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Yield and quality of spring barley in relation to root system size

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Abstract

The study introduces the evaluation of root system size (RSS) for the breeding of barley in particular for drought tolerance. From 2007 to 2009 about 20 varieties of spring barley were evaluated at two locations for RSS by its electric capacity. A significant correlation between electric capacity of the root system and its weight, volume and root surface was found. RSS was compared with yield and quality of the varieties in official registration trials. Varieties with greater RSS had significantly higher yields in the dry year 2007. Similar relationships between RSS and yield in the other years were found only for some environments. Malting barley varieties with greater RSS had significantly higher contents of starch, saccharide extracts and malt extracts, as well as higher yields of protein and starch in 2007. It can be concluded that lower RSS is related to lower grain yield and malt quality in dry environments independent of the genetic background of varieties, and higher yields are correlated with greater RSS.

Keywords

Hordeum vulgare, malting quality, protein, root system, starch, yield

Introduction

Drought is the most significant environmental stress worldwide and improving yield under drought is a main goal of plant breeding. Root growth may increase crop productivity in deep soils especially under drought stress conditions (RUSSELL 1977, ZHENG et al. 2009). Root system is an important factor affecting yield and quality in dry years or areas with inadequate rainfall. Pot experiments with wheat showed significant correlations between RSS measured by its electrical capacity and grain yield under different fertilization treatments. The results indicated that RSS correlates with grain yields in absence of fertilization. A large root system of barley is a prerequisite for rapid initial plant growth and stable yield (CHLOUPEK et al. 2010).

Length of roots, their area, diameter and root hairs are important indicators for ingestion of water and nutrients in the vegetation. Many factors of the soil environment can limit root growth including temperature, nutrient and water availability, pathogens and aeration (ZHENG et al. 2003). Soil physical stress was found to decrease root elongation and soil strength has a major effect on the distribution of plant roots. Drying soils can strongly affect root growth. Tillage systems may influence rooting depth and root distribution (DWYER et al. 1995).

Materials and methods

Electrical capacity (nF, nanofarad) of the root system was measured by a 131D LCR Meter device at a frequency of 1 kHz. The measurements were performed in field conditions by connecting the plant to one electrode and inserting the second electrode into the soil surrounding the plant. The circuit under alternating current that passes between the root system and the soil measured parallel capacity (Cp). One panel represents the root surface and the second panel represents the soil where the plant roots grow (CHLOUPEK 1972, DALTON 1995). We measured only the living part of the root which can be determined by the electrical activity of the membrane between the cells. The alternating current causes polarization of living membranes. Young roots and root hairs have the greatest capacity because they do not contain suberin in the cell wall. Older roots with suberinised cell walls have a greater distance between the 'plates', therefore, the value of electric capacity is lower.

Experiments with spring barley varieties were established in 2007-2009 at two sites in Želešice and Hrubčice. We focused on varieties that were tested in official registration trials without fungicide treatment. We evaluated 20 varieties

Table 1: **Mean root system size of spring barley (Želešice, 2007)**

Variety	Shooting (BBCH 30-33)	Heading (BBCH51-55)	Grain filling (BBCH 73-75)
Aksamit	2.056 ^{cdefg}	3.098 ^{fg}	**0.417** ^{j}
Blaník	1.925 ^{bcde}	2.545 ^{abcde}	0.278 ^{bcdef}
Bojos	2.236 ^{defg}	2.880 ^{def}	0.257 ^{abc}
Bolina $^{\#}$	***1.550*** ^{a}	2.142 ^{ab}	0.252 ^{abc}
Braemar	1.924 ^{bcd}	2.596 ^{bcdef}	0.292 ^{cdef}
Calgary	2.245 ^{defg}	3.537 ^{gh}	0.376 ^{ghij}
Diplom	1.815 ^{abc}	2.374 ^{abcd}	0.334 ^{defghi}
Jersey	2.063 ^{cdefg}	2.361 ^{abc}	0.303 ^{cdef}
Malz	2.113 ^{cdefg}	2.338 ^{abc}	0.270 ^{bcd}
Orthega $^{\#}$	2.266 ^{efg}	**3.822** ^{h}	0.396 ^{ij}
Poet	**2.382** ^{g}	**3.749** ^{h}	0.380 ^{hij}
Prestige	1.683 ^{ab}	***2.070*** ^{a}	0.345 ^{fghi}
Pribina $^{\#}$	2.363 ^{fg}	***2.080*** ^{a}	***0.200*** ^{a}
Radegast	2.183 ^{defg}	2.910 ^{ef}	0.341 ^{efghi}
Sebastian	1.943 ^{bcde}	2.445 ^{abcde}	0.336 ^{defghi}
Spilka	2.199 ^{defg}	2.613 ^{bcdef}	0.310 ^{cdefg}
Tocada	2.030 ^{cdef}	2.488 ^{abcde}	0.272 ^{bcde}
Tolar	1.933 ^{bcde}	2.100 ^{ab}	0.314 ^{cdefgh}
Westminster	1.982 ^{bcde}	3.068 ^{fg}	0.340 ^{efghi}
Xanadu	2.098 ^{cdefg}	2.703 ^{cdef}	0.212 ^{ab}

Means with the same letter are not significantly different (P≤0.05); groups with highest values are printed in bold, groups with lowest values in bold and italics; $^{\#}$, non malting barleys

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in 2007, 22 in 2008 and 24 in 2009. Electrical capacity of the root system was measured three times at different growth stages, i.e. shooting (BBCH 30-33), heading (BBCH51-55) and grain filling (BBCH 73-75).

Results

Year 2007

In 2007 electrical capacity of the root systems was measured only in Želešice (*Table 1*). *Table 2* shows the comparison of the average RSS and grain yield for all measurement dates. Varieties with small RSS values reached a mean yield of 5.38 t.ha^{-1}, varieties with medium RSS reached a mean yield of 6.12 t.ha^{-1} and varieties with high RSS achieved a mean yield of 6.07 t.ha^{-1}. *Table 3* shows the relationships between RSS and selected quality parameters. Statistically significant relationships were found between grain yield and RSS, as well as between starch content and RSS, and carbohydrate extract and malt extract.

Table 2: **Root system size (RSS) and yield of spring barley (Želešice, 2007)**

RSS (nF)	Mean yield (t.ha^{-1})	Varieties
1.31-1.57	5.38	Bolina, Diplom, Malz, Prestige, Pribina, Tolar
1.58-1.79	6.12	Blaník, Bojos, Braemar, Jersey, Sebastian, Spilka, Tocada, Xanadu
1.80-2.17	6.07	Aksamit, Calgary, Orthega, Poet, Radegast, Westminster

Year 2009

Values of RSS measured in 2009 are demonstrated in Table 6. As in 2008 RSS was generally higher in Hrubčice. *Table*

Table 3: **Group means for root system size (RSS), grain yield and quality traits of malting barley varieties in 2007**

RSS (nF) Range	RSS (nF) Mean	Varieties (*n*)	Yield (t.ha^{-1})	Protein (%)	Starch (%)	Saccharide extract (%)	Malt extract (%)
4.64-5.02	4.78	5	5.31	11.72	63.5	76.9	81.7
5.04-5.18	5.12	6	5.63	11.38	64.2	77.4	82.2
5.19-5.50	5.28	5	5.79	11.34	64.1	77.6	82.5
Correlation with RSS			0.82**	-0.48	0.64**	0.61*	0.50*

Table 4: **Mean root system size of spring barley (Želešice & Hrubčice, 2008)**

	Želešice			Hrubčice		
Variety	Shooting	Heading	Grain filling	Shooting	Heading	Grain filling
Acrobat	***3.803*** ^{a}	***1.236*** ^{a}	0.787 ^{bc}	6.147 ^{bcdefg}	6.286 ^{abcd}	2.217 ^{abc}
Aksamit	**5.700** ^{g}	2.350 ^{fg}	1.038 ^{bcde}	6.514 ^{fghi}	7.092 ^{abcde}	2.736 ^{efgh}
Aktiv	4.659 ^{abcde}	1.848 ^{cde}	1.145 ^{e}	5.609 ^{abc}	6.194 ^{abc}	2.362 ^{abcde}
Azit $^{\#}$	4.978 ^{defg}	1.927 ^{cdef}	0.981 ^{bcde}	6.456 ^{efghi}	7.032 ^{abcde}	2.462 ^{abcdef}
Blaník	4.090 ^{abc}	1.383 ^{ab}	0.753 ^{ab}	6.408 ^{defgh}	7.146 ^{abcde}	2.787 ^{efgh}
Bojos	4.818 ^{bcdef}	2.256 ^{efg}	1.132 ^{de}	7.121 ^{hi}	**8.354** ^{e}	**3.325** ^{i}
Bolina $^{\#}$	5.643 ^{fg}	1.880 ^{cde}	0.782 ^{bc}	6.743 ^{ghi}	7.093 ^{abcde}	2.629 ^{cdefgh}
Calgary	5.430 ^{efg}	1.791 ^{bcd}	1.032 ^{bcde}	6.708 ^{ghi}	7.831 ^{de}	2.997 ^{ghi}
Diplom	4.209 ^{abcd}	2.056 ^{cdefg}	1.099 ^{de}	5.429 ^{ab}	6.489 ^{abcd}	2.526 ^{abcdef}
Jersey	4.183 ^{abcd}	1.946 ^{cdef}	1.062 ^{cde}	6.876 ^{ghi}	7.678 ^{cde}	3.002 ^{hi}
Kangoo	4.603 ^{abcde}	2.041 ^{cdefg}	1.105 ^{de}	5.941 ^{bcdef}	6.773 ^{abcde}	2.669 ^{defgh}
Marthe	5.238 ^{efg}	1.807 ^{bcd}	1.017 ^{bcde}	5.878 ^{abcdef}	7.447 ^{bcde}	2.577 ^{abcdefgh}
Prestige	4.071 ^{ab}	1.717 ^{bc}	1.011 ^{bcde}	***5.168*** ^{a}	***5.677*** ^{a}	2.172 ^{ab}
Pribina $^{\#}$	3.998 ^{ab}	1.745 ^{bc}	***0.475*** ^{a}	5.667 ^{abcd}	6.494 ^{abcd}	2.281 ^{abcd}
Publican	4.817 ^{bcdef}	**2.389** ^{g}	**1.463** ^{f}	5.706 ^{abcde}	***5.676*** ^{a}	***2.126*** ^{a}
Radegast	4.960 ^{cdefg}	1.886 ^{cde}	1.077 ^{cde}	5.628 ^{abc}	6.689 ^{abcd}	2.612 ^{bcdefgh}
Sebastian	5.426 ^{efg}	1.803 ^{bcd}	0.963 ^{bcde}	6.131 ^{bcdefg}	7.829 ^{de}	3.021 ^{hi}
Spilka	5.043 ^{defg}	1.963 ^{cdefg}	1.192 ^{ef}	7.021 ^{hi}	7.762 ^{cde}	2.996 ^{ghi}
Tocada $^{\#}$	5.131 ^{efg}	2.217 ^{defg}	0.935 ^{bcde}	**7.211** ^{i}	7.793 ^{de}	2.547 ^{abcdefg}
Tolar	3.974 ^{ab}	1.701 ^{bc}	0.845 ^{bcd}	6.210 ^{cdefg}	5.921 ^{ab}	2.438 ^{abcde}
Westminster	5.282 ^{efg}	2.207 ^{defg}	1.016 ^{bcde}	6.199 ^{cdefg}	6.399 ^{abcd}	2.715 ^{defgh}
Xanadu	4.826 ^{bcdef}	1.734 ^{bc}	0.952 ^{bcde}	6.878 ^{ghi}	6.760 ^{abcd}	2.909 ^{fghi}

Means with the same letter are not significantly different (P≤0.05); groups with highest values are printed in bold, groups with lowest values in bold and italics; $^{\#}$, non malting barleys

Table 5: **Root system size (RSS) and yield of spring barley (2008)**

Site	RSS (nF)	Mean yield (t.ha^{-1})	Varieties
Želešice	1.94-2.46	6.74	Acrobat, Blaník, Diplom, Jersey, Prestige, Pribina, Tolar
	2.47-2.73	7.04	Aktiv, Azit, Kangoo, Marthe, Radegast, Sebastian, Spilka, Xanadu
	2.74-3.03	6.99	Aksamit, Bojos, Bolina, Calgary, Publican, Tocada, Westminster
Hrubčice	4.34-4.89	9.27	Acrobat, Aktiv, Diplom, Prestige, Pribina, Publican, Tolar
	4.90-5.49	9.26	Aksamit, Azit, Blaník, Bolina, Kangoo, Marthe, Radegast, Westminster
	5.50-6.27	9.30	Bojos, Calgary, Jersey, Sebastian, Spilka, Tocada, Xanadu

Table 6: **Mean root system size of spring barley (Želešice & Hrubčice, 2009)**

Variety	Želešice Shooting	Želešice Heading	Želešice Grain filling	Hrubčice Shooting	Hrubčice Grain filling
Advent	1.147 bcde	1.387 abcde	***0.294 a***	4.464 bcdefg	**2.976 c**
Aksamit	1.061 abc	1.382 abcde	***0.292 a***	5.259 g	2.588 abcde
Aktiv	0.913 ab	1.239 abcd	***0.268 a***	3.610 ab	2.381 abcd
Azit #	1.141 bcde	1.258 abcde	0.316 ab	4.122 abcde	2.865 de
Blaník	***0.886 a***	1.147 ab	***0.299 a***	**5.293 g**	2.734 cde
Bojos	1.254 cdefg	1.306 abcde	***0.274 a***	5.086 fg	2.730 bcde
Diplom	1.338 defgh	1.279 abcde	***0.281 a***	4.332 abcdef	2.430 abcd
Henley	1.039 abc	1.297 abcde	***0.279 a***	3.708 abc	2.243 ab
Henrike	1.183 cdef	1.294 abcde	0.327 ab	4.084 abcde	***2.222 a***
Jersey	1.119 abcd	1.469 cdef	0.329 ab	4.191 abcde	2.624 abcde
Kangoo	1.385 efgh	1.704 fg	0.378 bc	4.866 efg	2.756 cde
Kontiki	1.337 defgh	1.513 ef	***0.292 a***	4.565 cdefg	2.461 abcd
Marthe	1.140 bcde	1.171 ab	***0.264 a***	4.102 abcde	2.585 abcde
Prestige	1.228 cdefg	1.328 abcde	***0.279 a***	3.698 abc	2.378 abcd
Pribina #	1.210 cdefg	***1.123 a***	***0.299 a***	4.018 abcd	2.626 abcde
Publican	1.044 abc	**1.785 g**	**0.406 c**	4.672 defg	2.564 abcde
Radegast	1.434 gh	1.479 def	0.374 bc	4.476 bcdefg	2.348 abc
Sebastian	1.318 defg	1.404 bcde	0.330 ab	4.596 defg	2.721 bcde
Signora	1.427 fgh	1.253 abcde	***0.271 a***	***3.584 a***	2.353 abc
Streif	1.277 cdefg	1.326 abcde	0.313 ab	4.873 efg	2.755 cde
Tocada #	1.135 bcd	1.204 abc	***0.286 a***	5.133 fg	2.813 cde
Tolar	**1.585 h**	1.298 abcde	***0.294 a***	4.851 efg	2.648 abcde
Vista	1.099 abcd	1.277 abcde	***0.290 a***	4.477 bcdefg	2.492 abcde
Xanadu	1.403 fgh	1.515 efg	0.325 ab	3.810 abc	2.531 abcde

Means with the same letter are not significantly different (P≤0.05); groups with highest values are printed in bold, groups with lowest values in bold and italics; #, non malting barleys

Table 7: **Root system size (RSS) and yield of spring barley (2009)**

Site	RSS (nF)	Mean yield (t.ha^{-1})	Varieties
Želešice	0.78-0.90	7.47	Aktiv, Azit, Blaník, Henley, Marthe, Pribina, Tocada, Vista
	0.91-0.97	7.25	Advent, Aksamit, Bojos, Diplom, Henrike, Jersey, Prestige, Streif
	2.74-3.03	6.99	Kangoo, Kontiki, Publican, Radegast, Sebastian, Signora, Tolar, Xanadu
Hrubčice	2.97-3.34	7.61	Aktiv, Henley, Henrike, Marthe, Prestige, Pribina, Signora, Xanadu
	3.38-3.66	7.64	Azit, Diplom, Jersey, Kontiki, Publican, Radegast, Sebastian, Vista
	3.72-4.01	7.77	Advent, Aksamit, Blaník, Bojos, Kangoo, Streif, Tocada, Tolar

7 shows mean values of RSS and yield at both test locations. Mean RSS in Želešice was 0.78-1.16 nF and 2.97 - 4.01 nF in Hrubčice. Varieties with lower RSS in Želešice achieved on average a mean yield of 7.47 t.ha^{-1}, whereas varieties with medium and large RSS showed mean yields of 7.25 and 7.32 t.ha^{-1}, repectively.

Conclusions

Our experiments showed that the most appropriate selection criterion for grain yield in dry conditions is the size of the root system measured by its electrical capacity. Varieties with increased RSS provided higher yields in dry conditions and contained more photosynthates and less nitrogenous substances which is typical for irrigation in dry conditions (PAYNTER and YOUNG 2004).

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Literature

CHLOUPEK O, 1972: The relationship between electric capacitance and some other parameters of plant roots. Biol. Plant. 14, 227-230.

CHLOUPEK O, DOSTÁL V, STŘEDA T, PSOTA V, DVOŘÁČKOVÁ O, 2010: Drought tolerance of barley varieties in relation to their root system size. Plant Breeding 129, 630-636.

DALTON FN, 1995: In-situ root extent measurement by electrical capacitance methods. Plant Soil 173, 157-165.

DWYER LM, MA BL, STEWART DW, HAYHOE HN, BALCHIN D, CULLEY JLB, MC GOVERN M, 1995: Root mass distribution under conventional and conservation tillage. CLBRR Contribution 95-01, Centre for Land and Biological Resources Research, Agriculture and Agri-Food Canada, Ottawa.

PAYNTER BH, YOUNG KJ, 2004: Grain and malting quality in two-row spring barley are influenced by grain filling moisture. Aust. J. Agric. Res. 55, 539-550.

RUSSELL RS, 1977: Plant root systems: their function and interaction with the soil. McGraw-Hill Book Co., London.

ZHENG B, YANG L, ZHANG W, MAO C, WU Y, YI K, LIU F, WU P, 2003: Mapping QTLs and candidate genes for rice root traits under different water supply conditions and komparative analysis across three populations. Theor. Appl. Genet. 107:1505-1515.

ZHENG BS, LE GOUIS J, DANIEL D, BRANCOURT-HULMEL M, 2009: Optimal numbers of environments to assess slopes of point regression for grain yield, grain protein yield and grain protein concentration under nitrogen constraint in winter wheat. Field Crops Res. 113,187-196.