YIELD FORMATION IN WINTER WHEAT (*TRITICUM AESTIVUM* L.) IN ECOLOGICAL AGRICULTURE*

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This contribution presents the results of the formation of yield elements in winter wheat (*Triticum aestivum* L.) grown in ecological agriculture. Two cultivars of winter wheat, EBI and ESTICA , were grown in stands of different densities (with 250 and 500 seeds sown per 1 m^2 respectively) and in two periods of sowing (September and October). In the vegetative period there was a loss of plants during the period of sowing and germination of about 20% and with the higher sowing rates of up to 30%. With late sowing, 45 to 55% plants were lost during germination. Overwintering was worse in the stands that had been sown later, due to insufficient cold resistance. Tests for existing frost resistance in both years showed higher values of frost resistance at denser sowing rates. It has not been demonstrated that frost resistance under the conditions of ecological agriculture is worse. The yields were higher with early sowing in the second half of September. The sowing rate of 250 seeds per 1 m^2 was insufficient, the optimum rate would have been 400 seeds. In each ear up to 35 caryopsis with a mass of 1.65 g can be formed and the mass of 1000 grains should be high; in our experiment it was 47.2 g. In the described experiment this structure of the yield components brought an average yield of 6.56 tonnes per hectare. The hypothesis that a yield in ecological agriculture is formed by the ear productivity has been confirmed. This is also associated with the release of acceptable nitrogen in the soil.

ecological agriculture; wheat; yield components; structure of yield

INTRODUCTION

Ecological agriculture has been greatly expanding in recent years. Its methods of farming are being adopted by increasing numbers of farmers and with this the biofoods production is growing to satisfy the great demand. In 2007 there were 1318 ecological farms in the Czech Republic and their area has reached almost 7% of agricultural land. However, in the international market for biofoods the offer is unbalanced, with an unsatisfied demand for ecologically grown cereals.

Since 1993 the Czech University of Life Sciences in Prague is engaged in the research of ecological growing of cereals with the focus on the suitability of cultivars for ecological agriculture and on agricultural technology and quality of production (Petr, Škeřík, 1999; Petr, 2006). It has been confirmed that results are dependent on the entire system of farming, particularly on the pre-crops, release of nutrients, especially nitrogen during the vegetative period, and the flow of organic matter into the soil. Apart from the weather, all these influence the yield and its structure.

The actual formation in cereals yield is a dynamic process, which starts with the establishment of the crop stand, organisation of the stand, nutrients and treatment of the stand.

A specific feature of the ecological method of growing is the supply of nutrients, which is based on nutrients from organic fertilizers and, if necessary, from permitted natural mineral resources. Regulation of weeds, diseases and pests utilizes non-chemical methods which are based on integrated methods of the comprehensive growing system.

The essential yield elements are as follows:

1. the number of ears per area unit, which is given by the number of plants, and productive tillering, i.e. the number of fertile stems
2. the number of grains in the ear, which depends on the number of established spikelets and fertile florets
3. the mass of caryopsis (the mass of 1000 grains)

Each of these elements has during the period of formation – growth a point at which it reaches its maximum level and then its die-off or reduction occurs (see Fig. 1). The values of maximum levels represent potential possibilites of plants and the crop stand. The reduction of yield elements is caused by a range of factors, which is just as broad as the one involved in their creation. The whole process begins with the sowing of a particular number of germinable caryopsis. At the time of germination the number of plants has already been reduced, while in the winter cultivars the number of plants gets reduced during winter, and then, during the vegetation period, the number is further reduced by the effect of the weeds competition, diseases, pests, application of pesticides and mechanical treatment of the stands. The overall reduction can reach up to 50% or even more of the initially germinated plants.

Another yield element is tillering, formation of side stems, and during the harvest also the number of the fertile tillers – ears. There is, again, an important dependence on the weather (rainfall frequency), dynamics of released nutrients, which together with other factors, form but also reduce, the number of tillers, of which only some will produce ears.

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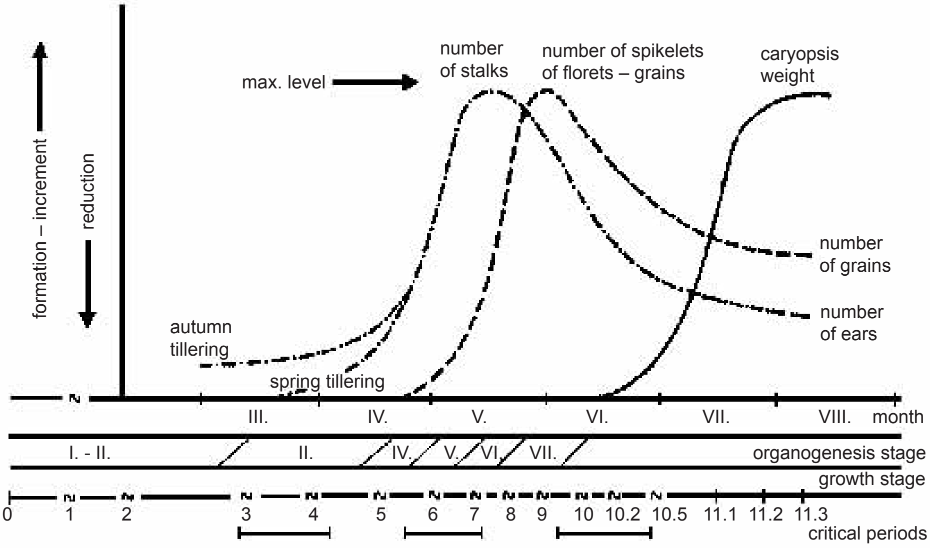

Fig. 1. Dynamics of the yield components formation in cereals

Establishment of ear productivity commences in the growth point (shoot apex), which is located in the sheath of the leaf where the bases of the spikelets and florets are formed. They represent potential productivity. However, before the harvest the number of generative organs is reduced due to the influence of a variety of factors and stresses, such those of the weather, lack of moisture and nutrients, attack by diseases and pests, but also by the influence of the interstem and interplant competition. This reduction varies between individual years and can range from 20 to 60% (P e t r et al., 1980). The mass of caryopsis is a more stable harvest element, but just like the other yield elements it depends on the conditions during the formation of caryopsis and on the structure of the crop stand. This is a demonstration of the law of compensation of the yield elements, where in the thin crop stands or in those with low numbers of ears, or low numbers of grain in the ear, the mass of caryopsis is increased and *vice versa*.

In ecological gowing the level of each element and also the final yield is a reflection of the production potential of the given condition (P e t r, D l o u h ý, 1992). In this study the process of the yield formation was observed in an independent experiment and was supplemented by an evaluation of long term varietal experiments under identical conditions. We studied the hypothesis that the yield of wheat (and probably of other cereals as well) in ecological growing is formed by the productivity of ear.

MATERIAL AND METHODS

We carried out experiments with the cultivars of winter wheat, Estica and Ebi, under the conditions of certified and checked Research Station for Ecological Agriculture, the Czech University of Life Sciences Prague, in Uhříněves (in accordance with the Act 242/2000 Coll. and EHS 2092/91), using two dates of sowing (late and early) and two standards of sowing rates (250 and 500 germinating grains per 1 m^2). The research station is located in a fertile area with brown soil on loess with deep arable soils and neutral pH. The production potential of the soils is relatively high at 84 points. Clover was used as a pre-crop in both years.

ESTICA is a late variety of the C quality group. EBI is a late variety of the A baking quality. The date of sowing in the first year was 14. 9. 2000 for the first period and 13. 10. 2000 for the second, with the sowing rate for both varieties being to same**.**

In the second experimental year the first date of sowing was 30. 9. and the second one was on 31. 10. 2001. The arrangement of the experiment was by randomised blocks (split plot) in three replicates. During the vegetation the following elements of the yield were observed: number of plants, number of ears, number and mass of grains in the ear. The weather is shown in Figs 2 and 3.

Determination of the up to date frost resistance is based on the sampling of plants, including the roots from the field conditions, with minimum damage to the root system. 100 plants were taken for evaluation. The plants were exposed to gradual low temperatures in freezing boxes for a period of three days. They were then replanted into a glasshouse with a constant temperature and air humidity. Under these conditions the plants restart their growth for a period of 21 days. Plants that die are counted and the lethal temperature (LT_{50}) at which 50% of the sampled plants die, is determined. This temperature represents the frost resistance up to date.

Apart from the above described experiment, the structure of yield was also observed in long term experiments in ecological agriculture using the same method, and the same winter wheat varieties and seeds as those in the state experiments of the National Office for Varieties of the Czech Republic. These experiments tested varieties suitable for ecological agriculture.

Every year a collection of 30 varieties has been tested resistance, yield structure, yield and grain quality (Table 6).

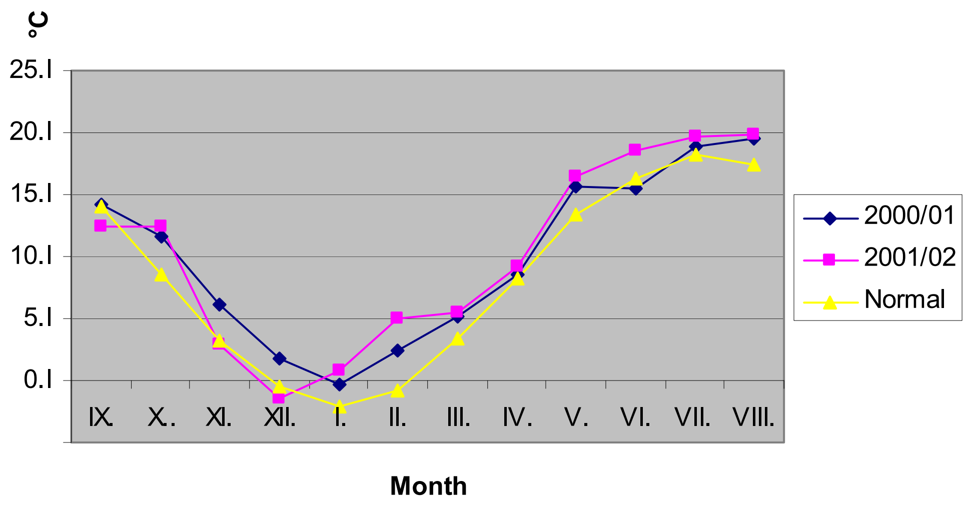

Fig. 2. Average monthly temperatures in the years of 2001 and 2002

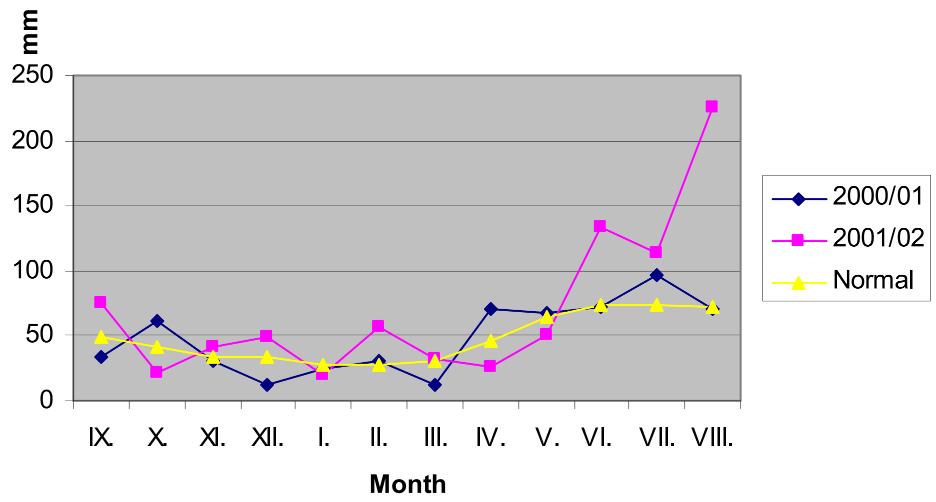

Fig. 3. Total monthly precipitation in the years of 2001 and 2002 (mm)

RESULTS AND DISCUSSION

As stated previously, during the years of 2000–2002, the formation of yield in the EBI and ESTICA varieties was observed at lower and higher sowing rates (250 and 500 caryopsis per m^2), with early and late periods of sowing.

Evaluation of the yield structure begins with determination of the number of germinated a overwintered plants. Tables 3 and 4 show the plant numbers that correspond with the aims of lower and higher rates of sowing (even though it is not always possible to obtain exact sowing rates). During the sowing-germinating period the number of plants is reduced and the reduction amounts to about 20%. This corresponds with our previous measurements and data from practical experience, when the plants number was reduced by about 10–20% (Petr et al. 1980). In ecological cultivation the farming system itself could reduce the germination by not using seed dressing to protect it against diseases. When using pre-crops, the influence of their exudates which can affect the reduction of the plant numbers not only during germination should also be considered. In our case, clover was present in both years and its possible influence in this direction has been mentioned by Černý et al. (1982).

At higher sowing rates the reduction in plant numbers during the sowing-germination period was higher and reached as much as 30%. A mutual competition of germinating caryopsis could have taken place here. This concerns mainly competition for water. A larger reduction in plant numbers germinating after later sowing, when about 45–55% of plants were lost, has been confirmed. This was given by worse conditions for the germination and emergence in late autumn, particularly due to lower temperatures and unfavourable water and air regimes of the soil. However, it was precisely the higher sowing rate at the delayed sowing time, which softened the impact of these conditions on the final yield. Despite the large reduction in the plants number there were 74 more plants in the spring, and 66 more plants by the harvest time. Stöppler (1989, cit. Šarapatka, Urban et al., 2006) observed in ecological method of cultivation the influence of the sowing rates and time of sowing on the number of plants, number of ears and number of grains in a ear in relation to the yield. His results are in agreement with the data shown in Tables 2 and 3. Similarly, Ozturk et al. (2006) who observed the influence of the time of sowing with different sowing rates have reached the same conclusions.

Table 1. Agrochemical analysis of soils

Sampling Nutrients reserves	P mg/kg In words*	K mg/kg In words	Ca mg/kg In words	Mg mg/kg In words	pH/KCL In words
Ecological area Autumn 2000	108 good	255 good	3100 good	149 satisfactory	6.7 neutral
Ecological area Autumn 2001	105 good	192 good	3015 good	150 satisfactory	6.8 neutral
Ecological area Autumn 2002	99 good	222 good	3110 good	145 satisfactory	6.8 neutral
Intensive area Average for three years	102 good	213 good	3100 good	134 satisfactory	6.76 neutral

*By Mehlich III. medium arable soil

Table 2. Mineral nitrogen in soil (N_{min}) and total contents of N

N_{min} content in the spring, mg/ kg soil into the depth of	0–30 cm	30–60 cm	Total N kg/ha 30–60 cm
Ecological area 2001	19.10	7.85	86
Ecological area 2002	17.20	9.75	78
Intensive area, average for 3 years	17.36	7.89	78

Table 3. Yield structure of winter wheat grown in ecological manner in 2001

Variety	Sowing rate time/sowing•	Number plants/m^2 autumn/spring/harvest			Number of ears/m^2	Mass in g of grain in ear	Number of grains in ear	Thousand grains weight g	Yield t/ha
Ebi	lower/I.	310	238	190	436	1.0	19	53.2	4.69*
Ebi	higer/I.	566	328	226	462	1.2	23	52.5	5.29*
Ebi	lower/II.	336	190	172	475	0.9	17	52.3	4.12*
Ebi	higher/II.	572	334	311	570	0.9	18	51.1	5.21*
Estica	lower/I.	322	189	139	393	1.0	20	52.2	4.05^x
Estica	higher/I.	504	208	157	469	0.9	17	51.5	4.22^x
Estica	lower/II.	314	238	152	435	1.0	20	54.2	4.60^x
Estica	higher/II.	500	322	224	517	0.9	17	52.6	4.72^x

• I. Sown on 14. 9. 2000, II. Sown on 13. 10. 2000
* Ebi *P* 0.05 sig. diff. from lower and higher sowing rate, not sig. diff. from I. and II. sowing time
^{x} Estica sig. diff. *P* 0.05 not from lower and higher sowing rate but sig. diff. from sowing time

Table 4. Yield structure of winter wheat grown in ecological manner in 2002

Variety	Sowing rate Date/sowing•	Number plants/m^2		Number of ears/m^2	Mass in g of grain in ear	Number of grains in ear	Thousand grains weight g	Yield t/ha
		autumn	spring					
Ebi	lower/I.	271	216	498	1.1	26	41.8	5.46*
Ebi	higher/I.	417	326	575	0.7	15	46.3	6.73*
Ebi	lower/II.	0	181	472	0.9	22	40.4	4.28*
Ebi	higher/II.	0	183	495	1.2	28	44.4	6.22*
Estica	lower/I.	157	231	539	1.1	27	42.2	6.12^x
Estica	higher/I.	432	303	541	1.3	29	43.1	6.88^x
Estica	lower/II.	0	119	349	1.2	29	41.2	4.13^x
Estica	higher/II.	0	299	466	1.3	30	44.3	6.29^x

• I. Sown on 30. 9. 2001, II. Sown on 31. 10. 2001
* Ebi *P* 0.05 sig. diff. from lower and higher sowing rate, and sig. diff. from I. and II. sowing time
^{x} Estica sig. diff. *P* 0.05 from lower and higher sowing rate, and sig. diff. from sowing time

Another period during which plants are lost is overwintering. The reduction varies according to the variety and mainly according to the weather during winter. In our experiments the loss of plants differed also in dependence on the time of sowing and sowing rates. Overwintering was poorer in late sowing, which can be explained by a low level of hardening and a low content of reserves. In 2000/2001 the winter was mild, warm, and they did not acquire much cold resistance. During the next season there were only mild frosts and the crop stands were not damaged. However, the crops stands from late sowings which germinated in the spring were damaged. The winter of 2002/2003 was so unfavourable that the experiments were cancelled due to severe damage.

We had also observed the values of up to date frost resistance which was determined in our samples by Prasilova of the Research Institute of Plant Production in Prague-Ruzyně. The results are shown in Table 5.

The results show that the plants from denser sowing rates achieved higher values of up to date frost resistance than those from the thinner crop stands. The plants from ecological cultivation had only inconclusively lower values of up to date frost resistance than the control plants. It is therefore not possible to prove the difference in the frost resistance of plants from ecological and conventional cultivation. The Ebi variety had higher values of up to date frost resistance.

The results from both experimental years show higher yields for early sowings in the second half of September. Likewise, higher yields were obtained with higher sowing rates in both years. It must also be emphasised that by the harvest time the numbers of plants had been drawn closer together due to the different reductions in both sowing periods. This would suggest that the ecological agricultural system can carry only a certain number of plants per unit of area. Based on long-term varietal experiments, this would correspond to about 270 plants per m^2 in the spring. The number of ears ranged from 350 to 450, occasionally up to 500 per m^2. In the long term experiments the number of ears in 30 varieties was more likely to be under 400.

The number of ears is dependent on the dynamics of the release of nitrogen in the soil. Apart form other external factors it influences the formation of tillers. Analyses determined that in 2001 the content of the soil mineral nitrogen – N_{min} to the depth of 30 cm was 19.1 mg/kg of soil, and in 2002 it was 17.8 mg, which is a low to medium level content. It was, therefore, not possible to expect greater tillering even when the stands were thin and would normally have produced more tillers. We must, of course, mention the influence of harrowing of the crop stands, which took place in April and beginning of May of both years three times in total and which, according to Dirauer and Stöppler (1994), leads to the release of nitrogen due to the aeration of soil. Simultaneously, however, the harrowing of the crop stands will also cause a certain reduction in the number of plants, more so in the stands from higher sowing rates. The thin stands, of course, had created conditions for the establishment of a greater number of spikelets, florets and, in the final period also a number or mass of caryopsis (Table 4). The number of ears and the number of grains in an ear and their mass were decisive for the final yield. This would confirm the hypothesis that in ecological agriculture the productivity of the ear is decisive for the yield of cereals.

The yields in both years have had similar regularities. In both varieties the higher sowing rates brought higher yields than the half rates of sowing. There were conclusively higher yields with higher sowing rates (except for the Estica variety in 2001) at the later sowing time. This however does not mean a generalization that it would be more advantageous to sow 500 grains per m^2. The differences between the sowing rates had been too great and they represented a double of the first sowing rates. The reductions in the plant numbers made the two variants in the sowing rates come closer together in the numbers of plants.

Conclusion of long term experiments in ecological agriculture

In the long term experiments in ecological agriculture it proved to be most optimal to sow 400 grains per m^2. This is supported by the results of Bicanová et al. (2008), which showed that the sowing rate of 400 grains brought the highest yields. Only when the sowing is late the sowing rate is increased in view of the higher risk of the plants loss. The evaluation of a seven year trial (Table 6) shows that the yield structure from an average of 213 varieties and 650 plots was at 272 plants per m^2 after emergence and 201 plants after overwintering. The average number of ears was 400 per m^2 and in each ear there were 35 caryopsis with the mass of 1.65 g. Thousand grains weight was high at 47.2 g. This structure brought yield of 6.56 tonnes per hectare on average in the described experiment. The attained yield and its structure are significantly influenced by pre-crops and the resulting quantity of the nitrogen released from the soil. The greatest quantity of mineral nitrogen is culminating during the period of the formation of the generative organs, as shown in Fig. 4.

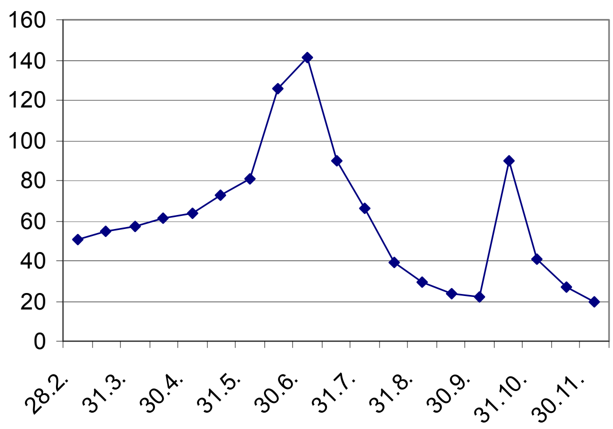

Fig. 4. The quantity of mineral nitrogen (N_{min} kg/hectar) in the soil during the vegetation period

Table 5. Critical temperatures of up to date frost resistance during experimental years

Variety/Variant Critical temperature	January 2001 LT_{50} °C	January 2002 LT_{50} °C	March 2002 LT_{50} °C
EBI higher sowing rate *Control	–12.5	–11.0	–8.5
EBI higher sowing rate EKO	–12.3	–10.9	–4.9
EBI lower sowing rate *Control	–11.2	–9.6	–4.2
EBI lower sowing rate ECO	–10.9	–9.6	–4.3
ESTICA higher sowing rate *Control	–11.4	–10.5	–6.8
ESTICA higher sowing rate ECO	–11.2	–10.2	–4.9
ESTICA lower sowing rate *Control	–10.8	–9.9	–4.2
ESTICA higher sowing rate ECO	–10.6	–9.9	–4.7

* The control was grown in a conventional area

Table 6. Structure of the yield in a seven-year experiment with winter wheat in ecological agriculture

Year	Number of varieties	Number of plants/m^2	Ovewintering %	Number of ears/m^2	Number of grains in ear	Mass of grains in ear g	Mass of 1000 grains in g	Yield t/ha
2000	30	359	90	487	38	1.75	45.5	8.55
2001	30	299	71	414	29	1.48	50.7	6.16
2002	32	304	79	500	30	1.30	44.1	6.64
2003	The crop stands were destroyed by the winter conditions of 2002/2003							
2004	27	201	55	323	34	1.82	53.5	5.91
2005	36	289	90	375	38	1.82	47.8	6.85
2006	29	186	50	335	35	1.58	45.1	5.30
2007	35	267	85	368	40	1.78	43.9	6.55
Average	31	272	74	400	34.8	1.65	47.2	6.56

Coefficient of variation 17%, standard error 1.06

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Tvorba výnosu ozimé pšenice (*Triticum aestivum* L.) v ekologickém zemědělství.

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Práce přináší výsledky sledování výnosových prvků u ozimé pšenice (*Triticum aestivum* L.) pěstované v ekologickém zemědělství. Dvě odrůdy pšenice ozimé EBI a ESTICA byly pěstovány při různé hustotě porostu (množství výsevu 250 a 500 obilek na 1 m²) a ve dvou dobách setí (v září a v říjnu). Pokusy byly vedeny podle zásad IFOAM na úrodné půdě certifikované Pokusné stanice pro ekologické zemědělství podle vyhlášky 242/2000 Sb. České republiky.

Během vegetace docházelo k úbytku rostlin v období setí-vzcházení o 20 %, u vyšších výsevků až o 30 %. Při pozdním setí ubylo 45 až 55 % rostlin během vzcházení. Na tom se nejvíce podílelo nepříznivé počasí pro vzcházení, vliv patogenů (osivo se v ekologickém zemědělství nemoří), mezirostlinná konkurence, případně vliv exudátů po předplodině (jeteli lučním).

Úbytek rostlin během zimy byl způsoben hlavně počasím. Přezimování bylo horší u porostů pozdě vysetých, pro nedostatečné otužení. Zkoušky na aktuální mrazuvzdornost (LT_{50}) v obou letech prokázaly vyšší hodnoty mrazuvzdornosti u hustších výsevů. Rozdíly u ekologicky pěstovaných a konvenčních variant byly malé, neprůkazné, takže se neprokázalo, že v ekologickém pěstování je horší mrazuvzdornost.

Výnosy byly vyšší při časném setí v druhé polovině září. Množství výsevu by mělo být vyšší než 250 obilek na 1 m². Z našich odrůdových pokusů vyplývá, že by mělo tvořit 400 obilek. Na jaře by mělo být minimálně 200 rostlin a ve sklizni 400 klasů na 1 m². V každém klasu pak 35 obilek s hmotností 1,65 g a hmotnost tisíce obilek by měla být vysoká – v našem pokusu byla 47,2 g. Tato struktura přinesla v průměru uvedeného pokusu výnos 6,56 tun na hektar. Potvrdila se pravdivost hypotézy, že u pšenice v ekologickém zemědělství se výnos tvoří produktivitou klasu.Významný vliv na struktura výnosu a celkový výnos měla dynamika uvolňování přijatelného dusíku z půdy, které vrcholí právě v období formování generativních orgánů.

ekologické zemědělství; pšenice; výnosové prvky; struktura výnosu

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