ČESKÁ AKADEMIE ZEMĚDĚLSKÝCH VĚD

# ROSTLINNÁ VÝROBA

# *Plant Production*

ÚSTAV ZEMĚDĚLSKÝCH A POTRAVINÁŘSKÝCH INFORMACÍ

7

Ročník 47
Červenec 2001
ISSN 0370-663X

# ROSTLINNÁ VÝROBA

Mezinárodní vědecký časopis vydávaný z pověření Ministerstva zemědělství České republiky a pod gescí České akademie zemědělských věd

# PLANT PRODUCTION

An international journal published under the authority of the Ministry of Agriculture and under the direction of the Czech Academy of Agricultural Sciences





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**Periodicita:** časopis vychází měsíčně (12krát ročně), ročník 47 vychází v roce 2001.

**Přijímání rukopisů:** Rukopisy ve dvou vyhotoveních je třeba zaslat na adresu redakce: RNDr. Eva Stříbrná, vedoucí redaktorka, Ústav zemědělských a potravinářských informací, Slezská 7, 120 56 Praha 2, Česká republika, tel.: + 420 2 27 01 05 07, fax: + 420 2 27 01 01 16, e-mail:editor@uzpi.cz. Den doručení rukopisu do redakce je publikován jako datum přijetí k publikaci.

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**Periodicity:** The journal is published monthly (12 issues per year), Volume 47 appearing in 2001.

**Acceptance of manuscripts:** Two copies of the manuscript should be addressed to: RNDr. Eva Stříbrná, editor-in-chief, Institute of Agricultural and Food Information, Slezská 7, 120 56 Praha 2, Czech Republic, tel.: + 420 2 27 01 05 07, fax: + 420 2 27 01 01 16, e-mail: editor@uzpi.cz. The day the manuscript reaches the editor for the first time is given upon publication as the date of receipt.

**Subscription information:** Subscriptions may be ordered only by calendar year (January–December) and should be sent to: Institute of Agricultural and Food Information, Slezská 7, 120 56 Praha 2. Subscription price for 2001 is 195 USD (Europe), 214 USD (overseas).

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# Crystallinic water regime and water quality in catchments

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**ABSTRACT**

The paper describes and summarizes some results of 25-year research into water regime and hydrologic parameters measured at many experimental localities on the border of two geomorphological units Košetická pahorkatina and Vyskytenská pahorkatina. Pedological, hydropedological and hydrologic conditions are analyzed that influence the present state of water and nutrient regimes in the landscape. It is stated that a system of the zones of differentiated soil and water conservation in the landscape intended for improvement of water quality and/or for revision of water protection zones can operate provided that all current knowledge of the problem is used and put into practice.

**Keywords:** infiltration areas; water regime; arable land use; permanent grasslands; water quality

There have always been long discussions about nitrate load of water in catchments trying to answer a question which factor is more important: area sources or point sources of contamination. The problems discussed in Order IV catchments, where no point sources occur, are whether contamination was caused by fertilizer residues, impacts of the management system, large area of arable land without vegetation cover in winter, climatic conditions of the year, or by overall ecological stability of the catchment. Other problems are the effect of drainage on deterioration of catchment water quality, and whether catchment infiltration areas contribute to water quality deterioration to a larger extent than transport areas. Proposals of water protection zones neglect the role of infiltration areas of the catchment and drainage systems, mainly for economic reasons.

Opinions concerning the causes of nitrate leaching from soil to water are not consistent. Some authors report the effect of fertilizing, some climatic conditions of the year, and others crop type. Repka (1991) and Kvítek (1999) found nitrate leaching in the period of vegetation rest to be several times higher than in the growing season. The highest nitrate losses were determined on plots left without planting in the winter season (Parkinson 1993). A potential load of the region is influenced by soil profile depth, soil texture, humus content in soils, soil type, potential drainage and hydrogeological structure of the subsoil. The shallower the soil profile and the higher the proportion of sandy particles in soil texture, the lower the soil retention of nitrates in the winter season (Burt and Haycock 1993, Simard and N'Dayegamieye 1993). The aerobic capacity of drained areas is higher than on the surrounding areas, and mineralization of organic nitrogen is also higher (Harris et al. 1984). Forman and Gordon (1993) believe that the reasons lie in ecological stability of the region. Nitrate content in waters is crucially affected by a share of forest land, permanent grasslands and arable land. As documented by Kvítek's (1999) results, nitrate leaching from forest land is considerably lower than from farm land. Current knowledge clearly indicates that it is mainly a complex problem when nitrate leaching and loss from the catchment may be influenced by a share of perennial plantings in the catchment, nitrogen application rates, prevailing soil type and kind, planted crop and climatic conditions of the year. These factors often act synergically.

## MATERIAL AND METHODS

Experimental localities with grasslands situated in the Českomoravská vrchovina region have been run by the Research Institute for Soil and Water Conservation in Prague since 1976 (the localities were described in detail in literature, especially in papers by Haken and Kvítek 1982, 1986). Experimental localities have different geomorphological and site conditions (they lie in infiltration areas of the region, in transport drained areas, as well as in flood plains with fluctuating groundwater levels). The localities are situated along the highway branch road Pelhřimov – Humpolec (90.0 km of D1 highway), approximately at a middle distance between the two towns. The localities are demarcated by the communes Kojčice – Dehtáře – Vadčice – Onšovice – Velký Rybník.

Geomorphologically (Demek 1987), the experimental localities are situated in the Českomoravská vrchovina region, in the Křemešnická vrchovina formation, in Želivská pahorkatina and Humpolecká vrchovina subformations, on the border of two units Košetická pahorkatina and Vyskytenská pahorkatina.

Weather characteristics have been measured at Vadčice station since 1976. Research results presented in this paper were acquired from the following localities.

**Vadčice locality – infiltration area** (years of observation 1976–1982):

A field trial on grassland was organized in two blocks – one block was on shallow soil, the other on medium-deep soil. The two-block design of experimental variants at four replications was as follows: 1 – control (without fertilizing); 2 – PK; 3 – $N_1$PK; 4 – $N_2$PK; 5 – $N_3$PK. Fertilizing was applied to newly planted swards (after fast regeneration) produced from a grass mixture (kg/ha): red clover – 6.0; meadow fescue – 18; timothy – 6.0; false oat – 6.0; red fescue – 6.0. Annual fertilizer application rates (kg/ha): P-35, K-66, $N_1$-80, $N_2$-160. Three cuts were carried out in experimental years, yields of fresh matter and forage dry matter were recorded. Soil samples were taken at layers by 10 cm to measure moisture content gravimetrically, soil temperature was registered at two depths of 0.1 and 0.2 m once a fortnight, physical and chemical properties of soil were determined.

**Dehtáře locality – transport area** (years of observation 1980–1986):

Water regime regulation at a water-logged grassland locality was investigated in a field trial. Complex amelioration of the water-logged site was based on implementation of three levels of soil drainage and parallelly of three levels of nitrogen fertilizing of swards according to this schedule:

Factor 1 – water regime of soil

Variant 1 – no drainage, or local drainage – Lo

Variant 2 – grassland drain spacing – L 20 m

Variant 3 – field drain spacing – L 13 m

Hydropedological conditions of the site and identified causes of water-logging were employed to select the variants:

Factor 2 – nitrogen fertilizing

Variant 1 – extensive fertilizing 25–69 kg NPK

Variant 2 – medium level of fertilizing 55–191 kg NPK

Variant 3 – high level of fertilizing 110–312 kg NPK

The size of drained plots in the different variants was 1.0 ha. The sward of this composition was planted (kg/ha): white clover – New Zealand cv. Huia – 4.0, meadow fescue – Rožnovská – 12.5, timothy – Rožnovský – 10.0, red fescue Rožnovská – 6.5, Kentucky bluegrass – Rožnovská – 10.0, total seeding rate 43.0 kg/ha. Yields of fresh matter, forage dry matter were recorded, drainage discharge was measured with water-level recorders at six measuring points, groundwater levels were registered in one-week intervals, soil moisture content to a depth of 1.0 m in fortnight intervals, soil temperature to a depth of 0.6 m, and chemical and physical properties of soil were determined at regular intervals.

**Velký Rybník locality – accumulation area** (years of observation 1986–2001):

This grassland locality is situated in the flood plain of Jankovský and Kopaninský streams of 5% gradient. Locality area is 8.1 ha. This land was temporarily put out of use in 1984 because it was water-logged as a result of high groundwater level (GWL) influenced by overflows from streams and springs. The sward at the locality was uncultivated, hardly accessible to mechanization in many parts because of a low bearing capacity of the ground surface. To solve the research project, micro-plot trials were established with five levels of soil water regime and three nitrogen application rates at three replications. Micro-plot size was 15 m² (3 × 5), there were nine plots in total in each water regime block. A three-cut system was used. The water regime levels: drained – GWL 0.90 m and more under the ground, regulation – GWL 0.70–0.80 m under the ground, regulation – GWL 0.50–0.60 m under the ground, regulation – GWL 0.30–40 m under the ground, undrained – GWL in relation to the stream groundwater level and precipitation. A grass mixture was planted at the locality in summer 1988. Drainage discharge was measured with water-level recorders at 10 points, groundwater levels once a fortnight, soil moisture content to a depth of 0.6 m once a fortnight, fresh matter yields from grasslands and dry matter yield were recorded, water quality was determined mainly with respect to nitrates once a fortnight.

All data were processed using STATGRAPHICS software.

## RESULTS AND DISCUSSION

Soils in the infiltration area are mostly shallow or medium-deep, stony, very permeable, with low yields of aboveground grass biomass. Biomass yields rise with increasing depth of the soil profile (Haken and Kvítek 1986). These soils are not influenced by the groundwa-

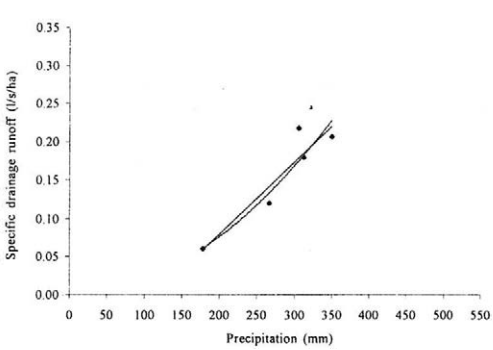


Figure 1. Relationship between specific drainage discharge and precipitation in the winter season X/1979–IX/1984 for drain spacing L 13 m

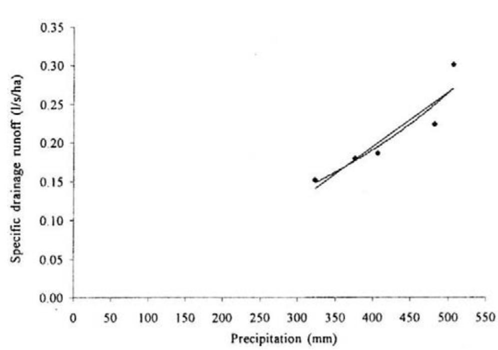


Figure 2. Relationship between specific drainage discharge and precipitation in the summer season X/1979–IX/1984 for drain spacing L 20 m

Table 1. Statistical data on correlations between specific drainage discharge and precipitation

| Drain spacing – season | Number of seasons | Correlation coefficient $R$ | Significance level $\alpha$ | Equations of the relationship between both variables |
|---|---|---|---|---|
| L 20 – out of season | 5 | −0.963103 | 0.00846 | $1/y = 20.75 - 0.053x$ |
| L 13 – out of season | 5 | 0.968115 | 0.00680 | $Y = -12.97x^{1.962}$ |
| L 20 – growing season | 5 | −0.972746 | 0.00538 | $1/y = 11.64 - 0.16x$ |
| L 13 – growing season | 5 | 0.755221 | 0.13992 | $Y = e^{-4.041 + 0.004}$ |

ter level, their moisture content does not exceed 50% of field water capacity throughout the growing season. They are sandy or loam-sandy, stony soils. Their water-retention capacity is low while water infiltration into the soil profile is fast. Soil permeability is higher than 1.0 m/day (Vadčice locality). Chemically, the soils are very acid or acid ($pH_{KCl} = 4.5–5.5$) with unsaturated sorption complex and with low content of humic substances (Kvítek 1992). To achieve identical yields on shallow soils and on medium-deep or deep soils, higher amounts of nutrients should be supplied. These shallow soils are not capable of providing average yield without high nitrogen rates in a dry growing season, and nitrogen utilization is very low (Haken and Kvítek 1986). If grasslands at these localities are used as arable land, direct contamination of shallow-circulating groundwater or of springs is imminent. Croppings at these localities contribute to the bulk of contamination of surface and shallow groundwaters, mainly in the winter season, when the lands – after plowing – are without vegetation cover. The infiltration areas of drainage systems are situated ca. 300–1000 m above drainage systems located in transport areas, consisting of these soils according to the Classes of Soil Evaluation Units: 7.37.01-04, 7.29.01-14.

Soils in the transport area are medium-deep or deep, loamy or loamy-clay, clay with good water retention, often little permeable or impermeable, on sloping lands with possible events of erosion. Confined groundwater may produce springs at places of subsoil dislocation caused by faults. Springs are produced in this transport area, but mainly in the spring season they do not appear at identical places, they are wandering. Water from these outflows is overflowing an extensive surface, contributing to the associations of differently waterlogged soils (pseudogleyic, gleyic and peaty). Drainage discharges from collected springs correlate with precipitation sums (Kvítek and Haken 1986). Precipitation infiltrated in the catchment infiltration area consequently causes land water-logging in the transport area in the form of springs. Therefore different drain spacings from 10–20 m were used in this transport area. Discharge was influenced by the number of collected springs and directly related to precipitation amount (Haken and Kvítek 1982) – see Figures 1 and 2. Statistical significance was proved except for drain spacing $L_{13}$ – growing season, the result is relevant to the number of periods of observation. It was demonstrated at the same time that drainage discharge was not influenced by drain spacing in these hydrogeological conditions.

Discharge coefficient (Table 2) was higher than 100% in some cases, that means water collected by a drainage system is not merely precipitation water falling onto a drained area, but it comes from a larger, infiltration area of the drainage system. If other than arable crop were grown on soils in the infiltration area of drainage systems, discharge would be quite different, and the extent of drainage would not have to be so large. It is to state that improper conversion of the top, infiltration parts (originally of forest stand) to arable land in the faraway past significantly contributed to a change in water regime, and liquidation of permanent grasslands with subsequent drainage after 1960 increased the changes in nutrient regime in many catchments of the Českomoravská vrchovina region.

Waters from drainage systems on arable land in the transport area have high nitrate concentrations (Table 3). This fact may be explained by a shorter time of potential nitrogen denitrification in the soil profile of arable lands,

Table 2. Specific drainage discharge and discharge coefficients at Dehtáře locality in the period X/1979–X/1984 – transport area

| Drain spacing | Period | X/79–III/80 | IV/80–IX/80 | X/80–III/81 | IV/81–IX/81 | X/81–III/82 | IV/82–IX/82 | X/82–III/83 | IV/83–IX/83 | X/83–III/84 | IV/84–IX/84 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | precipitation (mm) | 305.6 | 507.4 | 350.1 | 406.6 | 312.2 | 323.2 | 266.4 | 376.0 | 178.2 | 482.4 |
| $L_{20}$ | specific drainage dischargel ($s^{-1}.ha^{-1}$) | 0.276 | 0.301 | 0.293 | 0.187 | 0.308 | 0.152 | 0.137 | 0.180 | 0.087 | 0.224 |
| | drainage coefficient | 142.1 | 93.8 | 131.4 | 72.4 | 154.9 | 74.5 | 80.0 | 75.1 | 71.6 | 73.2 |
| $L_{13}$ | specific drainage dischargel ($s^{-1}.ha^{-1}$) | 0.218 | 0.236 | 0.206 | 0.074 | 0.180 | 0.089 | 0.120 | 0.100 | 0.0607 | 0.120 |
| | drainage coefficient | 112.4 | 73.4 | 92.7 | 28.6 | 90.9 | 43.4 | 70.0 | 42.2 | 53.9 | 39.1 |

Table 3. $NO_3^-$ concentrations (mg/l) in the Kopaninský stream catchment under different croppings in 1993–1995

| Nitrate concentrations (mg/l) Type of waters | Drainage | | Springs | | | | |
|---|---|---|---|---|---|---|---|
| Cropping | field | | field–forest | | grassland–forest | | forest |
| Maximum | 142.3 | 77.2 | 43.1 | 47.1 | 37.1 | 22.1 | 25.0 |
| Minimum | 2.9 | 17.0 | 9.2 | 12.0 | 8.3 | 2.9 | 5.6 |
| Average | 59.9 | 50.5 | 26.3 | 28.1 | 23.6 | 17.3 | 10.8 |
| Characteristic value | 94.6 | 74.5 | 37.8 | 43.1 | 36.4 | 21.4 | 19.0 |
| Quality class pursuant to standard ČSN 75 7221 | V. | V. | IV. | IV. | IV. | III. | III. |

by higher aeration of arable land than of soils of grasslands and forest stands in the transport area, and particularly by the use of arable land in winter in the infiltration area of drainage systems. Only springs in forest stands have maximum nitrate concentrations below 25 mg/l water because both the infiltration and the transport areas are forested. All values of nitrate concentrations largely fluctuate throughout the year, maximum values are recorded in the spring, minimum ones in the fall. The largest differences between minimum and maximum values were observed in arable and drained lands (Kvítek 1999).

The accumulation area is characterized by associations of gleyic soils accompanied by gleyic alluvial soils. The decline of groundwater level in the soils of this association is higher, with larger fluctuations, influenced by flow rates in the streams. Gravel-sand terraces regularly appear at a depth of 0.8–1.0 m. Combined water-logging with groundwater and surface water is typical of the association of hydrogleys, so in fact the profiles are fully saturated with water all the year round. The hydraulic conductivity of V. Rybník locality is different, 0.5 m/day as well as 0.116–0.011 m/day (measured in Kopecký's cylinders). From this aspect, the soil profile appears impermeable. The basic cause of water-logging at these localities is groundwater, mostly confined as a result of loam layers above the sand-gravel terrace. The groundwater level pressure is caused by a continuous inflow from surrounding colluvial deposits, and the level is affected by the amount of infiltrating precipitation. This water flows downslope. The groundwater level in a valley is influenced by the kind of soil in the infiltration area and whether valley precipitation is infiltrated into alluvia and percolated to the groundwater level or whether it changes into surface runoff in the transport area or remains on the ground surface as surface stagnant water. Massive springs, often under surface water as mentioned above, were revealed in the course of drainage measures. There exist two types of springs: those issuing directly in the middle of the flood plain and those outflowing in balks and faults in transport areas, causing surface water-logging of the locality. The surface layer of soil becomes saturated due to the insufficient internal drainage of soil in horizons 0.2–0.8 m, which decreases its bearing capacity. Table 4 shows the groundwater level e.g. in the period January–March 1983 in the flood plain of Kopaninský and Jankovský streams.

Eutrophication of spring waters is high, and due to water-logging and low bearing capacity lands of these localities stopped being used after higher-performance, heavier-duty mechanization was introduced. Croppings on these lands were largely degraded, they are of hygrophytic or mesophytic character (growths of low sedges, rushes, high sedges, reeds, and covers of foxtail, hair grass, meadowsweet). Geomorphologically, nutrient load is highest in flood plains. To improve their current condition (diversity, water quality, bearing capacity of the ground, groundwater level) at least one cut a year with biomass export is desirable.

Generalization of the results of research on water regime in the landscape and measurements of hydrologic parameters were used to develop a system of differentiated soil and water protection favoring permanent grasslands in the landscape, and to apply it to revision of water protection zones, as a response to the current inappropriate management of the agri-forest landscape.

Kašpar (1975) reported differences in vertical migration of elements between the afforested zone of weathering and the zone of weathering with grasslands and fields. Migrations of mobile elements bound in soluble salts such as nitrates, sulfates and chlorides show large seasonal variations affected by the amount of rainfall (or snow). When snow is melting, there arise capillary links between flowing solutions (of easily migrating elements – $NO_3^-$, $SO_4^{2-}$, $Cl^-$ and $HCO_3^-$) and more concentrated solutions in soil. Therefore waters in the spring contain a considerably higher proportion of soluble salts than

Table 4. Groundwater level in flood plains (cm under the ground) at V. Rybník locality

| Soil pit | Maximum | Minimum | Average |
|---|---|---|---|
| $S_1$ | 1 | 50 | 29.5 |
| $S_5$ | 0 | 30 | 11.7 |
| $S_6$ | 5 | 86 | 48.7 |
| $S_7$ | 10 | 77 | 53.4 |

waters in the other seasons of the year. Heavy rains have the same effect as melting snow.

Čížek in Novák (1998) presents the facts corresponding with our results. An equilibrium content of humus in brown soils in these areas is higher than in loess soils. It is caused by lower average activity of soil microorganisms due to lower temperature, lower content of fine particles and more intensive leaching of mineral and organic matters, typical of these soils. Lower biological activity is also influenced by the shorter growing season.

Humus quality is influenced by soil texture. As the substrate consists of coarse-grained weathering products of crystallinic rocks, the coatings of stable humus are not formed on fine mineral particles with active sorption, but they form relatively large globules. Humus bonds to mineral constituents are realized through iron and aluminium ions due to lower calcium concentration. Trivalent ions bind relatively more organic matter, but the bonds are much weaker in comparison with calcium action.

Humus in the given conditions contains a high share of aromatic type. These are substances from plant sources, mainly residues of lignin components. This composition results from a low rate of organic matter transformation. Low humus stability is reflected in seasonal variability of its amount. There is a decrease in $C_{ox}$ by up to 20% during the growth peak of the crop (e.g. corn) that is accompanied by high activity of soil microflora. This loss is compensated from post-harvest crop residues in the subsequent stage. A wide range of organic matter content from 1–1.8% $C_{ox}$ was determined in soils of the hilly country (measured in the course of Želivka mapping). Oxidation trend should be maintained at a lower degree than in well-developed loess soils (less intensive plowing, more organic manuring). A low rate of organic matter transformation supports the formation of the so-called light fraction of humus that is not bound to heavier mineral constituents. It is the so-called raw humus, in other words partly decomposed residues of plants or microorganisms (up to 40% $C_{org.}$). Therefore the curves of nitrate concentrations are also of a clearly sinusoid shape. This fact was reported by other authors as well (Kvítek 1999, Kašpar 1975).

These conclusions can be drawn from the above results:

- at approximately identical fertilizing levels in the catchment nitrate concentrations in Order IV catchments are influenced by the share of perennial croppings in the catchment and/or by the area of arable land,
- in comparison with other hydrogeological structures the crystallinic water regime is so specific (shallow circulation of water) that the catchment infiltration areas significantly influence nitrate concentrations in waters,
- drainage systems are draining water-logged soils in transport and accumulation areas, and therefore in relation to the area of arable land in infiltration areas they are important elements of water transport affecting water quality in the catchment.

Long-term results of 25-year research on water regime and of hydrologic and qualitative measurements at experimental localities allow to make up a synthesis of results from many special disciplines not only for a limited area of experimental localities but also for other areas of the Českomoravská vrchovina region as well as for a large part of crystallinic formations in the Czech Republic. The results can also be applied at localities not situated in the water protection zones.

This study could be carried out thanks to financial support of the National Agency for Agricultural Research, as part of Project EP 9155 and QC 0242 and Project MZe-M07-99-01-02.

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Received on January 15, 2000

## ABSTRAKT

**Vodní režim krystalinika a jakost vody v povodích**

V příspěvku jsou popsány a shrnuty výsledky 25letého výzkumu vodního režimu a hydrologických parametrů, měřených na experimentálních lokalitách na rozhraní dvou geomorfologických okrsků Košetické a Vyskytenské pahorkatiny. Jsou analyzovány pedologické, hydropedologické a hydrologické podmínky, které jsou příčinou současného stavu vodního a živinného režimu krajiny. Systém zón diferencované ochrany půdy a vody v krajině, který je uplatňován pro zlepšování jakosti vody, resp. při revizi ochranných pásem vodních zdrojů, může fungovat pouze za předpokladu, že budou využity a do praxe převedeny všechny současné znalosti o dané problematice.



**Klíčová slova:** infiltrační oblasti; vodní režim; zornění; trvalé travní porosty; jakost vod


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# Energy balance in model arable farming systems

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**ABSTRACT**

Eleven model arable farming systems (Norfolk crop rotation, crop rotation – ecological system, crop rotation – conventional system, spring barley continuous cropping, winter wheat continuous cropping, both continuous croppings in four variants of organic manuring) were compared using the following production parameters: energy production, total factor productivity (TFP), and efficiency of fossil energy (EFE). Results covering 1995–1999 were analysed and a method of energy balance was used for calculations. Relationships between production variation and a level of fossil energy inputs were also studied. The highest energy production per unit area was assessed in the crop rotation – conventional system (gross energy 181.2 GJ.ha$^{-1}$, digestible energy 62.9 GJ.ha$^{-1}$). The highest values of TFP were recorded in spring barley continuous cropping in variant D – a check without organic manuring (9.13 for gross energy and 3.25 for digestible energy). The highest efficiency of invested fossil energy was assessed in the crop rotation – conventional system (16.44 for gross energy and 5.71 for digestible energy). All variants of both continuous croppings exhibited significantly lower values of EFE than the crop rotation – conventional system and Norfolk crop rotation. Significantly higher values of EFE were found in the crop rotation – ecological system than in variants of continuous croppings where the main product is harvested only (variants A and B). An interannual variation in production increased along with a level of fossil energy inputs in the system. Variants B of spring barley and winter wheat continuous cropping, where organic matter (straw and green manure – mustard) is incorporated each year, significantly differed from the assessed relationship. It can be assumed that a regular supply of organic matter in the soil leads towards a higher stability of the system.

**Keywords:** arable farming systems; energy balance

With regard to changes in agriculture questions of effectiveness of arable farming systems are also discussed. One of important objective criteria measuring effectiveness of agricultural production is a method of energy balance. A number of authors have studied these problems since the early 1970s. A series of six volumes of Energy in World Agriculture (Stout 1986–1992) seems to be the most comprehensive view of energy balance in agriculture including a survey of energy equivalents for a variety of inputs. In our country, for instance, this method has been elaborated by Preininger (1987).

The objective of this study was to compare production characteristics of model arable farming systems using stationary field trials conducted at the Agricultural Research Institute Kroměříž, Ltd.

## MATERIAL AND METHODS

The trial is located in the sugar-beet growing region, 235 m above sea level. A mean annual temperature is 8.7°C and average annual precipitation is 599 mm. The soil type is Luvi-haplic Chernozem. These are medium soils with gley particles from 40 to 47%. Soils are mostly very deep with fully saturated sorption complex and neutral pH.

Model arable farming systems are represented by the selected long-term trials:

**Norfolk crop rotation** (established in 1970): 1 – clover, 2 – winter wheat, 3 – fodder beet, 4 – spring barley. Organic manuring with farmyard manure to fodder beet at a rate of 50 t.ha$^{-1}$. Both main and by-products (straw of cereal crops and beet tops) are harvested.

**Crop rotation – conventional system** (established in 1991): 1 – lucerne, 2 – lucerne, 3 – winter wheat, 4 – spring barley, 5 – sugar beet, 6 – spring barley, 7 – winter wheat, 8 – silage maize, 9 – spring barley. Organic manuring with farmyard manure to sugar beet (50 t.ha$^{-1}$) and silage maize (40 t.ha$^{-1}$). Both main and by-products are harvested (straw of cereal crops and beet tops).

**Crop rotation – ecological system according to IFOAM rules** (established in 1991): 1 – potatoes, 2 – spring barley, 3 – rye, 4 – peas, 5 – winter barley, 6 – oats, 7 – clover, 8 – winter wheat. Organic manuring with farmyard manure to potatoes (50 t.ha$^{-1}$) and oats (5 t.ha$^{-1}$). Main products are harvested only; straw of cereal crops and all post-harvest residues are left in the field and incorporated into the soil.

**Spring barley continuous cropping** (established in 1970) in four variants of organic manuring:

A – straw incorporation
B – straw incorporation + green manure
C – green manure
D – check without organic manuring

Grain and straw are harvested in variants C and D, and only grain is harvested in variants A and B.

**Winter wheat continuous cropping** (established in 1972) in four variants of organic manuring:

A – straw incorporation

B – straw incorporation + green manure

C – green manure

D – check without organic manuring

Both grain and straw are harvested in variants C and D, and only grain is harvested in variants A and B.

Results of the above-mentioned trials achieved from 1995 to 1999 were evaluated by analysis of variance (ANOVA); individual years were replications of the trial. The following characteristics were calculated using ANOVA: total energy production, total factor productivity (TFP), and efficiency of fossil energy (EFE); all parameters were related to gross energy (combustion heat) and digestible energy (conversion from starch units; for more details see Preininger 1987).

Variation in production (yields) in individual systems was a source of variation in TFP and EFE (there were minimal changes in a level of energy inputs in individual systems). Relationships between a value of coefficient of variation of gross energy production and an average amount of invested fossil energy were examined. Data were evaluated using robust LTS regression (Least Trimmed Squares Regression).

The system was delimited by the plot (field). All what flows into the system from outside (what is brought from elsewhere) are inputs (Table 1) and what leaves the system (what is carried away) are outputs. Calculations, therefore, include only the organic manures which enter the system from outside. Break crops, post-harvest residues and incorporated straw are not considered as inputs. They are not, however, considered as outputs either.

Total factor productivity (TFP) is a ratio between aggregate outputs and aggregate inputs. It reflects relationships between the so-called controlled inputs (in association with decision-making processes in production, for instance, fertilisers, pesticides, labour, etc.) and controlled outputs (main products and by-products).

Efficiency of fossil energy (EFE) is a ratio between outputs and inputs in the form of fossil energy. In addition to fossil energy in direct inputs we also take into account energy from fossil sources used for production of mineral fertilisers, pesticides, machines, and others).

Energy balances were calculated according to Preininger (1987). Some energy equivalents were adopted from the six-volume study Energy in World Agriculture (Stout 1986–1992). To assess equivalents of energy consumption in machines, results obtained within the project of the Grant Agency of the Czech Republic no. 504/94/1238 (Křen and Červinka 1997) were used.

Calculations were done each year for all crops. In the case of crop rotations obtained values were used for calculating a mean value of TFP and EFE related to 1 hectare of crop rotation – arable farming system.

The aim of this work was not to evaluate individual crops, or their management practices, but the system as a whole. Therefore, data were collected with this intention and detailed data on individual crops are not presented.

## RESULTS

The highest average production of energy (both gross and digestible) was obtained in the crop rotation – conventional system, the lowest one in the crop rotation – ecological system (Table 2). In gross energy, variants C and D in both continuous croppings are more productive than variants A and B (since the by-product straw is not harvested and is not taken as an output out off the system). The situation is similar in the case of digestible energy production; only variant D of spring barley continuous cropping falls down to a level of variant A (where only grain as a main product is harvested) even though the main product and by-product (grain and straw) are harvested. Winter wheat continuous cropping is generally more productive than the same variants of organic manuring in spring barley continuous cropping. The

Table 1. A level of invested energy inputs in model arable farming systems (mean of 1995–1999)

| System | Inputs of invested energy in total (MJ.ha$^{-1}$) | Inputs of invested fossil energy (MJ.ha$^{-1}$) | Proportion of fossil energy of total invested energy (%) |
|---|---|---|---|
| E | 26 815 | 7 182 | 26.78 |
| CI | 37 536 | 11 110 | 29.60 |
| Norfolk | 43 499 | 10 260 | 23.59 |
| SBCC_A | 16 230 | 14 302 | 88.12 |
| SBCC_B | 17 190 | 14 553 | 84.66 |
| SBCC_C | 17 342 | 14 700 | 84.77 |
| SBCC_D | 12 325 | 10 400 | 84.38 |
| WWCC_A | 20 797 | 18 327 | 88.12 |
| WWCC_B | 21 757 | 18 578 | 85.39 |
| WWCC_C | 21 909 | 18 725 | 85.47 |
| WWCC_D | 20 949 | 18 472 | 88.18 |

Table 2. Production characteristics of model arable farming systems (mean of 1995–1999)

| System | Production of gross energy (MJ.ha$^{-1}$) | Production of digestible energy (MJ.ha$^{-1}$) | TFP for gross energy | TFP for digestible energy | EFE for gross energy | EFE for digestible energy |
|---|---|---|---|---|---|---|
| E | 79 978 | 35 723 | 2.98 | 1.33 | 11.14 | 4.98 |
| C | 181 171 | 62 917 | 4.83 | 1.68 | 16.44 | 5.71 |
| Norfolk | 141 255 | 46 351 | 3.25 | 1.07 | 13.76 | 4.52 |
| SBCC_A | 84 950 | 39 215 | 5.24 | 2.42 | 5.94 | 2.74 |
| SBCC_B | 97 565 | 45 038 | 5.68 | 2.62 | 6.71 | 3.10 |
| SBCC_C | 143 048 | 49 224 | 8.24 | 2.84 | 9.72 | 3.35 |
| SBCC_D | 112 380 | 39 981 | 9.13 | 3.25 | 10.83 | 3.86 |
| WWCC_A | 89 050 | 43 634 | 4.31 | 2.11 | 4.89 | 2.40 |
| WWCC_B | 95 116 | 46 606 | 4.39 | 2.15 | 5.15 | 2.52 |
| WWCC_C | 166 104 | 53 778 | 7.61 | 2.47 | 8.92 | 2.89 |
| WWCC_D | 161 796 | 53 346 | 7.76 | 2.56 | 8.80 | 2.91 |
| Min. significant difference (Tukey $\alpha_{0.05}$) | 32 159.1 | 11 079.0 | 1.697 | 0.627 | 2.478 | 0.883 |

TFP = total factor productivity
EFE = efficiency of fossil energy
E = crop rotation – ecological system according to IFOAM
C = crop rotation – conventional system
SBCC_A = spring barley continuous cropping, variant of organic manuring A (straw incorporation)
SBCC_B = spring barley continuous cropping, variant of organic manuring B (straw incorporation + green manure)
SBCC_C = spring barley continuous cropping, variant of organic manuring C (green manure)
SBCC_D = spring barley continuous cropping, variant D (a check without organic manuring)
WWCC_A = winter wheat continuous cropping, variant of organic manuring A (straw incorporation)
WWCC_B = winter wheat continuous cropping, variant of organic manuring B (straw incorporation + green manure)
WWCC_C = winter wheat continuous cropping, variant of organic manuring C (green manure)
WWCC_D = winter wheat continuous cropping, variant D (a check without organic manuring)

Norfolk crop rotation is medium among the investigated systems. It differs less in gross energy than in digestible energy from the most productive systems.

A more suitable criterion for evaluation of production abilities of arable farming systems is a ratio between total inputs and total outputs, total factor productivity (TFP). With regard to high values of energy inputs in organic manures, the systems with crop rotations show generally lower values of TFP than continuous cropping. In contrast to energy production spring barley continuous cropping shows higher values of TFP than winter wheat continuous cropping. Also, variants C and D in both continuous croppings have higher values of TFP than variants A and B. Based on rather low inputs, the highest values of TFP were found in variant D of spring barley continuous cropping (9.13 for gross energy or 3.25 for digestible energy).

The crop rotation – conventional system exhibited the highest values of EFE (16.44 for gross and 5.71 for digestible energy). All crop rotations show better values of EFE than continuous croppings. Values of EFE are close to values of TFP in all variants of continuous croppings (no organic manures are applied originating outside the system; a major part of invested energy is the energy from fossil sources, see Table 1). Therefore, relations among individual variants are identical to those in TFP.

Considering the character of trials, the variation in TFP and EFE mostly reflects variation in production. Coefficient of variation of gross energy production increases along with invested fossil energy (Figure 1). Higher inputs of invested fossil energy in the system lead to a higher variation in production. This relationship is significant. Three points markedly differ from the assessed regression:

The points, which belong to variants B (straw incorporation + green manure) of spring barley continuous cropping (SBCC_B) and winter wheat continuous cropping (WWCC_B), lie under the estimated regression line. It can be concluded that application of a higher amount of organic matter each year contributes to stability of the system.

The point, which belongs to variant D (a check without organic manuring) of spring barley continuous cropping (SBCC_D), lies markedly above the estimated line. This system is most overexploiting among all examined systems and rather less productive. A lower stability of production is likely to be associated with a level of depletion of natural resource base of the system (average annual nitrogen balance in this system is approximately –30 kg N.ha$^{-1}$, i.e. the deficiency of about 900 kg N.ha$^{-1}$ for the 30-year conducting of the trial).

## DISCUSSION

Results and accuracy of energy analyses are critically influenced by:

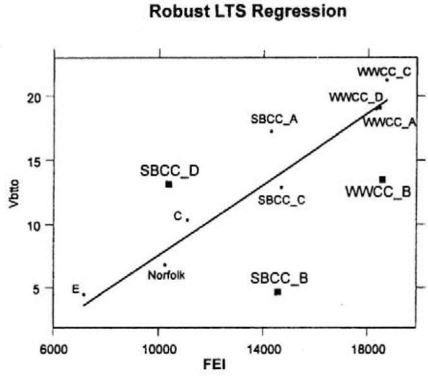


Figure 1. Relationship between coefficient of variation of gross energy and invested fossil energy

$Y = 0.0014x - 6.1817$
$R^2 = 0.8893$
$p$-value for $H_0 < 0.01$

FEI = fossil energy inputs
$V_{btto}$ = coefficient of variance of gross energy production

– delimitation of the investigated system
– assessment of energy equivalents

The applied energy equivalents hardly express energy content in products and actual energy consumption for agronomic treatments. With regard to technological and financial possibilities it is common to use values reported by experts who are engaged in problems of energy equivalents of inputs (outputs) in (from) production process. Therefore, these equivalents do not reflect an actual status in the given experiment, but a mean of analyses of other samples carried out in specialised laboratories.

Another typical problem is to measure application of organic manures. The fact that organic manures are the greatest part of energy inputs and considerably influence energy balance has been reported by a number of authors (for example, Krejčíř 1983, Skala and Křišťan 1984). Considering the methodology, this is the weakest point of analyses of energy balance in agricultural systems. There are three approaches how to assess energy equivalents of organic manures based:
– on nutrient content when energy necessary to produce an identical amount of individual nutrients in mineral fertilisers is considered
– on energy necessary for their production
– on combustion heat

The last approach ascribes a high value of the energy equivalent to organic manures, what significantly influences results of analyses. However, the effect of organic manures does not mean supply of nutrients only, but it is an important source of energy for soil microorganisms. Energy balance for evaluation of processes of agricultural production was used in order to discover reserves of fossil energy. Rather than to artificially decrease the equivalent of energy content of applied organic matters, it is more suitable to carry out an additional analysis of efficiency of fossil energy separately.

Energy balances, as they are usually used for evaluation of agricultural systems, are aiming at the so-called invested energy only. It is only a very small part of a whole energy flow in agricultural systems (the greatest part falls on energy of sunlight). Moreover, most of such spent energy is not a direct source of energy used by field crops for yield formation, but it canalises energetic processes. In this concept, energy balance is a technical tool rather than a tool for the analysis of biological processes.

Segeťová (1982), based on results published by Nátr (1977), is of the opinion that intensification of plant production enables to increase utilisation of sunlight. In other words, the increase in inputs should be expressed by higher total production. Our results are also in accordance with this conclusion. There are, however, some special characteristics:
– this relationship is valid if a level of total production is related to a level of inputs of fossil energy (the problem of including energy of organic manures is described above);
– comparing the systems, it is necessary to consider a nature of outputs, i.e. to judge separately a group of systems where outputs are both main product and by-product (for instance, grain and straw), and a group of systems where the output is a main product only.

The results also confirm that efficiency of invested energy falls down with a level of supplied inputs (it is necessary to consider a nature of outputs). This relationship is clearer if total invested energy including energy from organic manures are taken into account. If we consider only invested fossil energy, the Norfolk crop rotation and especially crop rotation – conventional system markedly differ from this relationship. The latter shows the best values of EFE among all studied systems. The reasons for that can be as follows:
– Intensification has not reached yet a level when the efficiency of inputs decreases.
– A good level of applied management practices. These are mostly management practices recommended by specialised professional institutions for agricultural practice.
– A suitable crop structure. The crop rotation includes two crops that have high energy production per unit area, sugar beet and silage maize.

In the crop rotation – ecological system, where a higher efficiency should be recorded with regard to a lower level of inputs, only a main product is harvested in individual crops, whereas in the crop rotation – conventional system a by-product is also harvested.

Studying relationships between variation in production and a level of inputs of invested fossil energy, a significant positive relation between the coefficient of variation of gross energy production and invested fossil energy was assessed for the experimental location Kroměříž. A similar relationship between a level of NPK rates in the form of mineral fertilisers and interannual variation in yields of cereals in the Czech Republic is reported by Křen (1995).

Variants of spring barley and winter wheat continuous cropping, where organic matter such as straw and green manure (mustard) are incorporated each year, significantly differ from the assessed regression. So we can assume that a regular supply of organic matter in the soil leads to a higher stability of the system. A question arises what is the role of the amount and form of organic matter. Another question is what groups of inputs cause increasing the variation and what groups cause stability of production.

## CONCLUSION

The highest energy production per unit area was assessed in the crop rotation – conventional system.

Variants C (green manure) and D (a check without organic manuring) of spring barley and winter wheat continuous cropping exhibited significantly higher values of TFP than crop rotations. The highest values of TFP were recorded in spring barley continuous cropping, variant D (especially due to a low level of inputs and a farming practice exhausting the soil).

By contrast, the best efficiency of invested fossil energy (EFE) was determined in the crop rotation – conventional system. All variants of both continuous croppings showed significantly lower values of EFE than the crop rotation – conventional system and Norfolk crop rotation. In the crop rotation – ecological system, significantly higher values of EFE were assessed in variants of continuous cropping where the main product is harvested only (variants A and B).

The interannual variation in production increased along with a level of fossil energy inputs in the system. Variants B of spring barley and winter wheat continuous cropping, where organic matter (straw and green manure) is incorporated each year, significantly differed from the assessed regression. It can be assumed that a regular supply of organic matter in the soil leads towards a higher stability of the system.

This study was supported by the National Agency for Agricultural Research of the CR, project no. EP 96 000 6179 and Ministry of Education, Youth and Physical Training of the CR, project no. MSM 432100001.

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Received on November 21, 2000

**ABSTRAKT**

**Energetická bilance v modelových systémech rostlinné produkce**

Jedenáct modelových systémů rostlinné produkce (osevní postup Norfolk, osevní postup s ekologickým pěstováním plodin, osevní postup s konvenčním pěstováním plodin, monokultura jarního ječmene, monokultura ozimé pšenice, obě monokultury na čtyřech variantách organického hnojení) bylo porovnáváno pomocí vybraných produkčních parametrů: produkce energie, souhrnný faktor produktivity (TFP) a účinnost fosilní energie (EFE). Analyzovány byly výsledky za období 1995 až 1999, pro výpočty bylo použito metody energetické bilance. Zkoumán byl rovněž vztah mezi variabilitou produkce a výší vstupů dodatkové fosilní energie. Nejvyšší produkce energie na jednotku plochy bylo dosaženo v osevním postupu s konvenčním pěstováním plodin (bruttoenergie 181,2 $GJ.ha^{-1}$, nettoenergie 62,9 $GJ.ha^{-1}$). Nejvyšší hodnoty souhrnného faktoru produktivity (TFP) byly zaznamenány v monokultuře jarního ječmene na variantě D – kontrola bez organického hnojení (9,13 pro bruttoenergii a 3,25 pro nettoenergii). Nejlepší účinnost dodatkové fosilní energie (EFE) byla zjištěna v osevním postupu s konvenčním pěstováním plodin (16,44 u bruttoenergie a 5,71 u nettoenergie). Všechny varianty obou monokultur dosahovaly průkazně nižších hodnot EFE než osevní postup s konvenčním pěstováním plodin a osevní postup Norfolk. V osevním postupu s ekologickým pěstováním plodin bylo dosahováno průkazně vyšších hodnot EFE než na variantách monokultur, kde je také sklízen pouze hlavní produkt (varianty A, B). Meziročníková variabilita produkce rostla s úrovní vstupů fosilní energie do systému. Od nalezené závislosti se výrazně odchylovaly varianty B monokultur jarního ječmene a ozimé pšenice, na nichž je každoročně zapravována do půdy organická hmota ve formě slámy a zeleného hnojení (hořčice). Lze předpokládat, že pravidelný přísun organické hmoty do půdy vede k větší stabilitě systému.

**Klíčová slova:** systémy rostlinné produkce; energetická bilance

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# Measurement of sustainability of model arable farming systems

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**ABSTRACT**

Nine model arable farming systems, long-term stationary field trials (Norfolk crop rotation, spring barley continuous cropping, winter wheat continuous cropping, both in four variants of organic manuring), were analysed for their sustainability using the following parameters: total factor productivity (TFP), trend of the TFP index, production stability and changes of selected soil properties – humus content and soil pH. A method for energy balance was used to calculate total factor productivity. Summarised data were analysed graphically. Among the examined long-term trials there was none that would have met all selected criteria of sustainability. Four systems failed in one of the studied parameters only as follows: Norfolk crop rotation – a decreasing trend of the TFP index was determined; spring barley continuous cropping, variant B (straw incorporation + green manure) – a considerable decrease in soil pH was assessed; winter wheat continuous cropping, variant C (green manure) and D (a check without organic manuring) – the systems show an unstable level of production. In variant D of spring barley continuous cropping, degradation of resource base (due to deficient nutrient balance and an inappropriate farming practice) affected productivity of the system in the delay of about 15 years. Development of productivity in all systems was affected by replacement of grown varieties.

**Keywords:** arable farming systems; long-term trials; sustainability; energy balance

Impacts of market mechanisms result in modifications in the structure of grown crops. Traditional management practices are replaced by new, more effective ones. On the other hand, the society is more and more aware of responsibility for the state of natural resources available to future generations. These views are based particularly on an idea of sustainable development. Objectives of sustainable agriculture are explained by Gips (1997).

Agricultural systems are multifactor and to measure their sustainability is very difficult. A choice of basic characters of the ecosystem, which are indicators of sustainable agriculture, is complicated by a number of biological, chemical and physical factors, their alternating interactions over time, space, and intensity (Klír 1997).

Pall and Ulčák (1999) studied problems of sustainability indicators. They are of the opinion that due to the ambiguous term of sustainability characteristics of unsustainability are of increasing significance (Pretty 1998).

To compare systems with various crops and different levels of inputs, total factor productivity (TFP) is used most frequently. TFP is a ratio of an index of aggregate outputs to aggregate inputs.

According to Rayner and Welham (1995), sustainability can be defined (related to productivity) in terms of several simple components: the TFP index series must have a non-negative trend, and the system must be profitable, i.e. the output/input ratio must be higher than 1. Another desirable feature is stability defined as a relatively small variation of the TFP index around the trend.

Results obtained in measuring sustainability of model arable farming systems (long-term trials) may be a source of information for decision-making in modifications of farming practices and for contemplation on long-term risks which are often associated with effort to meet short-term goals.

## MATERIAL AND METHODS

The trials are located in the sugar-beet growing region, 235 m above sea level. A mean annual temperature is 8.7°C and average annual precipitation is 599 mm. The soil type is Luvi-haplic Chernozem. These are medium soils with gley particles from 40 to 47%. Soils are mostly deep with fully saturated sorption complex and neutral reaction.

Model arable farming systems are represented by the following stationary long-term trials that have been conducted at the Agricultural Research Institute Kroměříž, Ltd., since 1970:

**Norfolk crop rotation** (1 – clover, 2 – winter wheat, 3 – sugar or fodder beet, 4 – spring barley). Manure at the rate of 50 $t.ha^{-1}$ is applied to the root-crop. Total rates of nitrogen in mineral fertilisers are in clover, winter wheat and sugar beet (fodder beet) 40, 80 and 40–80 kg $N.ha^{-1}$ (depending on the year), respectively. Spring barley is grown without nitrogen fertilisation. P and K rates are assessed on the basis of available nutrient content in the soil.

**Spring barley continuous cropping** in four variants of organic manuring (A – straw incorporation, B – straw incorporation + green manure, C – green manure, D – a check without organic manuring). In all variants a rate of 60 kg $N.ha^{-1}$ is supplied in ammonium sulphate before sowing. In addition to this rate, 50 kg $N.ha^{-1}$ are applied in variants A, B, and C in autumn as a compensatory rate to support organic matter decomposition (in ammonium sulphate again). P and K rates are assessed on the basis of available nutrient content in the soil.

**Winter wheat continuous cropping** in four variants of organic manuring (A – straw incorporation, B – straw incorporation + green manure, C – green manure, D – a check without organic manuring). The total nitrogen rate including the compensatory rate for organic matter decomposition is 180 $kg.ha^{-1}$. P and K rates are assessed on the basis of available nutrient content in the soil.

The system is delimited by the plot (field). All what flows into the system from outside (what is brought from elsewhere) are inputs and what leaves the field (what is carried away) are outputs. Therefore, calculations include only the organic manures which are put into the system from outside. Intercrops as a green manure, post-harvest residues and incorporated straw are not considered as inputs. They are not, however, considered as outputs either.

Based on available data from research reports and records on trials, aggregate inputs and aggregate outputs of the production process for each year and each model arable farming system were summarised. Missing data on yields of clover and sugar beet in the Norfolk crop rotation were calculated using interpolation. Agronomic practices for crop growing in long-term trials are not subjected to any extreme modifications. In case there were no available records in some years for applied treatments (missing records on clover and sugar beet in the Norfolk crop rotation for several years), management practices that were applied in the nearest years were used for calculations.

To calculate total factor productivity, a method for energy balance was used.

Obtained series of TFP values were further transformed to series of TFP indexes:

$$TFP/TFP_T = (Q_t/X_t)/(Q_T/X_T)$$

where: $TFP_t$ = total factor productivity for year $t$
$TFP_T$ = total factor productivity for base year $T$
$Q_t$ = aggregate outputs in year $t$
$Q_T$ = aggregate outputs in base year $T$
$X_t$ = aggregate inputs in year $t$
$X_T$ = aggregate inputs in base year $T$

All calculated indexes are related to the year 1999 (index of $TFP_t / TFP_T = 1$).

Since TFP was calculated using a method for energy balance where evaluations (weights) of all inputs and outputs are constant in each year, it was not necessary to include another indexes in the calculation, for example, index of prices, etc.

To judge profitability of systems (whether the outputs/inputs ratio is on average higher than 1), series of determined TFP values were illustrated in figures. Summarised data were analysed graphically, the course of a series of TFP values was compared with a limit TFP value being 1.

To measure development trends of production parameters of the system, series of TFP indexes were used. These time series were fitted by locally weighted regression smoothing. This method allows rather good detecting potential changes in the trend.

In addition to production indicators, changes in selected soil properties, such as humus content and exchange soil pH, were also measured. Statistical assessment was complicated by the fact that there were rather few records available for some trials. Therefore, trends in changes of soil properties are estimated according to fitting lines of

Table 1. Evaluation of sustainability of selected model arable farming systems

| | Output/input ratio | Trend | Stability | Unfavourable changes of soil properties? | Is the system sustainable? |
|---|---|---|---|---|---|
| Norfolk | higher than 1 | downward | stable | no | NO |
| SBCC_A | higher than 1 | no trend up to slightly downward | unstable | considerable decrease in pH | NO |
| SBCC_B | higher than 1 | no trend | stable in last years | considerable decrease in pH | NO |
| SBCC_C | higher than 1 | slightly downward | unstable | considerable decrease in pH | NO |
| SBCC_D | higher than 1 | downward | unstable | considerable decrease in pH | NO |
| WWCC_A | higher than 1 | downward in last years | unstable | no | NO |
| WWCC_B | higher than 1 | downward in last years | unstable | no | NO |
| WWCC_C | higher than 1 | no trend up to downward | unstable | no | NO |
| WWCC_D | higher than 1 | no trend up to downward | unstable | no | NO |

SBCC_A = spring barley continuous cropping, variant of organic manuring A (straw incorporation)
SBCC_B = spring barley continuous cropping, variant of organic manuring B (straw incorporation + green manure)
SBCC_C = spring barley continuous cropping, variant of organic manuring C (green manure)
SBCC_D = spring barley continuous cropping, variant D (a check without organic manuring)
WWCC_A = winter wheat continuous cropping, variant of organic manuring A (straw incorporation)
WWCC_B = winter wheat continuous cropping, variant of organic manuring B (straw incorporation + green manure)
WWCC_C = winter wheat continuous cropping, variant of organic manuring C (green manure)
WWCC_D = winter wheat continuous cropping, variant D (a check without organic manuring)

data series. Similarly to production parameters, the summarised data were analysed graphically only.

## RESULTS

Analysing individual series of TFP indexes, it is necessary to answer the question whether system productivity does not decline over time rather than to find exact regression formulas. It is also difficult to determine a rate or even a limit of stability.

The value of total factor productivity (TFP) in all examined systems was constantly higher than 1 (Figures 1–4). Owing to straw harvest variants C and D in both continuous croppings show higher TFP values (particularly related to gross energy – combustion heat) than variants A and B (Figures 1 and 2). Figure 4 shows rather small differences in grain yield (TFP related to digestible energy – conversion from starch units) among variants of winter wheat continuous cropping as compared to effects of years.

None of the studied systems was found to meet all selected criteria of sustainability (Table 1). Four studied systems (Norfolk crop rotation, spring barley continuous cropping – variant B, winter wheat continuous cropping – variant C and winter wheat continuous cropping – variant D) failed in one factor only.

A downward trend of the TFP index was found in the Norfolk crop rotation (Figure 5). The trend has been decreasing, though slightly but steadily, during the last 20 years; in the last 15 years we can see a slightly downward trend in yields of spring barley (Figure 14) and in the last 5 years yields of winter wheat have been decreasing (Figure 15).

A main reason why variant B (straw incorporation + green manure) in spring barley continuous cropping is considered as an unsustainable system is low soil pH. Its considerable decrease was found in all variants of spring barley continuous cropping (Figures 17–20). It is a result of long-term and regular application of ammonium sulphate for nitrogen plant nutrition. A question arises: what would have been the changes in soil acidity if more suitable fertilisers or regular liming had been applied.

A trend in the TFP index in variants C and D in winter wheat continuous cropping is affected by a low value of the index in 1998. If next-year results of these trials confirmed that it was only a random extreme, these variants would not exhibit a downward trend. A major reason why to consider these systems unsustainable would be high year-by-year variability in production (Figures 12 and 13).

The other systems fail in two or more studied parameters. These are mostly unstable production and a downward trend of the TFP index. It is also considerable decrease in soil pH in spring barley continuous cropping. In humus content in topsoil there were no remarkable changes in any of the investigated systems (Figures 16–24).

The course of series of TFP indexes is similar in some systems. There is an interesting coincidence in time when the trends change. A rate of effect is different, but the trend changes in the same period. In all variants of spring barley continuous cropping the direction of the trend changes around 1985. Similar changes (and in the same period) were recorded in the index of energy production in spring barley in the Norfolk crop rotation (Figures 6, 7, 8, 9, and 14). Similar situation is also in variants of winter wheat continuous cropping and in the index of energy production in winter wheat in the Norfolk crop rotation where the trend changes around 1985 and 1993 (Figures 10, 11, 12, 13, and 15).

## DISCUSSION

None of the studied systems have met all defined requirements of sustainability. This finding is particularly surprising in the Norfolk crop rotation. In continuous cropping, based on general assumptions, such a result would be logical. Quite the opposite, some variants in continuous cropping (variant B in spring barley continuous cropping and variants C and D in winter wheat continuous cropping) are nearest (regarding development of the TFP index) to be considered sustainable.

Barnet et al. (1995a) studied selected variants of long-term trials in Rothamsted (England) from the viewpoint of sustainability. Among 12 various variants of winter wheat continuous cropping they classified 9 as economically sustainable.

Similarly, Brown et al. (1995) found in the analysis of trials in Sanborn Fields (USA) during 1950–1989 that maize continuous cropping at balanced nutrient supply is a sustainable system from the economic point of view. On the other hand, they concluded that winter wheat continuous cropping without fungicide and insecticide treatments was not sustainable even at adequate rates of fertilisers.

We can define some potential causes of unsustainability of individual systems.

Variant D of spring barley continuous cropping is deficient in nitrogen balance (average annual nitrogen balance is approximately – 30 kg $N.ha^{-1}$; i.e. the deficiency of about 900 kg $N.ha^{-1}$ for the 30-year conducting of the trial). Reduction of productivity is apparently associated with depletion of resources base of the system.

The decrease in a trend of the TFP index in the Norfolk crop rotation can be caused by more factors. Modifications in the methodology of the trial are sure to have influenced the development of system productivity. Since 1980, clover has been planted as a monoculture in the spring of the harvest year (earlier it was underseeded in spring barley). In 1995, fodder beet was substituted for sugar beet in the crop rotation.

Another of potential causes is associated with yields of cereals and concerns not only the Norfolk crop rotation, but as well as both continuous croppings. Looking at series of TFP indexes (Figures 5–15), we can notice coincidence in the time when the trends change.

In all variants of spring barley continuous cropping the direction of the trend changes around 1985. In the same period, changes of the trend of the energy production index in spring barley in the Norfolk crop rotation were recorded. Similar situation is in variants of winter wheat continuous cropping and in the index of energy production in this crop in the Norfolk crop rotation where the trend changes around 1985 and 1993. So, the development of productivity of individual systems is apparently influenced also by factors that are not related to their resource base. In this case, these are probably implications of replacement of grown varieties and breeding lines, which took place in all trials.

It is beyond dispute that yield potential of new varieties of both spring barley and winter wheat has increased for the last 30 years. On the other hand, inputs in the studied systems are nearly on the same level. The first change in the trend (around 1985) could be explained by introduction of varieties that were able to make a better use of resources base of the system and inputs. Growing new varieties in subsequent years has not increased system productivity though it could be assumed that their yield potential would be higher in comparison with older varieties. New varieties were probably not able to realise their yield potential on a higher level at given resource base and level of inputs.

The second change in the trend apparent in winter wheat falls in the period around 1993. It is probably associated with change of choice of varieties in the trial. Earlier, perspective breeding lines were grown in the trial. New varieties and seed of higher propagation classes were used. In the 1990s, by contrast, registered and widely grown varieties were included in the trial in order to come near the agricultural practice. Also, the propagation class of seed was lower. The decrease in productivity of varieties can be considered as a regular phenomenon attributed to duration of their growing, the so-called growing old of the variety (caused by incorrect procedures of maintenance breeding).

A considerable decrease in soil pH in spring barley continuous cropping is most likely caused by long-term use of physiologically acid ammonium sulphate for nitrogen nutrition. A total rate of 110 kg $N.ha^{-1}$ (including a compensatory nitrogen rate for supporting organic matter decomposition or intercrop nutrition) was applied each year, which is about 525 kg of sulphate. The amount of 15,750 kg of this fertiliser has been applied to 1 ha for 30 years of conducting the trial. The above assumption is also supported by the fact that variant D, where no compensatory nitrogen rate is applied in autumn (which is the amount of applied ammonium sulphate per year 240 $kg.ha^{-1}$ lower, i.e. nearly by half), shows higher soil pH (the lowest measured value 5.75 vs. 4.81, 4.66 and 5.04 in variants A, B and C, respectively).

The Norfolk crop rotation is characteristic of a higher level of production stability than continuous croppings. In the multi-crop system a lower production of one crop can be compensated for by an increased production of the other crop. Continuous cropping is more sensitive to variations in vegetation factors.

The obtained results indicate some difficulties of transformation and restructuring agriculture in the Czech Republic. Possibilities of application of specialised, highly-productive systems typical for Western European countries are often discussed. As reported by Barnet et al. (1995b) and Brown et al. (1995), such systems can be sustainable from the viewpoint of production parameters. However, they need a higher level of inputs, as a rule in mineral fertilisers and pesticides. Flexibility in agronomic treatments is also important. If particular ones are not applied on optimum dates, usability of inputs decreases. Applying these systems under Czech conditions, it is necessary to take into account the fact that inputs shall reach a similar level as in Western European countries. Moreover, there will be higher requirements for soil and stand diagnostics and flexibility in agronomic treatments with regard to transient (from maritime to continental) climate. Furthermore, it is important to consider that the higher limiting effect of climatic and soil factors, the lower efficiency of high inputs. With their decreasing utilisation in crop yields environmental risks increase. It is necessary to seek optimum systems of agricultural production for each region.

## CONCLUSION

Considering energy balance, values of total factor productivity (TFP) were constantly higher than 1 in all studied systems.

None of the studied systems met all selected criteria of sustainability. Four systems failed in one factor only: Norfolk crop rotation – a decreasing trend of the TFP index was determined; spring barley continuous cropping, variant B (straw incorporation + green manure) – considerable decrease in soil pH was recorded; winter wheat continuous cropping, variant C (green manure) and variant D (a check without organic manuring) – the systems show an unstable level of production.

In all variants of spring barley continuous cropping, all variants of winter wheat continuous cropping and in both cereal crops in the Norfolk crop rotation, direction of the trend of the TFP index or the index of energy production (for crops in the Norfolk crop rotation) changed in the same period.

The development of productivity in all systems was influenced by replacement of grown genotypes. Introduction of new, higher yielding varieties and breeding lines resulted from the beginning in the increase in productivity of particular systems. After some time, however, productivity did not increase due to variety replacement. New varieties were not apparently able to realise their yield potential on a higher level at given resource base and level of inputs.

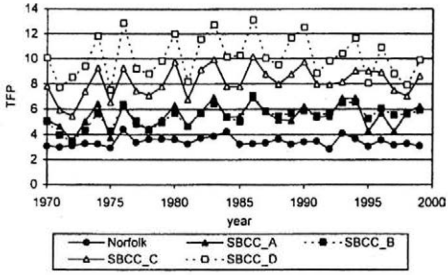


Figure 1. Total factor productivity (TFP) for gross energy – spring barley continuous cropping and Norfolk crop rotation

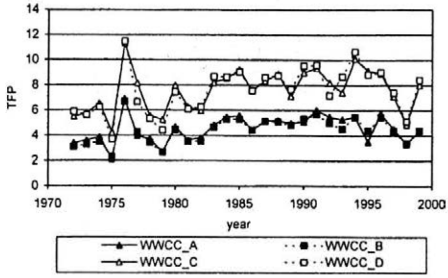


Figure 2. Total factor productivity (TFP) for gross energy – winter wheat continuous cropping

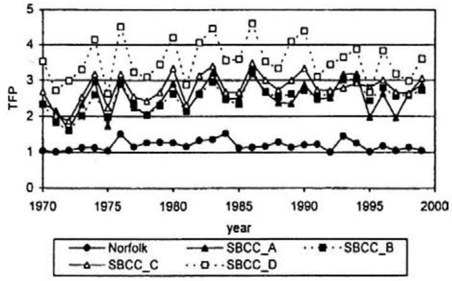


Figure 3. Total factor productivity (TFP) for digestible energy – spring barley continuous cropping and Norfolk crop rotation

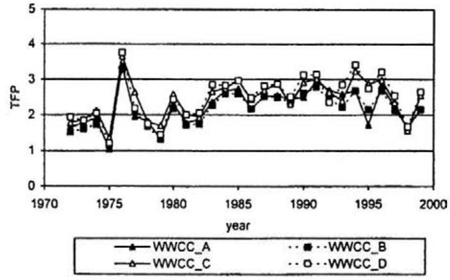


Figure 4. Total factor productivity (TFP) for digestible energy – winter wheat continuous cropping

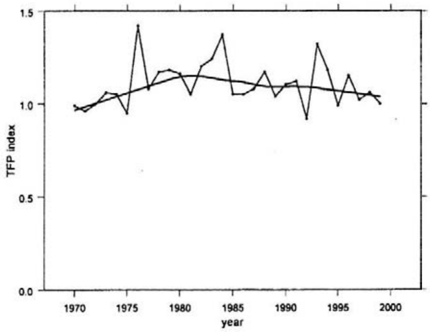


Figure 5. Trend of TFP index – Norfolk crop rotation

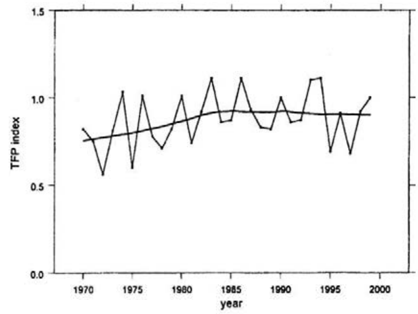


Figure 6. Trend of TFP index – spring barley continuous cropping, variant A

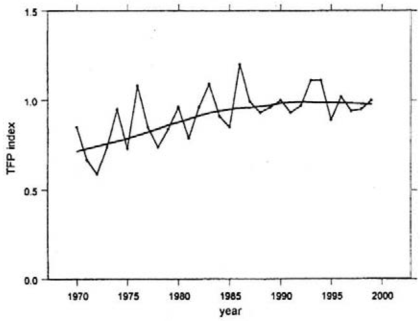


Figure 7. Trend of TFP index – spring barley continuous cropping, variant B

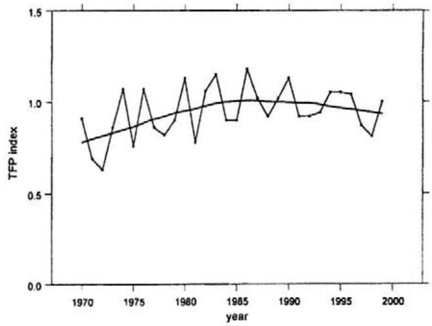


Figure 8. Trend of TFP index – spring barley continuous cropping, variant C

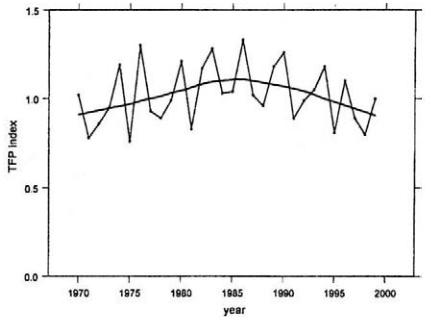


Figure 9. Trend of TFP index – spring barley continuous cropping, variant D

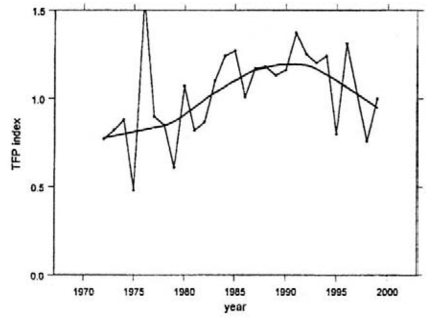


Figure 10. Trend of TFP index – winter wheat continuous cropping, variant A

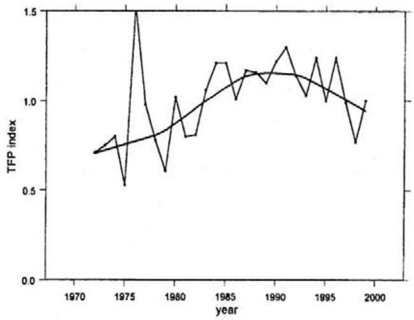


Figure 11. Trend of TFP index – winter wheat continuous cropping, variant B

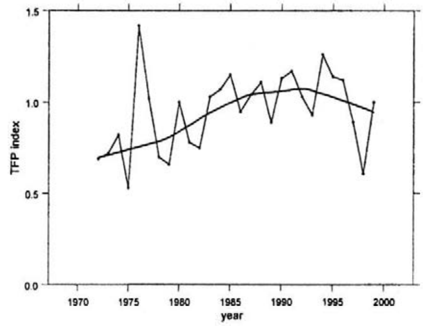


Figure 12. Trend of TFP index – winter wheat continuous cropping, variant C

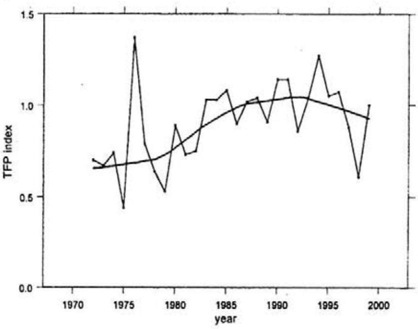


Figure 13. Trend of TFP index – winter wheat continuous cropping, variant D

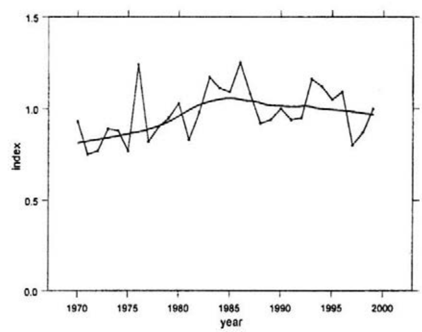


Figure 14. Trend of gross energy production index – spring barley at the Norfolk crop rotation

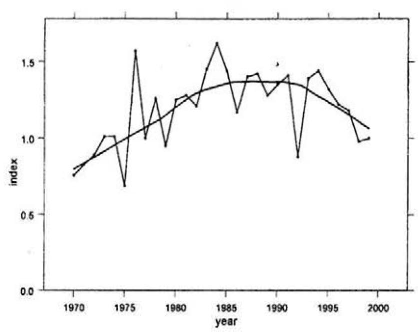


Figure 15. Trend of gross energy production index – winter wheat at the Norfolk crop rotation

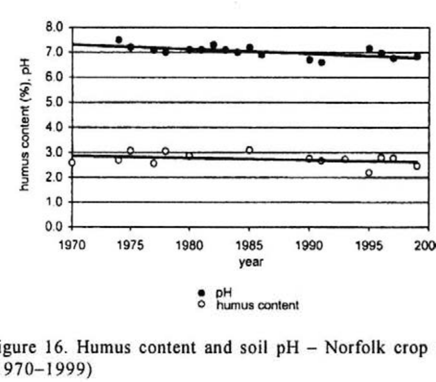


Figure 16. Humus content and soil pH – Norfolk crop rotation (1970–1999)

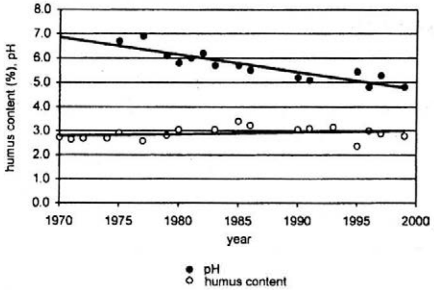


Figure 17. Humus content and soil pH – spring barley continuous cropping, variant A (1970–1999)

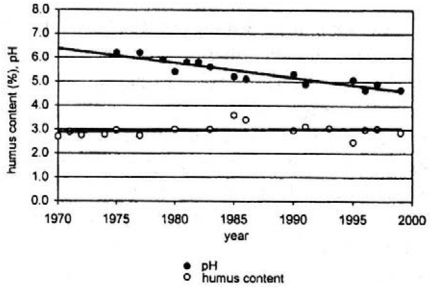


Figure 18. Humus content and soil pH – spring barley continuous cropping, variant B (1970–1999)

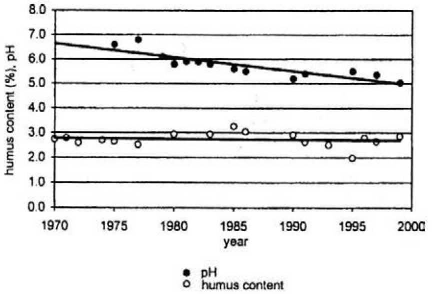


Figure 19. Humus content and soil pH – spring barley continuous cropping, variant C (1970–1999)

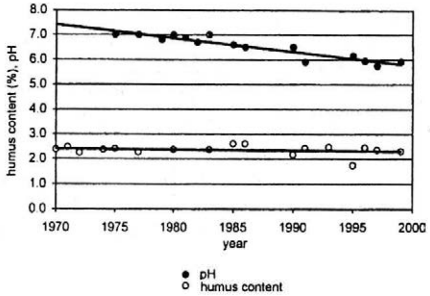


Figure 20. Humus content and soil pH – spring barley continuous cropping, variant D (1970–1999)

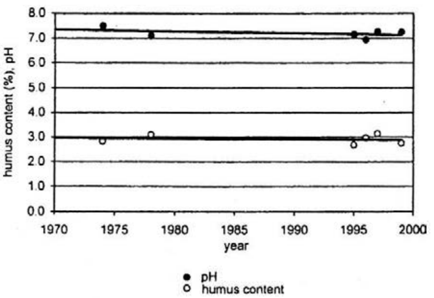


Figure 21. Humus content and soil pH – winter wheat continuous cropping, variant A (1972–1999)

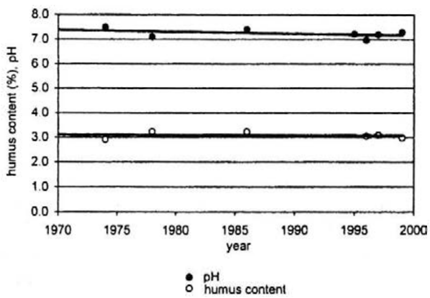


Figure 22. Humus content and soil pH – winter wheat continuous cropping, variant B (1972–1999)

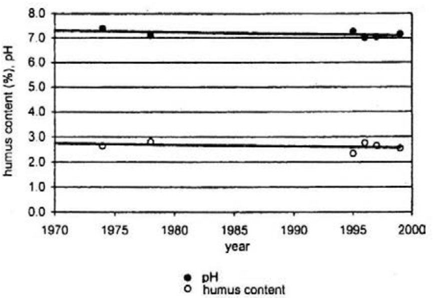


Figure 23. Humus content and soil pH – winter wheat continuous cropping, variant C (1972–1999)

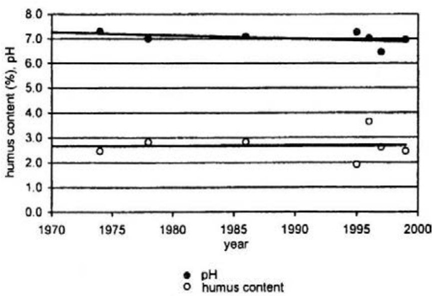


Figure 24. Humus content and soil pH – winter wheat continuous cropping, variant D (1972–1999)

Based on graphical illustration of the TFP index, the examined continuous croppings (except for variant B of spring barley continuous cropping) can be considered as unstable systems.

A marked decrease in soil pH in spring barley continuous cropping was caused mainly by long-term use of physiologically acid ammonium sulphate.

Responses to farming practices expressed by changes in system productivity usually delay and some persistence can be observed. Even deficient, unbalanced systems with hazardous farming practices can operate for some time. However, degradation of resource base is sure to influence the productivity of such systems over some time (see Figure 9 – course of the TFP index in spring barley continuous cropping, variant D).

Intensive specialised arable farming systems typical for Western European countries can be sustainable from the viewpoint of production even in the Czech Republic. However, they have to be applied in favourable regions and on an adequate level of inputs. With regard to the transient (from maritime to continental) climate, higher requirements for soil and canopy diagnostics and flexibility in agronomic treatments will be imposed.

This study was supported by the National Agency for Agricultural Research of the CR, project no. EP 96 000 6179 and Ministry of Education, Youth and Physical Training of the CR, project no. MSM 432100001.

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Received on November 21, 2000

## ABSTRAKT

### Hodnocení setrvalosti modelových systémů rostlinné produkce

U devíti modelových systémů rostlinné produkce – dlouhodobých stacionárních pokusů (osevní postup Norfolk, monokultura jarního ječmene, monokultura ozimé pšenice, obě monokultury na čtyřech variantách organického hnojení) – byla posuzována jejich setrvalost pomocí těchto parametrů: souhrnný faktor produktivity (TFP – Total Factor Productivity), trend indexu TFP, stabilita produkce a změny vybraných půdních vlastností – obsah humusu, pH. Pro výpočet souhrnného faktoru produktivity bylo použito metody energetické bilance. Shromážděná data byla analyzována graficky. Mezi sledovanými dlouhodobými pokusy nebyl nalezen žádný, který by splňoval všechna zvolená kritéria setrvalosti. Čtyři systémy nevyhověly pouze v jednom ze sledovaných znaků: osevní postup Norfolk – identifikován klesající trend indexu TFP; monokultura jarního ječmene, varianta B (zaorávka slámy + zelené hnojení) – zaznamenán výrazný pokles pH půdy; monokultura ozimé pšenice, varianta C (zelené hnojení) a D (kontrola bez organického hnojení) – systémy vykazují nestabilitu v úrovni produkce. U varianty D monokultury jarního ječmene se degradace základních zdrojů (v důsledku deficitní bilance živin a nešetrného způsobu hospodaření) projevila na produktivitě systému se zpožděním cca 15 let. Na vývoj produktivity všech systémů měla vliv obměna pěstovaných odrůd.

**Klíčová slova:** systémy rostlinné produkce; dlouhodobé pokusy; trvalá udržitelnost; energetická bilance

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# An effective set of primers for identification of spring barley varieties grown in the Czech Republic and genetic diversity of these varieties


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## ABSTRACT

Most top-grade Czech malting barley varieties have a common genetic background. Approximately 15% of the varieties grown in the Czech Republic show the same hordein spectrum. Primers, successfully used for identification of foreign varieties of malting barley, were tested for the Czech and Slovak varieties, too. From the 140 primers tested, only eight were found to be suitable for this purpose (AB 1.10, 3.13, 3.17, 4.09, 5.11, 5.17, 7.11 and 7.14). Very suitable primers were those for the locus HVWAXY which could detect the polymorphism of SSRs. This set of primers should be also suitable for identification of barley varieties in malt. Amulet characterized by the mean value of spectrum similarity ($S_m$) 0.740 according to the hordein spectrum was the most distant from the others. However, Sladko characterized by the mean value of genetic distance (D) 0.237 appears to be the most distant variety when DNA was analysed.



**Keywords:** barley; identification; genetic diversity


Similarly to other crops, malting barley varieties are characterized by their specific agronomy, technological and quality properties. To ensure the production of qualitatively homogeneous malt, it is of great importance to identify varietal purity and the authenticity of malted parts in malting barley.

Considering current knowledge and practical needs, the traditional identification of varieties based on their phenotypic distinctness at individual maturation stages is not appropriate for routine and effective use. For commercial purposes, the conventional method based on hordein polymorphism is employed to identify barley varieties in EBC reference laboratories. The advantage of this technique consists in an easy sample preparation and a trouble-free use of individual seeds whose hordein composition characterizes a particular variety. Not ever variety can clearly be distinguished from the others. This applies especially to those varieties possessing the same ancestors in their pedigrees. In the Czech Republic, primarily Czech and Slovak varieties have been grown (Valtický, Slovenský dunajský trh, Sladár, Ametyst, Rubín), whose genealogical ancestors are mostly landraces from the Hana region, especially Proskowetz Haná pedigrée (Lekeš 1997).

The implication for variety identification is that approximately 15 per cent of Czech and Slovak varieties show in partial or quite identical hordein spectrum when conventional methods of separation of storage proteins are used. One of these cases is the identity of hordein spectra obtained on aPAGE in the Czech malting variety Akcent and the Slovak variety Sladko. New possibilities of variety identification have been in relation to introduction of new molecular genetic techniques, especially of those based on PCR. RAPD, which had originally been used (Williams et al. 1990), allows to obtain more polymorphisms than analyses based on hordeins and isozymes separation. It is, however, rather sensitive due to the reproducibility of results between laboratories. Besides, on a regular basis, the screening of primers is required while a specific sample set is being analysed (Penner et al. 1993, Hoffman and Bregitzer 1996). Another possibility may be the use of polymorphous areas which are generated by PCR using specific long oligonucleotides. These polymorphisms are gradually being discovered in coding areas, as well as in non-coding areas (Chee et al. 1993, Becker and Huen 1995, William et al. 1997). The use of these primers largely decreases the possibility of the forming of non-specific products during PCR and the reproducibility of results presents no problem. The RFLP and AFLP techniques are other ways of identifying varieties. They are able of capturing a great amount of polymorphisms, but, at the same time, they are more time-consuming and more technically demanding. Their analytical capacity can rather be seen in the scanning of the barley genome, and in the studies of genetic divergence, than in a routine variety identification.

The polymorphous areas which show identical phenotypes in specific varieties are generally more frequent, the more genetically closer the followed phenotypes are. This implies identification difficulties, although, at the same time, they prove their common gene resources. This is even the case of Czech and Slovak varieties of malting barley which have been grown and cultivated for a hundred years period. It follows from the pedigrees of our varieties that almost all our malting varieties have been the result of a recombination of properties of the original landraces, whose genealogical branch is derived from adapted ancient forms grown in our country. The following genetic donors have had a decisive influence on the development of breeding our malting barley: landraces from the Haná region; the varieties Proskowetz Haná pedigrée (1882), Kneiflův ječmen – Opavský (1926), Valtický (1930), Diamant (1965), the varieties of the so-called Diamant – row (1972–1985).

The goal of the present paper was to identify individual varieties within the evaluated set of malting barley varieties using DNA markers, and estimate their genetic diversity by DNA fingerprintig and hordein variability, respectively.

## MATERIAL AND METHODS

### Plant material

Important varieties of malting barley were used which are listed in the List of Registered Varieties of the Czech Republic. These are represented by the best two-rowed malting varieties of Czech origin – Akcent, Amulet, Forum, Lumar, Olbram and Rubín; Slovak varieties – Jubilant, Kompakt, Sladko; German varieties – Krona, Scarlett and Danish varieties – Caminant non registered in the Czech Republic. The material came from the homogeneous seeds of the breeder seed used for the state variety tests. Prior to the trials, the material (100 seeds of each variety) was verified for varietal purity and homogeneity by means of hordeins separation according to the EBC method.

### Isolation of DNA

30 seeds of each variety were germinated in Petri dishes at a room temperature; 3–4 days old roots were crushed to fine powder, liquid nitrogen, 100 mg were instantly used, in accordance with the procedure, for the isolation of plant DNA by means of Plant Dneasy Isolation Kit (Qiagen).

### Testing and selection primers

First, a screening of 140 RAPD primers of kits AB 1–7 (Advanced Biotechnologies) was carried out to find the potential suitability of use in barley. Those primers generating extremely few, or, on the contrary, too many bands, and all of those generating only poor bands were eliminated. The number of bands generated by these

Table 1. Primers generating polymorphism utilizable for identification of varieties in studied set

| Primer | Sequences 5' to 3' | bp | Variety | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Ak | Fo | Kr | Lu | Vi | Sc | Ca | Am | Ju | Ko | Ol | Ru | Sl |
| RAPD | | | | | | | | | | | | | | | |
| AB 1.10 | CTGCTGGGAC | 450 | – | + | + | – | + | + | + | + | + | – | – | + | – |
| AB 3.13 | CCACACTACC | 260 | – | – | + | + | – | + | + | – | – | + | – | – | – |
| AB 3.17 | ACGCCAGTTC | 600 | – | + | + | + | + | + | + | + | – | + | + | + | + |
| | | 700 | + | – | – | – | – | – | – | + | + | – | – | – | – |
| AB 4.09 | TCCCACGCAA | 750 | + | + | – | + | + | – | – | + | + | + | + | + | + |
| | | 1500 | + | + | + | + | – | + | + | + | + | + | + | + | + |
| AB 5.11 | TTCCCCGCGA | 620 | – | + | – | – | – | – | – | – | – | – | – | – | + |
| | | 680 | + | + | – | – | + | + | – | + | – | + | + | + | + |
| | | 750 | – | – | + | – | – | – | – | – | – | – | – | – | – |
| AB 5.17 | CCAACGTCGT | 900 | + | – | + | + | + | + | – | + | + | + | + | + | + |
| | | 970 | – | + | + | – | – | – | – | – | – | – | – | – | – |
| AB 7.11 | CAATCGGGTC | 360 | + | – | – | + | – | – | – | – | – | + | + | – | – |
| AB 7.14 | GAACGAGGGT | 1200 | – | – | + | – | – | + | – | – | – | – | – | – | – |
| Specific | | | | | | | | | | | | | | | |
| HVWAXY | AAGACGTGGTGTTCGTGTG | 190 | + | + | + | – | + | + | + | + | + | + | + | + | – |
| | ATGGTTCCAGGGGTAAGTTC | 200 | – | – | – | – | – | – | – | – | + | – | – | – | – |
| | | 205 | – | – | – | + | – | – | – | – | – | – | – | – | + |
| | | 215 | – | – | – | – | – | – | – | – | + | – | – | – | – |

Ak – Akcent, Fo – Forum, Kr – Krona, Lu – Lumar, Vi – Viktor, Sc – Scarlett, Am – Amulet, Ju – Jubilant, Ko – Kompakt, Ol – Olbram, Ru – Rubin, Sl – Sladko

+/– presence/absence of band

primers was within 3–8. In the 31 RAPD primers selected in this way, their informativeness was tested on the evaluated varieties.

### Polymerase chain reaction

The PCR using RAPD primers was the modification of the original protocol (Williams et al. 1990). 25 μl of the reaction mixture contained 35 ng of template DNA and 1.5 mM $MgCl_2$, 0.1 mM dNTPs, 0.5 μmol primer and 1.6 U Taq DNA polymerase in 1× reaction buffer (Promega). The reaction was carried out on a thermocycler with a heated lid (PTC 200, MJ Research) in these conditions: 45 cycles at 38°C for 1 min, at 72°C for 2 min, at 94°C for 1 min, with the initial denaturation at 94°C for 5 min and the final 7-min extension step at 72°C. Amplification products were separated on 2% agarose gel (NuSieve 3:1) in 1× TBE buffer with ethidium bromide (0.1 μg/ml of the gel) and molecular markers (Promega). The vertical electrophoresis was carried out at 10 V/cm for 1.5 hr. The reaction mixture using primers for SSRs polymorphism associated with the locus HVWAXY was set up according to the following protocol: the initial denaturation step at 94°C for 2 min, 40 cycles of a 1-min denaturation at 92°C, a 1-min annealing step at 50°C, and a 2-min extension step at 72°C, and the final extension time was 5 min. The separation of amplification products was carried out on the vertical electrophoresis (Protean, Bio-Rad) in 8% polyacrylamide gel, and consequently dyed for 10 min being gently shaken in a 300 ml bath with ethidium bromide in the final concentration of 1 μg/ml, and then rinsed with distilled water. Both gels were visualized at 302 nm using a transilluminator (UVP) and photographed (Polaroid DS 34).

### Statistical evaluation

In electrophoreograms of hordeins and PCR the presence/absence of unambiguous bands was evaluated. Individual hordein spectra were considered in terms of the characteristics of individuals, and the determination of their similarity ($S$) was quantified according to the formula for: $[S_{i=\alpha}^{i=1}(A_i - B_i)] . 1/n$, where A = 1 represents the presence of a discrete band in individual A and A = 0 represents its absence, the same applies to individual B. The DNA fingerprints obtained by the separation of PCR products characterised varieties as populations and the determination of their similarity was based on the formule for the genetic distance (D) = –ln ($F$), where $F = 2X_{1,2} . 1/(X_1 + X_2)$, where $X_{1,2}$ is the number of amplified DNA fragments with the same molecular weight in both populations, $X_1$ is the complete number of fragments discovered in a population and $X_2$ is the total number of fragments found in second population (Yu and Pauls 1994). The data obtained through assessing the genetic distances and hordein spectra similarity were transformed and converted to a common vector and consequently subjected to the nearest neighbour cluster method, and then illustrated in dendrograms.

## RESULTS AND DISCUSSION

### Variety identification

In the process of verifying a variety purity of the evaluated followed material characteristic spectra were confirmed for 13 malting barley varieties by means of hordein separation on the aPAGE. Each of the varieties Jubilant, Kompakt, Olbram, Rubín and Scarlett has two types of hordein spectra. The varieties Akcent and Sladko have identical spectra in these separation conditions, and so have Jubilant (type B) and Krona. Both types of hordein spectra in the Jubilant variety are identical in the area of B and C hordeins. However, it is possible to distinguish the variety Akcent from the variety Sladko by using of esterase separation electrophorese. In the same way the variety Jubilant from the variety Krona can be distinguished (Bradová et al. 2001).

It is generally assumed that about 80–85% of the malting barley varieties listed in the National List of the Czech Republic can undoubtedly be identified on the basis of their hordein spectra. A complete or partial identity (in multi-line varieties) of spectra is probably, in many cases, the result of a common gene resource. In order to be able to unequivocally identify easily interchangeable varieties, we decided to employ the polymorphism at the level of DNA. Due to poor experience of an applicability of primers, which were, though, informative for some published sets of varieties, we began to test our own primers for RAPD. Our results suggest that e.g. primers labelled for a specific PCR as for loci B1-hordein, formerly published (Chee et al. 1993) and subsequently successfully tested on other varieties (Tsuchiya et al. 1995) or HVADH (Becker and Huen 1995) are not suitable for the identification of current Czech and Slovak varieties. For most of the varieties we studied in our research these primers generated a uniform phenotype of amplification products. The testing of some published primers for RAPD proved to be similar. This naturally supports the idea of a close genetic basis of Czech and Slovak varieties. Potentially suitable primers were tested with respect to the problematic reproducibility of the RAPD (Penner et al. 1993) and the goal of the follow-up use of results to be applied more widely in the production and treatment of malting barley. From the 31 primers for RAPD, as mentioned above, only 8 were informative for the studied set of varieties (Table 1). Four out of these – AB 1.10, AB 3.13, AB 7.11, AB 7.14 – provided a polymorphous band of one size, another three – AB 3.17, AB 4.09, AB 5.17 – two different sizes and primer AB 5.11 showed 3 polymorphous bands, and the specific primer for locus HVWAXY showed 4 polymorphous bands, which are very suitable for identification of malting barley varieties (Figure 1). All of the most commonly grown malting barley varieties in the Czech Republic are unequivocally identifiable on the

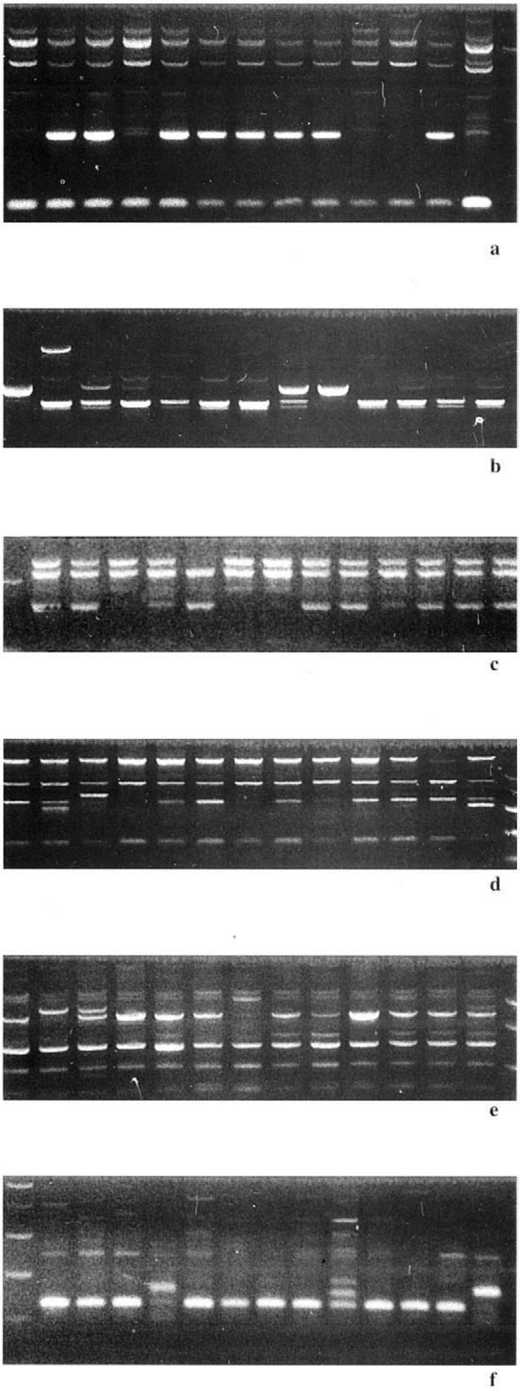

Figure 1. Polymorphism of RAPD (a–e) and SSR (f) markers; the used RAPD primers: AB 1.10 (a), AB 3.17 (b), AB 4.09 (c), AB 5.11 (d), AB 5.17 (e), and primer of the flanking region of microsatellites in loci HVWAXY (f); barley varieties are: 1. Akcent, 2. Forum, 3. Krona, 4. Lumar, 5. Viktor, 6. Scarlett, 7. Caminant, 8. Amulet, 9. Jubilant, 10. Kompakt, 11. Olbram, 12. Rubín and 13. Sladko; line M: DNA size marker – 1000*, 750*, 500, 300, 150, 50 bp (* visible on each gel record)

basis of the above-mentioned primers. In the next stage, we are going to employ the polymorphisms we have captured by means of RAPD, and suggest suitable primers for a specific PCR by means of sequencing techniques.

## Genetic diversity

Genetic diversity based on an assessment of the similarity of hordein spectra implies the closest relatedness between the varieties Akcent and Sladko. This applies to one of the two hordein lines of the Jubilant and Krona varieties, which have the same hordein spectra ($S = 0$). The two types of the hordein spectra of the Jubilant variety ($S = 0.150$) display a considerable degree of relatedness. The spectrum similarity between the two hordein lines in Kompakt variety is 0.567, 0.615 in Olbram, 0.667 in Rubín, as well as in Scarlett. Amulet is one variety which is the most distant from the others (the mean value of spectrum similarity $S_m = 0.740$) (Figure 2).

The assessment of genetic distance based on DNA polymorphism shows that Krona and Caminant (D = 0.013) are the genetically closest varieties in the evaluated set. Sladko (D = 0.237) has the highest average genetic distance (Figure 3).

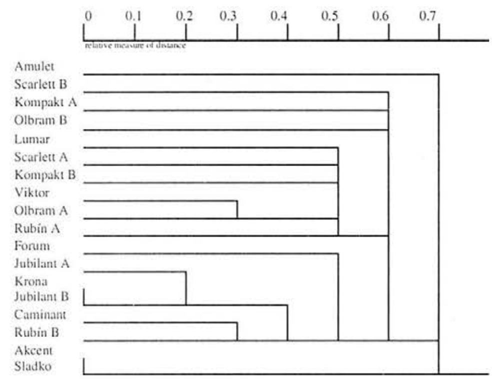


Figure 2. Dendrogram based on cluster analysis of hordeins of 13 malting barley varieties grown in the Czech Republic

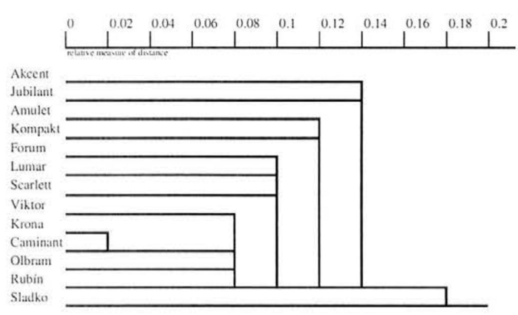


Figure 3. Dendrogram based on cluster analysis of DNA polymorphism of 13 malting barley varieties grown in the Czech Republic

Various strategies of studying genetic diversity may prove useful as additional sources of information in the process of establisment breeding programmes. We believe that it is necessary to consider individual strategies separately, as none of them showed universally the complete measure of relatedness. While genetic diversity estimated by means of the hordeins, displays a similarity in specific loci, genetic diversity assessed by an analysis of DNA tends to show a similarity of the complete genetic backgrounds of individual varieties.

The research was supported by the Ministry of Agriculture of the Czech Republic (Project No. EP 7283).

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Received on October 30, 2000

**ABSTRAKT**

**Identifikace a genetická diverzita odrůd jarního ječmene pěstovaných v ČR**

Většina českých odrůd sladovnického ječmene má společný genetický základ. Přibližně 15 % odrůd pěstovaných v ČR vykazuje stejné hordeinové spektrum. Pro úspěšnou identifikaci českých a slovenských odrůd sladovnického ječmene byly tak jako v zahraničí použity primery. Ze 140 testovaných primerů bylo nalezeno pouze osm vhodných pro verifikaci testovaných odrůd (AB 1.10, 3.13, 3.17, 4.09, 5.11, 5.17, 7.11 a 7.14). Byla prokázána vhodnost primeru pro locus HVWAXY, který detekuje polymorfismus SSRs. Tento soubor testovaných primerů ukazuje vhodnost pro identifikaci odrůd sladovnického ječmene. Nejvyšší střední genetickou distanci stanovenou na základě hordeinového spektra má ve sledovaném souboru odrůda Amulet ($S_m$) 0.740. Avšak analýzou DNA vykázala nejvyšší střední hodnotu genetické distance (D) 0.237 odrůda Sladko.

**Klíčová slova:** ječmen; identifikace; genetická diverzita

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# Yield and malting characteristics of winter barley (*Hordeum vulgare* L.) depending on agrotechnical arrangements and mineral nitrogen rates

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**ABSTRACT**

Dependence of yield and malting characteristics of winter barley cv. Rex on increased rates of mineral nitrogen in a long term experiment within two different agrotechnical arrangements (management of cattle raising farms with animal manure – MM; management with straw ploughing under and green manure – SM) was examined. The grain yield was increasing with increased rates of mineral nitrogen, the relationship between grain yield and yield of grain bigger than 2.5 mm was linear in both systems of management in both years. In 1999 the yield of grain bigger than 2.5 mm was increasing significantly with increased amounts of mineral nitrogen in MM and SM, in 1998 there were no significant differences between combinations of straw and manure with mineral nitrogen. Bigger quantity of mineral nitrogen was followed by higher grain protein content in MM and SM in 1998. Grain protein content was unacceptably high with bigger amounts of mineral nitrogen, except in 1999 in SM. There was linear relationship between protein and extract content in 1998 but neither linear nor quadratic in 1999. Some of the malting characteristics within the variety are not so much dependent on nitrogen rates but more in season.

**Keywords:** winter barley; malting quality; agrotechnical arrangements; nitrogen; yield; fertilising; protein content

The grain yield and quality of malting barley depend on a large number of agronomic factors including season, soil type, variety, date of sowing, seed rate, place in rotation, previous crop, amount of fertiliser nitrogen, timing of nitrogen, type of nitrogen fertiliser, disease control (Tajnšek 1990, Conry 1994, Tajnšek and Šesek 1996). Increasing amounts of fertiliser nitrogen show an increase of grain protein content (Carreck and Christian 1991), but grain yields do not always increase with increased amount of nitrogen (Tajnšek 1990). They generally level off at 90–120 kg $N.ha^{-1}$ (Conry 1994). Increasing the amount of fertiliser N above 100 $kg.ha^{-1}$ may not increase the yield of grain but it will always reduce the malting quality (Conry 1995).

The extract content decreases with increasing barley crude protein. In the thirties relation between protein and extract content was quantified with experimental data from England by Bishop as the increase of 1% in the barley crude protein content results in a 0.7% decrease in extract yield. Later it was stated that the inverse relationship between extract and protein had a varietal, i.e. genetic component, so a different correlation exists for each variety and there is a strong influence of environmental conditions (Molina-Cano et al. 2000). With the data of 346 trial sites with spring barley through Europe Molina-Cano et al. (2000) stated that the relationship between extract and protein content is fitted to a parabolic curve, in such a way that the higher the value of protein, the stronger the rate of decrease in extract.

The problem of many fertilising experimental data is the fact that they do not base on long term experiments where the actual situation in soil over years can be established (Asmus 1995, Schulz 1997). The present study was carried out to investigate the effect of increased amounts of mineral nitrogen in two different systems of management (application of cattle manure or straw ploughing under and green manure) on yield and malting characteristics of winter barley grown in a long term experiment in north-east of Slovenia.

## MATERIAL AND METHODS

The experiment was conducted in north-east of Slovenia (Murska Sobota; 46°38' northern latitude, 14°11' eastern longitude, 184 m above sea) in 1993 as a part of European project IOSDV (long-term experiment with rotation of maize, wheat and barley) on loamy sand soil (14.7% clay, 31.2% loam, 54.1% sand) classified as gleyic aerosol. The depth of the water table below soil surface is under 2.5 m. Clime is semiarid (Pannonic) with an average of 810 mm precipitation and 9.4°C. The experimental layout are three blocks (three replications) with 10 fertilising combinations (microplots of 30 $m^2$) (Table 1). Each microplot has been treated with the same fertilising combination from the beginning [control – no fertilising, m – cattle manure, s – straw ploughing under and green manure (oilseed rape after barley), N1 (rotation average 73 kg $N.ha^{-1}$), N2 (rotation average 147 kg $N.ha^{-1}$), N3 (ro-

Table 1. Fertilising combinations with timing and nitrogen fertilising rates

| | Fertilising | Average N/year/ha in circling | Doses of mineral N to barley in kg/ha |
|---|---|---|---|
| Control | no fertilising | – | – |
| N3 | mineral fertilising only | 220 | 165 (70 EC 21/22, 70 EC 31/32, 25 EC 45/50) |
| Manure | manure only | 50 | – |
| N1m | combinations of mineral fertilisers and manure | 123 | 55 (55 EC 21/22) |
| N2m | | 197 | 110 (55 EC 21/22, 40 EC 31/32, 15 EC 45/50) |
| N3m | | 270 | 165 (70 EC 21/22, 70 EC 31/32, 25 EC 45/50) |
| Straw | straw ploughing under and green manure | – | – |
| N1s | mineral fertilising, straw ploughing under and green manure | 73 | 55 (55 EC 21/22) |
| N2s | | 147 | 110 (55 EC 21/22, 40 EC 31/32, 15 EC 45/50) |
| N3s | | 220 | 165 (70 EC 21/22, 70 EC 31/32, 25 EC 45/50) |

tation average 220 kg N.ha$^{-1}$) – different amounts of mineral nitrogen (KAN)]. Within plots with straw management 20 kg mineral N.ha$^{-1}$ is added before straw ploughing under (for straw mineralisation).

All the other cultural treatments in terms of ploughing, cultivation, seeding rate, sowing method and PK fertilisers are the same for all plots. Phosphorus and potassium are applied at doses equivalent to 75 kg $P_2O_5$.ha$^{-1}$ and 160 kg $K_2O$.ha$^{-1}$. Manure (30 t.ha$^{-1}$) is applied before maize sowing. Plots are harvested with a combine.

The samples of winter malting barley cv. Rex were taken in 1998 and 1999. In 1997 sowing was on 3. 10. and in 1998 on 30. 9. at a seed rate of 250 kg.ha$^{-1}$. Weeds were controlled with a post-emergence herbicide (triasulfuron + klortoluron). The spring of 1998 was rather dry, the spring of 1999 was warm and wet (Table 2). The harvest was on 20. 7. in 1998 and on 5. 7. in 1999.

All the analyses were done on grain, bigger than 2.5 mm. The 1000-grain weight was calculated from the weight of eight samples of 100 grains and adjusted to dry matter. The protein content was determined by the Kjeldahl method, the factor 6.25 was used to convert nitrogen to protein. The extract content and all the malt analyses (Kolbach index, fine/coarse extract difference, malt protein content, malt soluble protein content, malting loss, diastatic power, Hartong 45°C, average embryo length) were done at the Institute of Hop Research and Brewing Žalec, Slovenia, the micro malting was done under standard conditions. Results were compared with requirements for malting barley of MEBAK Band I, 1997 standard for grain and MEBAK Band II, 1.7.2.1. (1993) standard for malt. Differences among fertilising combinations were determined by an ANOVA-protected Tukey multiple range test. Influence of increased amounts of mineral nitrogen on yield and malting properties was examined in two systems of management: management of cattle raising farms where cattle manure is used (MM) and management within farms with no animals (straw ploughing under and green manure) (SM). In both systems of management control (no fertilising) was considered.

## RESULTS AND DISCUSSION

Grain yields, yields of grain bigger than 2.5 mm, 1000-grain weight, grain protein and extract content with requirements for malting barley and significant differences between treatments are shown in Table 3.

Grain yield was increasing with increased rates of mineral N in both systems of management in both years, but not significantly in 1998. In 1998 it was significantly different from the other treatments only in straw in SM and in manure in MM. All the combinations of straw and manure with mineral nitrogen did not significantly differ from each other.

The relationship between yield and yield of grain bigger than 2.5 mm was in both years in both systems of management linear. In 1998 the yields of grain bigger than 2.5 mm were not significantly increasing with increased amounts of mineral N in SM, in MM only manure had

Table 2. Precipitation and mean temperatures in 1997, 1998 and 1999 in Murska Sobota, NE Slovenia

| Month | | 1. | 2. | 3. | 4. | 5. | 6. | 7. | 8. | 9. | 10. | 11. | 12. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1997 | temperature (°C) | –2.5 | 2.5 | 5.2 | 7.6 | 16.3 | 19.1 | 19.3 | 19.4 | 14.8 | 7.5 | 5.2 | 1.6 |
| | precipitation (mm) | 42 | 8 | 15 | 25 | 71 | 114 | 127 | 95 | 36 | 16 | 67 | 74 |
| 1998 | temperature (°C) | 1.6 | 4.2 | 4.4 | 11.3 | 15.1 | 19.4 | 20.3 | 20.1 | 15.0 | 11.2 | 2.6 | –4.1 |
| | precipitation (mm) | 5 | 0 | 39 | 61 | 38 | 82 | 120 | 105 | 157 | 82 | 122 | 29 |
| 1999 | temperature (°C) | –1.2 | 0.3 | 7.5 | 11.4 | 15.9 | 18.5 | 20.7 | 19.0 | 17.3 | 10.8 | 2.5 | –0.2 |
| | precipitation (mm) | 16 | 38 | 55 | 59 | 148 | 94 | 67 | 89 | 21 | 59 | 57 | 70 |

Table 3. Yields of dry matter of grain and grain bigger than 2.5 mm, 1000-grain weight (TGW), grain protein and extract content of winter barley cv. Rex in years 1998 and 1999 (Murska Sobota, NE Slovenia)

| Treatments | Grain yield (kg.ha$^{-1}$) | | Yield of grain > 2.5 mm (kg.ha$^{-1}$) | | TGW (g d.m.) | | Extract content (% d.m.) | | Protein content (% d.m.) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1998 | 1999 | 1998 | 1999 | 1998 | 1999 | 1998 | 1999 | 1998 | 1999 |
| Control | 3875 d | 1423 e | 3758 b | 1314 e | 43.3 a | 40.5 bc | 77.9 a | 76.1 a | 7.6 d | 12.3 a |
| N3 | 7424 a | 4453 b | 5880 a | 3799 b | 40.3 a | 40.6 bc | 72.4 b | 75.9 a | 13.5 a | 12.7 a |
| Straw | 5053 cd | 912 f | 4917 ab | 794 e | 42.2 a | 39.2 c | 75.3 ab | 76.0 a | 8.9 cd | 12.5 a |
| N1s | 6583 ab | 2662 d | 6098 a | 2405 d | 41.0 a | 40.0 bc | 76.9 ab | 76.0 a | 9.8 bcd | 11.6 ba |
| N2s | 6857 ab | 3264 c | 5920 a | 2930 cd | 40.2 a | 40.5 bc | 74.5 ab | 74.4 a | 12.4 ab | 11.2 ba |
| N3s | 7204 ab | 4203 b | 5990 a | 3665 bc | 40.5 a | 40.8 abc | 73.5 ab | 74.4 a | 13.7 a | 12.0 ba |
| Manure | 4105 d | 1548 e | 3891 b | 1419 e | 42.1 a | 41.2 abc | 76.7 ab | 75.6 a | 9.2 cd | 10.2 b |
| N1m | 5946 bc | 3493 c | 5692 a | 3263 bc | 42.8 a | 42.2 ab | 77.1 ab | 76.4 a | 9.4 bcd | 11.2 ba |
| N2m | 6178 abc | 4222 b | 5543 a | 3973 b | 42.1 a | 43.1 a | 75.3 ab | 75.7 a | 11.7 abc | 13.1 a |
| N3m | 6597 ab | 5337 a | 5606 a | 4827 a | 40.8 a | 43.0 a | 75.2 ab | 76.0 a | 13.0 a | 12.9 a |
| Requir. | | | | | 38–45 | | 75–82 | | < 11.5 | |

For each variable treatments with the same letter are not significantly different (Tukey *HSD* test, $p < 0.05$)
Requir. = requirements for malting barley (MEBAK Band I, 1997 standard)
d.m. = dry matter

significantly lower yield. In 1999 the yield of grain bigger than 2.5 mm was increasing significantly in both systems of management.

Bigger quantity of mineral nitrogen was followed by higher grain protein content in both systems of management in 1998 (grain protein content increased significantly with increased amount of mineral nitrogen). Grain protein content was unacceptably high when 110 kg N.ha$^{-1}$ or more was applied to barley in 1998 as was true for MM in 1999. In 1999 in SM less than 11.5% of protein contained only grains within fertilising combination N2s, all three combinations of straw and mineral nitrogen had lower protein content than variant straw. Also the control in 1999 had unacceptably high grain protein content (Figure 1, control and N3 are shown as comparison). Crops, suffering from stress during the growing season, either from draught or nitrogen deficiency, will tend to produce poor yields of high nitrogen content in grain (Carreck and Christian 1989), what showed out in control and straw in 1999 in our trial because of the lack of the nutrients. It was similar in the case of Conry (1994) where lower yields, caused by draught stress in the time of grain filling (nutrients could not be absorbed), were also followed by higher protein content.

Regression analysis made on our experimental data showed that there was a poor correlation between yields of grain bigger than 2.5 mm and their grain protein content. The results agree with findings of Conry (1994) for yield and its protein content for trials in Ireland.

There were no significant differences between 1000-grain weight in both systems of management in 1998 and in MM in 1999. In SM in 1999 1000-grain weight was significantly different in straw only. All treatments in both years fulfill the requirements. In 1998 heavier grains had lower protein content, in MM in 1999 it was contrary. In SM in 1999 1000-grain weight was increasing with increased amount of mineral N. With all the data from 1998 regression analysis showed a linear relationship between

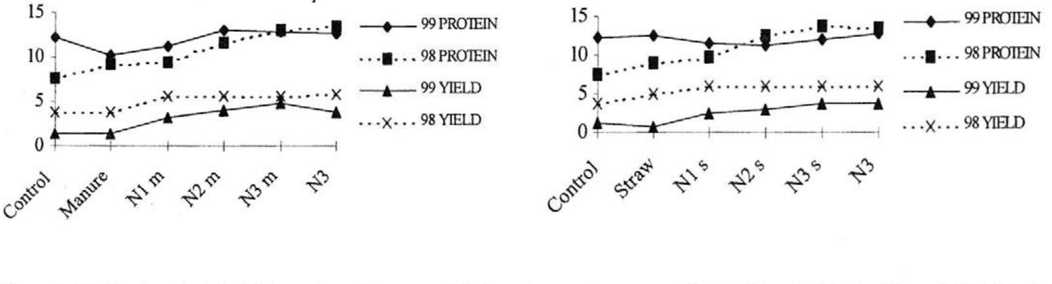


Figure 1. Yields of grain (t.ha$^{-1}$) bigger than 2.5 mm and their grain protein content (%) in 1999 and 1998 in MM and SM (Murska Sobota, NE Slovenia)

1000-grain weight and protein content. The correlation between these two variables was not strong in 1998 ($r = -0.66$) and poor in 1999 ($r = 0.09$).

The decrease of extract with protein increase showed out in our experiment too, but in two different seasons the same variety showed different relationship between these two properties. It showed out similar than in Mediterranean conditions (Molina-Cano et al. 2000), that seasonal differences in malt extract levels could not be completely explained by differences in protein concentration. The relationship between protein and extract content was neither linear nor quadratic with all the data from 1999 ($r = 0.2$). With all the data from 1998 there was linear relationship between these two variables ($r = -0.65$), the same was true if we considered all the data from both years ($r = -0.45$).

When the agricultural yield for a variety is improved by agrotechnical methods, e.g. by increasing nitrogen fertilisation, then the crude protein also increases. As a result, the extract and all the other malt properties are worsened (Schildbach 1981). In Table 4 malt analyses results for Kolbach index, fine/coarse extract difference, malt protein content, diastatic power and malting loss with requirements for malting barley and significant differences between treatments are shown.

Kolbach index was sufficient within all plots in 1998, in 1999 it was not sufficient only in N3m in MM. It was bigger with smaller amounts of applied nitrogen.

Fine/coarse extract difference was not sufficient with bigger amounts of nitrogen in SM (N2s, N3s) and in N3 in 1998. In 1999 fine/coarse extract difference was not sufficient at all plots, with bigger amounts of nitrogen it was even worsened [but the difference between plots was not significantly different ($p > 0.05$)].

Malt protein content was following the grain protein content, the correlation coefficient between them was strong (> 0.93 in both systems of management and both years). The same was true for malt soluble protein content (correlation between grain protein content and malt soluble protein content > 0.85 in both systems of management and both years). All three characteristics did not reach requirements for malting barley at the same plots in both systems of management in 1998 and in MM in 1999. In SM in 1999 the grain protein content reached requirements in N2s, malt protein content in N1s and N2s, malt soluble protein content in N2s and N3s.

When high nitrogen fertilisation is responsible for the high protein contents a greater extract loss occurs than when this high protein content is due to varietal or natural environmental factors (Schildbach 1981). In our trial malting loss was bigger with bigger amounts of mineral nitrogen in both systems of management in 1998 and in MM in 1999. In SM in 1999 the biggest malting loss was in N1s, in control and N1s it was bigger than in N2s and N3s, but there were no significant differences between treatments in 1999, in 1998 only control and N3m were significantly different. Malting loss was lower in 1999 comparing to 1998.

Diastatic power was increasing significantly with increased amounts of applied nitrogen in both systems of management in 1998, in 1999 it was decreasing in SM and varying in MM (the differences between treatments were not significant). The requirements for malting barley were reached at all combinations in both years (160–340 WK° dry matter). Seasonal differences showed out as an important factor for variability of diastatic power, as had been already stated as being the most influential factor (Molina-Cano et al. 2000).

All combinations reached the requirements in Hartong at 45°C too (> 36%), the value was varying in 1999, in 1998 it was decreasing in SM and increasing in MM.

Table 4. Kolbach index, fine/coarse extract difference, malt protein content, malt soluble protein content, diastatic power and malting loss of winter barley cv. Rex in 1998 and 1999 (Murska Sobota, NE Slovenia)

| Treatments | Kolbach index (%) | | Extract difference (%) | | Protein content (% d.m.) | | Diastatic power (WK° d.m.) | | Malting loss (%) | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1998 | 1999 | 1998 | 1999 | 1998 | 1999 | 1998 | 1999 | 1998 | 1999 |
| Control | 53 a | 40 a | 0.6 e | 3.4 a | 8.4 d | 12.1 ab | 234 edc | 245 a | 8.9 b | 6.1 a |
| N3 | 42 c | 42 a | 2.7 ab | 2.8 a | 13.3 a | 11.9 ab | 318 a | 289 a | 10.1 ab | 6.1 a |
| Straw | 51 ab | 45 a | 0.9 de | 2.4 a | 8.5 d | 11.8 ab | 227 edc | 292 a | 9.7 ab | 6.3 a |
| N1s | 49 abc | 44 a | 1.3 bcde | 2.6 a | 9.2 d | 10.7 ab | 258 dcb | 256 a | 9.6 ab | 7.5 a |
| N2s | 45 abc | 42 a | 2.2 abc | 5.1 a | 11.7 e | 10.4 b | 306 ba | 240 a | 9.7 ab | 5.6 a |
| N3s | 42 c | 40 a | 3.0 a | 3.7 a | 13.2 ab | 11.7 ab | 315 a | 223 a | 10.1 ab | 5.8 a |
| Manure | 50 abc | 43 a | 0.9 de | 2.2 a | 9.0 d | 10.6 ab | 204 e | 246 a | 9.5 ab | 5.6 a |
| N1m | 51 ab | 43 a | 1.1 cd | 2.4 a | 9.0 d | 10.8 ab | 215 ed | 272 a | 9.5 ab | 5.7 a |
| N2m | 43 bc | 40 a | 1.3 cde | 3.1 a | 11.2 c | 12.2 ab | 245 edc | 229 a | 9.3 ab | 5.6 a |
| N3m | 47 abc | 38 a | 1.6 abcd | 3.3 a | 13.1 ab | 12.8 a | 278 cba | 242 a | 10.5 a | 6.0 a |
| Requir. | > 39 | | < 1.8 | | < 11 | | 160–340 | | | |

For each variable treatments with the same letter are not significantly different (Tukey *HSD* test, $p < 0.05$)
Requir. = requirements for malting barley [MEBAK Band II, 1.7.2.1. (1993) standard]
d.m. = dry matter

The average embryo length did not reach the requirements (0.7–0.8%) only in N3m in 1998, the value was increasing in MM in 1998, in SM in 1998 and in both systems of management in 1999 it was varying.

## CONCLUSION

The environmental conditions (season) have strong influence on the response to N considering some malting properties. The results of our experiment suggest that some of them (diastatic power, Hartong at 45°C, the average embryo length) depend not so much on nitrogen rates, but more on season. The decrease of extract with protein increase showed out in our experiment, too, but in two different seasons the same variety showed different relationship between these two properties. There are also differences on response to N between SM and MM.

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Received on September 13, 2000


## ABSTRAKT


**Výnosové a sladovnické charakteristiky ozimého ječmene (*Hordeum vulgare* L.) v závislosti na systému agrotechniky a dávkách minerálního dusíku**

V dlouhodobém pokusu v rámci dvou odlišných systémů agrotechniky (hospodaření na farmě s chovem skotu a produkcí chlévského hnoje – MM; hospodaření se zaoráváním slámy a zeleným hnojením – SM) byla hodnocena závislost výnosových a sladovnických charakteristik ozimého ječmene odrůdy Rex na zvýšených dávkách minerálního dusíku. Výnosy zrna narůstají s zvyšujícími se dávkami minerálního dusíku, vztah mezi výnosem zrna a podílem obilek nad 2,5 mm byl v obou letech lineární u obou systémů hospodaření. Podíl obilek nad 2,5 mm se s vyššími dávkami minerálního dusíku významně zvýšil v systému MM i SM v roce 1999, zatímco v roce 1998 mezi kombinacemi sláma a hnůj s minerálním dusíkem nebyly zjištěny významné rozdíly. Vyšší dávky minerálního dusíku při MM i SM vedly k nárůstu obsahu bílkovin v zrnu. S výjimkou SM v roce 1999 byl obsah bílkovin v obilkách, ovlivněný vyššími dávkami minerálního N, vyšší než limitní hodnoty pro sladovnické účely. Vztah mezi obsahem bílkovin a množstvím extraktu byl lineární v roce 1998, v dalším roce nebyla zjištěna žádná korelace. Některé sladovnické charakteristiky jsou v rámci odrůdy méně závislé na dávkách dusíku a více na podmínkách vegetačního období.



**Klíčová slova:** ozimý ječmen; sladovnická jakost; systém agrotechniky; dusík; výnos; hnojení; obsah bílkovin



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# Using plough down of sugar beet tops to affect the production parameters of spring barley in a maize-growing region

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**ABSTRACT**

In a polyfactorial field experiment conducted in 1998–2000 we studied the effect of three systems of sugar beet top management, two sowing rates and two levels of nitrogen fertilisation, and their interaction, on production parameters of the spring barley variety Kompakt. Based on statistical evaluations using the variance analysis, it was found that the weather conditions of the respective year had a dominant effect on the variability of all the characters (number of spikes per $m^2$, number of grains per spike, TGW, yield, proportion of grain over 2.5 mm sieve). The effect of weather conditions of a year on the total variability of the characters ranged between 57.3% (number of spikes per $m^2$) and 88.6% (yields). The system of sugar beet top management had a statistically highly significant effect on TGW, yields and the proportion of grain over 2.5 mm sieve, and a significant effect on the number of grains per spike. The sowing rate had a highly significant effect of the number of spikes per $m^2$ and number of grains per spike. The level of N nutrition had a highly significant effect only on the proportion of grain over 2.5 mm sieve. A highly significant interaction between conditions of the year and the system of farming of sugar beet tops was observed in all the characters. The achieved level of the characters was considerably variable in dependence on weather conditions of the year. Yields were the highest in 1999 (7.37 $t.ha^{-1}$) and the lowest in 2000 (5.51 $t.ha^{-1}$). Grain from the 1998 harvest had the best qualitative parameters (yields were 6.22 $t.ha^{-1}$). Dependent on weather, and particularly on rainfall, the ploughed down tops promoted yield formation. It was found that the stands established using a lower sowing rate (3.5 MGS × 4.5 MGS) had a strong self-regulating capacity. Fertilisation with 30 kg $N.ha^{-1}$ compared to 0 kg $N.ha^{-1}$ resulted in a statistically significant yield increase (by 0.17 $t.ha^{-1}$) and worse technological parameters of the barley grain.

**Keywords:** spring barley; beet tops; yield; yield components; N fertilisation; sowing rate

Many factors determining the potential yields of the main product, i.e. grain, are involved in the formation of highly productive spring barley stands. The final commercial yield, its structure and quality, is the result of the concurrence of these factors during growth and development of the stand (Petr et al. 1980).

In terms of the yield and yield stability of spring barley the important factor is the forecrop (Kopecký 1983). As the area of fields with tuber crops is decreasing, so is the choice of suitable forecrops for spring barley. The traditional forecrop in the spring barley production regions is still sugar beet, which provides good conditions for obtaining yields of grain that have the required qualitative parameters.

The present technology of sugar beet harvest followed by ploughing down the tops provides the soil with a considerable amount of organic matter and nutrients from the tops. Mineralisation of the incorporated tops, when nutrients (especially nitrogen) are released, significantly influences the production process of spring barley (Zimolka et al. 1999).

The intensity and course of mineralisation of the organic matter of the beet tops are dependent, in the first place, on weather. Provazník et al. (2000) reported that, theoretically, through mineralisation of the incorporated beet tops, 102 kg N, 12 kg P, 148 kg K, 33 kg Ca and 18 kg Mg is delivered to the soil. However, if weather conditions delay mineralisation until the later stages of the production process (shooting, grain formation and maturing), the release of nitrogen becomes uncontrollable, causes considerable changes in its dynamics in the soil and has a negative impact on lodging, spreading of diseases and worsening of the qualitative grain parameters (Richter et al. 1999). The reason for deceleration, or even stopping, of the mineralisation processes in the soil is usually early and long-term freezing of the soil during winter, and dry and cold weather in the spring after spring barley sowing. The possibility of influencing these processes is associated with the date of the plough down of the beet tops and optimisation of spring barley nutrition. The focus is particularly on rationalisation of N nutrition (Kandera 1994, Kulík 1995, Tóth 2000).

## MATERIAL AND METHODS

The effect of various methods of management with beet tops on selected production characters of spring barley was studied at the station for plant production of the School Farm of Mendel University of Agriculture and Forestry in Žabčice in 1998–2000. The station is situated in the maize growing production type, barley sub-type, in an

Table 1. Agrochemical soil properties before the establishment of the experiment, depth 0–250 mm (Provazník et al. 2000)

| Year | pH/KCl | Available nutrients – Mehlich II ($mg.kg^{-1}$) | | | |
|---|---|---|---|---|---|
| | | P | K | Ca | Mg |
| 1998 | 6.9 | 67 | 209 | 4430 | 323 |
| 1999 | 7.0 | 102 | 254 | 5228 | 352 |
| 2000 | 6.84 | 91 | 263 | 3935 | 318 |

Table 2. Characteristics of the incorporated beet tops

| Year | Yield ($t.ha^{-1}$) | Dry matter (%) | Main macro-elements (% in dry matter) | | | | |
|---|---|---|---|---|---|---|---|
| | | | N | P | K | Ca | Mg |
| 1997 | 23.96 | 21.15 | 2.12 | 0.28 | 4.15 | 0.88 | 0.41 |
| 1998 | 18.80 | 14.55 | 3.55 | 0.37 | 3.16 | 0.76 | 0.54 |
| 1999 | 21.20 | 16.90 | 3.33 | 0.264 | 4.75 | 0.442 | 0.471 |

altitude of 185 m. The region is warm, moderately dry, with mild winter. The soil type is gleyey fluvisol ($FM_G$) on the river Svratka alluvium with less than 0.5% carbonates. In terms of granularity, the soil is moderately heavy-textured to heavy with 55–65% of clayey particles and accumulated horizon in a depth of 300–600 mm, where as much as 75% of the clayey particles are contained. Table 1 gives the agrochemical properties of the soil. Figures 1–4 show the course of weather in the respective years.

The following factors were evaluated in a block field trial: three systems of management with beet tops (A – early plough down of tops, B – late plough down of tops, and C – removed tops), and two levels of N fertilisation (0 and 30 kg $N.ha^{-1}$) and different sowing rates (3.5 and 4.5 MGS). Each variant, established on 12.5 $m^2$ plots, had four replicates. In the experiment we used the top malting barley variety Kompakt, a semi-early low variety with a lower resistance to lodging, medium large grain and high yielding capacity of grain over 2.5 mm sieve. The forecrop was sugar beet fertilised with 40 $t.ha^{-1}$ of farm manure. After harvesting the sugar beet in variant A (mid-October) the tops were crushed, spread evenly and incorporated into the soil using medium deep ploughing (250–280 mm). In variant B the tops were incorporated into the soil in the same way a month later (mid-November) and in variant C the tops were removed (ploughing as in variant B). Table 2 gives the average values of chemical analyses of the beet tops and the amount ploughed down in 1997, 1998 and 1999.

Seedbed preparation was carried out in spring (smoothing + harrow). Before sowing nitrogen was applied in single doses of 0 and 30 kg $N.ha^{-1}$ in ammonium nitrate with limestone. The stand was treated with pesticides against weeds, diseases and pests according to the methods valid for plant protection.

In each replication the number of spikes per $m^2$ and number of grains per spike were defined from an area of 0.25 $m^2$ before harvesting. The total grain yields from the plots were defined after drying (14%) and pre-cleaning, also the percent and yields of grain over 2.5 mm sieve and the TGW.

All the experimental data were computerised using the UNISTAT 5.0 program and the Statgraphics 7.0 polyfactorial variance analysis. To assay the average differences we used the test according to Tukey, level of significance 5%.

## RESULTS AND DISCUSSION

Table 3 summarises the statistical evaluations of the effect of individual factors on the studied characters, including their interaction in an experimental series carried out in 1998–2000. Table 5 shows the differences among the respective factors.

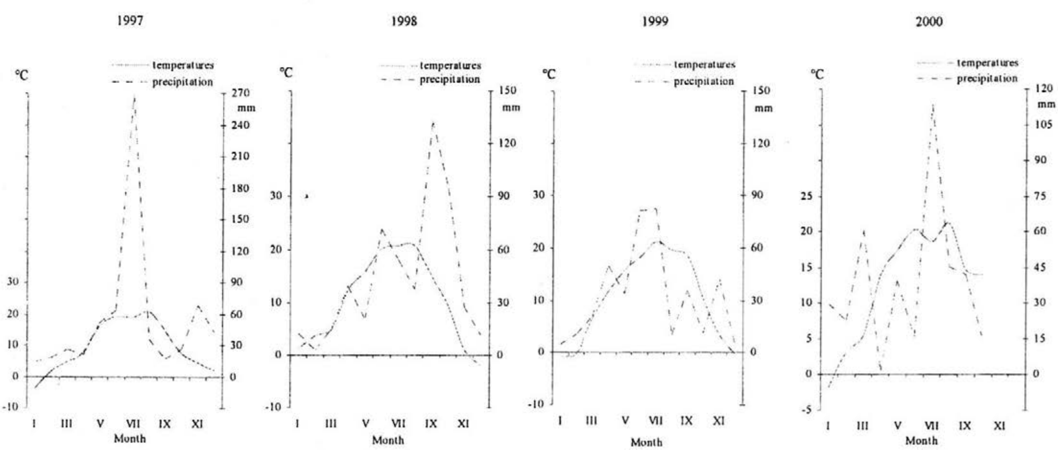


Figure 1–4. Average monthly temperatures and monthly sums of precipitation in 1997–2000 (after a climadiagram according to Walter-Lieth)

Table 3. Analysis of variance for examined characters for the years 1998–2000

| Sources of variability | | dF | Mean square | | | | |
|---|---|---|---|---|---|---|---|
| | | | number of spikes ($m^2$) | number of grains per spike | TGW (g) | yield ($t.ha^{-1}$) | grain > 2.5 mm sieve (%) |
| Year (a) | | 2 | 198 254.26** | 164.69** | 239.42** | 42.21** | 2970.08** |
| Variant of beet tops management (b) | | 2 | 3 311.63 | 5.68* | 29.00** | 1.27** | 472.70** |
| Sowing rate (c) | | 1 | 68 950.00** | 13.94** | 1.63 | 0.29 | 9.25 |
| N fertilisation (d) | | 1 | 18 655.00 | 1.91 | 6.13* | 1.01* | 101.51** |
| Interaction | a × b | 4 | 21 026.78** | 5.44* | 16.64** | 1.70** | 273.30** |
| | a × c | 2 | 24 770.34* | 1.51 | 2.05 | 0.18 | 79.19** |
| | a × d | 2 | 2 492.55 | 0.52 | 1.59 | 0.72* | 1.49 |
| | b × c | 2 | 2 589.84 | 1.08 | 2.22 | 0.00 | 37.66* |
| | b × d | 2 | 61.97 | 1.90 | 0.07 | 0.03 | 10.01 |
| | c × d | 1 | 16.67 | 1.07 | 0.43 | 0.02 | 1.54 |
| Residual | | 124 | 5 973.47 | 1.77 | 1.26 | 0.18 | 11.70 |
| Total | | 143 | | | | | |

* $P \leq 0.05$, ** $P \leq 0.01$

In the 3-year period it was found that the effect of weather conditions on the production process of spring barley was dominant (Table 4) and that its effect on the variability of all the studied characters was highly significant. The weather had the least effect on the number of spikes, and hence the formation of productive tillers per unit of area (i.e. 57.3%), most of all it affected grain yields (i.e. 88.6%). Flašarová and Onderka (1997), Kopecký (1983) and others achieved similar results. The contribution of the effect of weather on the variability of TGW values and proportion of grain over 2.5 mm sieve was 79.7 and 74.8%, respectively, and corresponded with the results of Frančáková (1992). The system of management with beet tops had a statistically highly significant effect on the thousand grain weight (TGW), yields and proportion of grain over 2.5 mm sieve, a significant effect on the number of grains per spike and contributed to variability of these characters (i.e. 9.6, 2.6, 11.9 and 2.8%, respectively, Table 4). The sowing rate had a highly significant effect on the number of spikes per $m^2$ and number of grains per spike (19.9 and 7%, respectively, contribution to the variability). The level of N nutrition had a statistically highly significant effect only on the proportion of grain over 2.5 mm, i.e. 2.6%. The interactions between weather conditions of the year and the system of management with beet tops were highly significant for all the studied characters, with exception of the number of grains per spike. The results of Ehrenbergerová et al. (1999) and Tóth (2000) also confirmed the important effect of the interactions among the respective factors as compared with their individual effect.

The achieved level of the characters was considerably variable and was dependent on intensity of the effect of the individual factors (Table 5). The variability of the yields in the individual years reflected the weather conditions. Grain yields were significantly highest in 1999, the average for all the variants was 7.37 $t.ha^{-1}$ (Table 5). On the other hand, the yields were lowest in 2000 (5.51 $t.ha^{-1}$) and were affected by long-lasting drought in the spring (Figure 4). Good conditions for achieving the highest yields in 1999 were formed as early as the stage of tillering, maintaining a large number of productive tillers with a differentiated significantly highest number of spikelets in the spike. Although the TGW was lower (42.83 g), these conditions were sufficient to achieve the highest yields. However, the proportion of grain over

Table 4. Proportion of factors on total variability of examined characters (%)

| Sources of variability Examined characters | Proportion of variability | | | | |
|---|---|---|---|---|---|
| | number of spikes ($m^2$) | number of grains per spike | TGW (g) | yield ($t.ha^{-1}$) | grain > 2.5 mm sieve (%) |
| Year | 57.3 | 82.5 | 79.7 | 88.6 | 74.8 |
| Variant of beet tops management | 1.0 | 2.8 | 9.6 | 2.6 | 11.9 |
| Sowing rate | 19.9 | 7.0 | 0.5 | 0.6 | 0.2 |
| N fertilisation | 5.4 | 1.0 | 2.0 | 2.1 | 2.6 |

Table 5. Differences among factors in 1998–2000

| Factors | Levels of factors | n | Number of spikes ($m^2$) | Number of grains per spike | TGW (g) | Yield ($t.ha^{-1}$) | Grain > 2.5 mm sieve (%) |
|---|---|---|---|---|---|---|---|
| | | | mean (differences) | | | | |
| Years | 1998 | 48 | 756.6 c | 19.56 b | 46.88 a | 6.22 b | 89.02 a |
| | 1999 | 48 | 884.8 a | 22.42 a | 42.83 b | 7.37 a | 77.19 b |
| | 2000 | 48 | 828.9 b | 18.95 b | 43.24 b | 5.51 c | 74.12 c |
| Variant of beet tops management | A | 48 | 821.2 a | 20.37 ab | 43.44 b | 6.55 a | 76.65 c |
| | B | 48 | 832.6 a | 20.62 a | 44.92 a | 6.29 b | 82.79 a |
| | C | 48 | 816.5 a | 19.94 b | 44.59 a | 6.26 b | 80.88 b |
| Sowing rate | 3.5 MGS | 72 | 801.5 b | 20.62 a | 44.42 a | 6.32 a | 80.36 a |
| | 4.5 MGS | 72 | 845.3 a | 20.00 b | 44.21 a | 6.41 a | 79.85 a |
| N fertilisation | 0 $kg.ha^{-1}$ | 72 | 812.1 a | 20.20 a | 44.52 a | 6.28 b | 80.95 a |
| | 30 $kg.ha^{-1}$ | 72 | 834.8 a | 20.43 a | 44.11 b | 6.45 a | 79.27 b |

A – early plough down, B – late plough down, C – beet tops removed; means with different letters are statistically significant at $P \leq 0.05$

2.5 mm sieve, i.e. malting grain, was lower (77.19%, i.e. 5.69 $t.ha^{-1}$). Grain from the 1998 harvest had the best parameters (6.22 $t.ha^{-1}$ yield) with a substantially higher proportion of grain over 2.5 mm sieve (89.02%) and total production (5.54 $t.ha^{-1}$).

The ploughed down beet tops boosted yield formation, although the differences among the variants were small (Table 5) and were considerably affected, in particular, by rainfall. The best conditions for good barley grain yields were provided in the variant where the beet tops were

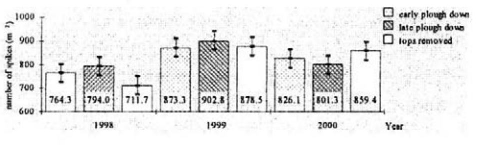


Figure 5. Number of spikes per m² in 1998–2000 based on the variants of beet top management (with confidence intervals for the mean, α = 5%)

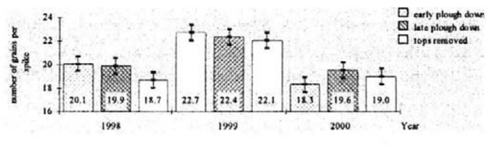


Figure 6. Number of grains per spike in 1998–2000 based on the variants of beet top management (with confidence intervals for the mean, α = 5%)

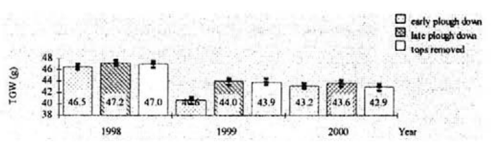


Figure 7. Thousand grain weight (TGW) in 1998–2000 based on the variants of beet top management (with confidence intervals for the mean, α = 5%)

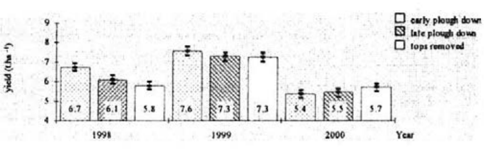


Figure 8. Grain yields in 1998–2000 based on the variants of beet top management (with confidence intervals for the mean, α = 5%)

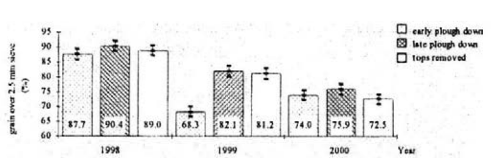


Figure 9. Yield capacity of grain (% of grain over 2.5 mm sieve) in 1998–2000 based on the variants of beet top management (with confidence intervals for the mean, α = 5%)

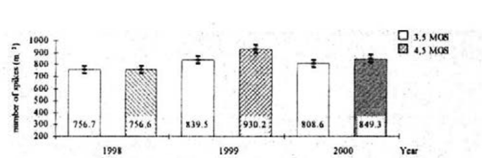


Figure 10. Number of spikes per m² in 1998–2000 based on the sowing rate (with confidence intervals for the mean, α = 5%)

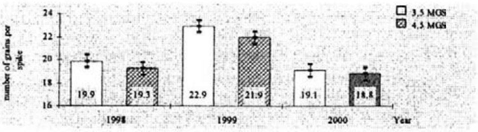


Figure 11. Number of grains per spike in 1998–2000 based on the sowing rate (with confidence intervals for the mean, α = 5%)

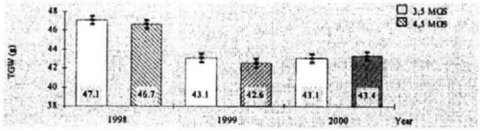


Figure 12. Thousand grain weight (TGW) in 1998–2000 based on the sowing rate (with confidence intervals for the mean, α = 5%)

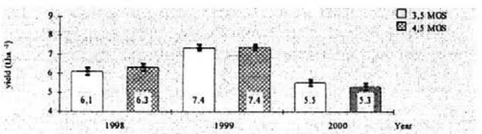


Figure 13. Grain yields in 1998–2000 based on the sowing rate (with confidence intervals for the mean, α = 5%)

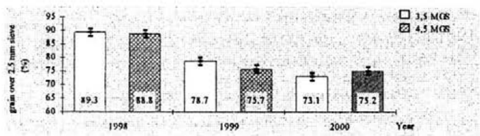


Figure 14. Yield capacity of grain (% of grain over 2.5 mm sieve) in 1998–2000 based on the sowing rate (with confidence intervals for the mean, α = 5%)

ploughed down later (832.6 spikes per m$^2$, 20.62 grains per spike), but the grain yields did not correspond to these conditions. While grain yields were the highest in the variant where beet tops were ploughed down early (Table 5), the grain had a significantly lower TGW (43.44 g) than the other variants and the proportion of grain over 2.5 mm sieve was only 5.02 t.ha$^{-1}$, when the tops were ploughed down later it was 5.21 t.ha$^{-1}$.

The sowing rate virtually did not affect the grain yield. The self-regulating capacity of the stand established with a lower sowing rate was reflected in a higher number of grains per spike, TGW and higher proportion of grain over 2.5 mm sieve. Kopecký (1983) presented similar results.

Fertilisation with 30 kg N.ha$^{-1}$ resulted in a statistically significant increase in yields (by 0.17 t.ha$^{-1}$), but significantly reduced the technological parameters of barley grain. This tendency was also confirmed by Flašarová and Onderka (1997), Kandera (1994) and Tichý et al. (1991). They all observed that the efficiency of N fertilisers was strongly influenced particularly by weather conditions of the year and by many other factors.

Figures 5–9 show the effect of various modes of management with sugar beet tops and its effect of the yield-forming factors in the course of the individual years. Since the dry matter of the tops contains a considerable amount of nutrients (Table 2), mineralisation of these post-harvest residues may play an important role and influence barley growth and development (Provazník et al. 2000). The main factor that may considerably influence the effect of the ploughed down tops is the weather. The grain yields must be evaluated in view of this fact. In the relatively favourable years, in terms of rainfall (1998 and 1999), when the rain in spring was distributed in a way to supply the plants with a sufficient amount of water (Figures 2 and 3), early ploughing down of the tops appears to be the best. On the other hand, if a dry spring with insufficient rainfall and above-the-average temperatures follows, the ploughed down tops may depress yield formation. The most suitable way of achieving a first-rate yield with the maximal TGW and relatively highest proportion of grain over 2.5 mm sieve is to wilt the tops and plough them down later (Figures 7 and 9).

In the opinion of Tichý et al. (1991), high or very low sowing rates may result in a depression of yields. Based on results given in Figure 13, we can conclude that the difference between the sowing rate of 3.5 and 4.5 MGS is not decisive in terms of the yield. A lower sowing rate and with it associated lower number of productive tillers (Figure 10) was compensated by a higher number of grains per spike in all the years (Figure 11), and in 1998 and 1999, when the weather was relatively favourable, the TGW and proportion of grain over 2.5 mm sieve were higher (Figures 12 and 14).

N fertilisation in the individual years also affected the level of yield forming elements and qualitative parameters of the grain (Figures 15–19). The application of 30 kg N.ha$^{-1}$ in ammonium nitrate with limestone during seedbed preparation had a positive effect on the number of spikes per unit of area and number of grains per spike in all the years (Figures 15 and 16) and insignificantly increased the yields in 1998 and 1999 when the weather was more favourable in terms of precipitation (Figure 18). On the other hand, no difference in yields was recorded after the application of nitrogen in 2000. The reason could be insufficient precipitation (Figure 4) in the early stages of development when the conditions for making use of the nitrogen dose were not favourable. After the application of 30 kg N.ha$^{-1}$ a statistically insignificant reduction in the TGW (Figure 17) and proportion of grain over 2.5 mm sieve (Figure 19) was recorded and with it a worse malting quality of the grain. Kandera (1994), Ložek et al.

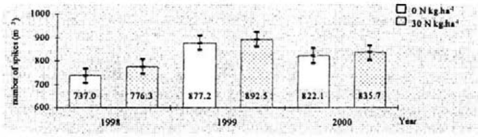


Figure 15. Number of spikes per m² in 1998–2000 based on dose of N fertilisers (with confidence intervals for the mean, α = 5%)

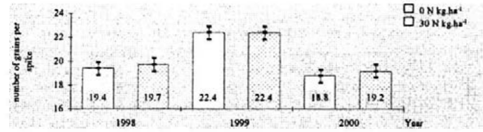


Figure 16. Number of grains per spike in 1998–2000 based on dose of N fertilisers (with confidence intervals for the mean, α = 5%)

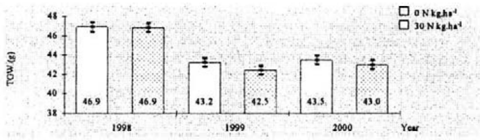


Figure 17. Thousand grain weight (TGW) in 1998–2000 based on dose of N fertilisers (with confidence intervals for the mean, α = 5%)

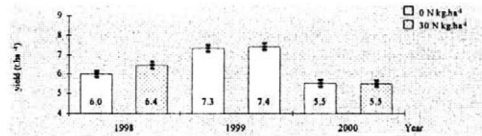


Figure 18. Grain yields in 1998–2000 based on dose of N fertilisers (with confidence intervals for the mean, α = 5%)

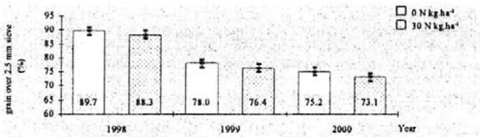


Figure 19. Yield capacity of grain (% of grain over 2.5 mm sieve) in 1998–2000 based on dose of N fertilisers (with confidence intervals for the mean, α = 5%)

(1991), Provazník et al. (2000) and others also drew attention to the problem of optimisation of nitrogen doses in relation to yields and its quality.

The present publication was funded by the NAZV project EP 7081 and research project of MŠMT – CEZ 2.308/98:432100001.

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Received on February 12, 2001

**ABSTRAKT**

**Ovlivnění produkčních ukazatelů jarního ječmene zaorávkou řepného chrástu v kukuřičné oblasti**

V polyfaktoriálním polním pokusu byl v letech 1998 až 2000 sledován vliv tří systémů hospodaření s řepným chrástem, dvou výsevků a dvou úrovní dusíkatého hnojení a interakcí těchto faktorů na produkční ukazatele jarního ječmene odrůdy Kompakt. Na základě statistického zhodnocení analýzou variance byl zjištěn dominantní vliv ročníku na variabilitu všech sledovaných znaků (počet klasů na $m^2$, počet zrn v klase, HTZ, výnos, podíl předního zrna). Podíl ročníku na celkové variabilitě znaků byl od 57,3 % (počet klasů na $m^2$) do 88,6 % (výnos). Způsob hospodaření s řepným chrástem ovlivnil statisticky vysoce významně HTZ, výnos a podíl předního zrna a významně počet zrn v klase. Volba výsevku vysoce významně ovlivnila počet klasů na $m^2$ a počet zrn v klasu. Úroveň dusíkaté výživy měla vysoce významný vliv jen na hodnoty podílu předního zrna. U všech sledovaných znaků s výjimkou počtu zrn na klas byly zjištěny i vysoce významné interakce ročníku se způsobem hospodaření s chrástem. Dosažená úroveň znaků byla značně variabilní v závislosti na průběhu povětrnostních podmínek ročníku. Nejvyšší výnos zrna byl dosažen v roce 1999 (7,37 $t.ha^{-1}$), nejnižší v roce 2000 (5,51 $t.ha^{-1}$). Nejlepší kvalitativní parametry vykázalo zrno ze sklizně 1998 (výnos 6,22 $t.ha^{-1}$) s podílem předního zrna 89,02 % a celkovou produkcí v přepočtu 5,54 $t.ha^{-1}$. Zaorávaný chrást podpořil tvorbu výnosu v závislosti na průběhu povětrnostních podmínek, zejména srážek. Projevila se silná autoregulační schopnost porostu založeného nižším výsevkem (3,5 oproti 4,5 MKZ). Hnojení dusíkem v dávce 30 kg $N.ha^{-1}$ ve srovnání s 0 kg $N.ha^{-1}$ se projevilo statisticky významným zvýšením výnosu (o 0,17 $t.ha^{-1}$) a zhoršením technologických parametrů zrna ječmene.

**Klíčová slova:** jarní ječmen; řepný chrást; výnos; výnosové prvky; N hnojení; výsevek

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# Screening of productive Czech winter wheat cultivars on resistance to aphids

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**ABSTRACT**

Eleven productive winter wheat cultivars were assessed on level of resistance to cereal aphids, *Metopolophium dirhodum* (MD), *Rhopalosiphum padi* (RP) and *Sitobion avenae* (SA) in the field and under the greenhouse conditions. The aphid density on plants in the field and their reproduction on artificially infested plants in the greenhouse were used as criteria of the levels of cultivar's resistance (suitability) to aphids. Correlations between results of both experiment types were found ($r$ = 0.7054–0.8080). The results of both field and greenhouse experiments showed different level of resistance of tested cultivars to individual aphid species. None within tested cultivars was resistant to all aphid species. Šárka and Asta were partly resistant to MD due to a relatively low aphid density on plants in the field tests and slow aphid reproduction on artificially infested plants in the greenhouse. Boka and Šárka expressed a certain level of resistance to RP and to SA. The developmental stage of cultivars at the period of the highest aphid occurrence may play an important role in plant suitability/unsuitability for aphids.

**Keywords:** wheat cultivars; cereal aphids; resistance; suitability; field experiments; greenhouse tests

Aphid-resistant cereals represent the key to integrated pest management in these crops and therefore high attention has been devoted to the research of cereal resistance to aphids (Burton et al. 1990, Reese et al. 1994, Lamb and MacKay 1995). The host damage caused by cereal aphids consists not only in draining of nutrients but also in transmission of viral diseases, inoculation of toxins, interference with photosynthetic efficiency and in providing medium for fungal growth (Shepers 1989).

Several thousands of small grain accessions are tested for resistance to cereal aphids yearly to develop the new source of resistance. Both field and laboratory tests were used for the assessment of categories of cereal resistance to aphids (Robinson 1992, Smith et al. 1992, Lee 1993). Our previous experiments described the character of resistance/suitability to aphids in a model set of winter wheat cultivars (Havlíčková 1993, 1997). The earlier elaborated methods were used for the evaluation of several productive Czech winter wheat cultivars for the resistance to main cereal aphid species.

## MATERIAL AND METHODS

Eleven perspective winter wheat cultivars were used in this experiment: Asta, Astela, Boka, Bruta, Ina, Ilona, Rexia, Samanta, Sida, Šárka, Vlasta. The research workers of the Division of Genetic and Plant Breeding Research Institute of Plant Production in Prague-Ruzyně recommended the collection of these cultivars. The cultivars were assessed on resistance to three aphid species, *Metopolophium dirhodum* (Wlk.) (MD), *Rhopalosiphum padi* (F.) (RP) and *Sitobion avenae* (Fabr.) (SA) in the field and under the greenhouse conditions.

### Field experiments (open)

The plants of individual cultivars were cultivated in the plots (2 × 2 m) in the locality Prague-Ruzyně. The field screening on various resistance of wheat cultivars to aphids was carried out in 1996–1999. The numbers of aphids present on 30 tillers of each cultivar were counted every year. The evaluation of aphid density was performed at the peak of aphid abundance when the most of cultivars were at the end of plant anthesis (GS 69).

### Greenouse tests (laboratory)

The air-conditioned greenhouse was used for the laboratory tests of cultivar resistance to aphids. The plants of individual cultivars were planted in the Mitcherlich pots, five plants per pot. The plants were infested with aphids at the end of stem elongation stage (GS 39). Three individuals of the first instar were placed on tiller. The plants in one pot were infested with one aphid species only. The nylon bags covered the pots with infested plants. At the end of plant anthesis the numbers of MD and RP present on 15 fertile tillers and SA present in 15 ears in each pot were counted. The experiment was performed under the similar conditions and in the same extent for four consecutive years (1996–1999).

The relative values of cultivar infestation with aphids (the aphid proportions on plants of individual cultivars in the total aphids present in all cultivars) served as the criteria of the level of cultivar resistance against individual aphid species.

## RESULTS

The observed differences in developmental stage of tested cultivars were more evident under the greenhouse conditions. Ilona was the earliest ripening cultivar both in the open and in the laboratory tests, while Boka was the latest one. Šárka and Vlasta, two highly productive new cultivars, also differed at the rate of development. The cultivar Šárka developed quicker than Vlasta till the beginning of inflorescence (GS 51). The developmental process of Sida and Samanta was slower in laboratory than in open tests.

Plant infestation with individual aphid species considerably varied in individual experimental years (Table 1). While MD was present in all studied years, the occurrence of RP in tested cultivars was negligible in 1996 and 1997. The highest aphid number per tiller occurred in 1999. The average reproduction of individual aphid species on artificially infested plants was rather similar in all repetitions (Table 2).

Both field and greenhouse tests revealed a different level of plant suitability for/resistance to the individual aphid species. None within tested cutivars was resistant to all aphid species. A significant correlation ($r = 0.8080$) was found between open and laboratory tests in cultivar suitability/unsuitability for MD. The results of both tests confirmed a high Samanta and Sida suitability for aphids, while Šárka and Asta were partly resistant. A relatively low number of MD was also observed in Ina and Vlasta (Figure 1).

The greatest differences among cultivars were found on the levels of their suitability for RP. Relative values of cultivar infestation in the field screening correlated with those received in the laboratory tests ($r = 0.7444$). The both types of assessments confirmed the extreme reproduction of RP on Ilona. A relative high aphid reproduction in Rexia in the laboratory did not correspond with the open tests and a high aphid infestation of Sida in the field was not in accordance with the lower aphid reproduction in the laboratory. Differences between field and laboratory results were also observed in Vlasta. The aphid numbers in the other cultivars were low, mostly not exceeding the average aphid density in the plants. A certain level of resistance to RP was assessed in Boka, Šárka and Asta (Figure 2).

Majority of tested cultivars represented good hosts for SA. Relative values of SA infestation on individual cultivars found in the field corresponded with those received in the laboratory experiments ($r = 0.7054$). According to the field and laboratory results Ilona and Vlasta represent the good hosts for SA, while a relative low infestation of Šárka and Boka may express their partial resistance to this aphid species (Figure 3).

Table 1. Aphid density in winter wheat cultivars in the field at the end of plant anthesis in individual years; 330 tillers were evaluated every year

| Year | Aphid number per tiller | | |
|---|---|---|---|
| | *M. dirhodum* | *R. padi* | *S. avenae* |
| 1996 | 3.38 | 0.28 | 0.96 |
| 1997 | 11.55 | 0.19 | 3.09 |
| 1998 | 8.78 | 6.19 | 5.56 |
| 1999 | 50.68 | 7.96 | 5.67 |

## DISCUSSION

The resistance of winter wheat cultivars to aphids is studied in the RICP for a long time and specific methods for evaluation of plant resistance to these important pests were elaborated (Havlíčková 1993). In accordance with data received by Honěk and Martinková (1999) the both occurrence and density of individual aphid species in winter wheats varied considerably in experimental years. Despite the high variability of aphid density in single years the evident differences among cultivar suitability/unsuitability for aphids were found.

No cultivar within the tested collection expressed the high level of resistance to all aphid species neither in the field, nor in the greenhouse experiments. Both open and laboratory experiments showed a possible role of plant developmental stage in express of cultivar suitability/unsuitability for individual aphid species. The high suitability of Ilona for RA and SA might result from the earliest ripening of this cultivar because both RP and SA prefer hosts at the higher developmental stage (Dedryver and di Pietro 1986, Havlíčková 1987). Early ripening Ilona is probably more attractive cultivar for aphids than in development delayed resistant Boka. It is known that both age and plant quality play an important role in host suitability for cereal aphids (Watt 1979) and that the changes in plant metabolism during wheat development influence considerably aphid behaviour of plants (Havlíčková 1993). In this aspect the developmental characteristics of cultivars should be taken into account in evaluating the cereal resistance to SA, one of the most

Table 2. Aphid density in winter wheat plants cultivated in the greenhouse at the end of plant anthesis, 20 days after infestation; average values from four repetitions, 165 tillers evaluated in every experiment

| Repetition | Aphid number per tiller | | |
|---|---|---|---|
| | *M. dirhodum* | *R. padi* | *S. avenae* |
| 1st | 113.2 | 116.8 | 54.6 |
| 2nd | 121.3 | 138.7 | 65.3 |
| 3rd | 133.6 | 145.7 | 48.3 |
| 4th | 113.2 | 150.0 | 60.2 |
| Averages | 120.3 ± 9.64 | 137.8 ± 14.75 | 57.1 ± 7.33 |

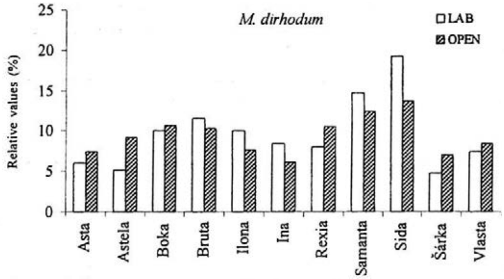


Figure 1. Relative values of cultivar infestation with *M. dirhodum*; averages from four experiments in the greenhouse (LAB) and from the years 1996–1999 in the field (OPEN)

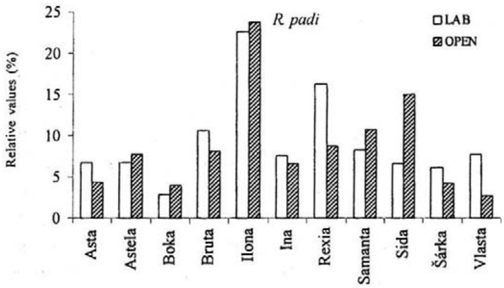


Figure 2. Relative values of cultivar infestation with *R. padi*; averages from four experiments in the greenhouse (LAB) and from the years 1996–1999 in the field (OPEN)

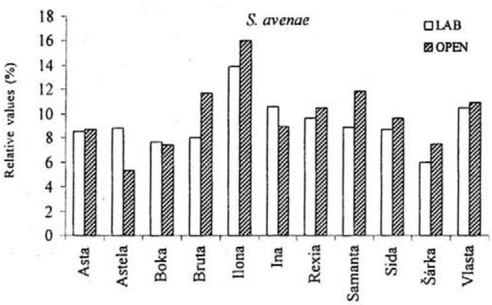


Figure 3. Relative values of cultivar infestation with *S. avenae*; averages from four experiments in the greenhouse (LAB) and from the years 1996–1999 in the field (OPEN)

harmfull pest of winter wheat, and RP, the most important vector of virus diseases.

Nevertheless, level of cultivar suitability for aphids was probably affected by further factors. This hypothesis has been confirmed by the results received by tests of two newly selected, highly productive winter wheat cultivars, earlier developing Šárka and later developing Vlasta. The former, although earlier, was less attractive for SA than the later ripening Vlasta. A relatively high suitability of Vlasta for SA could originate from Hana cultivar, which is highly attractive cultivar for SA (Havlíčková 1997), and was used for Vlasta selection. On the contrary, a partial resistance of Šárka to SA and MD may result from the use of Mironovskaya nizkorostlaja for Šárka selection. It may be supposed that the resistance factors to aphids from Mironovskaya cvs were transferred to Šárka regarding the high resistance observed in Mironovskaya 808 (Havlíčková 1993).

Our results showed that partial resistance of several winter wheat cultivars to the individual aphid species occurred in the tested collection. As Kogan and Ortman (1978) emphasised that the use of partly resistant crops to pests in combination with cultural practices might contribute to both reduction in pest damage and decrease in chemical control. According to Quisenberry and Schotzko (1994) resistance of crops to major insect pests must be incorporated into new cultivars just as agronomic characteristics are presently incorporated.

**Acknowledgement**

I thank Dr. M. Cvikrová for critical reading of MS. I am grateful to colleagues from the Division of Genetics and Plant Breeding RICP for the providing of seed material and valuable information, and Mrs I. Kubečková for excellent technical assistance.

The study was supported by Ministry of Agriculture of the Czech Republic, project EP 096-000-6442.

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Received on December 4, 2000


## ABSTRAKT


**Hodnocení rezistence produktivních českých odrůd ozimé pšenice vůči mšicím**

Na 11 výkonných odrůdách ozimé pšenice, vybraných na doporučení pracovníků Odboru genetiky a šlechtění Výzkumného ústavu rostlinné výroby, byla v polních a skleníkových podmínkách zjišťována hladina rezistence vůči mšici střemchové, *Rhopalosiphum padi* (L.), kyjatce travní, *Metopolophium dirhodum* (Wlk.) a kyjatce osenní, *Sitobion avenae* (F.). Kritériem rezistence vůči mšicím byla v polních i skleníkových testech hustota mšic na rostlinách na konci fáze kvetení. V polních podmínkách se vycházelo z přirozeného napadení rostlin, ve skleníku z rychlosti reprodukce mšic na uměle infestovaných rostlinách. Mezi výsledky polních a skleníkových pokusů byl stanoven vztah statisticky významné korelace (v rozmezí $r = 0{,}7054$ až 0,8080). Výsledky obou typů testů ukázaly různou hladinu rezistence vůči jednotlivým druhům mšic. Žádná z testovaných odrůd nebyla rezistentní vůči všem druhům mšic. Odrůdy Šárka a Asta byly částečně rezistentní vůči kyjatce travní podle relativně nízkého stupně napadení v polních podmínkách a nízké množivosti mšic na uměle infestovaných rostlinách. Odrůdy Boka a Šárka vykázaly určitý stupeň rezistence vůči mšici střemchové a kyjatce osenní. Je diskutován vliv růstové fáze rostlin na hladinu vhodnosti/rezistence testovaných odrůd vůči obilním mšicím.



**Klíčová slova:** odrůdy pšenice; obilní mšice; rezistence; vhodnost; polní pokusy; skleníkové testy


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# The influence of fertilization and weather conditions on winter rape yield in the East Slovakian Lowlands

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**ABSTRACT**

In field experiments conducted between 1981 and 1999, the influence of fertilizer regimes in conjunction with yearly weather conditions were observed on the yield of winter rape plants (*Brassica napus* L.). Based on the statistical evaluation of the analysis of variation, it was concluded that the fertiliser regime was the dominant factor in determining the yield variability in this crop. The influence of the weather factors in the East Slovakian Lowlands was secondary during 18 year period.

**Keywords:** winter rape; fertilization; yield; weather conditions

Growing any crop and especially one of economic importance, is not possible without an intensification of farming practices that ensure adequate fertility. At the same time, it is necessary to take into account the suitability of the crop for local conditions and the local economy. When growing winter rape, high input of fertilisers insures adequate growth, but the system and results are now being looked in conjunction with environmental conditions year by year (Petr et al. 1987, Bízik 1994).

These problems have been studied by many workers in Slovakia as well as in other countries. Much of the work has focussed on nitrogen, due to its intransigent nature, as well as other nutrients and actual agronomic techniques (Damaška 1985, Petr et al. 1987, Janiševskij et al. 1991). More and more workers are bringing together the interactions between fertilization and environment, rather than just taking one factor in isolation (Vašák and Fábry 1996, Ložek 1998).

The goal of this work was to evaluate fertilizing as an intensification factor and also the influence of the environment. As well as being assessed as individual factors, they were also considered in conjunction with each other.

## MATERIAL AND METHODS

Trials were done on varieties of winter rape at the Research Institute of Agroecology Michalovce, Slovakia, next to the village of Vysoká nad Uhom, from 1981 to 1999 inclusive. The Institute is situated in the centre of the East Slovakian Lowlands. The soil is a luvisol (LM).

The crop was grown using traditional cultivation techniques. There were three application rates of fertilization (K – the control with no-fertilization, I. 205 kg $NPK.ha^{-1}$ and II. 286 kg $NPK.ha^{-1}$) with four replicates. Crushed limestone was also added to all treatments at the rate of 6 $t.ha^{-1}$, ploughed into the depth of 100 mm into stubble, and the ground was then rolled. Fresh manure at a rate of 40 $t.ha^{-1}$ was ploughed into a depth of 220 mm three weeks prior to sowing. N, P and K were also applied prior to sowing and worked into the surface layers. Chemical control was made by suitable pesticides. The varieties of winter rape Brink (1981–1985), Tandem (1986–1988), Jetneuf (1989–1995), Lirajet (1996–1998) and Olymp (1999) were used during last 18 years. Seed-rate was 1 million of germinating seeds per hectare. Pre-crop for winter rape cultivation in the East Slovakian Lowland conditions is usual winter wheat.

Results were evaluated by total analysis of variance (Dubovský et al. 1969).

### Soil conditions

Soil extractable nutrient levels, soil reaction and soil organic matter were determined during the study from 1981 to 1999. In regard to average results, content of organic matter is 0.969%, soil pH 6.81, 225.60 mg $N.kg^{-1}$, 67.75 mg $P.kg^{-1}$, 272.50 mg $K.kg^{-1}$ and 94.60 mg $Mg.kg^{-1}$.

Luvisol (LM) approximately occurs 17.80% of the total area in the East Slovakian Lowlands.

### Weather conditions

The East Slovakian Lowlands is a North-Eastern promontory of the Great Tiszian Lowlands. This area is planed with an altitude 94 up to 140 m and belongs to dry and semidry regions with an average year temperature 9°C, average temperature through a vegetative period 15.2°C. The average year precipitation 557 mm, average precipitation through vegetative period 397 mm. The meteorological station, which is situated near the fields, was given the information about weather conditions.

The detail soil and weather characteristics in relation to experiment years were published by Tóth (1998).

Table 1. Results of complete analysis of variance

| Component | $N$ | $S_x^2$ | $F_{cal}$ | $F_{tab}$ | $s$ | Significance | Absolutely | % ($F_{tab}$ = 100%) | Order |
|---|---|---|---|---|---|---|---|---|---|
| Total variability | 114 | 88.207 | 1 453 | – | – | – | – | – | – |
| Years | 18 | 24.582 | 2 541 | 2.5 | | ×× | 2 538 | 101 647.54 | 2 |
| Fertilization | 2 | 54.810 | 50 995 | 5.2 | | ×× | 50 990 | 980 668.94 | 1 |
| Repetition | 1 | 5E–05 | 0.087 | 4.1 | | – | –4.013 | 2.1215601 | – |
| Years × fertilization | 36 | 8.782 | 453.9 | 2.1 | | ×× | 451.8 | 21 615.011 | 3 |
| Years × repetition | 18 | 0.013 | 1.301 | 1.8 | | – | –0.499 | 72.286229 | – |
| Fertilization × repetition | 2 | 0.002 | 1.385 | 3.2 | | – | –1.815 | 43.285397 | – |
| Rest | 36 | 1.51 | – | – | 0.023 | – | – | – | – |

$N$ = degree of freedom; $S_x^2$ = sum of squares per item; $F_{cal}$ = calculated value; $F_{tab}$ = tabular value; $s$ = standard deviation; absolutely = differences between $F_{cal}$ and $F_{tab}$; rest = experimental error

## RESULTS AND DISCUSSION

Influence of following factors: variants of fertilization, year weather conditions, replication was evaluated in experiments as all double interactions (Table 1). It was concluded that the fertilization was the main factor in determining the yield variability of winter rape. The similar results were obtained by Bízik (1994), but without the consequent analysis of fertiliser interactions, and by next workers (Vašák and Fábry 1996, Ložek 1998).

Petr et al. (1987), Damaška (1985) and Janiševskij et al. (1991) studied in more details relationship between N and a content of nutrients in soil. It is confirmed that there is a considerable stage of variability in the mineralization of N in accordance with weather conditions. The variability at level of 13–20% of winter rape yield was caused by these conditions (Fábry et al. 1975).

On the other hand, relationship between the crop yield and soil-weather conditions are considerably different and dependent on many factors. An expression of influence of the concrete factor on the crop yield is not constant, because it refers to the range of environmental conditions. The present theory and practice results showed that fertilizer regime of winter rape cultivation relieves unfavourable effects of abiotic and biotic growth factors (Voškeruška 1972, Vašák 1989, Šrojtová 1993, 1997, Vašák and Fábry 1996).

The result analysis in relation to winter rape yield or its stability is presented by the influence of factors in the order: fertilization and year weather conditions. This order is interesting because the difference of fertilizer variants exceeded the influence of the year weather conditions with strongly different character of weather.

When the difference of winter rape yields during evaluated years is higher than 15.19 kg.ha$^{-1}$, these results are significant respectively higher than 20.31 kg.ha$^{-1}$,they are very significant. The highest crop yield was in 1992, respectively the lowest in 1981.

When the difference of winter rape yields in relation to fertiliser variants (K the control with a basal fertilization, I. 205 kg NPK.ha$^{-1}$ and II. 286 kg NPK.ha$^{-1}$) during evaluated period is more than 38.23 kg.ha$^{-1}$, the results are significant, or when they are higher than 51.11 kg.ha$^{-1}$, they are very significant (Figure 1). The very high significance in order to crop yields was computed among the variants of fertilizer regime in conjunction with yearly climatic conditions.

Finally, when the difference of crop yields in respect to fertiliser variants and different years together during this period is higher than 10.74 kg.ha$^{-1}$, the results are significant or higher than 14.36 kg.ha$^{-1}$, they are very significant. The yield results of the variant K in comparison with the variants I and II are very significant, respectively. The calculation between variants I and II determined the significance except for years: 1981, 1984, 1989 and 1998 (Figure 2).

The conclusion of the research is presented in order to establish the statistical evaluation of the analysis of variation, that the fertiliser regime was the dominant factor in determining the yield variability of winter rape in weather conditions on the East Slovakian Lowlands.

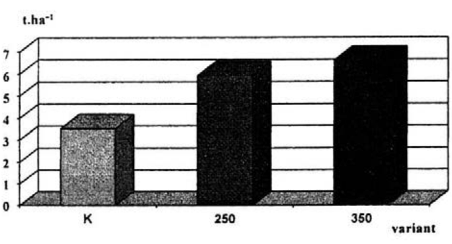


Figure 1. Winter rape seed yields according to fertiliser variants

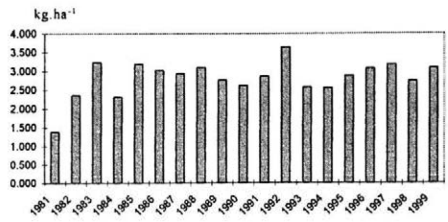


Figure 2. Winter rape seed yields in relation to weather conditions during years

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Received on April 18, 2000

## ABSTRAKT

**Vliv hnojení a povětrnostních podmínek na výnosy ozimé řepky ve Východoslovenské nížině**

V polních pokusech jsme v letech 1981 až 1999 sledovali vliv hnojení, povětrnostních podmínek a interakce těchto faktorů na tvorbu výnosů ozimé řepky (*Brassica napus* L.). Na základě statistického vyhodnocení úplnou analýzou variance se jako dominantní zdroj proměnlivosti ozimé řepky na Východoslovenské nížině po dobu 18 hodnocených let projevilo hnojení před povětrnostními podmínkami.

**Klíčová slova:** ozimá řepka; hnojení; výnos; povětrnostní podmínky

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ROSTLINNÁ VÝROBA PLANT PRODUCTION

Volume 47, No. 7 July 2001

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