THE EFFECT OF DROUGHT ON PRODUCTION OF DRY MATTER IN SPRING BARLEY (*HORDEUM VULGARE* L., CV. AMULET, KRONA AND HISTORICAL CV. NÜRNBERG)*

V. Hejnák

Czech University of Agriculture, Faculty of Agronomy, Department of Botany and Plant Physiology, Prague, Czech Republic

Production of dry matter of spring barley (*Hordeum vulgare* L., *conv. distichon*) was compared in small-plot trials in two present malting varieties, the Czech variety Amulet and the German variety Krona, and the historical variety Nürnberg of 1832 cultivated on medium-heavy fluvisol in the years 2000 and 2001. The diagram of the experiment included two variants of moisture conditions in small plots for variety: normal – soil moisture during the whole vegetation on the level 60–70% of maximal water capacity (MWC); and drought – soil moisture on the level 30–35% MWC induced in half of plots in the period from phase 25.DC to phase 61.DC. Above-ground parts of plants (leaves, stems and spikes) were taken from each variant in selected phases of ontogeny (21.DC, 31.DC, 61.DC, 75.DC, 91.DC) to determine dry matter. Leaf blades had mostly maximal amount of dry matter in the third sampling (phase 61.DC), with subsequent decrease in the time of ripening. Stems reached usually maximal weight of dry matter a little later, during the fourth ripening (phase 75.DC). In the time when dry matter stagnated or was falling in vegetative organs, i.e. in the period of ripening between phases of milk (phase 75.DC) and full (phase 91.DC) ripeness, they showed intensive increase of dry matter by generative organs, i.e. the spikes. The dynamics of this process was higher in new, modern high-yielding varieties of spring barley. The drought stress was statistically significant limiting factor of the plant growth of all three studied varieties and particularly in 2000 it critically reduced the growth of photosynthetic apparatus and prolonging growth of stems in the period of shooting. The stagnation of the size of assimilation apparatus even after end of drought period caused fall of production of assimilates required for filling of grain in spikes in the period of ripening in stressed plants compared with non-stressed variants. Another negative consecutive manifestation was the reduction of the capacity of plants to transform assimilates from the site of production (source) in leaves to the place of consumption (sink) in spikes, what led to the growth of dry matter of stems in the period between phases 75.DC and 91.DC on behalf of dry matter of spikes.

spring barley (*Hordeum vulgare* L., *conv. distichon*); production of dry matter; drought stress; small plots

INTRODUCTION

Growth and production processes in plants are determined by their genetic potential and the effect of many ecological factors that are in mutual interactions. Water management has a principal meaning beside the radiation regime and nutritional condition. Drought is the most frequent environmental limit factor, which can induce internal water deficit in plant or water stress, respectively (Švihra, 1984; Brestič, 2001). Regarding the global weather changes on the Earth agriculture in the future will be faced in various parts of the earth to the growth of aridization and fluctuation of precipitation during vegetation period of agricultural crops (Nátr, 1998). Evaluation of drought-hardiness, polygenically based factor manifesting by complex of anatomic, morphological, physiological and biochemical properties of genotypes of cultural crops are therefore a long-term topical problem. Markers of stress and physiological criteria are sought for, that reflect sensitivity of genotypes to drought, whereas there is an effort to introduce favourable traits of tolerance or resistance into new cultivars (Gorny, 2001). Water stress inhibits a prolonging growth, synthesis of cellular walls, formation of protochlorophyll, activity of nitrate reductase, conductivity of stomata, transpiration, assimilation of CO_2. On the contrary, it supports production of α-amylase and some other hydrolases, ABA, amino acids proline. Distant transports are relatively little sensitive (Zámečník, 2002). Even a low decrease of water potential can lead to serious physiological disorders of synthetic processes, structure of proteins and activity of enzymes (Pospíšilová et al., 2000). The level of decrease of the yield depends on intensity and length of activity of drought, on specification of plant species or cultivar, respectively.

Experiment represented in this contribution deals with the effect of water stress on dry matter production and some physiological processes in plant that are closely correlated with production of biomass. Three different genotypes of spring barley (historical variety Nürnberg of 1832 and two modern malting varieties – Amulet from Czech and Krona from German breeding) were chosen purposefully.

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MATERIAL AND METHOD

Small-plot experiments were carried out in the years 2000 and 2001 on the experimental site at Sojovice near Lysá nad Labem. The village is situated on the headward portion of the river Jizera in Polabská Lowlands at the altitude 195 m above sea level.

As it can be seen from the climatographic regionalization of the Czech Republic this region belongs to the IIIrd class, characterised by 166–177 days of average lasting of the period with the air temperature 10 °C and higher, average yearly sum of precipitation ≤ 580 mm and with the period without precipitation > 22 days. This class includes 1 800 032 hectares on the territory of the Czech Republic, e.g. Labe river basin and southern Moravia (Klabzuba et al., 1999).

As reported meteorological station at Stará Boleslav (5 km) an average annual air temperature in this region is 9.2 °C, out of it for cold half-year (X–III) 3.0 °C and for warm half-year (IV–IX) 15.4 °C. Average annual sum of precipitation is 575 mm, out of it in cold half-year 199 mm and in warm half-year 376 mm. Average monthly air temperatures and average monthly sums of precipitation (normals 1961–1990) are presented in Table 1 (Klabzuba et al., 1999).

Small plots were of area 0.029 m^2 and were restricted by cylindrical pots without bottom with diameter 19 cm and by 30 cm imbedded into soil profile at an experimental site. In 2000 in the spring small plots were filled with medium-heavy fluvisol that had favourable moisture conditions, very high supply of available phosphorus, suitable supply of available potassium and magnesium, medium content of humus and neutral reaction (Table 2). 9000 g of fresh soil with moisture on the level 60–70% of maximal water capacity (MWC) was used to form one small plot.

Spring barley (*Hordeum vulgare* L., *conv. distichon*) was a model plant, historical variety Nürnberg of 1832 and two present malting varieties – Czech variety Amulet and German Krona. The seed of the variety Nürnberg comes from the gene bank of the Research Institute for Crop Production, Prague-Ruzyně, the seed of present varieties Amulet and Krona was received from the experimental station of the Department of Plant Production of the Faculty of Agronomy of the Czech University of Agriculture in Prague-Uhříněves. Each small plot was seeded with 25 barley grains and covered by 2 cm of soil. After emergence the number of plants was reduced to 21 per small plot. Plants were not chemically treated.

Diagram of the trial included 2 variants for each variety of moisture conditions in small plots:

1. Normal moisture conditions – on half of small plots the soil moisture was ranging on the level 60–70% of MWC.
2. Drought induced by covering of the whole experimental site by transparent foil mounted to the structure at the height of 1.5 m above small plots, by interruption of watering on the second half of small plots and gradual drying out of the soil to the level 30–35% of MWC; the period of interrupted watering and action of drought started after the 1st sampling of plants in phase of full shooting (25.DC) and ended after the 3rd sampling of plants at the onset of anthesis (61.DC).

Physiological measurement done in morning hours by infrared analyser LCA-4 (Bio Scientific) did not show any significant reduction of incident solar radiation caused by covering of plants by a thin transparent gardening foil. There were no changes in parameters of exchange of gases between leaves of experimental plant and external medium, i.e. in conductivity of stomata, in immediate rate of photosynthesis and in immediate rate of transpiration. On the other hand, it was not possible fully eliminate and exclude the effect of the foil on microclimate of the stand, e.g. on the temperature inside the stand and relative air moisture, and thus on influencing of metabolic and growth processes in experimental plants. Therefore, to preserve comparable and definable conditions for all experimental variants, a transparent foil covered the whole area of the experimental plot and not only variants, in which water stress was induced by interrupted watering.

In each variant of moisture conditions plants of the above varieties were cultured in four variants with nitrogen fertilization in three replications. The control variant (N_0) was fertilized only with phosphorus (255 mg per small plot), i.e. in conversion 90 $kg.ha^{-1}$) and potassium

Table 1. Average monthly air temperature (calculated from t_{max} and t_{min}) and average monthly sum of precipitation (normals 1961–1990) on the meteorological station at Stará Boleslav (in Klabzuba et al., 1999)

	Cold half-year							Warm half-year							AMT. year
	X	XI	XII	I	II	III	X–III	IV	V	VI	VII	VIII	IX	IV–IX	
Average monthly air temperature (°C)	9.6	4.2	0.5	–1.5	0.5	4.5	3,0	9.1	13.9	17.3	18.7	18.4	14.8	15.4	9.2
Average monthly sum of precipitation (mm)	35	40	32	30	28	34	199	41	73	75	75	75	43	376	575

Table 2. Agrochemical characteristics of soil

Soil	Humus (%)	pH/KCl	Content of available nutrients ($mg.kg^{-1}$)			N total (%)	N min. ($mg.kg^{-1}$)	N mineralizable ($mg.kg^{-1}$)
			P – Mehlich II	K – Mehlich II	Mg – Mehlich II			
Neutral	2.85	6.9	161	168	127	0.29	85	12

(320 mg per small plot, i.e. in conversion 110 $kg.ha^{-1}$) in the form potassium dihydrogen phosphate, in other three, except this, graduated rates of nitrogen were applied (85, 170 and 255 mg of N per small plot, i.e. in calculation 30, 60 and 90 kg of $N.ha^{-1}$). Ammonium nitrate was used as a nitrogen fertilizer. All fertilizers were applied in the form of watering solution after emergence and reduction of plants on small plots.

Five samplings of above-ground parts of plants were done during ontogeny:

1st sampling – start of tillering (phase 21.DC)
2nd sampling – start of shooting (phase 31.DC)
3rd sampling – start of flowering (phase 61.DC)
4th sampling – milk ripeness (phase 75.DC)
5th sampling – full ripeness (phase 91.DC)

Nine plants from each variant were taken, without roots, by cutting of the plant closely above the ground of soil. Plants were dried at 80 °C, cut and then the weight of dry matter of leaf blades, stems and spikes was determined.

Statistical evaluation was done by computer program Statgraphics by multiple analysis of variance at $\alpha = 0.05$ and regression analysis.

Experimental years 2000 and 2001 evaluated in this study were significantly distinct by course of weather conditions. In 2000 average air temperature in the period from the beginning of April to the end of June was almost by 3 °C higher than in 2001. The distribution also and the amount of precipitation during the vegetation of spring barley was different. In 2000 the sum of precipitation for the period from April to July was 142 mm that was unevenly distributed (April: 0 mm, May: 25 mm, June: 62 mm, July: 55 mm). On the other hand, in 2001 the sum of precipitation for identical period was significantly higher, i.e. 256 mm in total (April: 62 mm, May: 57 mm, June: 76 mm, July: 61 mm). These different meteorological conditions influenced the pattern of the trial, particularly in the period from the mid-May to the end of the first decade of June, when water stress was induced in plants by covering with transparent foil over the experimental site and by interruption of watering in the half of small plots. Its induction in 2000 with respect to higher evapotranspiration was much more dynamical and faster than that in 2001. Drying out of soil and subsequent induction of stress in plants was much slower. The above facts are reflected in the results obtained described in the following chapter.

RESULTS AND DISCUSSION

The effect of ontogeny phase or the date of plant sampling, respectively, on the amount of produced dry matter of above-ground segments of plants of evaluated spring barley varieties is in Figs. 1 to 6 and statistical evaluation in Table 3.

It was found out that leaf blades had mostly maximal amounts of dry matter during the third sampling (phase 61.DC) with subsequent fall in the time of ripening in all studied varieties during vegetation in control, drought-unstressed plants in evaluation of dry matter production of different organs (leaf blades, stems, spikes). Stems usually reached the maximal weight of dry matter a little later, at the fourth sampling (phase 75.DC). There was

Table 3. The effect of selected factors on production of dry matter of above-ground part of spring barley plant – statistical evaluation by multiple analysis of variance at $\alpha = 0.95$

Factor	Level	Number	Mean	Homogenous groups				
Variety	Amulet	12	1.633	*				
	Krona	12	1.675	*				
	Nürnberg	12	1.233				*	
Moisture conditions	normal	18	1.867	*				
	drought stress	18	1.160				*	
Plant part	leaf blades	36	0.263	*				
	stems	36	0.538		*			
	spikes	36	0.713				*	
Year	2000	18	1.563	*				
	2001	18	1.463	*				
Nitrogen fertilization	N_0	36	0.923	*				
	N_{30}	36	1.158		*			
	N_{60}	36	1.374				*	
	N_{90}	36	1.459				*	
Date of sampling or phase of ontogeny, resp.	1. (21.DC)	36	0.190	*				
	2. (31.DC)	36	0.448		*			
	3. (61.DC)	36	1.125			*		
	4. (75.DC)	36	1.793				*	
	5. (91.DC)	36	2.590					*

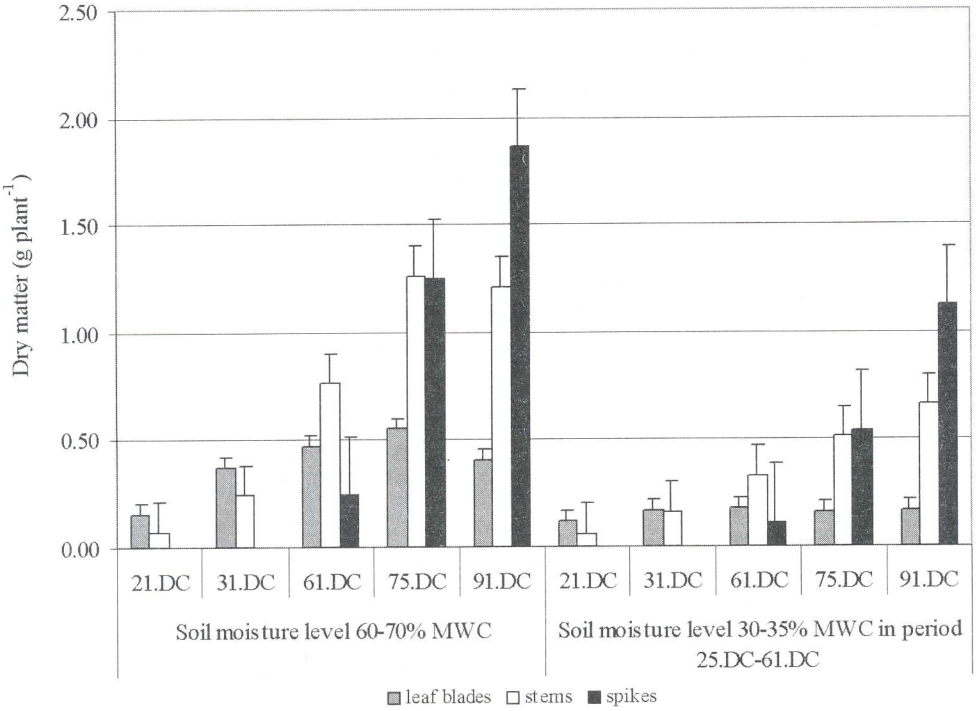

Fig. 1. Dry matter production (g.plant^{-1}) during ontogeny of spring barley variety Amulet under normal moisture conditions and drought stress – the year 2000

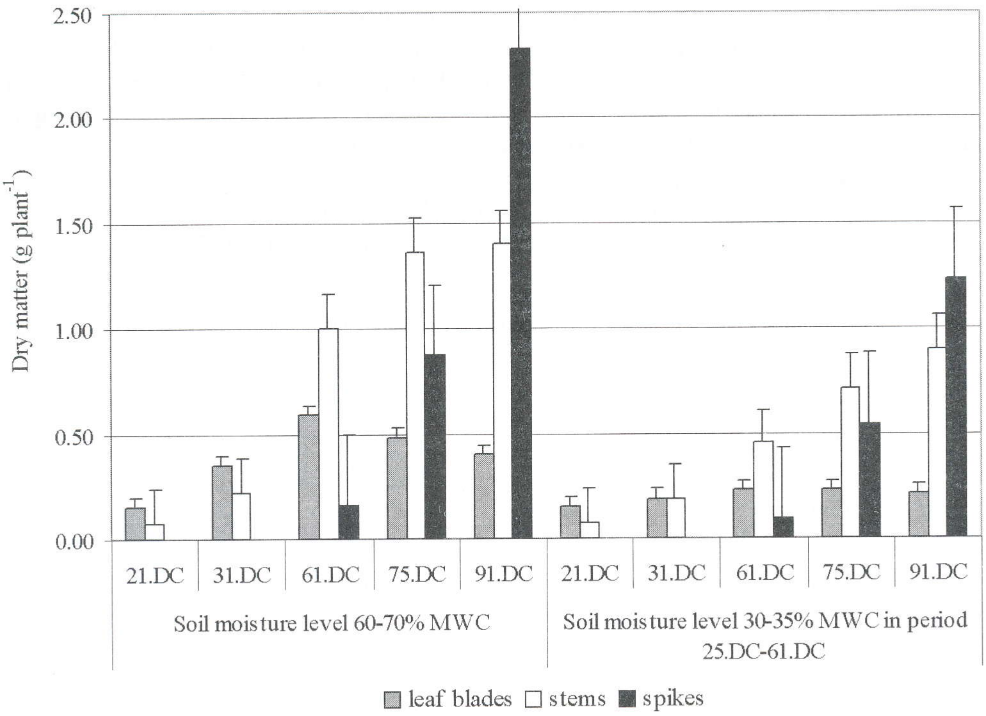

Fig. 2. Dry matter production (g.plant^{-1}) during ontogeny of spring barley variety Krona under normal moisture conditions and drought stress – the year 2000

a trend to slip of time of maximum in dry matter of leaves as well as stems to later phases of ontogeny.

In the time when dry matter stagnated or was falling in vegetative organs, i.e. in the time of ripening between the milk phase (75.DC) and full ripeness (phase 91.DC), generative organs, i.e. spikes, showed intensive growth of dry matter. Dynamics of this process were higher in new, modern, high-yielding varieties of spring barley, what had been confirmed by the experiments carried out by Petr et al. (1980, 2002) with old (Nürnberg) varieties of spring barley and oats. It follows from them that one of the main reasons of the progress in breeding is substantially better (more economical) distribution of assimilates in favour of economically important organs, i.e. grain. It is associated with breeding for short-stemness when modern varieties invest more into grain and less into straw at total identical yield of dry matter of above-ground biomass. It has also been confirmed in the published results of Mattsson et al. (1992) experiments with land little-yielding spring barley race Laevigatum and two modern high-yielding cultivars Golf and Mette.

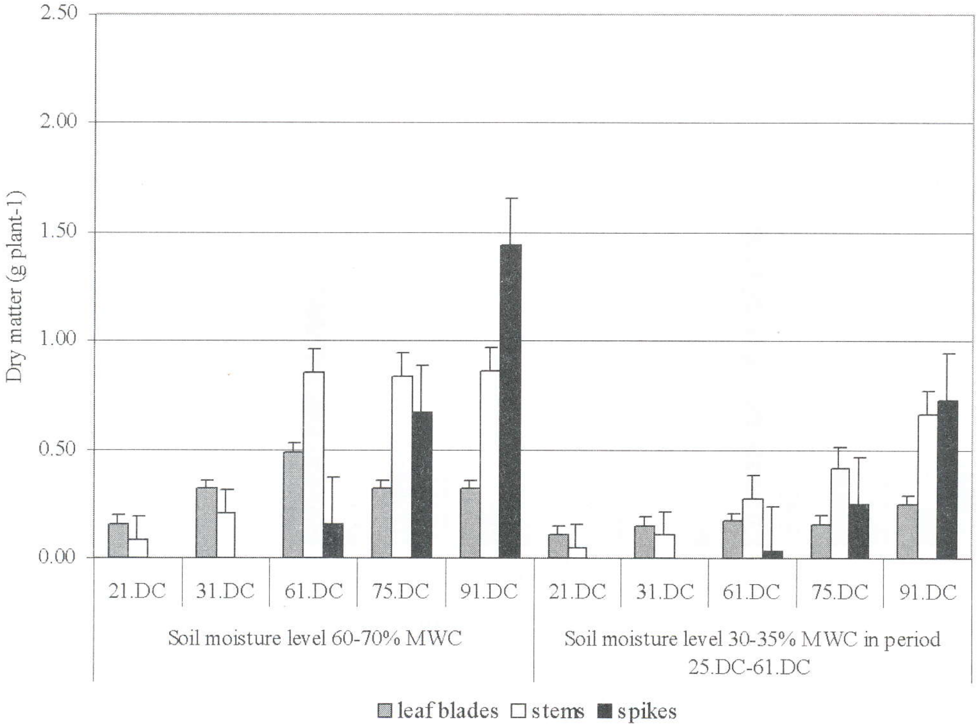

Fig. 3. Dry matter production (g.plant^{-1}) during ontogeny of spring barley variety Nürnberg under normal moisture conditions and drought stress – the year 2000

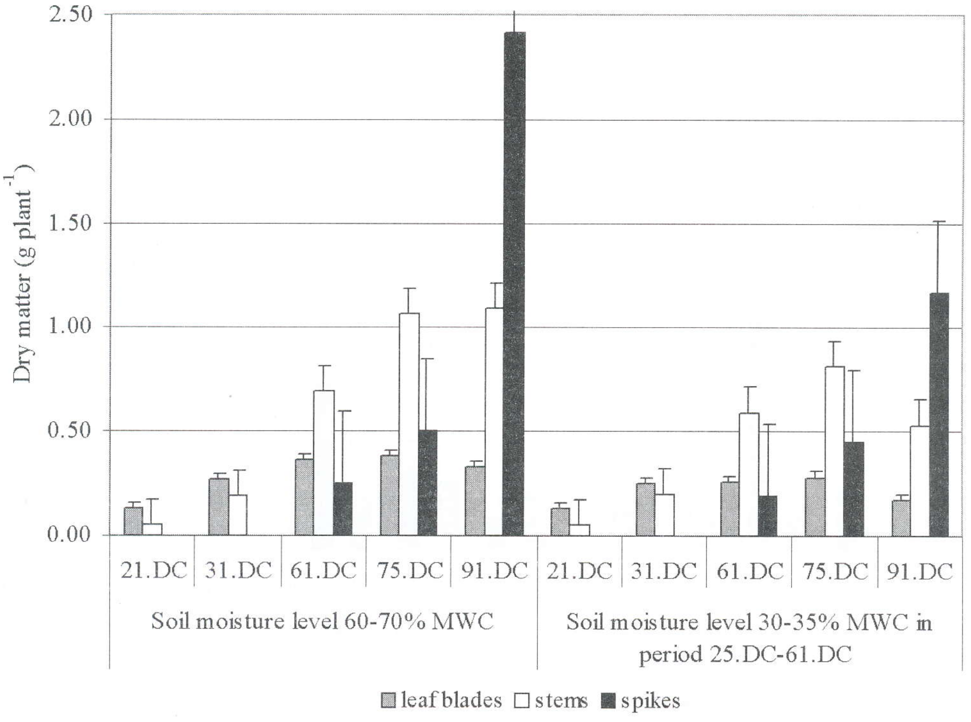

Fig. 4. Dry matter production (g.plant^{-1}) during ontogeny of spring barley variety Amulet under normal moisture conditions and drought stress – the year 2001

Greater production of dry matter in post-floral period (P e t r et al., 1980, 2002) is more suitable for grain yield and modern varieties are better in it. This fact was manifested in statistically significantly higher average weight of dry matter of one harvested plant of the varieties Amulet and Krona compared with the variety Nürnberg (Table 3). When evaluating production of dry matter in initial phases of growth, on the other hand, significant differences were not recorded. However, it dose not mean that previous pattern of growth should not be important for final yield. On the contrary, in the vegetative period and in the time of great period of growth should be produced such a structure of plant and such assimilation apparatus to secure needed amount of dry matter (assimilates) for high weight of grain. It all depends on the capacity of plants to transform assimilates into grains and on total distribution of assimilates in plant (P e t r et al., 1980).

Experiment proved that plant nutrition remains a factor that participates very markedly in the control of production efficiency of field crops. Applied rates of nitrogen increased production of dry matter in all evaluated

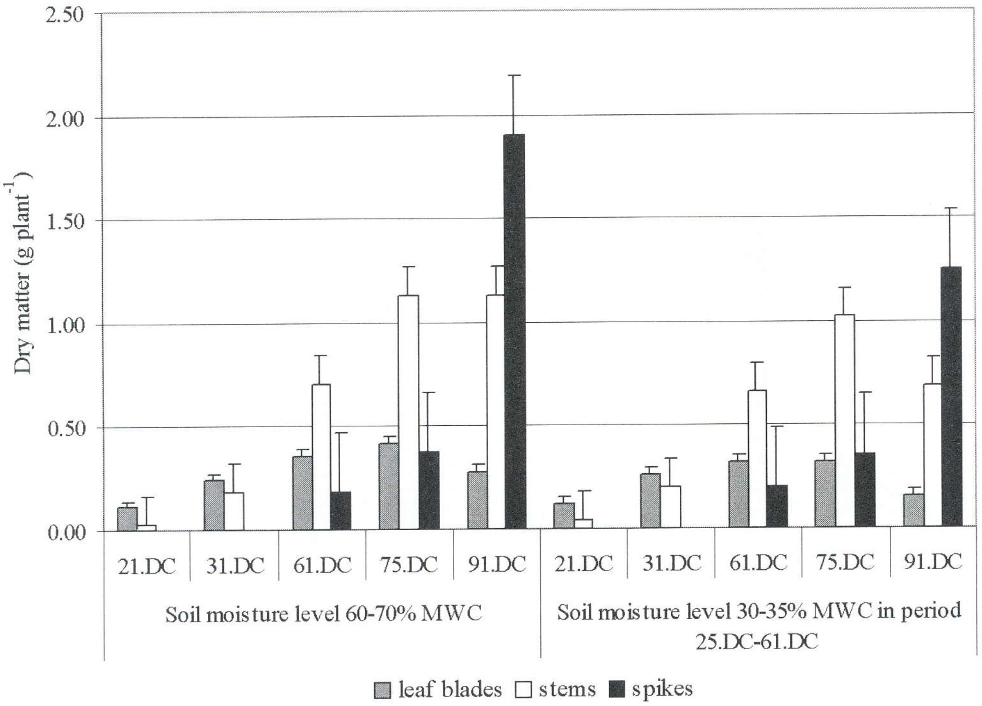

Fig. 5. Dry matter production (g.plant^{-1}) during ontogeny of spring barley variety Krona under normal moisture conditions and drought stress – the year 2001

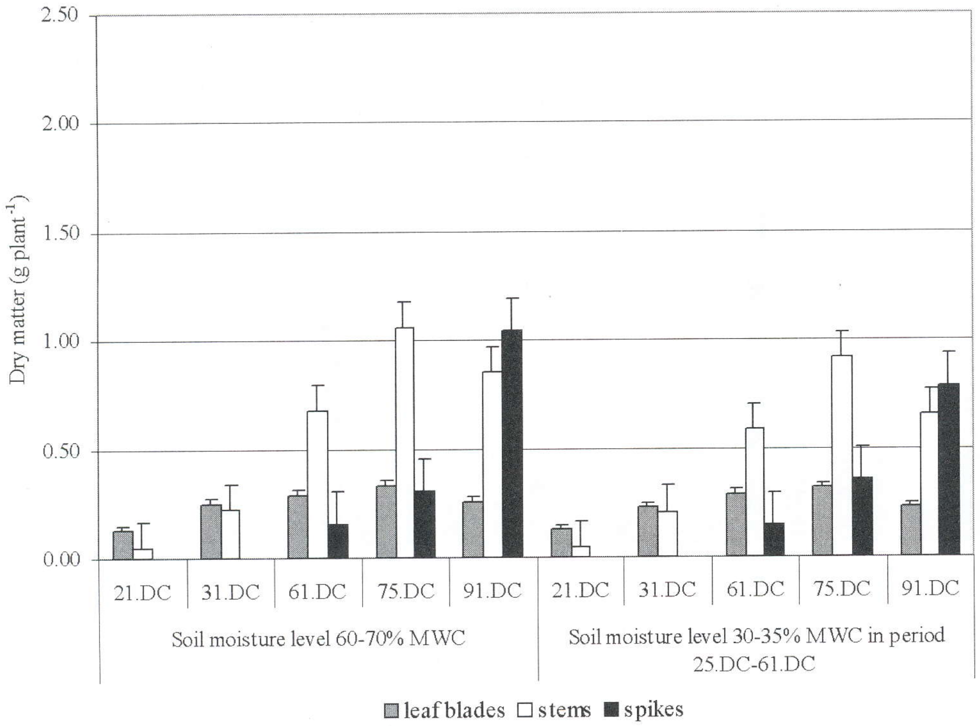

Fig. 6. Dry matter production (g.plant^{-1}) during ontogeny of spring barley variety Nürnberg under normal moisture conditions and drought stress – the year 2001

varieties of spring barley, even in the variants that passed the period with artificially induced water deficit. This was manifested in its final effect in statistically significantly higher average weight of plants harvested in variants treated with nitrogen compared with the control plants nitrogen untreated (Table 3).

The drought stress was statistically significantly a limiting factor of the plant growth of all three studied varieties (Table 3). Particularly in 2000 it restricted the growth and other physiological processes passing in spring barley plants. It is evident from Figs 1 to 3 that drought caused a notable restriction of growth of photosynthetic apparatus (first of all turning yellow and subsequently drying of lower leaves) and prolonging growth of stems in the period of shooting. For example, in the third sampling, following closely the end of drought, average weight of dry matter of leaves per plant in the control unstressed variant was 0.47 g in the variety Amulet and in the stressed variant it was 0.18 g (i.e. only 38% of the control), in the variety Krona in unstressed variant the weight was 0.59 g and in stressed variant 0.23 g (i.e. 40% of the control), and in the variety Nürnberg in unstressed variant 0.49 g and in stressed variant 0.17 g (i.e. 35% of the control). Stagnation of the size of assimilation apparatus even after end of drought caused decrease in production of assimilates needed for filling of grain in spikes in the period of ripening compared with unstressed variants. Restriction of the capacity of plants to transform assimilates from the site of production (source) in leaves to the site of consumption (sink) in spikes, was another negative subsequent manifestation, what led to the growth of dry matter of spikes in behalf of dry matter of leaves in the period between the fourth and fifth sampling. Švihra and Talapka (1995) and Brestič (1996) reported also that in deficit of water or under strong water stress, respectively, transport processes are limited in spring barley in post-floral period and assimilates are concentrated in stems and do not get into grains. Regarding production process of the stand the size of assimilation apparatus, its photosynthetic activity and the length of its duration is decisive in cereals, i.e. also in spring barley, what has been confirmed by studies written by Švihra (1984). Procházka (1985) noted that out of accumulation processes the rate of transport and distribution of assimilates among organs of plant or the number and size of grains, followed by their activity during accumulation of assimilates, respectively, are placed in front position.

The total average weight of dry matter per plant was in the variety Amulet in the control variant 3.47 g in the fifth sampling in the period of full ripeness (phase 91.DC) and in the stressed variant it was 1.95 g (i.e. 56% of the control), in the variety Krona in the control variant 4.13 g and in the stressed variant 2.34 g (i.e. 57% of the control), and in the variety Nürnberg in the control variant 2.62 g and in the stressed variant 1.64 g (i.e. 63% of the control). Similar to this, when comparing the produced dry matter of generative organs, the weight of dry matter of spikes per average plant was found in the variety Amulet 1.12 g in the stressed variant (i.e. 60% of the level of unstressed plant), in the variety Krona 1.23 g (i.e. 53% of the level of unstressed plant) and in the variety Nürnberg 0.73 g (i.e. 51% of the level of unstressed plant).

In 2001 (Figs 4 to 6) the start of water stress in plants was slower after interruption of watering, what was manifested in the habit of plants and their physiological parameters. Turning to yellow and drying out of leaves did not occur; only the plants started to grow slower. After end of drought during the third sampling weight of dry matter of assimilation apparatus of average plants in unstressed as well as stressed variant in the variety Nürnberg was practically identical, in the variety Amulet in unstressed variant it was 0.36 g and in the stressed variant 0.26 g (i.e. 72% of the control) and in the variety Krona in unstressed variant 0.36 g and in stressed variant 0.32 g (i.e. 89% from the level of the control). Greater reduction of assimilation apparatus as an indication of water stress in the variety Amulet reflected into great decrease of the value of dry matter of spikes per plant in the time of full ripeness – 1.17 g represent 49% of the value found in unstressed plant. For comparison: water stress manifested in the variety Krona by fall of weight of dry matter of spikes in the period of full ripeness to 66% and in the variety Nürnberg to 76% of the value found in unstressed variant.

Moreover, it should be mentioned that in 2001 weight of dry matter of stems fell in all three varieties in post-stressed period between fourth and fifth sampling. It can be assumed that assimilates from stems were translocated into spikes during ripening and used for grain filling. It should testify lower intensity of action of drought on plants than in 2000.

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HEJNÁK, V. (Česká zemědělská univerzita, Agronomická fakulta, katedra botaniky a fyziologie rostlin, Praha, Česká republika):

Vliv sucha na tvorbu sušiny v jarním ječmeni (*Hordeum vulgare* L., cv. Amulet, Krona a historická cv. Norimberský).

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V mikroparcelkových pokusech na středně těžké fluvizemi byla v letech 2000 a 2001 porovnávána tvorba sušiny ječmene jarního (*Hordeum vulgare* L., *conv. distichon),* dvou současných sladovnických odrůd – české Amulet a německé Krona, a historické odrůdy Norimberský z roku 1832. Průměrné měsíční teploty vzduchu a průměrné měsíční úhrny srážek (normály 1961–1990) pokusného stanoviště jsou uvedeny v tab. 1 (Klabzuba et al., 1999), agrochemická charakteristika použité zeminy je uvedena v tab. 2. Schéma pokusu zahrnovalo u každé odrůdy dvě varianty vláhových poměrů v mikroparcelkách: normální – vlhkost zeminy v průběhu celé vegetace na úrovni 60–70 % maximální vodní kapacity (MVK); a sucho – vlhkost zeminy na úrovni 30–35 % MVK navozená u poloviny mikroparcelek v období od fáze 25.DC do fáze 61.DC. Ve vybraných fázích ontogeneze (21.DC, 31.DC, 61.DC, 75.DC, 91.DC) byly z každé varianty odebírány nadzemní části rostlin (listy, stébla a klasy) pro stanovení sušiny.

Vliv fáze ontogeneze, resp. termínu odběru vzorků rostlin na množství vytvořené sušiny nadzemní části rostlin hodnocených odrůd ječmene jarního je ukázán na obr. 1–6, statistické vyhodnocení je uvedeno v tab. 3. Listové čepele měly většinou maximální množství sušiny při třetím odběru (fáze 61.DC), s následným poklesem v době zrání. Stébla dosahovala zpravidla maximální hmotnosti sušiny o něco později, při čtvrtém odběru (fáze 75.DC). V době, kdy u vegetativních orgánů sušina již stagnovala nebo klesala, tedy v době zrání mezi fází mléčné (fáze 75.DC) a plné (fáze 91.DC) zralosti, vykazovaly intenzivní nárůst sušiny generativní orgány, tedy klasy. Dynamika tohoto procesu byla vyšší u nových, moderních výnosných odrůd jarního ječmene, čímž byly potvrzeny výsledky pokusů autorů Petr et al. (1980, 2002) se starými (norimberskými) odrůdami jarního ječmene a ovsa. Z nich vyplývá, že jednou z hlavních příčin pokroku ve šlechtění je výrazně lepší (ekonomičtější) distribuce asimilátů ve prospěch hospodářsky významných orgánů, tj. zrna. Pro výnos zrna obilnin je výhodnější větší tvorba sušiny v postflorálním období (Petr et al., 1980, 2002), a v tom jsou moderní odrůdy lepší. Tato skutečnost se projevila i ve statisticky průkazně vyšší průměrné hmotnosti sušiny jedné sklizené rostliny odrůd Amulet a Krona v porovnání s odrůdou Norimberský (tab. 3).

Stres suchem byl statisticky významným limitujícím faktorem růstu rostlin všech tří sledovaných odrůd (tab. 3) a zejména v roce 2000 (obr. 1–3) významně omezil růst fotosyntetického aparátu a dlouživého růstu stébel v období sloupkování. Stagnace velikosti asimilačního aparátu i po ukončení sucha způsobila u stresovaných rostlin v porovnání s nestresovanými variantami snížení tvorby asimilátů potřebných pro naplnění zrna v klasech v období zrání. Dalším negativním následným projevem bylo omezení schopnosti rostlin převádět asimiláty z místa tvorby (source) v listech do místa spotřeby (sink) v klasech, což vedlo v období mezi fázemi 75.DC a 91.DC k nárůstu sušiny stébel na úkor sušiny klasů.

V roce 2001 (obr. 4–6) byl po přerušení zálivky nástup vodního stresu u rostlin pozvolnější, což se projevilo na habitu rostlin a jejich fyziologických parametrech. Nedošlo k žloutnutí a zasychání listů, rostliny pouze zpomalily růst. Za pozornost dále stojí, že v roce 2001 došlo u všech tří odrůd v postresovém období mezi 4. a 5. odběrem k poklesu hmotnosti sušiny stébel. Domníváme se, že asimiláty ze stébel byly při dozrávání translokovány do klasů a využity k naplnění zrna. To by svědčilo o nižší intenzitě působení sucha na rostliny než v roce 2000.

ječmen jarní (*Hordeum vulgare* L., *conv. distichon)*; tvorba sušiny; stres suchem; mikroparcelky

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Contact Address:

Doc. Ing. Václav Hejnák, Ph.D., Česká zemědělská univerzita v Praze, Agronomická fakulta, katedra botaniky a fyziologie rostlin, Kamýcká 957, 165 21 Praha 6-Suchdol, Česká republika, tel.: +420 224 382 514, e-mail: hejnak@af.czu.cz