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RELATIONSHIP OF SEMINAL ROOTS ANGLE AND GRAIN YIELD OF WINTER WHEAT CULTIVARS UNDER THE CONTINENTAL CLIMATE OF ROMANIA

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ABSTRACT

Root system traits are important for accessing water from different soil depths, for nutrient capture from the soil profile and for plant anchorage influence on lodging resistance. All these can have complex and sometimes contradictory effects on grain yield. Wheat root system architecture is closely related to seminal roots axis angle in the seedlings stage. Our research is an attempt to define the most desirable seminal root angle for the continental climate of Romania, by studying its correlation with grain yield of several winter wheat cultivars tested in a representative sample of 108 yield trials, covering a wide range of environmental conditions.

Correlation coefficients varied from -0.46 to +0.77, with an average of +0.17. In most yield trials correlations were positive, but low and mostly not significant. This suggests that for most of Romania and for regions with similar conditions, winter wheat breeding should aim at creating mainly cultivars with large seminal roots angle that could better use rainfall falling during the vegetation season, but also cultivars with a small seminal roots angle that can improve the access to water in the soil depth profile during severe drought conditions.

Keywords: root system architecture, seminal roots angle, yield, drought, nutrient capture.

INTRODUCTION

Root system architecture plays an important role in determining crops efficiency. First, root system architecture has important functional implications for water extracted from the soil (Blum and Arkin, 1984; Manschadi et al., 2006). But root system architecture is also important for nutrient use efficiency (Lynch, 2019). By exploring the subsoil, a steep and deep root system is beneficial not only for accessing water from the soil depth (Singh et al., 2011), but also for N capture from the soil profile. In contrast, a shallow but dense root system is not only better for using rainfall during the vegetation season (Liao et al., 2006), but also has advantages regarding P capture and should also be useful for capture of K, Ca, and Mg in acid soils (Lynch, 2019).

Finally, the root system is important in wheat for lodging resistance, by its effect on anchorage strength. Crook and Ennos (1994) reported that plants with stronger, more widely spread coronal roots produced larger soil cones during anchorage failure and resisted larger forces, while Pinthus (1967) found high correlations between root spreading angles and lodging rates from a series of field trials grown under various environmental conditions.

There is a large genotypic variation in crop plant root systems, that could be exploited in breeding programs (O'Toole and Bland, 1987; Fukai and Cooper, 1995; Kato et al., 2006; Manschadi et al., 2008), but not much progress has been made so far, because of difficulties in studying and selecting for improved root systems.

The root system traits expressed in the early development stages (seminal roots angle and number) were found to be associated with the root system architecture of the mature plants (Richard et al., 2015), the differences in the seminal roots angle being related to the horizontal and vertical exploration of the soil. This allowed the development of a rapid method for high-throughput phenotyping of seminal root traits in wheat, which opened new perspectives in

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breeding for improved root system (Richard et al., 2015). Seminal roots are not only directly important for adaptation to drought due to their early development, but also their association with the root system of mature plants can be used for breeding. Several studies on wheat, rice, sorghum, etc. have shown that a small angle in seedlings is a precursor of a deep root system and large branches in soil depth.

These characteristics are advantageous for terminal drought conditions, when there is water stored in the soil depth (Manschadi et al., 2006; Uga et al., 2011; Mace et al., 2012; Christopher et al., 2013). Every extra millimetre of water extracted during filling grain has produced a plus yield of 55 kg ha^{-1} (Manschadi et al., 2008). In sorghum, a small root angle was associated with the phenotype "stay-green", due to improving the access of water in the soil depth profile (Singh et al., 2011).

On the other hand, the wheat genotypes with a wide root angle can to use the rainfalls in the vegetation season (Liao et al., 2006). The gene *DRO1* (Deep rooting 1) increased the yield in rice grown under drought conditions, by increasing rooting depth (Uga et al., 2013)

As characteristics of the root system can have complex, and sometimes contradictory effects on yield, this study is an attempt to evaluate the relationship between seminal root angle and grain yield of winter wheat grown in several locations and years under the continental climate of Romania.

MATERIAL AND METHODS

Seminal root angle was measured in 16 winter wheat cultivars, which has been grown in Romania and were tested in yield trials in some years during 2010-2018.

For determination the seminal root angle, we were inspired by the work of Richard et al. (2015) and used 0.75 L transparent pots. The transparent pots were filled with two types of soils mixture (70% turba and 30% chernozem soil). Seeds were sown at a depth of 2 cm every 2.5 cm along the pot wall. The seeds were carefully placed vertically, embryo downwards and facing the wall to facilitate root growth along the transparent wall. Three grains of each genotype were sown, 3 seeds x 4 replications. After sowing, the clear pots were wrapped in aluminum foil and placed in dark-colored paper bags to exclude light from the developing roots. The pots were watered after sowing and no additional water or nutrients were supplied thereafter.

The roots were photographed at 7 days after sowing, then foto images of each individual seedling were transferred in PC. The angle between the two most outer seminal roots was measured with ImageJ program (Figure 1).

Data were analysed using the statistical analysis software ANOVA in Microsoft Excel.

Figure 1. Differences between genotypes in seminal roots angle

Available data about grain yield recorded in 108 yield trials in several locations during 2010-2018, which included at least eight of the cultivars characterized for seminal root angle, were used for computing correlation coefficients.

Data about grain yield in yield trials were available from the National Agricultural Research and Development Institute Fundulea (44°26`N latitude and 26°31`E longitude), and six Agricultural Research Stations (ARDS) from different regions of the country: ARDS Teleorman (44°07`N - 25°45`E), ARDS Şimnic (44°36`N - 25°45`E), ARDS Valu lui Traian (44°16`N - 28°48`E), ARDS Oradea (47°50`N - 21°93`E), ARDS Mărculeşti (44°40`N - 27°50`E), and ARDS Piteşti (44°78`N - 24°85`E). These included a large variation of weather and soil conditions, as well as crop management. For example, soil conditions varied from chernozem to luvisol, and crop management included various preceding crops, sowing dates and fertilization. Concerning the rainfall, at Fundulea average annual rainfall is 571 mm, of which 72% during the vegetation period, especially in May-June. In the summer season, only 35% of the total annual precipitation falls, these being torrential. The frequency of droughty years is over 40%. At Şimnic annual precipitation is about 540-550 l/sqm, very unevenly distributed during the vegetation season, while in Piteşti the average annual rainfall varies between 700-800 mm. At Fundulea, Piteşti and Şimnic, trials were performed with and without Nitrogen fertilization. All these were reflected in the average yield of the analysed cultivars, which varied from 1837 kg ha^{-1} at Piteşti without Nitrogen fertilization in 2011 to 9516 kg ha^{-1} at Teleorman in 2011.

Pearson's correlation coefficients between seminal root angles and recorded grain yield were computed using Microsoft Excel data analysis tool.

RESULTS AND DISCUSSION

A significant variability was found between the studied genotypes for seminal roots angle. ANOVA showed a significant effect of wheat cultivars (Table 1).

Table 1. ANOVA for seminal root angle of 16 analysed cultivars

Source of variation	SS	df	MS	F	F crit
Between cultivars	5985.93	15	399.06	9.67	1.88
Within cultivars	1981.71	48	41.29		
TOTAL	7967.64	63			

The angle of seminal roots varied from about 67° in cultivar Pitar to more than 100º in cultivar Miranda (Table 2).

A similar variation was previously found in Romanian wheat cultivars by David (2018).

Table 2. Seminal root angle of 16 Romanian winter wheat cultivars

Cultivar	Seminal root angle (°)	Variance
Pitar	66.96	15.14
Boema 1	67.44	28.21
Fundulea 4	73.39	1.70
Izvor	74.94	35.10
Zamfira	76.13	3.15
Ursita	76.79	45.84
Otilia	78.88	44.14
Voinic	79.81	40.30
Alex	81.74	44.82
Litera	84.06	12.21
Glosa	87.24	22.67
Unitar	87.53	18.99
Adelina	88.83	16.42
Fundulea 29	95.26	30.82
Pajura	97.76	3.46
FDL Miranda	100.08	37.54
LSD 5%	9.17	

Correlation coefficients between the seminal root angle of wheat cultivars and grain yield of the respective cultivars tested in any of 108 yield trials varied very much, from -0.46 to +0.77, with an average of +0.17. Most correlation coefficients were not significant, only 5 of the yield trials showing significant correlations, all positive. In most trials, correlation coefficients varied from +0.20 to +0.40 (Figure 2).

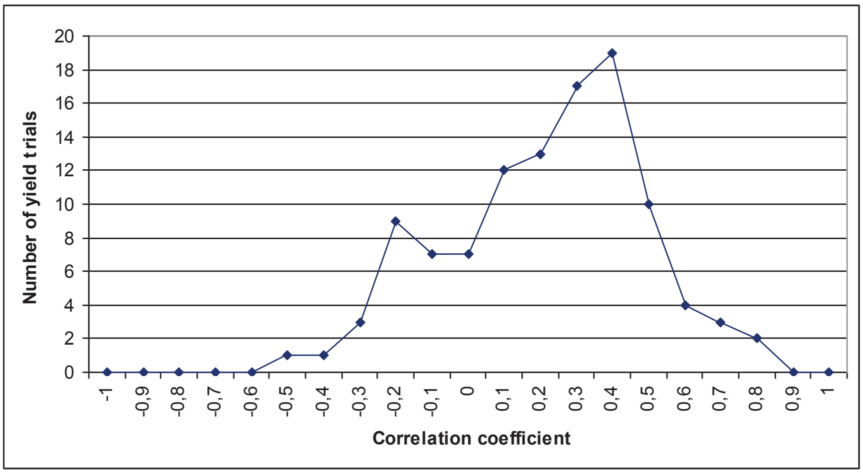

Figure 2. Histogram of the correlation coefficients between seminal root angle and grain yield

Other studies on wheat, which compared the architecture of drought-adapted genotypes to that of standard genotypes, showed that drought-adapted genotypes had a compact root system (the roots are laterally dispersed at a maximum of 45 cm from the main stem), the roots occupy a volume of soil uniformly and grew more in the depths of soil (3.8 times more than standard), (Manschadi et al., 2006). This type of root system allows the plant to access moisture in deeper layers. Our results suggest that, in the environmental conditions represented by most of the 108 analysed yield trials, a small seminal root angle, corresponding to a deep root system was not associated with higher grain yield. This might be explained by the fact that conditions when wheat plants must rely mostly on water stored deep in the soil profile are rare, and/or the advantages of a shallower root system from the point of view of nutrient capture or plant anchorage counteracted the effects of better use of water from deeper soil profile.

From the breeding point of view, in the continental climate of Romania, seminal root angle does not seem to deserve a high priority. Our results suggest that medium angles might be associated with higher average yield. Alternatively breeding should aim at creating cultivars with diverse root angles, able to exploit the highly variable conditions of the region. The large variation of the seminal root angle among the cultivars that have been successfully grown in the area can be considered a further argument for this approach.

CONCLUSIONS

Yields recorded for several Romanian winter wheat cultivars in a representative sample of 108 yield trials, covering a wide range of environments from Romania, showed low and mostly not significant correlation with seminal root angles. In only 5 trials grain yields showed significant positive correlation with seminal root angle, while none of the negative correlations were significant.

Our results suggest that for most of Romania and for regions with similar conditions, winter wheat breeding should aim at creating diverse cultivars, including mainly cultivars with large seminal roots angle that could better use rainfall during the vegetation season, from superficial soil layers. This could be beneficial in capitalizing small amounts of precipitation during periods of drought, but also cultivars with a small seminal roots angle that can improve the access to water in the soil depth profile during severe drought conditions.

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