Spring barley stand structure as an indicator of lodging risk

Pavel MATUŠINSKY, Ilona SVOBODOVÁ, Petr MÍŠA

Agrotest Fyto, Ltd
Havlíčkova 2787, 767 01 Kroměříž, Czech Republic
E-mail: matusinsky@vukrom.cz

Abstract

Field experiments were performed in Kroměříž, Czech Republic in 2012–2014 and evaluated for spring barley comprising treatments which different sowing rates and nitrogen fertilization rates. The objective of this study was to determine parameters of stand structure in early (BBCH 39) growth stages of barley that would enable evaluation of lodging risk. Lodging was significantly affected by both year and nitrogen fertilization rate. Increased nitrogen fertilization rates demonstrably increased lodging. Higher fertilization rates manifested in increased tiller biomass weight, greater plant height, and smaller roots. Similarly, the protein content of harvested grain was strongly affected by year and nitrogen application rate. Higher fertilization rates also resulted in grain with higher protein content. Sowing density did not affect either lodging level or protein content. Yields were affected only by year. Increased tiller biomass weight and increased plant height during early growth stages are significant indicators of lodging risk. Correlation between lodging and tiller biomass and plant height was higher than 0.5 and statistically significant ($P = 0.000$).

Key words: agronomic practices, *Hordeum vulgare*, nitrogen fertilization, plant density.

Introduction

Barley (*Hordeum vulgare* L.) is the fourth most important cereal crop in the world after wheat, maize, and rice. It is an important crop for direct human consumption as well as for animal fodder. It is an important raw material for producing beer and other products. Barley grain yields and quality can be diminished not only by such biotic and abiotic harmful agents as fungal diseases, low temperatures, and drought, but also as a result of lodging. Lodging occurs in barley when the plant stem is unable to support its own weight. Lodging is often associated with yield loss (Pinthus, 1974). Early lodging can increase moisture in the plant canopy, which adds to the risk of fungal diseases. Early lodging in barley causes the greatest reduction in grain yield potential compared to lodging at later growth stages but also allows higher potential for physical recovery from that lodging (Briggs, 1990). The level of yield loss depends on cultivar, growth stage, and lodging severity (Jedel, Helm, 1991). High levels of soil nitrogen make barley more prone to lodging by inducing more fine-stemmed tillers, taller growth, greater numbers of grain, and reduced straw strength. Such weather conditions as strong wind or thunderstorm can cause lodging even under good crop management conditions with optimal fertilization and stand density. Two forms of lodging in cereals are known, the first caused by stem fragility and the second by poor root development – thus indicating those factors needing to be adjusted (Ennos, 1991). Plant breeders, have reduced lodging risk by introducing dwarfing genes to produce shorter varieties (Chen et al., 2013; Kuczyńska et al., 2013; Ren et al., 2014) and by increasing stem strength (Ma, 2009), e.g., by higher starch accumulation (Kashiwagi et al., 2006). Structural carbohydrates (cellulose and lignin) should also play an important role for stem strength (Ma, 2009). Farmers employ a range of methods to reduce lodging, the most common of which is the use of plant growth regulators to shorten stems. Other lodging-preventing methods that are less commonly used include reducing seed rate, delaying sowing, reducing and delaying nitrogen application, and rolling the soil (Scott et al., 2005; Berry et al., 2007).

The objective of this study was to determine parameters of stand structure in early (BBCH 39) growth stages of barley that would enable evaluation of lodging risk. Determination of significant indicators of lodging risk appropriate for diagnostic of stand structure parameters could be important part of a decision support system of barley growing strategies. Early decision support system based on relatively cheap measurement of stand parameters could prevent among others fungal infection of cereal heads.

Material and methods

Field experiment. Field experiments were performed in Kroměříž, Czech Republic in 2012–2014 and evaluated for spring barley comprising treatments which different sowing rates and nitrogen fertilization rates. A small-plot field experiment with a plot size of 10m² was established using the variety 'Bojos', which is less resistant to lodging. The preceding crop was winter wheat. Sowing rates of 2.5, 3.5 and 4.5 million germinable seeds (MGS) ha⁻¹ were selected. Each sowing rate included three levels of nitrogen fertilization: 0, 45 and 95 kg ha⁻¹ N. These

combinations thus encompassed a total of nine treatments. Fertilization was prior to sowing and using ammonium nitrate with limestone. The combination of different rates of sowing and nitrogen fertilization created the conditions for establishing various morphological and anatomical stem types (different stem types in terms of height and strength) and stand density in individual treatments. Experiments were set up in Kroměříž, Czech Republic (49°17′ N, 17°22′ E, 235 m a.s.l.), which is a beet-growing area. Soil type is *Luvic Chernozem* (classification: silt earth), mean annual temperature is 9.2°C, and mean annual rainfall is 576 mm.

Sampling and assessment. Productive tillers were counted during the stage of flag leaf ligule emergence (BBCH 39). Fresh weight and dry weight were determined separately for productive and non-productive tillers as was stand height. Productive tillers' proportion of dry weight was determined, and the fresh weight and dry weight of one productive tiller were calculated. Prior to harvest, the number of ears per m^2 was determined. At full maturity, grain yield, 1,000 kernel weight, and grain protein content were determined. Stand lodging was evaluated using European and Mediterranean Plant Protection Organization standard PP 1/144(3). For each plot, the percentage size of the area lodged and lodging intensity as the stem's divergence from vertical in tens of degrees were determined. The lodging index was acquired by multiplying these values and dividing them by 100.

Statistical analysis. Software *STATISTICA* was used for statistical processing. Analysis of variance was carried out based on differences among measured parameters. Similar results were obtained using log10 transformation, and data are therefore displayed untransformed. The relationship between the lodging index and monitored stand characteristics was evaluated by correlation coefficient as calculated in *STATISTICA*.
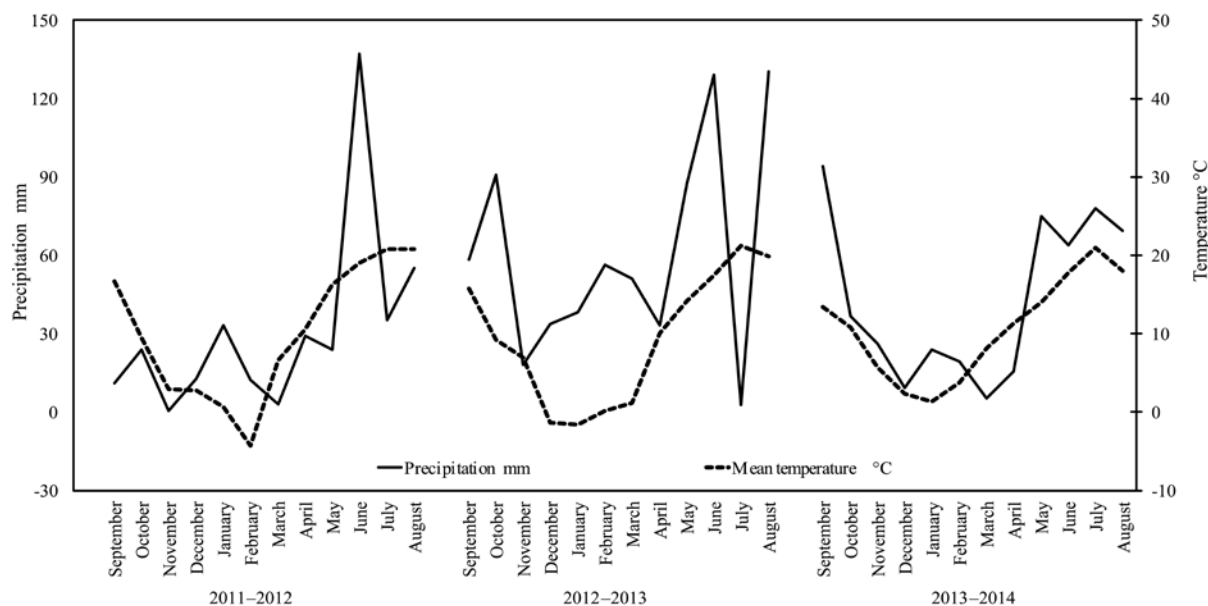
Results and discussion

Lodging resistance in cereals is determined by both genetic and environmental factors (Verma et al.,

2005). Many authors have observed that lodging resistance of barley is affected by the physical and morphological properties of the stem (Chen et al., 2014). Another important factor affecting lodging resistance is stand structure. In the present study, important stand structure parameters were determined, their dependence on experimental factors ascertained, and their relationships with lodging examined. The morphological, physical, and chemical characteristics of stems have been studied by a number of authors in connection with wheat and barley varieties' lodging resistance (Zuber et al., 1999; Berry et al., 2000; 2003; Jeżowski et al., 2000). Various methods have been used to artificially induce lodging, such as dragging weights across the land (Navabi et al., 2006) and using an aerodynamic tunnel (Sterling et al., 2003). Instruments have been developed to measure stem resistance to lateral pressure simulating blasts of wind and rain (Berry et al., 2003). In this study, we analysed field trials under natural conditions without any artificial wind or rain.

In the present study, year was the factor having the largest effect on individual monitored parameters. Year substantially affected the number of ears as well as the number of productive and unproductive tillers and their fresh and dry weights. Year also had a significant effect on lodging, yield, 1,000 kernel weight and protein content (Tables 1–4). The only parameter not affected by year was plant height. The humidity and temperature conditions during 2011–2014 are shown in a climate diagram according to Walter and Lieth (1967) (Fig. 1). The ratio of total precipitation per month to mean monthly temperatures in the climate diagram for Central Europe and the Czech Republic is 3:1. Times when the precipitation curve fell below the temperature curve indicate periods of drought, and vice versa. The climate diagram shows that barley growing season in 2012 was predominantly dry, while in 2014 it was predominantly wet.

Precipitation in June 2012 supported the growth of weak secondary tillers. Some developed productive ears, but these were short with few kernels. The number of productive tillers estimated at BBCH 39 was therefore

Figure 1. Climate diagram for 2011–2014 at Kroměříž, Czech Republic

lower than was the number of ears actually formed. July 2012 was a very hot and dry month, with 48% of the long-term mean precipitation. Treatments with higher nitrogen fertilization rates displayed uneven maturation. There were several storms during June and July, but they did not include both strong wind and heavy precipitation, which otherwise could have caused stand lodging. There was therefore no stand lodging in any treatment in 2012. The most ears, highest yield, and highest protein content were determined in 2012 in comparison to 2013 and 2014 (Tables 1–4).

Table 1. Analysis of variance and Tukey's test ($P < 0.05$) for plant height, number of ears, number of productive tillers and fresh weight of productive tillers at various levels of experimental factors

Factor	Factor level	Plant height			Number of ears			Number of productive tillers			Fresh weight of productive tillers		
		mean cm	*F*-stat	*p*-value	mean	*F*-stat	*p*-value	mean	*F*-stat	*p*-value	mean g	*F*-stat	*p*-value
Year	2012	57.68 a			1077.69 c			765.33 a			2494.79 a		
	2013	56.25 a	1.847	0.1629	709.56 a	50.318	0.0000	844.44 a	19.477	0.0000	3632.22 b	42.374	0.0000
	2014	59.10 a			947.72 b			1014.67 b			4264.11 c		
N level	0	50.50 a			832.00 a			793.33 a			2920.08 a		
	45	59.94 b	114.740	0.0000	915.64 ab	4.806	0.0101	892.00 ab	5.305	0.0064	3519.79 b	9.098	0.0002
	90	62.58 c			987.33 b			939.11 b			3951.25 b		
MGS	2.5	57.42 a			894.28 a			887.56 a			3444.78 a		
	3.5	57.58 a	0.087	0.9170	898.00 a	0.533	0.5884	864.44 a	0.12	0.8872	3442.27 a	0.035	0.9653
	4.5	58.03 a			942.69 a			872.44 a			3504.08 a		

Nitrogen level = kg ha^{-1} N; MGS – sowing rate at million germinable seeds; N = 36

Table 2. Analysis of variance and Tukey's test ($P < 0.05$) for dry weight of productive tillers, fresh and dry weight of nonproductive tillers and productive tillers' proportion of dry weight at various levels of experimental factors

Factor	Factor level	Dry weight of productive tillers			Fresh weight of nonproductive tillers			Dry weight of nonproductive tillers			Productive tillers' proportion of dry weight		
		mean g	*F*-stat	*p*-value	mean g	*F*-stat	*p*-value	mean %	*F*-stat	*p*-value	mean g	*F*-stat	*p*-value
Year	2012	433.91 a			411.92 b			63.96 c			17.37 b		
	2013	489.18 a	164.839	0.0000	441.28 b	17.863	0.0000	53.57 b	34.81	0.0000	13.52 a	303.53	0.0000
	2014	886.61 b			291.24 a			36.35 a			21.41 c		
N level	0	551.01 a			335.28 a			47.78 a			18.65 c		
	45	611.43 a	1.557	0.2156	376.17 ab	5.767	0.0043	50.41 a	1.79	0.1724	17.25 b	25.03	0.0000
	90	647.26 a			432.99 b			55.69 a			16.41 a		
MGS	2.5	607.00 a			335.94 a			47.30 a			17.82 a		
	3.5	598.10 a	0.0136	0.9865	376.98 ab	5.289	0.0066	49.18 ab	3.27	0.0422	17.35 a	2.40	0.0958
	4.5	604.59 a			431.52 b			57.40 b			17.13 a		

Nitrogen level = kg ha^{-1} N; MGS – sowing rate at million germinable seeds; N = 36

Table 3. Analysis of variance and Tukey's test ($P < 0.05$) for fresh and dry weight of one productive tiller and lodging at various levels of experimental factors

Factor	Factor level	Fresh weight of one productive tiller			Dry weight of one productive tiller			Lodging		
		mean t ha^{-1}	*F*-stat	*p*-value	mean g	*F*-stat	*p*-value	mean %	*F*-stat	*p*-value
Year	2012	3.26 a			0.57 a			0.00 a		
	2013	4.28 b	122.12	0.0000	0.58 b	298.11	0.0000	22.89 b	36.035	0.0000
	2014	4.18 b			0.89 c			34.21 c		
N level	0	3.67 a			0.69 a			4.61 a		
	45	3.92 b	21.51	0.0000	0.67 a	0.84	0.4359	18.79 b	20.662	0.0000
	90	4.14 c			0.67 a			33.69 c		
MGS	2.5	3.85 a			0.68 a			17.35 a		
	3.5	3.93 a	0.91	0.4070	0.68 a	0.41	0.6633	17.18 a	0.661	0.5184
	4.5	3.94 a			0.67 a			22.57 a		

Nitrogen level = kg ha^{-1} N; MGS – sowing rate at million germinable seeds; N = 36

Table 4. Analysis of variance and Tukey's test ($P < 0.05$) for yield, 1,000 kernel weight and protein content at various levels of experimental factors

Factor	Factor level	Yield			1,000 kernel weight			Protein content		
		mean t ha^{-1}	*F*-stat	*p*-value	mean g	*F*-stat	*p*-value	mean %	*F*-stat	*p*-value
Year	2012	6.73 b			44.79 a			13.69 c		
	2013	5.94 a	16.72	0.0000	49.60 b	94.840	0.0000	13.02 b	48.081	0.0000
	2014	6.65 b			50.06 b			11.70 a		
N level	0	6.19 a			49.01 b			12.04 a		
	45	6.61 a	1.383	0.1377	48.19 ab	8.691	0.0019	12.76 b	28.870	0.0000
	90	6.52 a			47.25 a			13.61 c		
MGS	2.5	6.42 a			48.91 b			12.62 a		
	3.5	6.36 a	0.589	0.5566	48.08 ab	5.962	0.0093	12.93 a	1.231	0.3134
	4.5	6.54 a			47.46 a			12.86 a		

Nitrogen level = kg ha^{-1} N; MGS – sowing rate at million germinable seeds
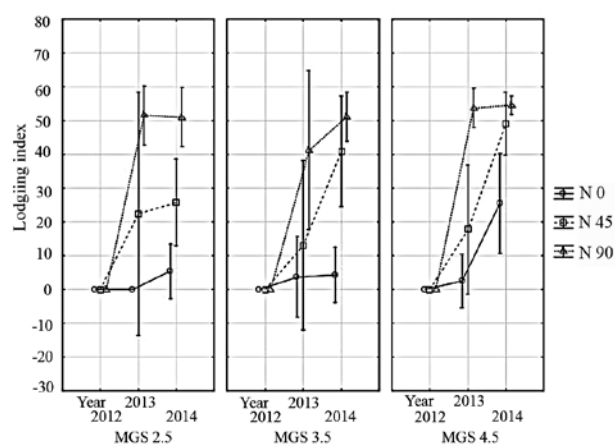
In 2013, a cold March caused a delay in sowing. Snow still covered the fields at the beginning of April. At the time of stem elongation, the cold and rainy weather supported rapid growth of plant matter with not very strong stem walls and shallow, thin roots. Root lodging occurred on 23 and 24 June 2013 during intense, short rainfall. According to data from a meteorological station 800 m distant, between 20 and 24 June 2013 there was a total of 65 mm of rainfall and soil humidity at 10 cm reached 31.9%. At that time, plants were in BBCH 71 stage when the first grains had reached their final size and grain content was watery. Stem lodging did not occur. In the following period, stems rose through growth from one side of their nodes. In mid-July, the plants were still milky ripe as a result of the delayed sowing. July 2013 was extraordinarily dry with rainfall of only 2.7 mm, i.e. 4% of the long-term mean, and was also very hot. Grains withered away in a number of ears, and so the actual number of ears was lower than the number of productive tillers. Drying occurred mainly with weak productive tillers in the low and medium sowing rate treatments (the most drying occurred at the sowing rate of 2.5 MGS ha^{-1} with no N application and the sowing rate of 3.5 MGS ha^{-1} with 90 kg ha^{-1} N). Dry and hot weather in the second half of July accelerated grain ripening. The lowest number of ears and lowest grain yields over the entire experiment were measured in 2013.

The winter of 2013–2014 was mild, and above-average temperatures in March along with little rainfall enabled early sowing. A longer germination period was caused by dry weather, as rainfall in March 2014 was 16% of the long-term mean. During tillering in April, rainfall was low and evenly distributed, which supported root system growth. Higher rainfall in May along with lower temperatures during stem elongation enabled rapid growth of plant matter with not very strong stem walls and decreased tiller reduction. There were many productive stems. In lower density stands, particularly those with a sowing rate of 2.5 MGS ha^{-1}, additional productive tillers were produced. Grain initially formed under advantageous temperature and humidity conditions, and despite predominantly dry and hot weather during 11–20 July 2014 grain weight and therefore yield remained at a relatively good level. Lodging occurred as milky ripe became waxy ripe on 29 June 2014 during storms with heavy rain accompanied by wind. In the following period, the stems rose through growth from one side of the node at the uppermost internode below the ear. Grain ripened early during above-average temperatures in July 2014. The highest lodging level and lowest grain protein content over the entire experiment were measured in 2014.

Another factor substantially affecting the monitored stand parameters in our experiment was nitrogen fertilization level. Previous studies have shown that high N application leads to thinner stems and significant increases in lodging of wheat (Kong et al., 2014) and rice (Yang et al., 2009). Although the content of cellulose or lignin is related to stem rigidity (Taylor et al., 1999; Jones et al., 2001), the relationship between cellulose or lignin content and lodging resistance has not been clear. Stalk strength in previous work with maize significantly negatively correlates with lodging observed in the field (Hu et al., 2012). Application of abundant nitrogen at the ripening stage increases the accumulation of carbohydrates in stems and improves lodging resistance, but it also reduces cellulose content (Matsuzaki et al., 1972). By comparing fertilization rates and lodging within our experiment, it was determined that increasing fertilization rates (0, 45 and 90 kg ha^{-1}) demonstrably increased plant height, number of ears, weight of one productive tiller, number and fresh weight of productive tillers, and grain protein content (Fig. 2), but also lodging level (Tables 1–4, Fig. 3). In contrast, productive tillers' proportion of dry weight decreased with increasing fertilization rates.

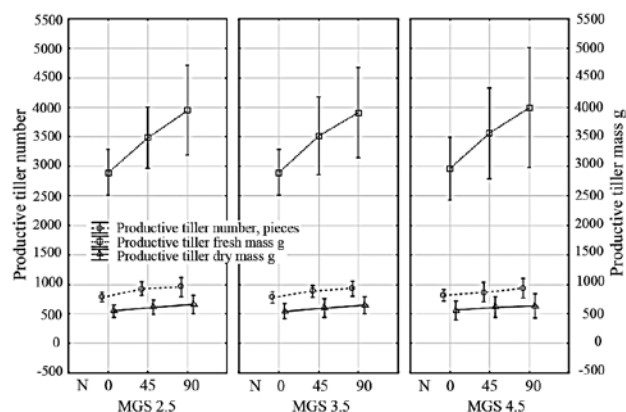***Figure 2.*** Barley grain protein content at various nitrogen fertilization levels (2012–2014)

MGS – sowing rate at million germinable seeds

Figure 3. Spring barley lodging index in various years at various sowing and nitrogen fertilization (kg ha⁻¹) rates

In stems, higher accumulation of starch contributes to greater bending strength (Matsuzaki et al., 1972). Such results suggest that higher contents of carbohydrates accumulated in lower stems might enhance the bending strength of the basal stem and, as a consequence, cause higher lodging resistance. In addition to resistance in stems, roots also are affected by fertilization rates. With increasing sowing rate at fertilization rates 0 and 45 kg ha⁻¹, roots shorten and weaken due to competition and fewer tillers with adventitious roots are produced. The effect of sowing rate is clearly visible for fertilization rate 90 kg ha⁻¹, where for lower sowing rates there is not such competition for resources as there is at higher sowing rates, which therefore result in longer and narrower root bundles. The effect of nitrogen is more noticeable at the lowest sowing rate where plants are further apart and there is therefore less competition for space. Roots were deeper in the treatments without nitrogen fertilization at sowing rates 2.5 and 3.5 MGS ha⁻¹ in comparison to the treatments fertilized with nitrogen. In the absence of fertilization, roots must grow deeper to acquire more nitrogen from the soil. At fertilization rate of 90 kg ha⁻¹ and sowing rates 2.5 and 3.5 MGS ha⁻¹, sufficient nitrogen and little competition among plants meant roots did not need to grow deeper, and therefore roots in the bundles were shallow. At the highest sowing rate, differences in root density were not visible among fertilization rates; roots were not as deep, but root bundles grew more sparsely and weaker (data not shown). Generally, with increasing fertilization rates roots shortened and weakened and root bundles narrowed, while with increasing sowing rates root bundles grew more sparsely and narrower and roots weakened. Crook and Ennos (1994) developed simple equations to investigate lodging phenomena in cereals. These static equations predict a relative degree of susceptibility to anchorage failure and shoot failure, known as root and shoot lodging, respectively. According to Crook and Ennos (1995), lodging susceptibility in cereals depends on three factors: first, the size and dynamics of the forces to which the plant is subjected; second, the bending strength of the shoot and its

resistance to buckling; and third, the anchorage strength of the root system. The model was adjusted for barley by Berry et al. (2006).

The factor having the smallest effect on monitored parameters in the current study was sowing rate. Sowing rate had a less considerable effect probably due to a stand's compensatory abilities. As sowing rate increased, the number of ears per m² slightly increased, but the values of the remaining characteristics rather decreased. Unproductive tillers increased in weight (Tables 1–4). The number and weight of productive tillers were not affected by sowing rate (Fig. 4).

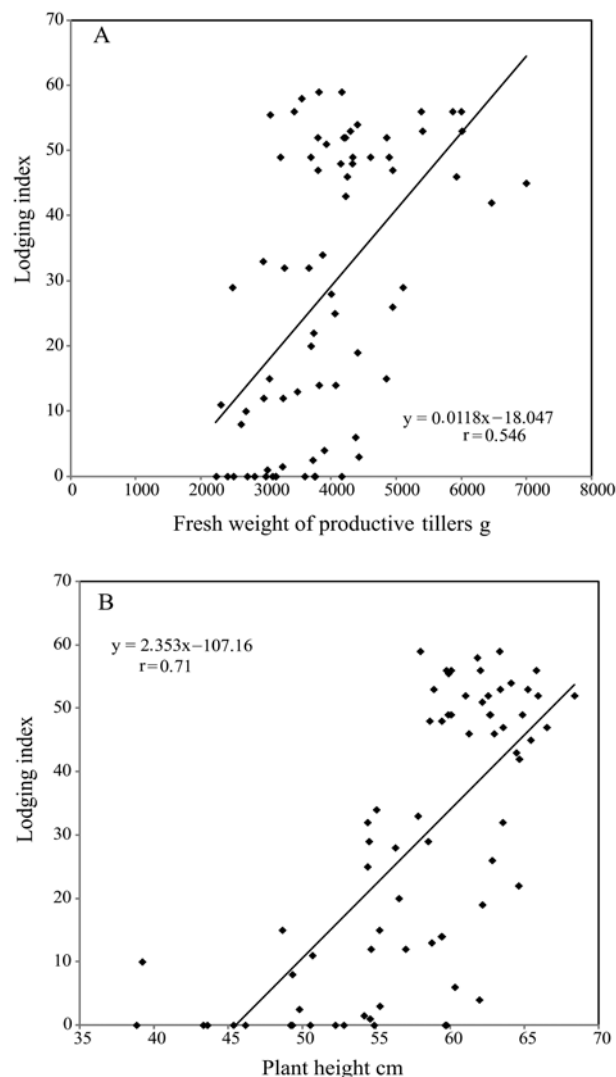MGS – sowing rate at million germinable seeds

Figure 4. Productive tillers of spring barley at various sowing and nitrogen fertilization (kg ha⁻¹) rates (2012–2014)

Correlation coefficients higher than 0.5 were determined between lodging and the parameters plant height, fresh weight of productive tillers, and fresh weight of one productive tiller (Table 5, Fig. 5). No correlation with lodging was determined for the remaining parameters. Plant height was the factor with the highest positive correlation coefficient with lodging index. A similarly high positive correlation coefficient was calculated between lodging and fresh weight of productive tillers. Here, the weight and height of plants' above-ground parts were important for stands' lodging resistance. Taller stands with greater productive tiller weight were discernibly more susceptible to lodging. In evaluating factors that can be affected agro-technically, Tables 1–4 make it clear that these parameters (plant height and fresh weight of productive tillers) are affected by fertilization rates. At higher nitrogen levels, plant height and fresh weight of productive tillers increased. Plant height appears to be the major contributor to lodging tolerance (Chen et al., 2013; Kuczyńska et al., 2013; Ren et al., 2014). In previous study, lodging severity in short-stem varieties was very low and no significant variation was observed for yield and lodging scores while plant height was strongly correlated with lodging scores at all growth stages (Navabi et al., 2006).

Barley variety is an important factor. Jeżowski et al. (2000) found that six-rowed, doubled haploid barley lines were characterized by lower elasticity and shorter stems than were two-rowed lines, and six-rowed

Table 5. Correlation coefficients for lodging and characteristics measured at BBCH 39 stage (2012–2014)

Factor	Correlation coefficient (r)	p-value
Plant height	**0.710**	**0.0000**
Number of ears	0.412	0.0003
Yield	0.135	0.2573
Fresh weight of non-productive tillers	0.167	0.1610
Dry weight of non-productive tillers	0.006	0.9593
Number of productive tillers	0.392	0.0007
Fresh weight of productive tillers	**0.546**	**0.0000**
Dry weight of productive tillers	0.403	0.0004
Productive tillers' proportion of dry weight	−0.002	0.9868
Fresh weight of one productive tiller	**0.564**	**0.0000**
Dry weight of one productive tiller	0.221	0.0619
1,000 kernel weight	0.452	0.0178
Protein content	−0.151	0.4502

Figure 5. Correlation coefficients of lodging and fresh weight of productive tillers (A) and plant height (B) (2012–2014)

lines were more susceptible to lodging. Two- and six-rowed genotypes displayed similar genetic backgrounds of lodging resistance. The effects of additive gene action were important for all morphological and physical stem characteristics, while dominance effects were significant only for stem length and lodging grade (Jeżowski et al., 2000). Previous studies have reported different levels of yield reduction: 21% (Briggs, 1990), 30% (Pinthus, 1974), 40% (Eassen et al., 1993) and up to 66% (Berry et al., 2003), depending on crop stage at the date of lodging and on lodging intensity. When lodging occurs before elongation, plants are able to recover their upright position, as opposed to when it occurs after heading. In our experiment, yield was affected only by year.

Conclusions

1. Increased tiller biomass weight and increased plant height during early (BBCH 39) growth stages are significant indicators of lodging risk. The correlation between lodging and tiller biomass and plant height was higher than 0.5 and statistically significant ($P = 0.000$). Diagnostic of stand structure parameters during early growth stages could be important part of decision support system of barley growing strategies.

2. Lodging was significantly affected both by year and nitrogen fertilization rate. Level of lodging in years from 2012 to 2014 was 0.00, 22.89 and 34.21 %, respectively. Increasing nitrogen fertilization rates (0, 45 and 90 kg ha^{-1}) significantly increased lodging level (4.61, 18.79 and 33.69 %, respectively).

3. Protein content in harvested grain was strongly affected by year and fertilization rate. Grain protein content in years from 2012 to 2014 was 13.69, 13.02 and 11.70 %, respectively. Increasing nitrogen fertilization rates (0, 45 and 90 kg ha^{-1}) significantly increased protein content (12.04, 12.76 and 13.61 %, respectively).

4. Sowing rates used in this study − 2.5, 3.5 and 4.5 million germinable seeds (MGS) − had a less considerable effect on lodging due to compensatory abilities of a stand.

5. Yield was affected only by year. Grain yield in years from 2012 to 2014 was 6.73, 5.94 and 6.65 t ha^{-1}, respectively.

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Vasarinių miežių pasėlio struktūra kaip pasėlio išgulimo rizikos rodiklis

P. Matušinsky, I. Svobodová, P. Míša

Agrotest Fyto Ltd, Čekijos Respublika

Santrauka

Lauko eksperimentai 2012–2014 m. buvo vykdyti Kromeriže, Čekijos Respublikoje. Bandymų metu tirtos įvairios sėjos ir tręšimo azotu normos. Tyrimo tikslas – nustatyti pasėlio struktūros rodiklius, kurie leistų įvertinti pasėlio išgulimo riziką jau ankstyvuoju vasarinių miežių augimo tarpsniu (BBCH 39). Pasėlio išgulimui didelės įtakos turėjo ir metai, ir tręšimo azotu normos. Didesnės azoto trąšų normos žymiai padidino pasėlio išgulimą. Didesnės trąšų normos lėmė didesnį ūglių biomasės svorį, didesnį augalų aukštį ir mažesnes šaknis. Baltymų kiekiui nukultuose grūduose didelės įtakos taip pat turėjo metai ir azoto trąšų normos. Dėl didesnių azoto trąšų normų grūduose padidėjo baltymų kiekis. Sėjos tankumas neturėjo įtakos nei pasėlio išgulimui, nei baltymų kiekiui grūduose. Derliui turėjo įtakos tik metai. Reikšmingi pasėlio išgulimo rodikliai yra ankstyvaisiais augimo tarpsniais padidėję ūglių biomasės svoris ir augalų aukštis. Koreliacija tarp pasėlio išgulimo, ūglių biomasės ir augalų aukščio buvo didesnė nei 0,5 ir esminė ($P = 0,000$).

Reikšminiai žodžiai: agrotechnika, augalų tankumas, *Hordeum vulgare*, tręšimas azotu.