RELATION OF CEREALS YIELDS AND VARIABILITY TO SOIL-CLIMATE AND PRODUCTION CHARACTERISTICS OF DISTRICTS OF THE CZECH REPUBLIC

VZTAH VÝNOSŮ A VARIABILITY VÝNOSŮ OBILOVIN K PŮDNĚ-KLIMATICKÝM A VÝROBNÍM CHARAKTERISTIKÁM OKRESŮ ČESKÉ REPUBLIKY

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ABSTRACT

The relations between yields (Y) or yield year-to-year variability (YV) of winter wheat and spring barley in years 1993-2001 in districts of the Czech Republic to environmental and production indicators were studied. We found mostly significant relationships between Y and soil conditions, average precipitation and temperature, fertilizer consumption, animal production and concentration of cereals. Fertilizers explained up to 70 % of Y differences among districts, but other factors only 50 % and less. The relations of YV and the indicators were mostly weaker than that of Y.

KEY WORDS: yield stability, region, climate, soils, GIS

ABSTRAKT

Byl studován vztah mezi výnosy (Y) nebo variabilitou výnosů (YV) pšenice a ječmene v okresech České republiky a přírodními nebo výrobními podmínkami. Byl pozorován průkazný vztah mezi Y a půdními podmínkami, průměrnými srážkami a teplotou, intenzitou hnojení a dalšími ukazateli. Intenzita hnojení vysvětlovala až 70 % rozdílů v Y mezi okresy. Vztah YV a těchto indikátorů byl většinou slabší než u Y.

KLÍČOVÁ SLOVA: stabilita výnosů, regióny, klima, půdy, GIS

DETAILED ABSTRACT

Výnos (Y) a výnosová variabilita (YV - koeficient variability) hodnocené jak v čase tak v prostoru závisejí na řadě přírodních a výrobních faktorů. Zemědělské oblasti České republiky se vyznačují odlišnými orografickými, klimatickými a půdními podmínkami, které podmiňují zastoupení jednotlivých plodin a průměrnou výnosovou úroveň. V tomto příspěvku jsme zkoumali vztah mezi Y nebo YV obilovin v okresech České republiky v letech 1993-2001 a přírodními nebo produkčními charakteristikami těchto regionů. Výnosy obilovin, zastoupení jednotlivých druhů na orné nebo celkové výměře zemědělské půdy, koncentrace živočišné výroby a spotřeba NPK hnojiv byly převzaty z údajů Českého statistického úřadu a Ministerstva zemědělství. Průměrné srážky a teplota v okresech byly vypočteny pro ornou půdu v prostředí GIS z digitálních map, půdní podmínky v okresech byly charakterizovány zastoupením 16 agregovaných skupin půd. Průměrné výnosy ozimé a jarní pšenice a jarního ječmene v daném období spolu silně korelovaly (korelační koeficient r > +0,92; zde a dále je korelační koeficient průkazný na úrovni p<0,01 pokud r >|0,29|), korelace mezi výnosy v jednotlivých letech byla méně těsná (r= +0,72 a +0,79). V článku jsou prezentovány výsledky pro ozimou pšenici a jarní ječmen. Vztah mezi variabilitou těchto druhů v daném období byl slabší (r < 0,6). Zaznamenali jsme negativní vztah mezi výnosem a ročníkovou variabilitou (r = - 0,58 a - 0,55), který byl ovlivněn vysokou YV (nad 0,19) a nízkým výnosem (pod 3 t/ha) u několika okresů s malou a kolísající výměrou pšenice a ječmene v marginálních oblastech. Průkazný, ale nepříliš těsný vztah (r < │0,51│) existoval mezi výnosy obilovin a zastoupením skupin některých půd v okresech. Vztah výnosů k průměrné spotřebě hnojiv a koncentraci obilovin byl silnější (r < + 0,82). Také s vyšší koncentrací živočišné výroby v okresech se průměrný výnos zvyšoval (r < +0,5). Vztah výnosové variability k uvedeným indikátorům byl většinou slabší. Výnos obou obilovin se zvyšoval s rostoucími srážkami a Langovým indexem (r < +0,53) s maximem okolo 600 mm. Nejnižší YV pšenice byl zaznamenán okolo hodnoty Langova indexu 85, u jarního ječmene byl vztah slabší (r = +0,25 oproti +0,44 u pšenice). Těsnost vztahu se výrazně zlepšila (r = +0,70 a +0,57) pokud byly z korelačního pole vypuštěny okresy s velmi nízkou výměrou a s YV nad 0,19. Vztah mezi průměrnými teplotami a výnosy byl slabší než u srážek (r = +0,39 a +0,39).

INTRODUCTION

Yields of crops in a long term are the result of interaction of farmer's skill and technical equipment with rather conservative environmental conditions of sites (altitude, soil, climate). The actual yield and quality is affected by occurence of biotic and abiotic stresses in a year governed by weather course. The scales at which the factors affect yields and are studied greatly differ, from plot to continent scale. Besides yields also year-to-year yield variability is a vital important trait as it has a negative effect on farm's budget. The fluctuation of yields and quality at farm and higher levels (from regions to whole states) is also of interest to government agencies because of food safety concerns, to commodity and food companies or insurance sector [2, 3].

The yield variability is mostly the result of fluctuations of weather, especially of precipitation, during growth but indirect effects, e.g. leaching of residual nitrate from previous year may be important as well [11]. It is assumed that the fluctuations are reflected in long-term averages. The risk of low precipitation in dry areas will be greater than in regions with higher average precipitation. Other factors may contribute to higher yields or yield variability, for example higher input of farm organic fertilizers improves soil quality and stability of soil fertility. Further, political and socio-economic factors [3, 6, 12] may indirectly affect yields and yield stability.

Objective of the study was to assess relation among environmental or production factors and yields or yield variability of cereals at the scale of regions.

MATERIALS AND METHODS

The average yields of winter and spring wheats, and spring barley in 77 administrative units, districts of the Czech Republic in years 1993-2001 were obtained from the reports of the Czech Statistical Office (CSO) and Ministry of Agriculture (MA). Average area of districts is about 100 thousands ha, the area of arable land ranges between 2 and 100 thousands ha in district, with average 37,8 thousands ha and median 41,4 thousands ha. Proportions (concentration) of the cereal crops on arable and all agricultural land were calculated.

The data on the acreage of 16 soil agro-ecological groups in the districts [7] were used; the authors aggregated original 78 main soil unit (HPJ) according to their fertility to be used for planning of fertilizer use. Average consumption of N, P and K and concentration of animal production per ha (in livestock units, 1 LU=500 kg live weight) in the districts were provided by CSO and MA [1, 8].

Digital climatic map of average year temperature, sum of precipitation and Lang's rain factor (total mean annual precipitation in millimeters divided by average annual temperature of air in degrees centigrades, regions with value under 70 are classified as dry, above 90 as wet), and polygons of arable land from CORINE land cover [4] were used in GIS (ARC View 8.3) to calculate average climatic indicators for arable land. The procedure excluded high altitude areas of districts covered mostly with meadows and forests, with a higher precipitation and lower temperatures; available climatic data could not be used as they were calculated for the whole area of districts. Climatic maps were constructed in Czech Hydrometeorological Institute, Praha, from 30-year meteorological data.

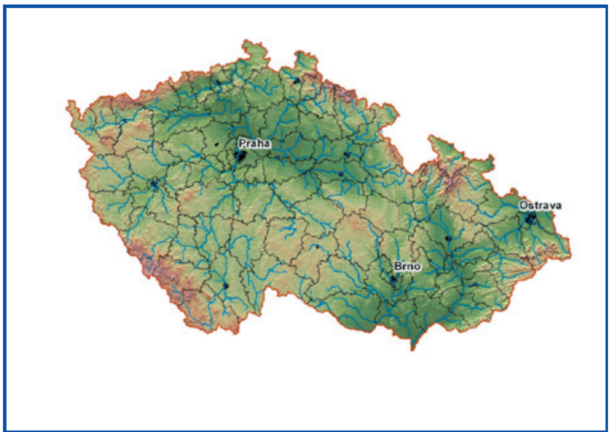
The variability of yields (YV) in districts was expressed as coefficient of variation (CV). The relation between Y or YV and the indicators were evaluated with linear and non-linear regression analysis in MS-EXCEL and UNISTAT statistical programmes. Some data are presented in the form of maps constructed in GIS.

RESULTS

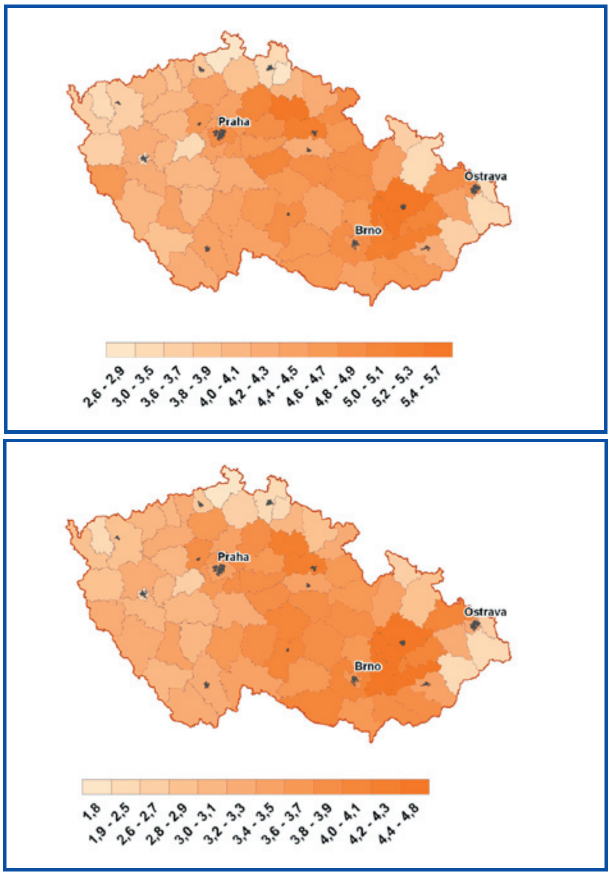
Yields and yield variability of cereals

There was a strong correlation between nine-year average yields of the three cereals in the districts, coefficient of correlation (r) was from +0,92 to +0,95 (here and elsewhere r is significant at p<0,01 and p<0,05 if r >|0,29| and |0,22|, respectively). Therefore we present only results for winter wheat and barley. Correlation coefficients between wheat and barley yields in particular years were slightly lower than between average yields of the whole period. The relation between year-to-year variability (CV) among the cereals was less tight (r= +0,72 and +0,79). High-yielding areas of Czechia are situated mostly in lowlands and partially also in lower parts of highlands about 400-500 m a.s.l. (Map 1,2). The districts showing the greatest yield stability (the lowest variability) are situated not only in the fertile lowlands (Map 3). Marginal districts with low area of cereals showed a high YV. From regression analysis of YV on Y comes that YV of wheat and barley decreases by 5 % with yield increase by about 1t/ha (r = - 0,58 and - 0,55). The results of regression analysis were strongly affected by a high YV (above 0,19 and low Y (under 3 t/ha) in districts with a small acreage of evaluated crops. As apparent from maps (2, 3) there were districts with a low Y and both, low and high YV. On the other side, there were districts with high yields and both low variability and medium or high variability. Such differences are probably caused several interacting factors.

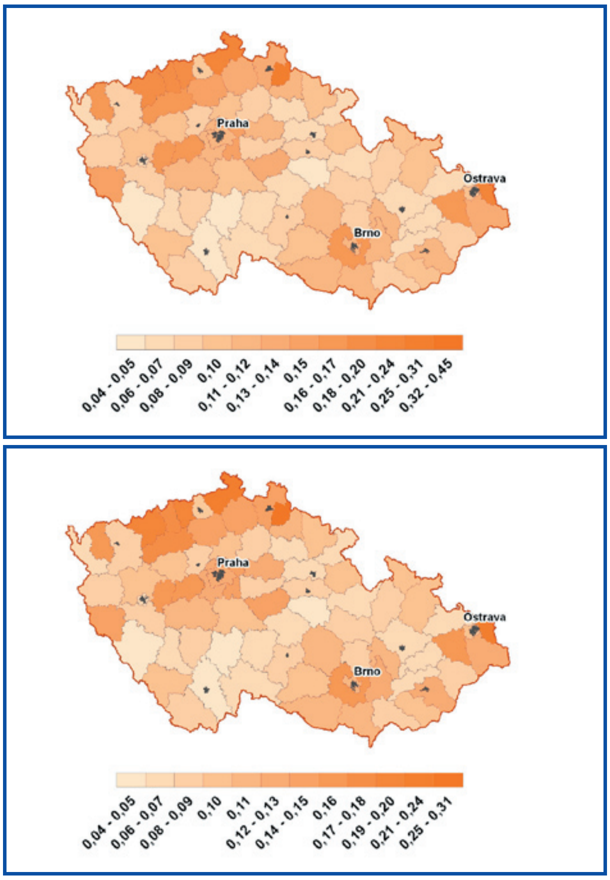
To exclude the possibility that YV and studied relations were affected by a single extreme drought year 2000 we performed calculations without the year. We did not find a significant effect of the exclusion on the observed relations between Y, YV and the studied factors.



Map 1 Geography and administrative units, districts, of the Czech Republic.
Mapa 1 Geografie a okresy České republiky.



Map 2 The average yields (t/ha) of winter wheat (top) and spring barley (bottom)
Mapa 2 Průměrné výnosy (t/ha) ozimé pšenice (nahoře) a jarního ječmene (dole)



Map 3 The yield variability of winter wheat (top) and spring barley (bottom)

Mapa 3 Průměrná výnosová variabilita ozimé pšenice (nahoře) a jarního ječmene (dole)

The effect of concentration of cereals, mineral fertilization and intensity of animal production.

As expected, the average fertilization (NPK) consumption per ha of agriculture land in districts was in positive linear relation with Y of wheat and barley, r = +0,83 and + 0,82, respectively (Figure 1). It simply confirms the notion that fertilizers are used reasonably by farmers, in relation to yield level and it suggests no interacting effect of climate or soil on the fertilization efficiency. When fertilizer consumption per ha of arable land was used the relation was weaker r = +0,52 and +0,48. From the negative relation between Y and YV comes that NPK was also negatively (loosely) correlated with YV.

With increasing concentration of cereals in a district wheat and barley yields grew (r = +0,61 and +0,64); above the concentration of 30 % yields showed some signs of stagnation (Figure 2). The stagnation was not apparent in barley when only barley concentration on arable land was used in the regression. Concentration of animal production (LU/ha of agricultural soil) showed also positive relation to yields of wheat and barley (r= +0,48 and +0,43) and negative one with YV (r= -0,51), but there was almost no relation when LU per unit of arable land was used.

The relation of yields and yield variability to soil conditions

As expected, high yields in districts were positively correlated with a high proportion of fertile soils of group 7 (Maps 4) (Chernozems and Cambisols of warm regions), the correlation with yields of wheats and barley was +0,63 and +0,70, respectively. However, there were

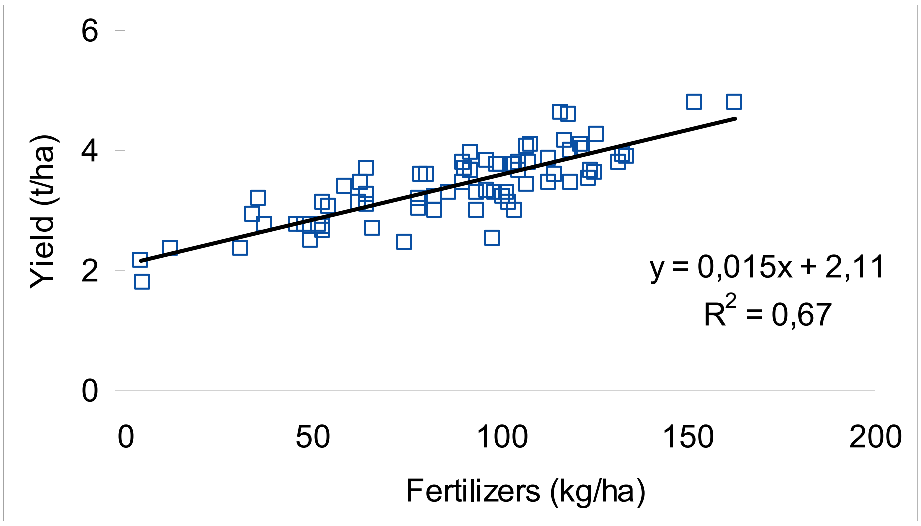


Figure 1 The relation between barley yields and average NPK consumption per unit of agriculture land.

Vztah mezi výnosy ječmene a průměrnou spotřebou NPK na jednotku zemědělské půdy.

some districts with a low proportion of groups 7 and 8 and relatively high yields (Map 2). The regions have a high acreage of soil group 10 (deep and medium Cambisols and Rendzinas of medium cold regions), but at same time there were districts with a low yields and a high area of group 10. Also group 8 (a deep Gleyic Fluvisols), and groups 6 and 9 (fertile soils of regions with high average temperatures) were (loosely) correlated with high yields. Oppositely, there were shallow and medium gleyic soils of groups 12-15 which indicated lower yields (Maps 2, 4) but the relation was not tight ($r < |-0,45|$). Multiple regression did not improve the correlation, probably, the effect of soil groups in districts is intermingled with effect of geological substrate, altitude and climate that determines a long-term soil development.

The effect of climatic conditions on yields and yield variability in districts

The regression analysis showed a non-linear relationship between yields and precipitation or Lang's rain index (Fig 3). The yields of wheat and barley increased with average precipitation ($r = +0,50$), maximum was around 600 mm, above the level yields decreased. The yields of wheat and barley also increased with Lang's index ($r = +0,53$

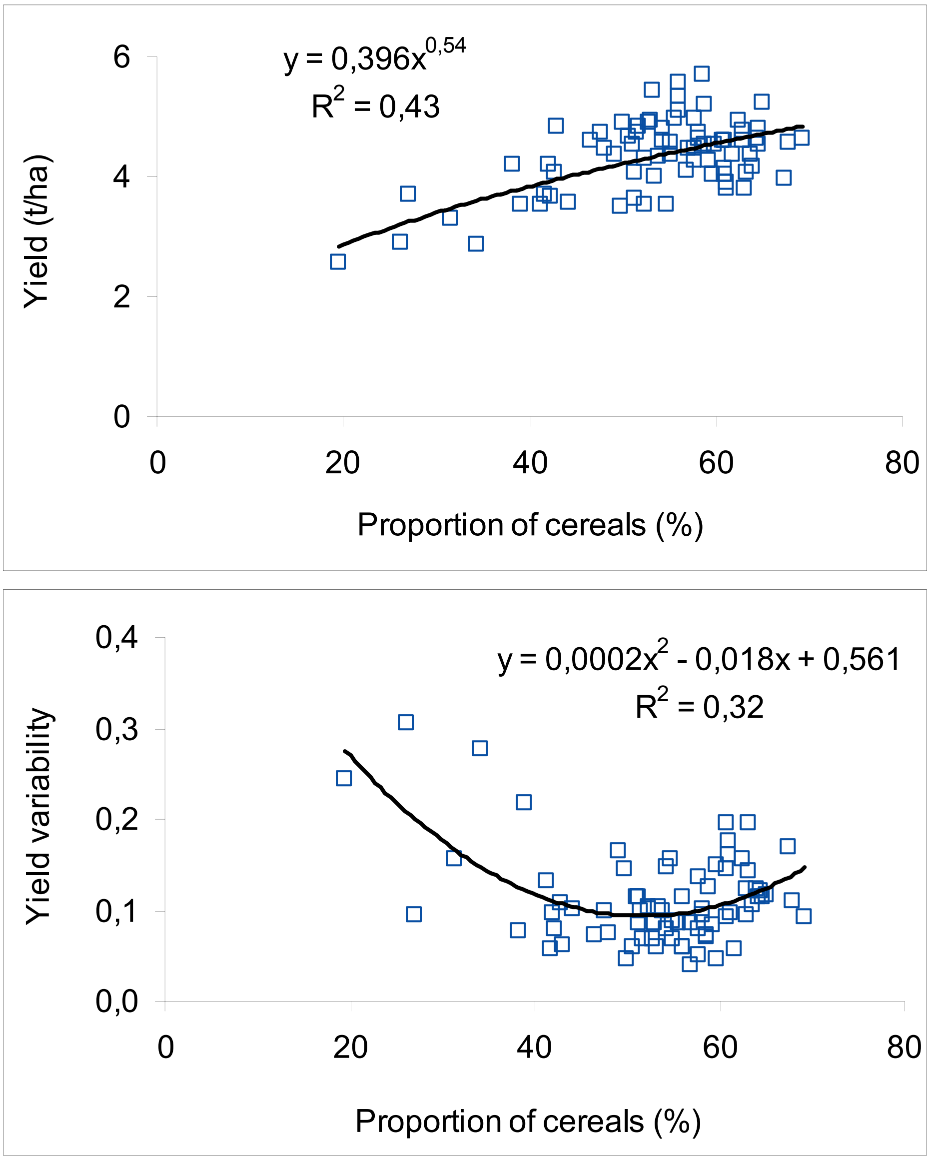
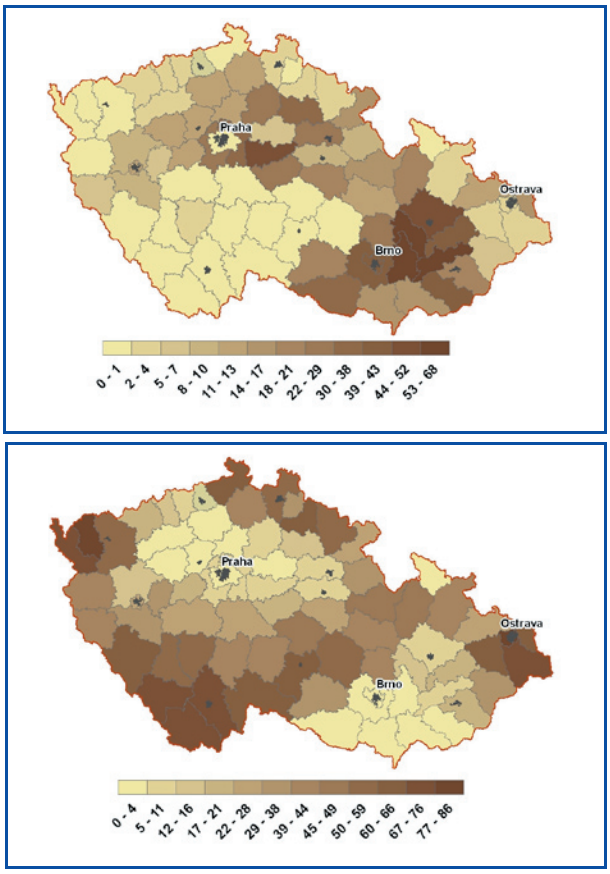


Figure 2 The dependence of wheat yields or yield variability on the concentration of cereals on arable land in districts.



Maps 4 The proportion of fertile soil groups 7 and 8 (top) and less fertile groups 12-15 (bottom) of agriculture land in districts (see text).

Mapa 4 Zastoupení úrodných půd skupiny 7 a 8 (nahoře) a méně úrodné skupiny půd 12-15 (dole) z výměry zemědělské půdy(blíže v textu).

and +0,52, respectively) and declined at higher values (wet regions). The lowest wheat's yield variability were about Lang's index 85 (Fig. 3); in barley the relation was weak (r = +0,25 in comparison with +0,44 in wheat). The relation pronouncedly improved to r = +0,70 and +0,57 when evident outliers, the district with extremely low cereal acreage and YV above 0,19 were excluded. The relations between average temperatures in districts and yields were weaker than in precipitation, r = +0,39 and +0,39 for wheat and barley, with signs of stagnation above 8 °C.

DISCUSSION

The analysis of yield and yield variability of main cereals in years 1993-2001 showed some relationships to environmental and production indicators at the scale of districts. The relations were mostly significant but not tight - the analysis explained at the most 50 % and 35 % of yield differences among districts and yield year-to-year variability, respectively. Only consumption of fertilizers explained up to 70 % of Y differences among districts but the indicator is apparently dependent on yield level. In Norway [6] a multiple regression model based on 15 significant predictors explained only 17 % and 19 % ov variation of barley and wheat yield, the best predictor was percent area of wheat, iirigation, pH and silt content.

There are several assumptions and simplification that affect the date used for the study. The average (statistical) yields are undoubtedly distorted to some extent as they were calculated on the basis of survey at selected farms and from the total national production. Average NPK use is also an approximation due to inevitable transfers of the

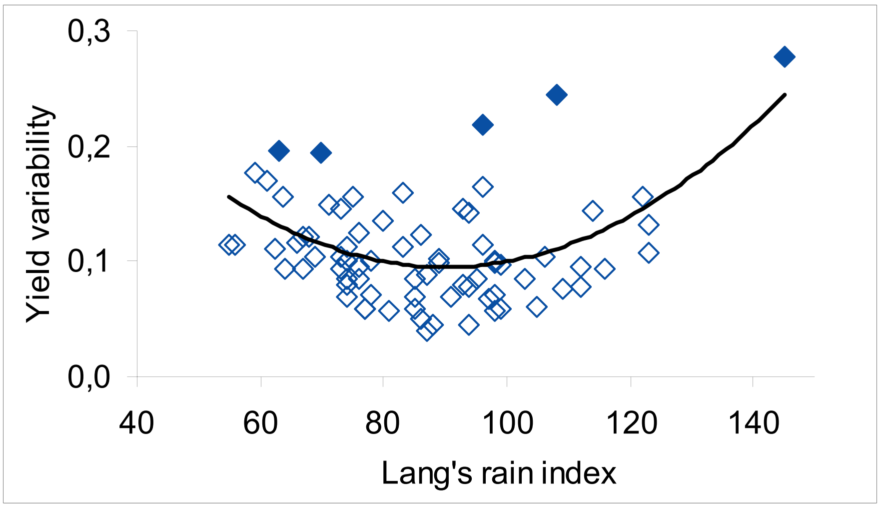


Figure 3 The dependence of Lang's rain index and wheat yield variability; possibly excluded values (see text) are shown as empty symbols.

stuffs over borders of districts. The same pays for farm organic fertilizers assumed to be related to intensity of animal production in a region.

The effects of climate and weather, soil conditions or fertilizer rates and other production factors on yields and variability are studied at various levels, from field, crop rotation or farm to regional or national ones [3, 5, 6, 8]. For example [10] analyzed regional yield series from a ten-year period on the basis of maximal yields of main crops, and sources and consumers of carbon in agrosystem. In published studies data are aggregated at different levels [5] found a negative relationship between crop yield variability and the scale of area aggregation - from plot data to average national yields. We observed a negative relation (r = - 0,51) between average YV of winter wheat and the area of agricultural soil in districts in our study, but it may be explained simply by the fact that greater districts are situated in more productive areas [6].

Another factor possibly affecting yields in a long-term are changes of market demand and the structure of agriculture [3]. After political change and transition to free market in 1989 [12], there was a sharp drop of N and chiefly P and K rates, use of chemicals, in the start of 90‘, the yields of cereals also decreased a little [9]. In half of 90's the situation stabilized, fertilizers have been allocated preferably to cash crops (cereals, oilseed rape, sugar beet, potatoes, maize), but average P and K rates have been still low. Average national winter wheat yields had increased trend (25 kg/year), while trends of spring wheat and barley were decreasing (75 and 25 kg/ha). Still, there was apparently no need to detrend the yield series as performed in long-term yield series [3, 8]. There was no abrupt change of cultivars in evaluated period. It may be speculated that other factors as anthropogenic (pollution) and socio-economic ones (structure of crops near big towns, qualification structure of farmers) also affect the yield and variability data ([6]. Further, the data are influenced by a year-to-year allocation of the crops to different fields (soils) by farmers, but the position of a crop in a crop rotation determines also the allocation to a field (soil) due to sowing term, pre-crop fertility value and other aspects. Still, the fluctuation of total area of wheat (744 - 870 thousands ha) and barley (338-489 thousands ha) in country during years 1993-2001 implies possible site-specific effects of weather (frost damage, wet or dry soils at tillage and sowing) on yield data.

CONCLUSIONS

Generalization of yields and yield variability at the scale of districts enables to find some general relations that are caused by manifold interacting factors and conditions. The regional approach confirmed that the sources of yield variability are recognizable at district level. The analysis can not substitute more detailed year and site analysis of yield variability but it may concentrate the research on causes of gaps in yield variability between districts at the same yield levels.

ACKNOWLEDGMENT

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