = 1 - FNF$, it is easy to see that $UD = -FD$, therefore $YSI = 2 \times (FRF - FNF)$.

In Vízvári and Bacsi (2002) the absolute number of residuals and normal distribution values are used for computing yield stability, therefore the index developed by these authors depend on the number of years, i.e. the sample size. Bacsi and Vízvári (2002), in developing a yield risk index, took care of this problem, by dividing their index value by the number of years in the analyzed periods. The present paper makes another adjustment, using proportions of the residual values falling in the various segments of the residual range.

This way the index values can be directly compared between time periods of different lengths. Theoretically, the *YSI* values fall between $-2$ and $+2$, because both *FRF* and *FNF* can take values between $0$ and $1$, therefore *FD* changes between $-1$ and $+1$. In assessing the actual values *YSI* computed for any particular series, these theoretical limits may be kept in mind to judge the actual level of stability achieved.

These minimum and maximum limits are, of course, broad estimations and not precise values, and they are used only to indicate the possible magnitudes of the index values. To give a more precise estimation, a normal distribution of zero mean and standard deviation $s$ is distributed in a way that approx. 95% of its values fall between $-2s$ and $+2s$, and approx. 68% of the values fall between $-s$ and $+s$. However, we use the range between the largest (*MAX*) and smallest (*MIN*) value of the yields of all the assessed countries, and then the range (*MIN, MAX*) is divided into 10 segments. In general, $MIN < -2s$ and $MAX > +2s$, but it cannot be determined how far *MIN* is below $-2s$, or how far *MAX* is above $+2s$, therefore the position of the favorable 4 segments, and the value *FNF* cannot be predicted exactly. Knowing the general pattern of the normal distribution we may reasonably assume that the range (*MIN, MAX*) is lower than $5s$, therefore the length of a segment is at least $0.5s$, and the four middle segments cover at least the interval $(-s, +s)$, which means $FNF > 0.68$. Then $YSI = 2 \times (FRF - FNF) < 2 \times (1 - 0.68) = 2 \times 0.32 = 0.64$. On the other hand, we may reasonably assume that the range (*MIN, MAX*) is larger than $10s$, therefore the length of a segment is smaller than $s$, and the four middle segments will not cover more than the interval $(-2s, +2s)$, which means $FNF < 0.95$. Then $YSI = 2 \times (FRF - FNF) > 2 \times (0 - 0.95) = 2 \times -0.95 = -1.9$. *YSI* is then expected to fall between $-1.9$, and $+0.64$, i.e. values falling between -2 and 0 with larger probability than between 0 and +2, which is due to the fact that the actual yield residuals, and therefore the *FRF* value cannot be better specified, while the normal distribution, and therefore *FNF* is relatively well known.

In Vízvári and Bacsi (2002) the yield stability was computed for 10 countries and 18 crops for the years 1961-2000. The 18 crops selected for the analysis were: barley, wheat, maize, rice, rye, oats, sunflower, rapeseed, potatoes, sugarbeet, hops, green peas, onions, cabbages, spinach, carrots, cucumbers and soybean. These crops cover *64%* of the cropland in the world and *85%* of the cropland in Europe, and they include the major arable crops and the most important vegetables of the world or Europe (FAO, 2018). The 10 countries were: Canada (CA), Denmark (DK), France (FR), Hungary (HU), Italy (IT), The Netherlands (NL), Turkey (TU), The United Kingdom (UK), USA (US) and Japan (JP). Naturally, the list of countries could be longer, but our focus was the significant agricultural producers of the EU. For the sake of comparison, developed non-European countries with significant production of staple crops were included. Naturally, a more detailed analysis could include South America, more countries of Asia, and the Pacific region.

The present paper uses the same crops and same countries and computes the adjusted yield stability index for 2004-2016, based on yield data of the FAO database (FAO, 2018). For the sake of comparison, the original results of 1961-2000 presented by Vízvári and Bacsi (2002) were also re-computed with the adjustment presented in this paper. Hungary entered the EU in 2004, therefore the results of the 2004-2016 period compared to those of the 1961-2000 period can indicate the impact of the EU-membership on the agricultural performance of the country. Naturally, more meaningful comparisons can be drawn from the 1961-2016 period, but this will be the topic of a further research paper.

## Results and Discussion

The averages of the annual yields are presented in Table 1 for the period 2004-2016 for each country and each crop. The average yields of each crop widely differ among the countries, depending on the environmental conditions and production technologies. It is not rare to see 200% differences among countries, but potato yields, for example, are 3.6 times higher in the USA than in Canada, and cucumber yields are more than 44 times higher in the Netherlands than in the USA.

The Yield Stability Index is determined for each crop and each country for 1961-2000 (Table 2) and for 2004-2016 (Table 3).

Comparing the Yield Stability Index values for the 18 crops between the two periods 1961-2000 and 2004-2016, differences among countries and differences among crops can be identified.

Considering a major staple crop, wheat, 7 of the 10 countries had positive YSI values in 2004-2016, while 6 of the 9 wheat producing countries had positive YSI in 1961-2000 (Japan did not have wheat yield data for that period). Five countries improved their YSI from 1960-2000 to 2004-2016, two countries (Denmark and the United Kingdom) experienced a small decrease (but with still positive index values). Japan did not have an old index value to compare with, France showed a considerable fall of the index turning the formerly positive value into negative, and Hungary is the only country where the old and the new values are consistently very negative, with a slight improvement after 2004. This is rather surprising, considering that wheat is one of the major crops in Hungary (Figure 1).

The situation is very similar for barley. Most of the barley producers have stable (positive) index values for both periods, but 8 of them had positive index values in 1961-2000. The most unstable country is Hungary again, followed by Turkey, while the US has a slightly negative *YSI* value deteriorating from a former positive one since 2004. Rye seems to be a very stable crop for all the countries in the analysis. Again 7 of the ten countries produced positive YSI indices for the newer period, most of them with a notable increase compared to the past. Japan did not have rye data, the UK index value decreased from a formerly positive value to a rather negative one, and Hungary is the only country for which both the old and the new values are similarly negative. Rice reached stable yields in the USA, Turkey, Japan and Italy, while in Hungary and France *YSI* is negative for both periods. The remaining 4 countries did not have relevant data for rice. Oat yields are stable in 6 countries, and unstable in 4 ones. Maize seems to be a rather unstable crop, it produced positive *YSI* values only in 5 countries (Figure 1).

Vegetables, in general, seem to be more stable than cereals. Carrots, cabbages, spinach and cucumbers show positive YSI for nearly all countries in 2004-2016. Onions and green peas are less stable (Figure 2), with only half of the countries showing positive yield stability index values. As it was mentioned earlier, the construction of the index makes the crops comparable even if the production technologies are very different. This way a country applying greenhouse technology can be correctly compared to an arable crop system, as long as the basic technology is not radically changed within the time period. Our yield series show that there were no such radical changes in the assessed years.

Among the rest of the assessed crops only sunflower shows strong stability, with only one negative value in Canada. Potatoes and sugarbeet are reasonably stable, showing an improving tendency with time, though the United Kingdom has very low stability index values in 2004-2016 (Figure 3).

Looking at the stability index values, Hungary, country-wide seems to be in the worst position among the 10 analyzed countries.

**Table 1.** Average annual yields of 2004-2016 for 18 crops and 10 countries (t/ha)

| | *CA* | *DK* | *FR* | *HU* | *IT* | *NL* | *TU* | *UK* | *US* | *JP* |
|---|---|---|---|---|---|---|---|---|---|---|
| barley | 3.28 | 5.40 | 6.38 | 3.91 | 3.72 | 6.47 | 2.52 | 5.90 | 3.69 | 3.11 |
| wheat | 2.88 | 7.27 | 6.98 | 4.37 | 3.80 | 8.58 | 2.52 | 7.85 | 2.98 | 3.88 |
| maize | 9.06 | 6.12 | 8.91 | 6.24 | 9.34 | 11.22 | 7.66 | | 9.75 | 2.58 |
| rice | | | 5.23 | 3.51 | 6.48 | | 7.69 | | 8.01 | 6.51 |
| rye | 2.50 | 5.37 | 4.76 | 2.48 | 2.93 | 4.34 | 2.41 | 5.43 | 1.74 | |
| oats | 2.93 | 4.75 | 4.48 | 2.56 | 2.37 | 5.33 | 2.27 | 5.72 | 2.29 | 1.91 |
| sunflower | 1.66 | | 2.32 | 2.35 | 2.19 | | 2.04 | | 1.63 | |
| rapeseed | 1.90 | 3.64 | 3.35 | 2.51 | 2.20 | 3.74 | 3.10 | 3.35 | 1.76 | 1.33 |
| potatoes | 12.62 | 40.15 | 43.35 | 24.78 | 25.41 | 44.02 | 29.86 | 41.25 | 45.52 | 31.03 |
| sugarbeet | 58.20 | 60.40 | 86.34 | 55.73 | 55.91 | 75.20 | 53.25 | 64.95 | 61.99 | 60.54 |
| hops | | | 1.40 | 4.21 | | | | 1.36 | 2.21 | 2.07 |
| green peas | 4.34 | 5.29 | 7.50 | 5.56 | 5.73 | 5.42 | 9.67 | 7.74 | 6.74 | 6.51 |
| onions | 37.92 | 39.11 | 41.29 | 27.36 | 31.03 | 46.15 | 29.35 | 41.04 | 54.63 | 47.32 |
| cabbages | 22.34 | 38.07 | 28.33 | 28.14 | 19.45 | 47.21 | 26.91 | 27.33 | 38.89 | 54.61 |
| spinach | 7.13 | 4.63 | 19.72 | 16.85 | 13.96 | 18.34 | 11.69 | | 19.17 | 12.34 |
| carrots | 41.37 | 47.48 | 41.82 | 31.97 | 44.73 | 58.48 | 47.88 | 64.86 | 40.59 | 33.07 |
| cucumbers | 21.86 | 208.29 | 97.43 | 48.45 | 29.65 | 696.10 | 43.48 | 519.55 | 15.69 | 49.78 |
| soybean | 2.76 | | 2.69 | 2.21 | 3.41 | | 3.86 | | 2.95 | 1.62 |

Source: FAO (2018)

**Table 2.** Yield Stability Index Values, 1961-2000

| YSI | CA | DK | FR | HU | IT | NL | TU | UK | US | JP | *Average* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| barley | 0.081 | 0.006 | 0.081 | -0.245 | 0.006 | 0.056 | 0.031 | 0.081 | 0.081 | | *0.019* |
| wheat | -0.028 | 0.047 | 0.122 | -0.303 | 0.072 | 0.047 | -0.078 | 0.072 | 0.072 | | *0.003* |
| maize | 0.078 | | 0.078 | 0.003 | 0.078 | -0.072 | 0.078 | -0.297 | -0.172 | | *-0.028* |
| rice | | | -0.088 | -0.288 | 0.013 | | 0.088 | | 0.113 | 0.088 | *-0.013* |
| rye | -0.004 | 0.046 | 0.121 | -0.129 | 0.096 | 0.046 | 0.021 | 0.046 | -0.029 | | *0.024* |
| oats | 0.092 | -0.083 | 0.067 | -0.433 | -0.008 | -0.008 | 0.092 | 0.092 | 0.067 | | *-0.014* |
| sunflower | 0.141 | | 0.216 | 0.041 | 0.216 | | 0.241 | | 0.166 | | *0.170* |
| rapeseed | 0.049 | -0.001 | 0.024 | 0.024 | -0.051 | 0.049 | -0.076 | 0.024 | | | *0.005* |
| potatoes | 0.102 | -0.023 | -0.023 | -0.198 | 0.102 | -0.023 | 0.002 | 0.052 | 0.102 | | *0.011* |
| sugarbeet | 0.074 | 0.049 | 0.099 | -0.101 | 0.049 | -0.001 | -0.101 | -0.101 | 0.149 | | *0.013* |
| hops | 0.029 | | -0.021 | 0.104 | | | | 0.204 | -0.146 | | *0.034* |
| green peas | 0.042 | -0.008 | 0.042 | -0.083 | -0.108 | 0.042 | 0.017 | 0.017 | -0.033 | | *-0.008* |
| onions | 0.009 | -0.117 | -0.042 | -0.317 | 0.184 | -0.117 | 0.159 | 0.009 | 0.184 | | *-0.005* |
| cabbages | -0.067 | -0.217 | 0.108 | -0.242 | 0.083 | 0.108 | 0.083 | -0.317 | 0.108 | | *-0.039* |
| spinach | 0.112 | 0.012 | 0.062 | -0.013 | 0.162 | -0.038 | 0.012 | | -0.238 | -0.063 | *0.001* |
| carrots | 0.090 | -0.035 | 0.115 | -0.110 | 0.115 | -0.160 | -0.260 | -0.035 | 0.165 | | *-0.013* |
| cucumbers | -0.048 | -0.423 | -0.023 | -0.148 | 0.077 | -0.173 | 0.077 | 0.077 | 0.077 | | *-0.057* |
| soybean | 0.088 | | -0.262 | -0.112 | 0.088 | 0.000 | -0.087 | | 0.088 | 0.063 | *-0.017* |
| *Average* | *0.049* | *-0.058* | *0.038* | *-0.142* | *0.069* | *-0.016* | *0.017* | *-0.006* | *0.044* | *0.029* | |

Source: Authors' own computations based on Vízvári and Bacsi (2002)

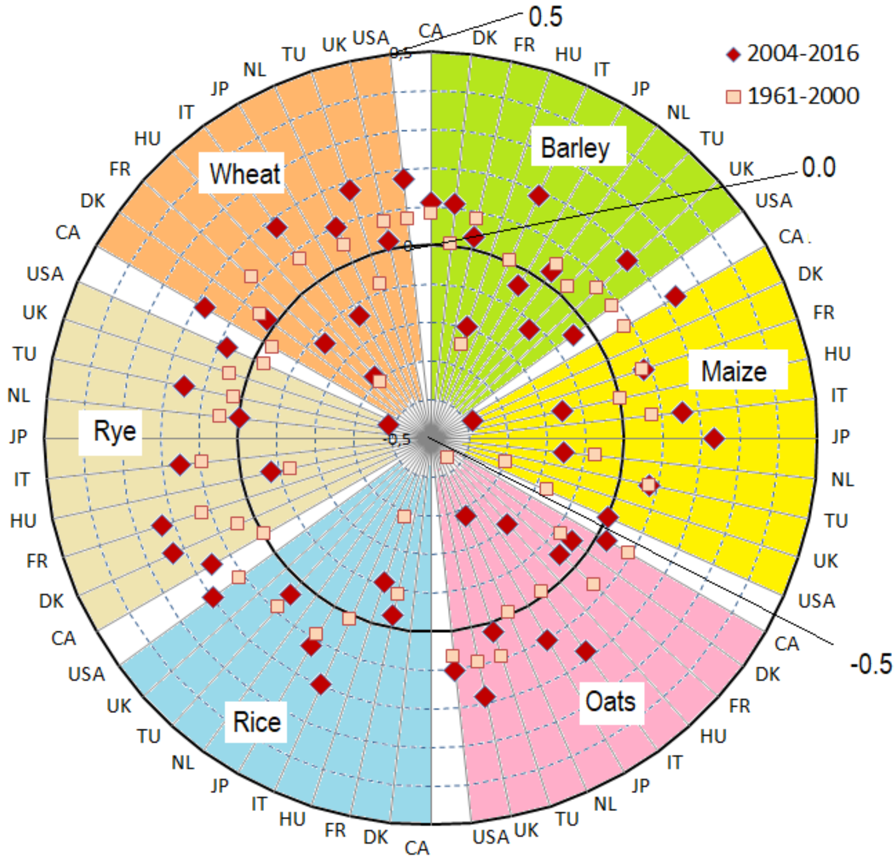


**Figure 1.** The Yield Stability Index for Cereals (Source: Authors' own construction based on the data of Table 1 and Table 2.)

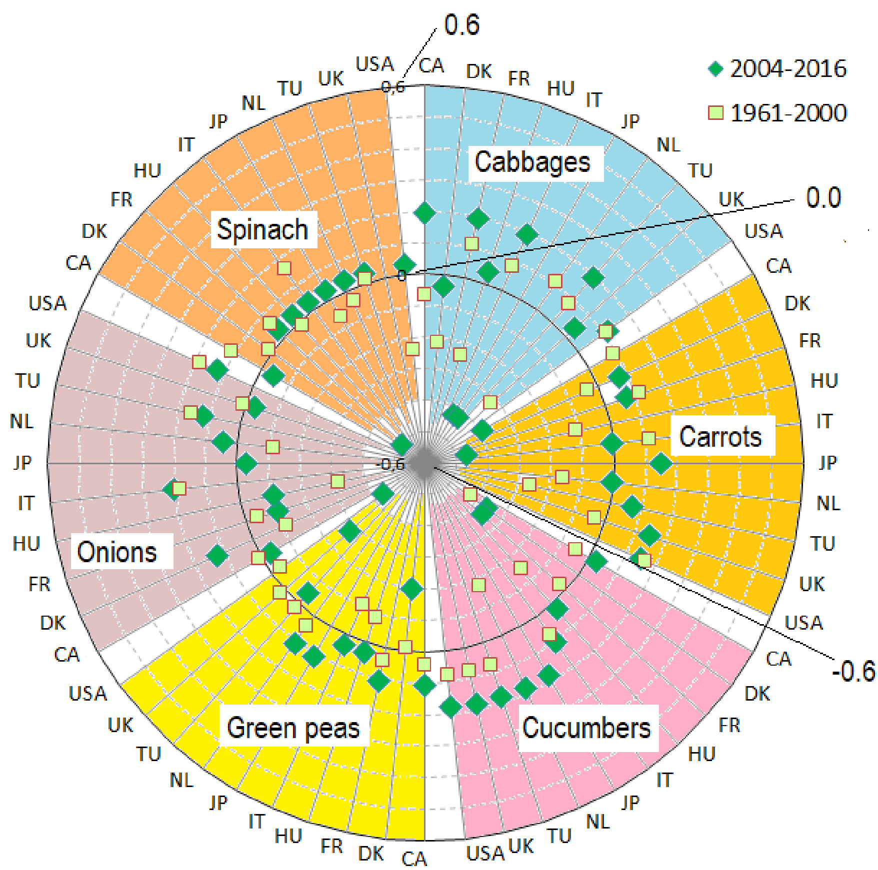


**Figure 2.** The Yield Stability Index for Vegetables (Source: Authors' own construction based on the data of Table 1 and Table 2.)

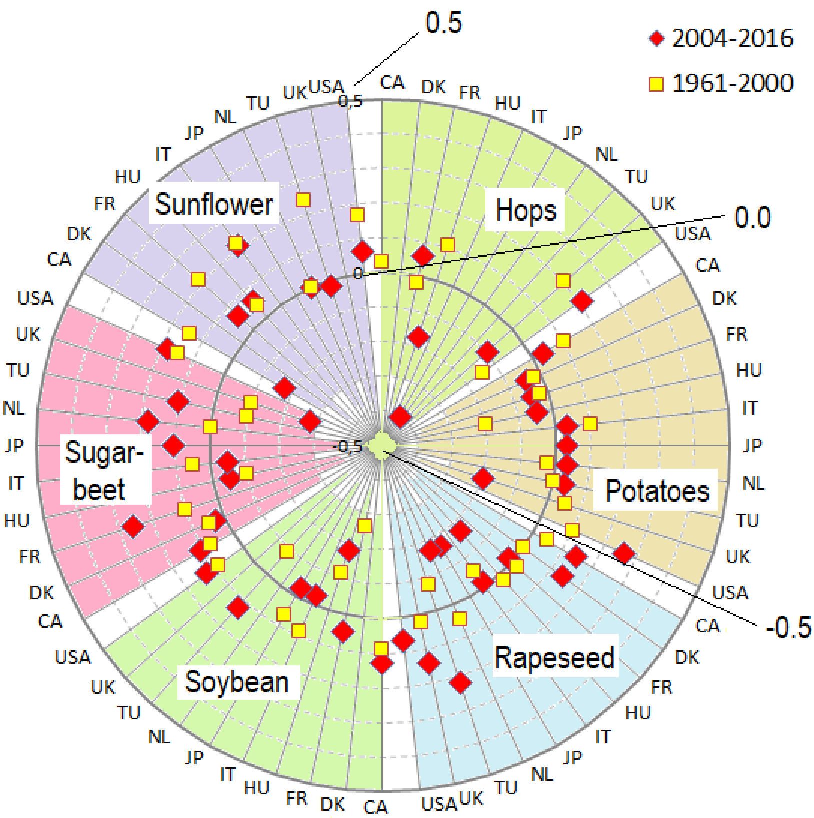


**Figure 3.** The Yield Stability Index for Hops, Potatoes, Rapeseed, Soybean, Sugarbeet, and Sunflowers (Source: Authors' own construction based on the data of Table 1 and Table 2.)

**Table 3.** Yield Stability Index Values, 2004-2016

| YSI | CA | DK | FR | HU | IT | NL | TU | UK | US | JP | *Average* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| barley | 0.110 | 0.110 | 0.033 | -0.198 | 0.187 | 0.033 | -0.121 | 0.187 | -0.044 | -0.044 | *0.025* |
| wheat | 0.176 | 0.022 | -0.132 | -0.285 | 0.176 | 0.099 | 0.176 | 0.022 | 0.176 | -0.132 | *0.030* |
| maize | 0.233 | -0.383 | 0.079 | -0.152 | 0.156 | -0.152 | 0.079 | | 0.002 | 0.233 | *0.010* |
| rice | | | -0.034 | -0.111 | 0.197 | | 0.043 | | 0.197 | 0.120 | *0.068* |
| rye | 0.152 | 0.229 | 0.229 | -0.078 | 0.152 | -0.001 | 0.152 | -0.386 | 0.076 | | *0.058* |
| oats | 0.027 | -0.049 | -0.049 | -0.203 | 0.181 | -0.280 | 0.027 | 0.181 | 0.104 | 0.104 | *0.004* |
| sunflower | -0.171 | | 0.060 | 0.060 | 0.214 | | -0.017 | | 0.060 | | *0.034* |
| rapeseed | 0.141 | 0.141 | -0.013 | -0.167 | -0.013 | -0.167 | 0.218 | 0.141 | 0.064 | -0.167 | *0.018* |
| potatoes | 0.032 | -0.045 | -0.045 | -0.045 | 0.032 | 0.032 | 0.032 | -0.199 | 0.263 | 0.032 | *0.009* |
| sugarbeet | 0.105 | 0.028 | 0.259 | -0.049 | -0.049 | 0.182 | 0.105 | -0.280 | 0.182 | 0.105 | *0.059* |
| hops | | | 0.058 | -0.173 | | | | -0.096 | 0.212 | -0.404 | *-0.081* |
| green peas | 0.108 | -0.200 | 0.108 | 0.031 | 0.031 | 0.108 | -0.046 | -0.277 | -0.431 | 0.108 | *-0.046* |
| onions | -0.030 | 0.124 | -0.107 | -0.107 | 0.201 | 0.047 | 0.124 | -0.030 | 0.124 | -0.030 | *0.032* |
| cabbages | 0.194 | -0.037 | 0.194 | 0.040 | 0.194 | -0.422 | 0.194 | 0.040 | 0.117 | -0.422 | *0.009* |
| spinach | -0.044 | -0.506 | 0.033 | 0.033 | 0.033 | 0.033 | 0.033 | | 0.033 | 0.033 | *-0.036* |
| carrots | -0.390 | 0.072 | 0.072 | -0.467 | -0.005 | -0.005 | 0.072 | 0.149 | 0.149 | 0.149 | *-0.021* |
| cucumbers | 0.027 | -0.358 | -0.358 | 0.027 | 0.104 | 0.181 | 0.181 | 0.181 | 0.181 | 0.181 | *0.035* |
| soybean | 0.128 | | 0.051 | -0.180 | -0.026 | | 0.128 | | 0.128 | -0.026 | *0.029* |
| *Average* | *0.050* | *-0.061* | *0.024* | *-0.112* | *0.104* | *-0.022* | *0.081* | *-0.028* | *0.088* | *-0.010* | |

Source: Authors' own computations

In the period 2000-2016 altogether 18 crops are measured for Hungary, of which 13 have negative yield stability index values. The situation has only slightly improved compared to 1960-2000. The best performance is in the USA and Turkey (2 and 3 crops out of 18 show negative YSI, respectively), followed by Canada and Italy, with 4 of 17 crops having negative YSI (Figure 4, Figure 5 and Figure 6).

It may be surprising to notice that the non-European countries perform generally better than the European countries, Italy being the only country having similarly good yield stability as the USA, Turkey or Canada for both time periods. Although this comparison may be felt somewhat misleading, because the selected crops may grow much better in one geographical zone than in another, this does not affect the stability measure, as the stability index is based on the relative yield fluctuations, regardless of a crop producing high or low yields on average.

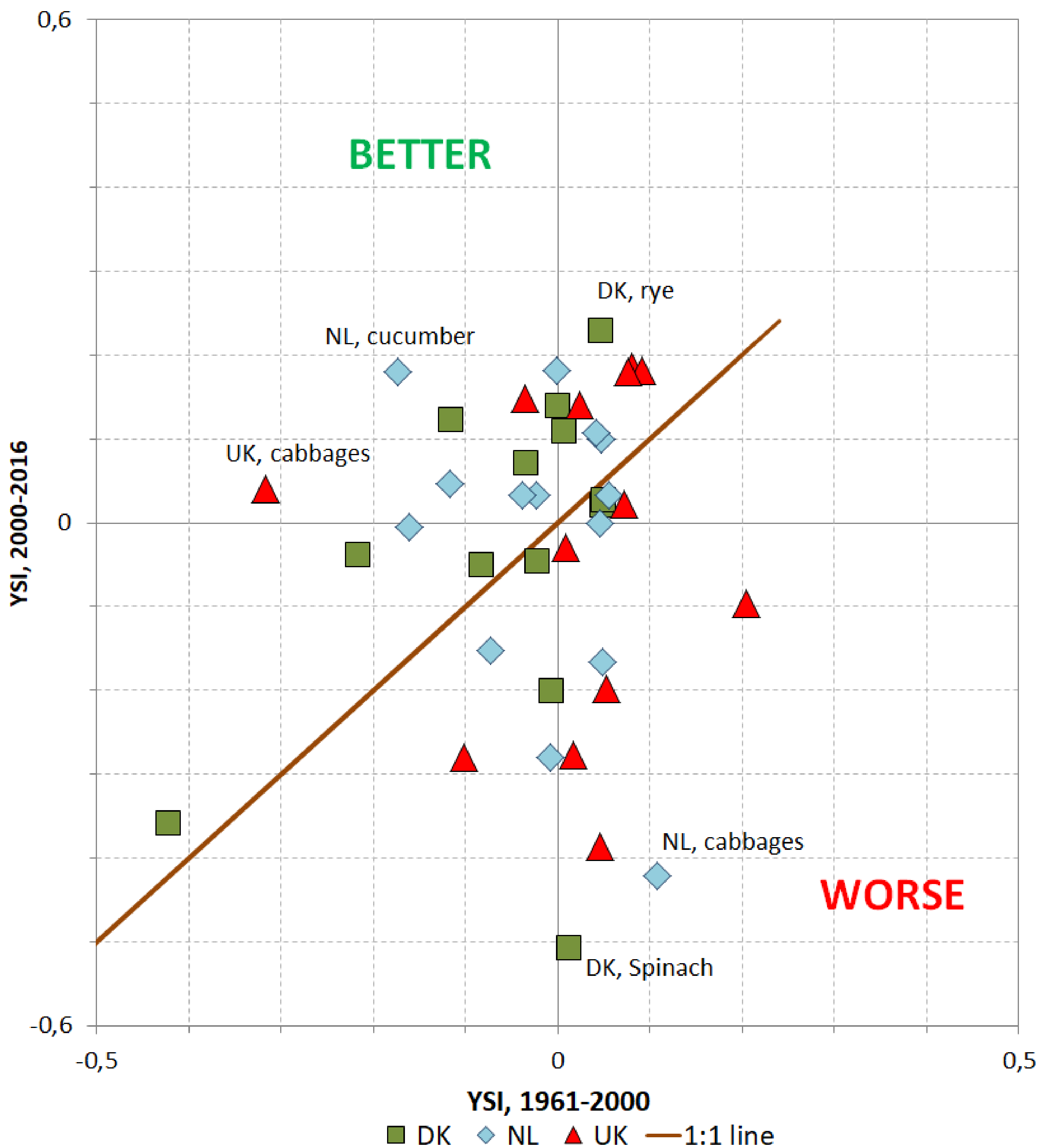


**Figure 4.** Comparison of YSI for 1961-2000 and 2004-2016, 18 crops, Denmark, The Netherlands, UK (Source: Authors' own construction based on the data of Tables 1 and 2)

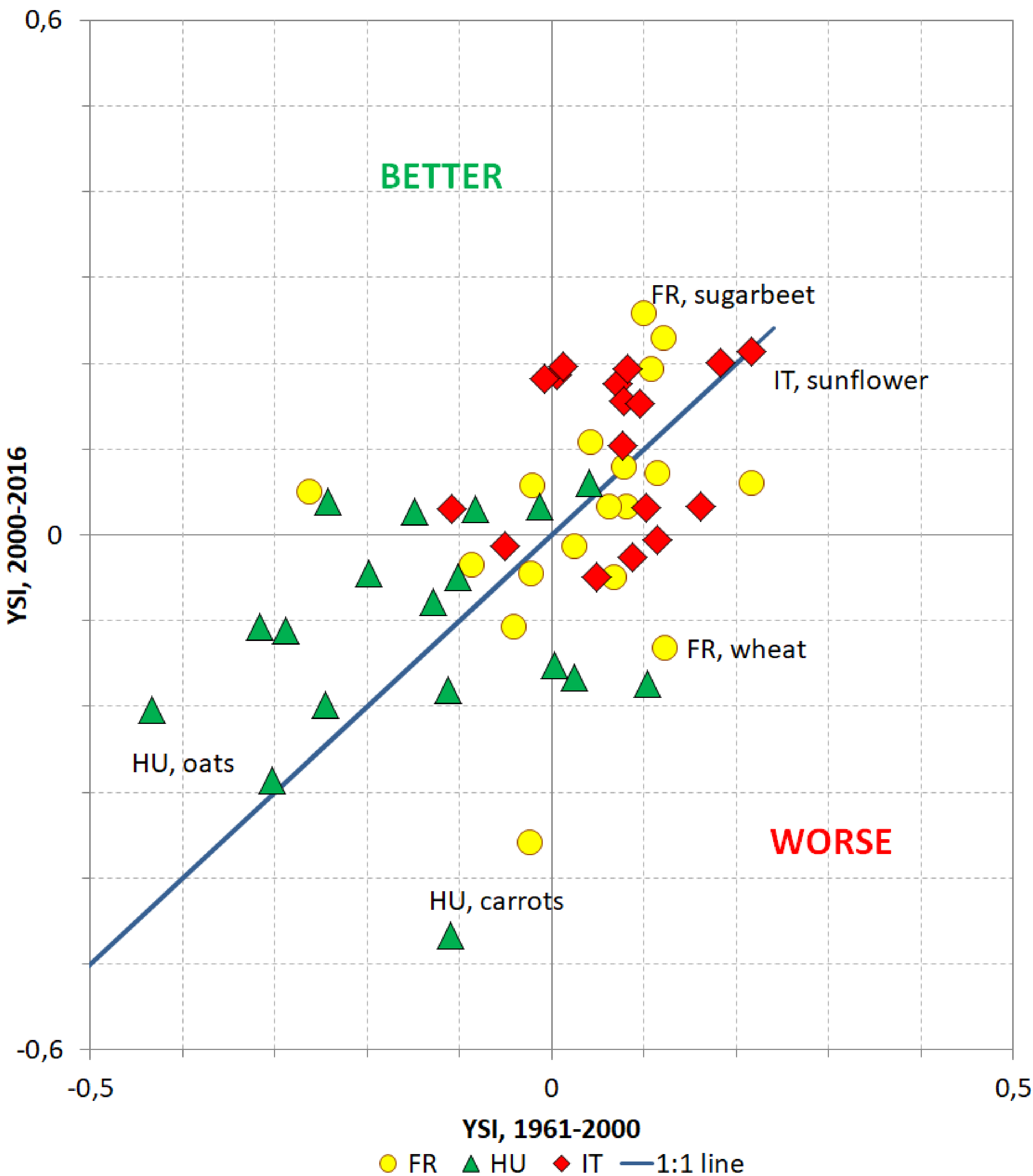


**Figure 5.** Comparison of YSI for 1961-2000 and 2004-2016, 18 crops, France, Italy, Hungary (Source: Authors' own construction based on the data of Tables 1 and 2)

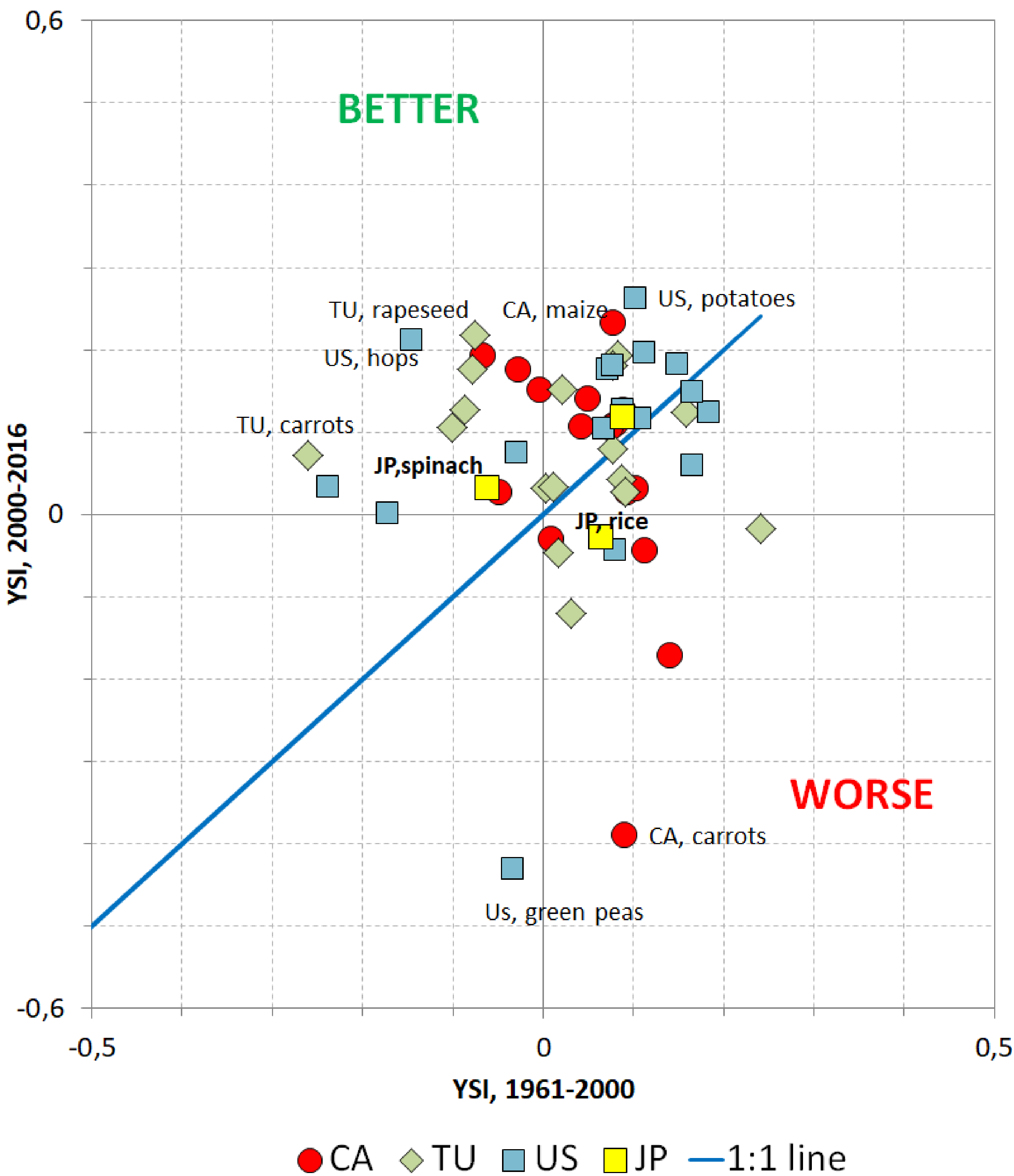


**Figure 6.** Comparison of YSI for 1961-2000 and 2004-2016, 18 crops, Non-European Countries (Source: Authors' own construction based on the data of Tables 1 and 2)

Bacsi and Vízvári (2002) introduced the term „weakly technologized crop" for crops having negative *YSI* values. In Table 4 weakly technologized crops are counted both for 1961-2000 and 2004-2016 for the 10 countries.

Since in some countries the number of crops assessed for 2004-2016 considerably differs from that of 1961-2000, the number of weakly technologized crops is also given as the proportion of all crops analysed for the actual countries (Table 4 and Figure 7).

In 2004-2016 only 4 of the countries showed improvement, i.e. a decrease in the proportion of weakly technologized countries: Hungary, the Netherlands, Turkey and the USA. A considerable deterioration of more than 10 percentage points is seen in the case UK and Japan, although the latter may be explained by the fact that in the 1961-2000 period it was represented only by three crops, while in 2004-2016 data for 16 crops were available for the analysis. Hungary is a negative extreme among countries, with more than 70 % of its crops being weakly technologized, i.e. very unstable, in spite of the small improvements from 1961-2000 to 2004-2016.

**Table 4.** Number of Weakly Technologized Crops (WTCs)

| Countries | CA | DK | FR | HU | IT | NL | TU | UK | US | JP |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 1961-2000 | | | | | |
| No. of all crops | 17 | 13 | 18 | 18 | 17 | 14 | 17 | 14 | 18 | 3 |
| No. of WTCs | 4 | 8 | 6 | 14 | 3 | 8 | 5 | 4 | 5 | 1 |
| WTCs, % of all | 23.5 | 42.6 | 33.3 | 77.8 | 17.6 | 57.1 | 29.4 | 28.6 | 27.8 | 33.3 |
| | | | | | 2004-2016 | | | | | |
| No. of all crops | 16 | 14 | 18 | 18 | 17 | 14 | 17 | 13 | 18 | 16 |
| No. of WTCs | 4 | 7 | 7 | 13 | 4 | 6 | 3 | 6 | 2 | 7 |
| WTCs, % of all | 25.0 | 50.0 | 38.9 | 72.2 | 23.5 | 42.9 | 17.6 | 46.2 | 11.1 | 43.8 |

Source: Authors' own computations

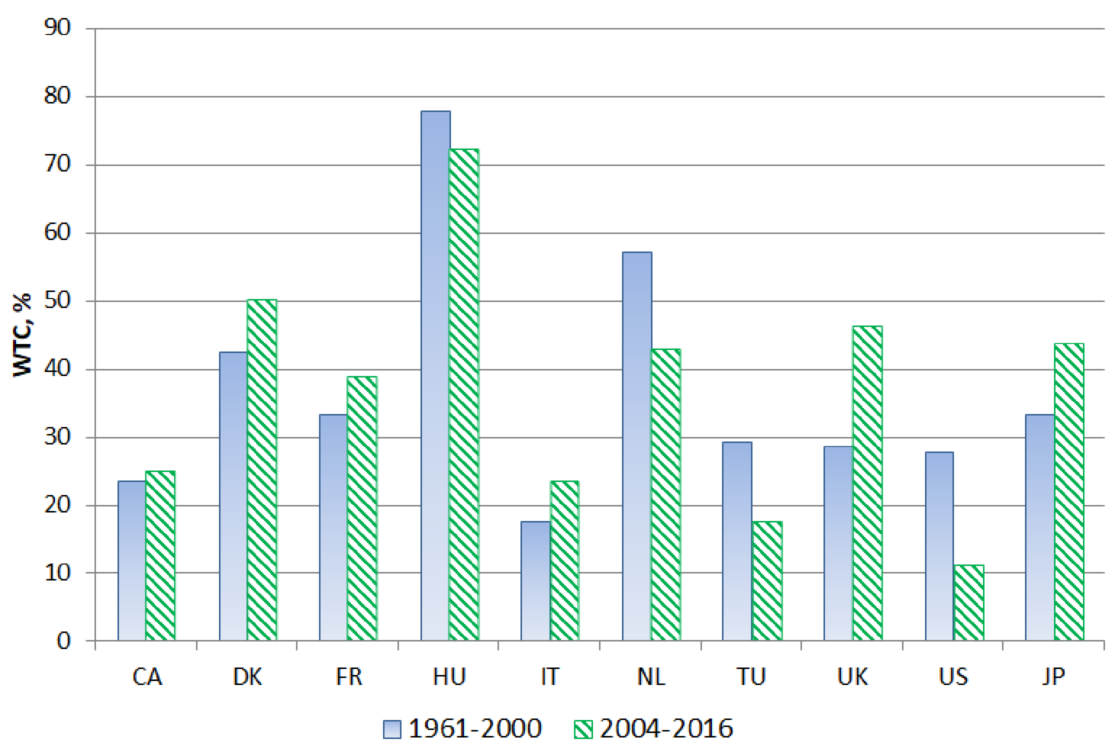


**Figure 7.** Proportion of Weakly Technologized Crops in the analyzed time periods (Source: Authors' own constructions based on the data of Table 4.)

## Conclusions

The goal of the present paper was to test the performance of the Yield Stability Index, and demonstrate its use for distinguishing between crops and production that are well suited to the environmental conditions of particular countries and those that perform badly. For this purpose crop yield stability was assessed for two distinct time periods: 1961-2000 and 2004-2016 to assess improvements in crop production technology, in view of climate change and changing agricultural policies.

The other purpose was to demonstrate the applicability of the index for the agricultural policy of a country and identify the weakly technologized crops for each analysed country. As our results show, the adjusted Yield Stability Index gives a meaningful measure of yield stability, considering only large deviations as instability. In this way it is different from the usual measures of dispersion, and more suitable to assess the suitability of crops and cropping technologies across countries and time periods. Therefore, applying it to the same country can indicate the efficiency of production technology. The positive values of the index indicate a stable technology, i.e. one that can respond to the year-by-year variations of environmental conditions. It can also assess the technology development in this respect. If the index values of the later period are higher than those of the earlier period, we can conclude that the technology has improved. This kind of change cannot be simply put down to a climatically less varied time period, because the index is created in such a way that the normal distribution used as the basis of comparison is always defined by the standard deviations of the same period. Then a climatically stable period would have a small standard deviation, and then smaller deviations of the yield would be counted as more stable than in a period of more varied weather.

The computations for the periods 1961-2000 and 2004-2016 show this kind of technology improvement for many countries, e.g.: for barley, maize and wheat in Canada, for wheat and maize in the USA, for rapeseed, potatoes and sugarbeet in Turkey, for maize, rye, sugarbeet and cabbage in Framce, for barley, wheat, rye and oats in Italy. However, none of the countries experienced improvement for all the crops, and there is no crop for which stability improved in all the countries. The YSI of cucumbers improved everywhere except in France, and the YSI of cabbages improved in 8 countries (the Netherlands and Japan are the exceptions). On the contrary, for sunflower yield stability improved only in one country (Hungary), the other five producers could not achieve higher YSI values than before 2000. Even for countries in which the index values remain negative, some increase can be noticed, as is seen in Hungary for barley, wheat, rye, oats, potatoes, sugarbeet and onions.

Generally, non-EU countries performed better, providing more stable yield series, and this may suggest a better adapted technology to the changeable environment, and more risk-conscious attitude by farmers.

The actual *YSI* and its change throughout several time periods may indicate the suitability of the actual crop to the actual geographical environment. A positive *YSI* with an increasing tendency indicates that the crop and its production technology are well adapted to the environment, and technology improvement is also possible. This crop is a prospective success in the particular country. On the contrary, a negative and decreasing *YSI* means that the crop may not be suitable, and technological improvement has not been achieved. Therefore either the crop should be abandoned as too risky, or a profound change has to be done in technology, as is the case for sugarbeet in the United Kingdom, or for rapeseed in the Netherlands, with negative and decreasing YSI values.

When *YSI* is negative, but shows some increase from the earlier period to the later one, then a formerly less well adapted production technology starts to be improved and development goes in the right direction. This is the case for barley, wheat, rye, oats, potatoes, sugarbeet and onions production in Hungary, or for oats, cabbages and cucumbers in Denmark, showing negative, but increasing YSI index values.

When *YSI* is positive but decreasing, then care must be taken, as the technology that is still suitable is becoming more and more risky. In that case either an improvement of the technology is needed, or, in an extreme case, the country is facing a profound long-term climate change, which makes a formerly well adapted crop unsuitable in the future. These considerations should be taken into account when deciding about cropping structures and R&D directions. The computations of the weakly technologised crops were done with this idea in mind.

Finally, although yield stability is a crucial issue, the actual yield levels are equally important. Therefore, decision makers should consider the trend of the yield and yield stability together. A good cropping system should be able to produce high yields (high mean yield with a positive slope of a yield trend) with high level of stability (high *YSI*).

## References

Bacsi Z., Vízvári B. (2002). A Method for Analysing the Fluctuation of Crop Yields. (Módszer a termésátlagok ingadozásának elemzésére). Gazdálkodás, 46 (3): 63-74. (In Hungarian)

Brink D. (2010) Essentials of Statistics. Ventus Publishing APS.

Coble K. H., Heifner R. G., Zuniga M. (2000). Implications of Crop Yield and Revenue Insurance for Producer Hedging. Journal of Agricultural and Resource Economics 25 (2): 432-452

Cuddy J. A., Della Valle P. A. (1978). Measuring Instability of Time Series Data. Oxford Bulletin of Economics and Statistics 40: 79-85.

FAO (2018) http://www.fao.org/faostat/en/#data/QC., FAO Statistical Database, Accessed: 10 March 2018

Gollin, D. (2006). Impacts of International Research on Intertemporal Yield Stability in Wheat and Maize: An Economic Assessment. Mexico, D.F.: CIMMYT.

Grover K. K., Karsten H. D., Roth G. W. (2009). Corn Grain Yields and Yield Stability in Four Long-Term Cropping Systems. Agronomy Journal, 101: 940–946

Imai K., Gaiha R., Thapa G. (2008): Supply Response to Changes in Agricultural Commodity Prices in Asian Countries. Univ. of Manchester Economics Discussion Paper Series, EDP-0808

Khalili M., Pour-Aboughadareh A. (2016). Parametric and Non-parametric Measures for Evaluation of Yield Stability and Adaptability in Barley Doubled Haploid Lines. Journal of Agricultural Science and Technology 18: 789-803

Kovářová K., Nádeník M., Pícha K. (2017). The Czech Republic Sugar Market Development in the Context of the Phasing out of Sugar Quota. Deturope, 9 (2): 110-117.

Kovářová K., Procházková K. (2017). Influence of the Seasonal Progress of the Quality Characteristics on the Purchase Prices of Milk in Context of the Market Situation (Vlív sezónní dynamiky jakostních ukazatelcú na vykupní cenu méka v kontextu situace na trhu.). Deturope, 9 (1): 35-46. (In Czech)

Mizik T. (2019): A Közös Agrárpolitika üzemszintű hatásai magyar szemszögből. [The Farm-Level Impacts of the Common Agricultural Policy from the Hungarian Viewpoint – In Hungarian]. Gazdálkodás 63 (1): 3–21.

Molnár T., Molnárné Barna K. (2015). The Impacts of Extreme Weather Events (A szélsőséges időjárási jelenségek hatásai). Deturope, 7 (1): 79-94. (In Hungarian)

Nielsen D. C., Vigil M. F. (2018). Wheat Yield and Yield Stability of Eight Dryland Crop Rotations. Agronomy Journal 110: 594–601. doi:10.2134/agronj2017.07.0407

Piepho, H.P. (1998). Methods of Comparing the Yield Stability of Cropping Systems. J. Agron. Crop Sci. 180: 193–213. doi:10.1111/j.1439-037X.1998.tb00526.x

Sherrick B. (2012). Relative Importance of Price vs. Yield variability in Crop Revenue Risk. Farmdoc Daily 2:198. https://farmdocdaily.illinois.edu/2012/10/relative-importance-of-price-v.html

Takács-György K., Takács I. (2012). Changes in Cereal Land Use and Production Level in the European Union during the Period 1999-2009, Focusing on New Member States. Studies in Agricultural Economics, 114: 24-30.

Tóth- Kaszás N., Keller K., Ernszt I., Péter E. (2017). Local Products: Safe Livelihood or Additional Income? (Helyi termék: biztos megélhetés vagy keresetkiegészítés?). Gazdálkodás 61(4): 335-354. (In Hungarian)

Vízvári B., Bacsi Z. (2002). Technological Development and the Stability of Technology in Crop Production. Journal of Central European Agriculture 3 (1): 63-72.

Wang X., Li Y., Qian Z., Shen Z. (2012). Estimation of Crop Yield Distribution: Implication for Crop Engineering Risk. Systems Engineering Procedia 3: 132 – 138

acs84_40