ADAPTATION STRATEGIES TO CLIMATE CHANGE – THE PLANT ROOTS

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The increasing air temperatures and the simultaneous changes in rainfall distribution during the year, as the climate models predict, enhance the importance of the crop root system in the future. Plant varieties with a larger root system use soil water and nutrients in dry environments more effectively than varieties with a smaller root system. Many researchers and breeders involved in plant's root system research consider the roots as the "key to the second green revolution". The „soil core" method and the method of measuring electrical capacitance of the root system size (RSS) are the two approaches used on Department of Crop Science, Breeding and Plant Medicine at Mendel University in Brno for screening of drought resistant barley and wheat genotypes. The "soil core" method provides information about root properties – length, area, diameter, and root length density in different soil layers. Method for measuring electrical capacitance enables rapid acquisition RSS values of hundreds of individuals without damaging the plants. It is applicable in field conditions, and allows detection of fine structures of the root system. The results of long-term field trials confirm a significant effect of the RSS on the yield, especially in dry years without sufficient rainfall totals. For example the root biomass of barley produced by the plant to the vegetation phase of heading (BBCH 50) in 2012 and 2013 had a statistically significant positive effect ongrain yield (r= 0.636, respectively r= 0.643). The large root system was a possible key to the success of plants in conditions of drought stress. Selection for higher wheat root system size can be easily used to breed for drought tolerance and higher efficiency of water and fertilizer use.

Keywords: soil, drought, root system, yield, electrical capacitance

INTRODUCTION

In recent years, European agriculture faces enhanced frequency of drought season. In healthy plants an abiotic stress is the main cause of reduction in production and the effect of the root system in this respect is at least as significant as the above-ground plant parts. With increasing temperatures, changing environments, and the current distribution of local rainfall during the year, as the climate models predict, will grow in the future the effect of the root system as an acquireing apparatus.

The roots are very sensitive to environmental conditions of the soil and are often the first body plant that responds to some stress.

Already a relatively small amount of underground water can be very valuable for increasing grain yield (Kirkegaard et al., 2007) and can promote the formation of a greater root system. It is therefore obvious that the size and architecture of the root system can affect the efficiency of uptake of water and on yield and quality production.

For example, the length and weight of roots affected grain yields in the official variety experiments in Sweden and Denmark (Středa et al., 2014). Investments in the root system and the associated economic returns, resulting in more efficient water intake is twice that of nitrogen uptake, as documented Palta et al. (2011). Greater root system to the depth of 0.7 m resulted in a significantly higher water and nitrogen absorption. The presence of water reserves in deeper layers of the soil gives the varieties with a more powerful root system the chance to achieve a greater yield. Kirkegaard, et al. (2007) reported an increase in grain yield of 59 kg per ha per 1 mm of water supplied to the layer of 1.35 to 1.85 m during drought stress after flowering.

The positive influence of the root system to yield confirm results of the authors Chloupek et al. (2010) when grain yield and grain quality of malting barley in the dry year the 2007 positively correlated with the size of the root system.

The most widely used technique for obtaining volumetrical samples of soil with the roots is the "soil-core" method (Böhm, 1979; Gregory, 2006). This method is normally used for evaluation of qualitative, quantitative parameters of the root system and its architecture. The principle of the method consists in obtaining a soil sample of a certain volume, separation of components by using water and separation of roots that are present. For subsequent evaluation (weight, length, diameter, number of root caps etc.) can be used also other methods (line-intersect method, a visual estimation, root scanning and their analysis - using software). The method is destructive and time consuming because of sample preparation and its analysis.

In contrast, methods based on measurement of electrical characteristics of the root system are usually technically and in terms of work undemanding, inexpensive and time-saving. They can be used both in the laboratory (measuring) and under field conditions in a terms of measuring the intact root system. The disadvantage is the effect of soil properties on the measured results. To these methods can be arranged the measurement of electrical capacity of roots (Chloupek, 1972; Svačina et al., 2014). The method is especially suitable for measuring intervarietal differences in the size of the root system in the same environment, in an identical time and of the same plant species.

MATERIALS AND METHODS

Field experiments with spring barley (*Hordeum vulgare* L.) were conducted (i) in the years 2010-2013 in the Czech Republic Hrubčice and Želešice locations (ii) a container experiment was established in 2013 and 2014 in the premises of the Mendel University in Brno (iii) in 2014 was realized field experiment with spring barley in the area of Horní Kunčice (Moravian-Silesian region). In selected spring barley varieties were evaluated the root system size (RSS) by measuring its electrical capacity (Chloupek, 1972; Klimešová et al., 2011). Electrical capacity [nF] was measured by LCR meter (Extech Instruments) at 1 kHz. The root system was measured in three different vegetative stages – shooting

(BBCH 31-39), heading (BBCH 51-59) and grain filling (BBCH 71-75). On the territory of the experimental localities was continuously monitored soil moisture with the sensors VIRRIB (AMET Velké Bílovice). The measurement results of the root system of different varieties were in 2010-2012 compared with the average yield values from the field trials of Central Institute for Supervising and Testing in Agriculture (ÚKZÚZ).

The yield was ascertained for two growing systems S1 (extensive) and S2 (intense), defined by ÚKZÚZ. At the same time in 2012, 2013 and 2014 were RSS values from field and laboratory experiments correlated with the grain yield and biomass of identical plants in the area of experimental locations. For these experiments were selected four varieties of spring barley and their hybrids. By "soil-core" (Böhm, 1979; Hajzler et al., 2010), followed by digital image analysis using software WinRHIZO (Regent Instruments Inc., Quebec, Canada) was evaluated root length density – RLD [$cm.cm^{-3}$] of selected varieties of soil profile to a depth of 0.6 meters. For statistical data processing was used software the STATISTICA.

RESULTS

Tightness of the relationship of the root system size and the barley grain yield was strongly affected by a year. Decreased availability of soil water in dry years has highlighted the positive effect of the root system size on grain yield.

In terms of soil moisture was less than favorable especially the year 2012, when during the months of March to May the rainfall values reached in the Czech Republic only 64 % of the long-term normal and in the South Moravian region only 48.5 %. The years 2011 and 2013 were from the rainfall point of view an average, but at the beginning of the growing season in 2011 and 2013, the moisture deficit could also negatively impact the further development of field crops. The years 2010 and 2014 were above an average rainfall, but the significant effect of RSS on grain yield was not observed.

Statistically significant effect of RSS on grain yield was observed in the terms of field conditions in 2011, 2012 and 2013 also within laboratory experiments.

In experiments with barley varieties tested in the field trials by ÚKZÚZ in 2011, the average RSS of the whole vegetation period affected grain yield in both planting systems S1 and S2 in the area of Hrubčice, in 2012 was found a significant correlation in the extensive system S1 in the grain filling phase. The larger root system in the system with higher input S2 had no effect on yield or as a competitive place where consumption of nutrients and assimilates take place slightly decreased the yield.

The expression of varieties with the large root system can be expected under conditions of drought stress. As evidenced by Středa et al. (2012), varieties that had by 21 % greater RSS, provided increased grain yield in an extremely dry year of 2007 by 420 kg per ha. In 2010, when water was not a limiting factor for field was a big root system of the plants unnecessary investment, and decreased (statistically insignificant) grain yield. A detailed description of the effect of the root system size in the phase of shooting, heading and ripening on grain yield indicates Tab. 1.

Table 1: Table of correlation coefficients of relation of spring barley varieties RSS evaluated in three stages of vegetation in location of Hrubčice and the average grain yield in cultivation systems S1 and S2 of test stations ÚKZÚZ in 2010 (n = 19), 2011 (n = 15) and 2012 (n = 18).

		Hrubčice			
Year		Shooting	Heading	Grain filling	Average
2010	S1	0,329	-0,030	-0,249	0,135
	S2	0,067	-0,056	-0,268	-0,036
2011	S1	0,476	0,429	0,126	0,514**
	S2	0,377	0,555*	0,436	0,686**
2012	S1	0,145	0,264	0,483*	0,319
	S2	-0,194	0,177	0,300	0,067

Experiments with selected varieties of spring barley and their hybrids also confirmed a major impact of the root system on the yield. In 2012 and 2013 were found statistically significant positive correlation between the RSS and yield primarily from the phase of heading. As reported Středa et al. (2014) heading phase is an essential period for the manifestation of the effect of the root system properties on grain yield. In the phase of shooting to heading an intensive biomass production is observed, and the plants increase in this period their water requirements (Martyniak, 2008), a water intermediary is just and only the root system. The influence of the root system size on grain yield of 12 barley genotypes documents Tab. 2.

Tab. 2: Table of correlation coefficients of relation of spring barley varieties RSS evaluated in three stages of vegetation and grain yield in the localities of Hrubčice, Želešice and Horní Kunčice in 2012 - 2014 (n = 12).

Area	Shooting	Heading	Grain filling	Average
Hrubčice 2012	-0,029	0,636*	0,332	0,469
Hrubčice 2013	0,596	0,643*	0,447	0,645*
Želešice 2013	0,650*	0,824**	0,839**	0,895*
H. Kunčice 2014	0,489	0,354	-0,166	-0,117

Results of long-term field experiments show evidence of the fundamental importance of the root system as an instrument of adaptation of varieties to changing climate conditions.

Within the laboratory experiments conducted in 2013 and 2014 were simulated drought stress conditions, when the value of available water holding capacity of the soil fell below 65 % up to the wilting point. In these conditions were sought continuity between an achieved biomass yield, respectively grain yield and the RSS of selected barley genotypes. Across variants, after data adjustment from experimental influences (variety, treatment) according Chloupek (1996) showed a statistically significant effect of RSS on yield. The closest relationship was found in the phase of heading in 2014 (see Tab. 3).

Tab. 3: Table of correlation coefficients of relation of spring barley varieties RSS evaluated in three stages of vegetation and grain yield and biomass in laboratory experiments in 2013 and 2014 (n = 9).

2013	Shooting	Heading	Grain filling	Average
Grain yield	----	0,312	0,383	0,509
Biomass yield	----	0,515	0,647*	0,754**
2014	Shooting	Heading	Grain filling	Average
Grain yield	0,014	0,765*	0,663	0,615
Biomass yield	0,298	0,816**	0,741*	0,804**

Measuring methods of electrical capacity enables the evaluation of the root system as a whole, but does not provide information about its structure or a root penetration depth. Now a deep root system is considered by many authors as the key assumption to success of drought-resist varieties.

For this type of root evaluation is an appropriate the "soil-core" method. Malting barley varieties were assessed using the soil-core method and subsequent digital image analysis. Depth and intensity of root penetration to the soil profile in the area of Hrubčice and Želešice in 2010 and 2011, characterized by values of rooting (RLD). The highest values of rooting, that are typical for cereals, were found in the upper soil layer 0-10 cm. The roots present in this layer consisted of 63 % of the total root biomass of varieties, but statistically significant effect on grain yield was associated with RLD values at depths of 30-40 and 40-50 cm!

In a humid year 2010 was observed a negative correlation of monitored parameters in the layer 30-40 cm (r = -0.874*) and 40-50 cm (r = -0.910*). In relatively dry year 2011 across different areas was confirmed positive correlation between yield and RLD at a depth of 20-30 cm (r = 0.881*), 30-40 cm (r = 0.874*) and 40-50 cm (r = 0.983**).

Very variable property of plants is thus apparent effect of the amount of formed root biomass on yield. This property is related to the response strategies to different environmental conditions.

CONCLUSION

Long-term experiments with spring barley varieties in field conditions even in laboratory conditions demonstrate a statistically significant positive correlation between the root system size, respectively root length density in the deeper layers of the soil profile with the amount of grain yield and biomass.

This relationship was confirmed always in conditions of water shortage, that occurred within 2011–2014 mainly during the spring months at the beginning of the growing season.

The large size of the root system in the phase of heading can be described as significant for the formation of crop yield. Availability of water in the deeper layers of soil profile and the ability of plants to take it with extensive root system is also an important feature for achieving a satisfactory yield in drought stress conditions.

Statistically significant dependence between the intensity of rooting and grain yield in contrasting years 2010 and 2011 illustrates the vital importance of the root system as an instrument of adaptation of varieties to changing climate conditions.

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