YIELD FORMATION IN THE SPRING BARLEY IN ORGANIC FARMING*

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In a fifteen-year experiment with 21 European varieties of spring barley in organic farming system in a fertile area, the stability of the yield, specialties of yield formation and its structure were evaluated. The current varieties of spring barley form their yields by the number of ears per unit area and thus, they are dependent on productive tillering. A great variability in the yield has been determined – the coefficient of variation was 28%, average yield 4.47 t/ha, and standard deviation $s = 1.27$ t.ha^{-1}. This variability was caused by the great dependence of the tillers formation on weather conditions and on the quantity of nitrogen available for their establishment and growth. Tillering period is very long and open to a direct influence of changeable weather. Furthermore, every year there were different conditions for nitrification and release of mineral nitrogen from the soil. This leads to varying quantity of nitrogen available for the support of tillering. A direct dependence between the available nitrogen in the soil during early spring and the period of ripening, and the number of ears as well as the yield of grain has been shown. The number of caryopses in an ear had a stable range of 17–22, but their mass was influenced by the number of ears, or the number of grains per unit area. The proportion of the overtail grain was over 90%.

organic farming; spring barley; yield formation; yield structure; nitrogen release

INTRODUCTION

Organic farming (OF), also known in Czech as ecological agriculture, is a type of cultivation that merges traditional farming with the knowledge of modern agriculture. It is managed according to established international principles and national regulations, and their observance is monitored (IFOAM and Act 242/2000 Ministry of Agriculture Czech Republic). This makes it possible to declare the products of organic farming as biofoods. The fact that industrial fertilizers, regulators and other agricultural chemicals are not used changes considerably the conditions of cultivation and agricultural technology. A complete management system, which is based on the structure of the cultivated crops, their crop rotation, organic manuring system and the use of certified natural mineral fertilizers, forms an essential part of the production conditions. Selection of varieties is determined by their productivity in conventional cultivation, because modern varieties are high yielding, relatively resistant to diseases and pests, and have a high capacity to utilize nutrients.

A great change had occurred in the breeding of spring barley in the 1960s. As a result of radiomutation the Diamant variety was obtained. This was a new type of barley with a short stem which was more resistant to lodging, and had a different structure of yield-forming components. Compared to the Valtický maternal variety, the yield of the Diamant variety was produced by the number of fertile tillers and a higher formation of spikes (Bouma, Ohnoutka, 1990). The number of spikes per unit area increased by up to 60%, while the average number of grains per spike remained unchanged. This type of variety became a model for further breeding of spring barley varieties and nowadays they are used in ecological agriculture. We have described the patterns of the yield formation in these new varieties together with the original Czech and Moravian varieties and the historical Nürnberg variety of 1832 in the study by Petr et al. (2002). However, there are opinions that this character of the varieties is more sensitive to the weather pattern and growing conditions (Hubík, 1993).

Over the past 20 years the variability of spring barley yields in the entire cropping area of the Czech Republic amounted on average to 14.5%, with the standard deviation $s = 0.57$ tonnes per hectare (Kůst, Potměšilová, 2008). In ecological agriculture the conditions for the cultivation of spring barley are much more complex, because the supporting inputs such as fertilization and chemical protection are not used. The yield under the ecological system depends on the release of nitrogen and other nutrients from the soil reserves and on the mineralisation of organic matter. Together with some other factors, the yield formation is affected by the weather, so that the yield of spring barley is considerably dependent on the weather pattern (Colective of authors, 2008). These factors include the onset of the spring and hence also the earliness of barley seeding, moisture and temperature conditions for emergence and tillering and the already mentioned content of the available soil nitrogen. This is often difficult to provide as this depends on the temperature and moisture conditions that support the mineralisation of organic matter in the soil.

In this study we present the results of the long-term cultivation of a wide assortment of the spring barley vari-

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eties to assess their yield stability and to determine the character of the yield components formation under the conditions of organic farming. In addition, the stability of nutrients reserves in the soil and the dynamics of available nitrogen release were also studied.

MATERIAL AND METHODS

The research was conducted at the University Experimental Station in Prague-Uhříněves. The station is certified for ecological agriculture. It is located in a region with an average altitude of 295 m and a production potential of the soil being 84 points, which is a very high value. The soil type is Luvisol on the soil forming loess substrates. There are heavy soils in this region with the topsoil depth of 32 cm and a humus horizon of 70 cm. The humus content in the topsoil is 1.74% to 2.12% which is medium to moderate quantity. The reserves of available nutrients (P, K, Mg and Ca) in individual years were continuously analysed and considered as good (V a n ě k et al., 2007). We assume that apart from the weather the quantity of the nitrogen released from the soil in the spring and during the vegetative period should have a decisive effect on the yield. The mineral nitrogen in soil was about 1% solution KCl in soil extract and was measured using the photometric method with Skalar equipment.

The region is semi-humid. Favourable water regime ensures stable soil water content. The normal period annual average air temperature is 8.45 °C, and the annual precipitation totals reach 575 mm, of which 380 mm fell during the April–September period.

The experiment was established according to the methodologies of the National Plant Variety Office 1993. The experimental design was a complete randomised block with three replicates; each plot was 10 m^2. The previous crops were either red clover (*Trifolium pratense*) or a pulse crop-cereal or pulse crop mixture (pea, horse bean and field pea) as green manure. The varieties were identical to those tested in the experimental year in the National Variety Office for the List of Recommended Varieties. 21 varieties were studied annually.

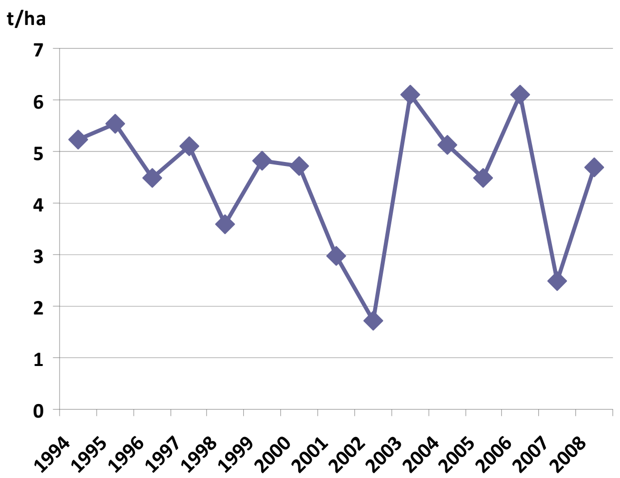

Fig. 1. The yield variability of 21 varieties of the spring barley in organic farming 1994–2008

The structure of the varieties yields was determined during the years of 2001 and 2008 for the varieties tested and newly registered at that time. The yield elements were calculated on the basis of the number of ears, the yield and the mass of one thousand grains.

The variability of the yield and yield components per year was statistically evaluated by the standard deviation and variation coefficient and the correlation of some elements with the grain yield.

RESULTS AND DISCUSSION

The results of the observed spring barley varieties in organic farming (OF) were unstable – Fig. 1. The high variability of the spring barley yields was confirmed by the standard deviation ($s = \pm 1.27$) and the variation coefficient of 28% by average yield 4.47 t/ha. This provides evidence of the great vulnerability of spring barley to this cultivation method.

We cannot look for the causes in the differences of agricultural technology, because that was identical in all the years. For example, the sowing time ranged in the period running from the end of March till the first week of April. The treatment of the growth stands with harrowing was also identical.

Furthermore, the yearly reserves of the main nutrients have been good for the entire period of the experiments, with the average contents being as follows: P 97 mg/kg, K 199 mg/kg, and Mg 131 mg/kg, which are all satisfactory. The ratio of K : Mg was also good. The soil reaction was neutral – pH 6.8, which is suitable for spring barley and in our case it favourably influenced the release of nitrogen (V a n ě k et al. 2007). The variability of the available nutrients content in the soil was relatively small, under 20% (P e t r et al., 2009). The variation coefficients were 14.1% for phosphorus, 19.5%, for potassium and 10.2% for magnesium.

When looking for the causes of the yields instability, the main attention should be focused on the weather pattern and its effect on the processes of the yield elements formation, as well as on the process of the mineralisation of nutrients, particularly that of nitrogen from the soil reserves. The overall quantity of nitrogen and the dynamics of the release of available nitrogen throughout the entire vegetation period will, undoubtedly, participate significantly in the yield levels. The outlines of the weather pattern in the years with extremely low yields and the character of the weather in the years with high yields and good malting quality are presented here. These data can then be compared with the weather that is suitable for a high yield and good quality malting barley (P e t r et al., 1991).

In the years with extremely low yields (2001, 2002 and 2007) there have been very warm winters, early springs and late springs. In 2002, and especially 2007, there was a very dry April and excessively warm May. The months

Table 1. Weather pattern in two years with low and high yields and a long-term average

Year	Average monthly temperature and precipitation total	I	II	III	IV	V	VI	VII	Yield (t/ha)
2001	temperature °C	0.4	2.4	5.2	8.5	15.6	15.5	18.9	**2.98**
	precipitation mm	25.4	30.9	13.0	71.6	67.3	71.9	97.5	
2002	temperature °C	0.8	5.0	5.5	9.1	15.5	18.6	19.5	**1.72**
	precipitation mm	19.6	56.1	31.7	26.5	50.1	132.7	113.9	
2003	temperature °C	–0.7	–2.7	5.4	9.1	16.5	20.9	20.0	**6.11**
	precipitation mm	29.4	5.3	7.9	22.2	72.8	30.9	76.0	
2006	temperature °C	–4.8	–1.2	2.2	9.7	14.2	18.4	23.2	**6.09**
	precipitation mm	18.7	60.6	50.1	48.4	100.9	86.6	12.2	
2007	temperature °C	5.0	4.4	6.6	12.2	15.9	19.5	19.8	**2.48**
	precipitation	55.5	31.8	22.6	2.6	52.2	88.1	69.7	
2008	temperature °C	2.8	3.9	4.7	8.9	14.7	18.9	19.2	**4.68**
	precipitation mm	26.1	13.0	26.4	47.2	98.9	48.0	79.7	
Long term average	temperature °C	–2.1	–0.8	3.4	8.2	13.4	16.3	18.2	
	precipitation mm	28.0	27.0	31.0	46.0	65.0	74.0	74.0	
Ideal weather pattern (Petr et al., 1991)	temperature °C				8.5	13.5	17.0	19.0	
	precipitation mm				32.0	52.0	70.0	75.0	

of June and July were rather wet and in 2002 there was damage to the growth stands by excessive precipitation.

By contrast, in the years with high yields the first three months were cold, close to the long-term average weather. Although April and May were warmer than average, they had sufficient precipitation and May actually received above average precipitation (Table 1). The weather pattern in other months was similar to the long-term standard, favourable for good yield and quality of malting barley. H u b í k (1993) also provides evidence for such a weather pattern, which brings a high yield and a number of ears, as well as the final yield.

Since no industrial nitrogen fertilizers are used in ecological agriculture, the basis of the plant nutrition is supplied by manure. We therefore assume that apart from the weather the quantity of the nitrogen released from the soil in the spring and during the vegetative period should have a decisive effect on the yield. In the high yielding years a high content of available nitrogen in the soil in the spring has been detected. For instance, in 2003 there were 22.9 mg of N per 1 kg of the soil down to the depth of 30 cm and 9.9 mg/kg of the soil down to the depth of 60 cm, which represented 103 kg N in the top soil. In the year 2006 this quantity was similar and made it possible for the plants to produce more tillers (K l e m , 2009). Furthermore, during the ongoing process of mineralization which, in biologically active soils, culminates in the middle of May and June, according to Fig. 2 (R e i n e r et al., 1992), it helped to support the strong formation of tillers and ensured their fertility. This process is confirmed in Fig. 2 and Fig. 3 based on our experimental plot of 2008.

The described situation is also testified by the number of ears in both high yield years, of which there were 740 per square metres in 2003 and 744/m^2 in 2006 (Table 2). Such yields have occurred only twice during the fifteen years of experiments. In the other years the values of N_{min} in the spring were low. For example, in 2001 the N_{min} content in April was 7.85 mg/kg of the soil, which represented 35 kg N per hectare, and in 2007 this was 8.17 mg/kg, or about 36 kg N per hectare. The plants formed few

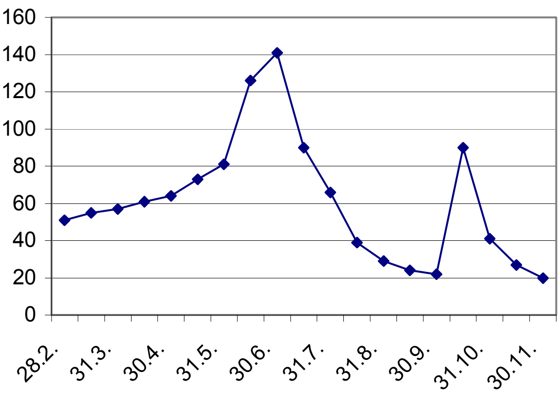

Fig. 2. The model process of N release during the vegetative phase

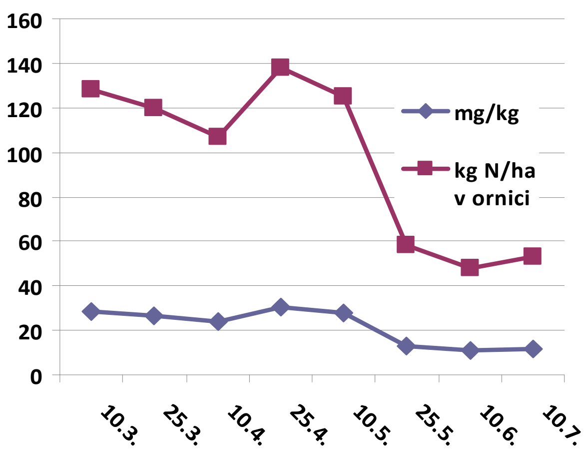

Fig. 3. The process of N release in the experimental year 2008

Table 2.Yield structure of the set of tested varieties during 2001–2008

Years	Number of varieties	Number of plants per 1 m²	Number of ears per 1 m²	Number of grains per ear	Mass of grains per ear in g	Mass of 1000 grains in g	Yield t/ha	Height of the growth in cm
2001*	21	249	314	17.7	0.85	48.0	2.98	58
2003	20	263	740	17.7	0.82	46.4	6.09	62
2004	20	224	477	21.4	1.07	48.8	5.12	59
2005	21	312	344	26.0	1.30	50.0	4.50	64
2006	22	278	744	19.6	0.82	41.8	6.09	64
2007	24	294	312	17.4	0.70	40.5	2.44	48
2008	22	260	413	25.0	1.12	44.7	4.68	69
Mean	**21**	**268**	**484**	**20.7**	**0.95**	**45.7**	**4.55**	**60.5**
		s_x = 29	s_x = 186	s_x = 3.5	s_x = 0.21	s_x = 1.78	s_x = 1.08	s_x = 2.3
		V = 10.8%	V = 38.5%	V = 17.3%	V = 22.2%	V = 4.1%	V = 16.6%	V = 7.0%

* In 2000 the growth stands were damaged by field mouse and in 2002 by flood

tillers so that the final number of ears was low at 312 and 314 ears per 1 m^2, respectively.

The results of the yield structure of 21 varieties in the last 7 experimental years show that, on average, when 350 germinable seeds were sown 268 plants came up. The variability of different yield elements fluctuates greatly (Table 2). In the number of plants it is low, in the number of spikes it is very high. The most stable yield-forming component is thousand-kernel weight (TKW) with the variability of 4.1%. The medium variability is demonstrated by the number of grains, weight of grains per spike, and the grain yield per 1 ha. As outlined above, apart from the weather, the reserves of the soil nitrogen had determined the tillering, while the final number of ears was determined by the release of nitrogen during the stem elongation and the differentiation of the ear. The drought in April 2007 strongly affected emergence as well as tillering. Abnormally warm May accelerated the generative development and shortened the phase of tillering and differentiation of the ear. Excessive precipitations during the ripening phase negatively influenced the formation of caryopses in several years under observation. The grain

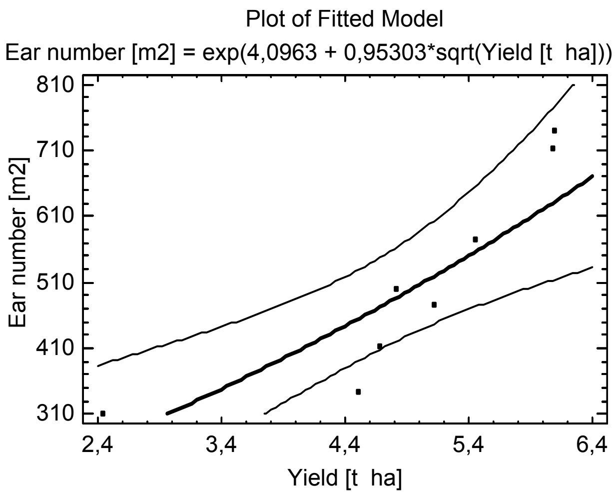

Fig. 4. Simple regression – Ear number (m^2) vs. Yield (t.ha^{-1}) = 0.8699 Logarithmic–Y square_root–X model: Y = exp(a + b*sqrt (X)), Ear number (m^2) = exp(4.0963 + 0.95303*sqrt (Yield (t.ha^{-1}))

mass was also affected, but that had also been the result of the yield elements compensation, when the low number or ears and caryopses in the ear usually increases the yield level of the last yield element – the grains and vice versa. The grain mass or, more precisely, the mass of 1000 grains is considered to be a relatively stable yield element. However, in our experiments it turned out to be rather variable. This was caused by the great differences in the number of ears per 1 m^2 and a different number of grains per m^2 which, on average, ranged around 10 500 grains and, in the high yields of over 6 tonnes, the grain number exceeded 13 000 grains per 1 m^2. The assessment of the yield structure shows unambiguously that the number of ears per unit area has a decisive effect on the yield of the current varieties of spring barley in both the ecological and conventional methods of cultivation. Correlation coefficient is r_{xy} 0.86.

This is also confirmed by the correlation coefficient of the relation between the number of ears and yield in our former experiments (P e t r et al., 1988).

CONCLUSIONS

Barley under such conditions is very vulnerable to unfavourable weather, since the yield in the current varieties is formed by the number of fertile tillers (ears) per unit area of soil. The formation of tillers and their differentiation into fertile and sterile takes up 80 or more days and that presents an open period for both favourable and unfavourable effects of the weather. This is the cause of the great fluctuation in the number of ears which, in turn, is a decisive element in the final yield of grain.

The low yields occurred in the years with abnormally warm winters, when the mineral nitrogen was washed out and was not available to young plants. Another fluctuation in the yields was caused by drought in April and excessively warm temperatures in May. High yields are more likely to occur if May is cold. A good reserve of mineral nitrogen N_{min} in the soil has also made a contribution. The reduction in the number of tillers is set by the autoregulation of the growth stand, when due to the competition for nutrients, light, water as well as due to other causes, they die back. Each set of the growing conditions has a certain capacity to support a specific number or plants and to produce a certain quantity of dry matter and farm yield. Under the conditions of our closely observed seven-year experiment, 268 plants per 1 m^2 came up on average and by the harvest time an average of 500 ears had been forming. The number of grains in an ear is relatively stable in barley and ranged from 17 to 22, but the mass of 1000 grains was quite high – 45.7 g, with the average yield of 4.55 t/ha. The overtail grain exceeded 90%.

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Tvorba výnosu jarního ječmene v ekologickém zemědělství.

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V patnáctiletém pokusu s 21 evropskými odrůdami jarního ječmene v ekologickém zemědělství vedeném v úrodné oblasti se hodnotila variabilita výnosu, stabilita obsahu základních živin, dynamika uvolňování přijatelného dusíku, zvláštnosti tvorby výnosu a jeho struktura. V dlouhodobém pokuse se ukázalo, že současné odrůdy jsou v ekologickém zemědělství výnosově nestabilní při průměrném výnosu 4,47 t, se směrodatnou odchylkou s = 1,27 t/ha a variačním koeficientem 28 %. Ječmen je v těchto podmínkách velmi zranitelný nepříznivými podmínkami počasí, protože se výnos u současných odrůd tvoří počtem plodných odnoží (klasů) na ploše půdy. Tvorba odnoží a jejich diferenciace na plodné a sterilní trvá 80 a více dní, což je otevřené období pro nepříznivé i příznivé působení počasí. Je příčinou velkého kolísání počtu klasů, který je rozhodujícím prvkem konečného výnosu zrna.

Systém ekologického zemědělství vedený podle zásad IFOAM a pokynů MZe ČR udržel dobrou zásobu základních živin P, K a Mg. Nedokázal však v některých letech vlivem počasí dosáhnout takové úrovně mineralizace, která by v počátečních obdobích zajistila dostatek přijatelného dusíku právě pro tvorbu odnoží.

Nízké výnosy byly v letech s abnormálně teplými zimami. Další kolísání výnosů způsobilo sucho v dubnu a nadměrné teplo v květnu. V letech s dobrými výnosy to byl spíše naopak chladný květen. K tomu přispěla i dobrá zásoba minerálního dusíku ($N_{min)}$ v půdě, která podpořila založení vyrovnaných odnoží, a další uvolněný dusík pak pomohl většině z nich přinést klas.

Redukce odnoží je dána autoregulací porostu, kdy vlivem konkurence o živiny, světlo a o vodu a z dalších jiných příčin dochází k jejich odumření. Každé pěstitelské podmínky mají určitou kapacitu k udržení určitého počtu rostlin a k vyprodukování určitého množství sušiny, počtu plodných odnoží-klasů a zrn na plošnou jednotku. V podmínkách našeho sedmiletého sledování formování výnosu vzešlo průměrně 268 rostlin na 1 m² a do sklizně se vytvořilo průměrně okolo 500 klasů. Počet obilek v klasu byl stabilní, průměr 21, ale hmotnost tisíce zrn dosáhla hodnoty 45,7 g. Podíl předního zrna (na sítech) byl přes 90 %.

ekologické zemědělství; jarní ječmen; tvorba výnosu; struktura výnosu; přijatelný dusík

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