Jpn. J. Crop Sci. 63(3) : 524--530 (1994)

# Varietal Differences of Root Systems in Winter Wheat Seedlings*

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Received October 7, 1993

**Abstract** : Varietal differences in root system morphology in winter wheat (*Triticum aestivum* L.) were investigated using seed pack growth pouches in a greenhouse. Different genotypic cultivars, shorter B-288 D for dwarf type, Pioneer 2548, Clark and Madison for semi-dwarf type, Cardinal and Verne for tall type, were used in this experiment under two different nutrition levels ($NO_3$-N ; 10 mg/l and 50 mg/l) with three replications. One germinated seed of each cultivar with primary seminal root less than 1.0 mm in length was transplanted into each seed pack on Dec. 5, 1991. Significant varietal differences were recognized in the spread of the root system, but there was no diffrence between the nutrition levels. Madison and Shorter B-288 D showed a large spread of the root system, whereas Cardinal showed a small spread. Total root length per plant was significantly different among the cultivars, with Cardianl showing the largest total root length per plant and Shorter B-288 D showing the smallest. On the other hand, there were no significant differences in stem number or leaf number per plant. These varietal differences in the lateral spread of the root system and total root length per plant were considered to be controlled by genotypic parameters. The semi-dwarf gene in wheat that affects the plant type did not influence the spread of root system and total root length per plant.
**Key words** : Root length, Root system, Spread of root system, *Triticum aestivum* L., Varietal differences, Winter wheat.

**コムギ幼植物の根系形態における品種間差異 :** 鯨　幸夫・ジョン H. グローブ**・ペドロ ロンザリ Jr.***
(金沢大学教育学部・**ケンタッキー大学農学部，アメリカ・***フィデェラル大学農学部，ブラジル)
**要　旨** : コムギの生産に関わる種々の品種的要因の一つに根系の問題がある．作物の根系は，土壌環境に対する適応性や養水分の吸収効率等の観点のほか，地上部形質との相互関連性の面から研究することが重要と考えられる．ここでは，草丈が遺伝的に異なる品種を材料に用いて，コムギ幼植物の根系形態に及ぼす品種間差異をシードパックグロウスパウチを用いて検討した．実験に用いた材料は，わい性のShorter B-288 D，半わい性品種のPioneer 2548，Clark，Madison，それに普通タイプ（Tall type）の Cardinal と Verne である．シードパックには，硝酸態窒素（10 mg-N/l，50 mg-N）を用いた Hewitt の培養液を入れ，温室内において 3 反復の実験を行った．個体の根系開度の品種間差異は，播種後 20 日目と 25 日目において有意に認められたが，培養液の硝酸態窒素濃度による有意差は認められなかった．個体あたりの総根長は播種後 25 日において，品種間および培地レベル間の双方において認められた．Madison と Shorter B 288 D は広い開度の根形態を示したが，Cardinal は狭い開度の根系形態を示していた．他方，Cardinal は最大の総根長を示し，Shorter B-288 D は最小の総根長を示していた．本実験の範囲内では，同じ半わい性品種群の中でも各品種の根系には有意な差異が認められた．他方，個体あたりの茎数，葉数および地上部乾物重に品種間による有意な差異は認められなかった．地下部形質である個体の根系開度と個体あたりの総根長は遺伝的形質であり，地上部の半わい性を表現する遺伝子に影響されていないものと考えられる．
**キーワード** : コムギ，根系，根系開度，根長，品種間差異．

Improvement of crop root systems has lagged behind that of above-ground plant characteristics. This disparity may be attributed to the root system's concealment in the soil and its variable nature, both of which enormously complicate observation and experimentation[7].

A comprehensive root study program was initiated in 1965 at the Rothamsted Experiment Station to evaluate root systems of modern, semi-dwarf wheats[5,12]. Differences in rooting pattern between the semi-dwarfs and traditional taller varieties were small, and the modern lines may have been more extensively rooted deep in the profile[7]. In this experiment we examine some varietal differences of root

* Part of this work was presented at the 194 th meeting of Crop Science Society of Japan held in October, 1992.

systems in soft winter wheats at the young stage and will discuss with reference to genetical background characteristics of shoot.

## Materials and Methods

This experiment was carried out during 1991 in a greenhouse at the Department of Agronomy, University of Kentucky, U.S.A.. Soft winter wheat (*Triticum aestivum* L.) was used in this experiment. The different genotypic cultivars, Shorter B-288 D for dwarf type, Pioneer 2548, Clark and Madison for semi-dwarf type, Cardinal and Verne for tall type, were used to determine the spread of root system and total root length per plant under two nutrition levels (Nitrate-nitrogen level is 10 mg/l and 50 mg/l of Hewitt's water solution) with three replications.

One germinated seed of each cultivar with primary seminal root less than 1.0 mm in length was transplanted into each seed pack (12.7 cm × 15.2 cm) (Vaughan's Seed Company, U.S.A.) on December 5, 1991. 20 ml water solution of 10 mg/l and 50 mg/l was added into each seed pack. 15 ml of water solution was added every 10 day during this experimental period. Seed pack growth pouches were fixed by using push pins into large wooden boxes (1 m × 1 m) covered with thick black vinyl (Containing many 10 cm slits to insert the seed pack) to avoid the light. Twenty and 25 days after sowing, total root length per plant, spread of root system and other growth parameters of 5 to 10 plants in each treatment were measured. The spread of root system of each cultivar was determined as shown in Fig. 1. Total root length per plant was determined using a digital image analysis system (Decagon Devices, Inc.) and following the procedure of Harris and Campbell[3]. Wet root samples were spread evenly, to avoid overlapping among roots, on a glass tray. Samples were then counted by photoimage. Each sample was read twice. The second reading was made after rotating the glass tray 90 degrees from the first reading position.

According to Radford[9], the following formula was shown as to the relative growth rate of root systems :

$$RGR_{RL} = \frac{1}{RL} \cdot \frac{dRL}{dt} = \frac{d}{dt} (\log_e RL)$$

where, RGR is the relative growth rate ($day^{-1}$), RL is the root length density ($cm/cm^3$) and t is the time (day). The term on the left side of the equation was designated as the "relative growth rate of root length" in agreement with Radford[9]. However, Bar-Yosef and Lambert[1] called it the specific root elongation rate.

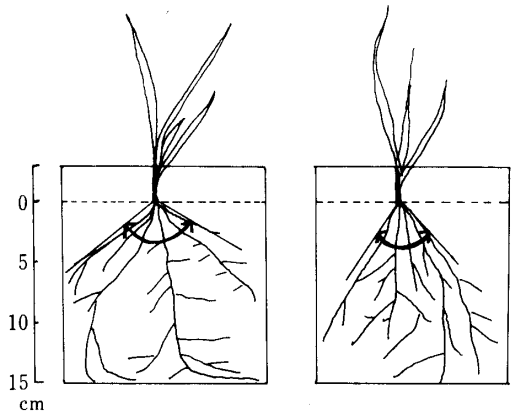


Fig. 1. Spread of root system of winter wheat.

In this experiment, we discussed the relative total root length growth rate (RTRLGR) per plant between either different cultivars or nutrition levels. RTRLGR was calculated by using the following equation ;

$$RTRLGR = \frac{\log TRL_{t_2} - \log TRL_{t_1}}{t_2 - t_1}$$

$TRL_{t1}$ is total root length per plant at sampling $t_1$ (day) and $TRL_{t2}$ is the total root length per plant at sampling $t_2$ (day), respectively.

## Results and Discussion

Significant varietal differences were recognized in the spread of root system on 20 days after planting (significant at $p<0.05$) and 25 days after planting (significant at $p<0.01$) (Table 1) between nutrition levels. Madison showed the largest spread of root system, whereas Cardinal showed small spread of root system.

Total root length per plant (Table 2) was significantly different among cultivars and nutrition levels on Dec. 28. Cardinal showed largest value of total root length per plant, and Shorter B-288 D and Pioneer 2548 showed a small value of total root length per plant. On the other hand, there were no significant differences in the root number per plant among either different cultivars or nutrition levels (nonsignificant at $p<0.05$) (Table 3).

Table 1. Varietal differences on the spread of root systems in winter wheat.

| Cultivar | Duncan's grouping | Low nutrition level | | High nutrition level | |
|---|---|---|---|---|---|
| | | Dec. 23 | Dec. 28 | Dec. 23 | Dec. 28 |
| B-288D | b | 108.0±5.0° | 110.8±5.2° | 86.4±10.1° | 110.8±8.3° |
| Pioneer 2548 | b c | 98.1±6.6 | 99.6±7.1 | 90.9± 7.6 | 92.3±1.8 |
| Cardinal | c | 83.1±6.7 | 87.0±5.2 | 93.3± 8.3 | 90.0±2.7 |
| Verne | b | 116.3±6.9 | 103.0±5.4 | 118.3± 7.4 | 90.8±3.3 |
| Clark | b | 117.6±6.1 | 113.8±2.1 | 97.5± 4.9 | 107.5±5.9 |
| Madison | a | 125.5±5.3 | 124.2±5.9 | 128.1± 6.3 | 131.7±3.1 |

# Mean±Standard Error

## Within columns, means followed by the same letter are not significantly different at the 0.05 level of probability according to the Duncan's multiple range test.

Table 2. Varietal differences of total root length per plant in winter wheat.

| Cultivar | Duncan's grouping | Low nutrition | | High nutrition | |
|---|---|---|---|---|---|
| | | Dec. $23_f$ | Dec. $28_e$ | Dec. $23_f$ | Dec. $28_d$ |
| B-288D | c | 156.0±11.5 cm | 262.0±19.0 cm | 179.1±11.5 cm | 256.9±21.7 cm |
| Pioneer 2548 | b c | 185.1±18.6 | 228.0±14.7 | 234.0±20.4 | 296.0±26.6 |
| Cardinal | a | 252.2±19.4 | 384.6±42.7 | 261.7±13.4 | 489.1±36.6 |
| Verne | b | 186.2±16.9 | 304.9±14.3 | 220.3±30.1 | 380.7±23.4 |
| Clark | b | 208.3±16.0 | 317.7±30.1 | 239.9±10.5 | 328.2±17.4 |
| Madison | b | 190.3±10.3 | 330.0±17.3 | 195.0±12.7 | 381.6±28.5 |

# Mean±Standard Error

## Low mutrition and high nutrition is 10 mg-N/l and 50 mg-N/l, respectively.

### Within columns, means followed by the same letter are not significantly different (a~c, d~f) at the 0.05 level of probability according to the Duncan's multiple range test.

Table 3. Root number per plant in winter wheat.

| Cultivar | Root number per plant | | | | |
|---|---|---|---|---|---|
| | Duncan's grouping | Low nutrition level | | High nutrition level | |
| | | Dec. $23_e$ | Dec. $28_d$ | Dec. $23_e$ | Dec. $28_d$ |
| B-288D | a b | 5.8±0.3 | 7.7±0.3 | 6.7±0.3 | 8.1±0.4 |
| Pioneer 2548 | a b | 6.3±0.2 | 7.4±0.5 | 6.1±0.2 | 8.3±0.3 |
| Cardinal | a | 6.5±0.3 | 8.0±0.4 | 6.4±0.2 | 9.2±0.4 |
| Verne | a b | 6.1±0.2 | 8.3±0.5 | 6.2±0.2 | 8.2±0.3 |
| Clark | b | 5.9±0.3 | 7.4±0.2 | 6.0±0.2 | 7.5±0.2 |
| Madison | a b | 6.6±0.4 | 8.7±0.4 | 5.3±0.2 | 8.8±0.3 |

# Mean±Standard Error

## Within columns, means followed by the same letter are not significantly different (a~b, d~e) at the 0.05 level of probability according to the Duncan's multiple range test.

RTRLGR unber the conditions of different cultivars and nutrition levels was shown in Table 4. RTRLGR did not show significant differences according to the cultivars and nutrition levels in this experiment.

Varietal differences in root genotypic responses which appear to affect the distribution pattern of roots have been observed in wheat[8,10]. Oyanagi et al.[8] discussed $F_1$ and $F_2$ plants from the cross between Norin 58 and Chinese Spring in wheat, and reported that the limited geotropic response associated with

Table 4. Relative total root length growth rate in winter wheat.

| Cultivar | Relative total root length growth rate (RTRLGR : $\times 10^{-2}$) | |
|---|---|---|
| | Low nutrition level$_{n.s.}$ | High nutrition level$_{n.s.}$ |
| | From Dec. 23 to 28 | From Dec. 23 to 28 |
| B-288D | 4.50 | 3.02 |
| Pioneer 2548 | 1.82 | 2.04 |
| Cardinal | 1.99 | 3.84 |
| Verne | 4.28 | 4.76 |
| Clark | 3.66 | 2.72 |
| Madison | 3.05 | 5.84 |

Table 5. Top dry weight/root dry weight ratio in winter wheat.

| Cultivar | Top dry weight/Root dry weight Ratio | | | |
|---|---|---|---|---|
| | Low nutrition level | | High nutrition level | |
| | Dec. 23 | Dec. 28 | Dec. 23 | Dec. 28 |
| B-288D | 1.3 | 1.8 | 2.5 | 2.7 |
| Pioneer 2548 | 1.9 | 1.9 | 2.4 | 2.1 |
| Cardinal | 2.0 | 1.9 | 2.7 | 2.8 |
| Verne | 1.5 | 1.9 | 2.6 | 2.9 |
| Clark | 1.6 | 1.8 | 2.4 | 2.4 |
| Madison | 1.5 | 1.7 | 2.0 | 2.9 |

Analysis of Variance

| | Cultivar | Nutrition level |
|---|---|---|
| Dec. 23 | n.s. | n.s. |
| Dec. 28 | ** | ** |

** : shows significant differences at 5% level.

small spread of the root system was considered to be controlled by a single dominant gene.

The pattern of root distribution was studied in 9 wheat varieties by Katyal et al.[4]. Kalyan Sona, NP 890, Durum Dwarf, Sonora 64, Lerma Rpjo and NP 404 were found to be deeper-rooting varieties. NP 880 and Sonora 64, which have the most compact root system, can be planted more closely to increase the yield potential. Thus, under shallow placement of phosphatic fertilizer in soil, NP 880 and Sharbati Sonara, with the maximum root distribution in the surface layer (to a depth of 8 cm) are likely to have high utilization of applied phosphorus. Welbank et al.[12] examined whether short-stemmed varieties of wheat (*T. aestivum* L.) derived from Japanese variety Norin 10 (generally called semi-dwarfs) had smaller root systems than taller European varieties. Consideration of root length did not show any striking differences compared to root dry weight[12].

It is interesting that individual dwarfing genes when brought into the same characteristic genetic background also tend to influence shoot and root equally[6]. Such an interpretation appears valid for at least the Norin 10 and Tom Thumb type of dwarfing. When Prince spring wheat and Starke winter wheat were used as background types, the dwarfing gene acted like an overall diminishing factor with probably no effect on the characteristic ratio patterns of the background varieties[6].

In this experiment, total root length per plant of semi-dwarf cultivars, Pioneer 2548, Clark and Madison, did not show significant differences (Table 2). There was no significant difference between semi-dwarf cultivars at Dec. 23, but significant differences ($p<0.01$) at Dec. 28 in the ratio of top dry

Table 6. Total root length per plant/Root dry weight per plant Ratio in winter wheat.

| Cultivar | Total root length/Root dry weight Ratio | | | | |
|---|---|---|---|---|---|
| | Duncan's grouping | Low nutrition level | | High nutrition level | |
| | | Dec. $23_{d\ e}$ | Dec. $28_{d}$ | Dec. $23_{e}$ | Dec. $28_{e}$ |
| B-288D | a b | 13.5 | 13.8 | 16.0 | 12.3 |
| Pioneer 2548 | c | 12.8 | 9.5 | 14.7 | 10.2 |
| Cardinal | a | 15.8 | 14.8 | 16.7 | 11.4 |
| Verne | b c | 11.9 | 12.4 | 14.7 | 11.3 |
| Clark | a b c | 14.0 | 12.9 | 13.2 | 12.2 |
| Madison | a b c | 12.9 | 14.7 | 13.5 | 13.8 |

# Within columns, means followed by the same letter are not significantly different (a~c, d~e) at the 0.05 level of probability according to the Duncan's multiple range test.

Table 7. Varietal differences of stem number per plant in winter wheat.

| Cultivar | Stem number per plant | | | | |
|---|---|---|---|---|---|
| | Duncan's grouping | Low nutrition level | | High nutrition level | |
| | | Dec. $23_{d}$ | Dec. $28_{d}$ | Dec. $23_{d}$ | Dec. $28_{e}$ |
| B-288D | a | 1.0±0 | 1.5±0.2 | 1.0±0 | 2.7±0.2 |
| Pioneer 2548 | a | 1.0±0 | 1.0±0 | 1.0±0 | 2.0±0.4 |
| Cardinal | a | 1.0±0 | 1.0±0 | 1.0±0 | 1.6±0.2 |
| Verne | a | 1.0±0 | 1.0±0 | 1.0±0 | 2.0±0 |
| Clark | a | 1.0±0 | 1.0±0 | 1.3±0.2 | 1.8±0 |
| Madison | a | 1.0± | 1.0±0 | 1.0±0 | 1.2±0 |

# Mean±Standard Error.

## Within columns, means followed by the same letter are not significantly different (a~c, d~e) at the 0.05 level of probability according to the Duncan's multiple range test.

weight : root dry weight ratio (Table 5). Total root length : Root dry weight ratio per plant was shown in Table 6. This ratio is called the Specific Root Length (SRL). The value of this ratio indicate the thickness in diameter of the root (Table 6). There is significant differences ($p<0.05$) during cultivars. There were significant differences in the spread of root system and total root length per plant between cultivars. On the other hand, there were no significant differences in stem number (Table 7) or leaf number (Table 8) per plant during this experimental period. In addition to these growth parameters, top dry weight per plant on Dec. 28 did not show significant differences (Table 9) among these cultivars. These varietal differences in the lateral spread of the root system and total root length per plant were considered to be controlled by genotypic parameters. The semi-dwarf gene in winter wheat that affects the plant type did not influence the spread of the root system and total root length per plant.

Cardinal, tall type cultivar, showed the smallest spread of root system and showed the largest total root length per plant. Cardinal is the most popular cultivar grown in Kentucky. However, we can not conclude what is the optimum root system for high yield.

In contrast to the effects of nutrients on root dry weight, which are generally small and may be negative[11], an increase in light intensity has a large effect on root development which may even exceed its effects on growth above ground[11]. Dobben[2] showed that low light intensity, red light and high temperature lead to high shoot : root ratios, indicating a need under these circumstances for photosynthesis. In this experiment, light intensity, temperature and humidity in the greenhouse were all normal during the experimental period.

**Acknowledgement** : The authers are

Table 8. Varietal differences on leaf number per plant of winter wheat.

| Cultivar | Leaf number per plant | | | |
|---|---|---|---|---|
| | Low nutrition level | | High nutrition level | |
| | Dec. 23 | Dec. 28 | Dec. 23 | Dec. 28 |
| B-288D | 3.0±0 | 4.7±0.2 | 3.8±0.2 | 6.5±0.5 |
| Pioneer 2548 | 3.0±0 | 3.6±0.2 | 3.2±0.1 | 5.5±0.5 |
| Cardinal | 3.0±0 | 3.7±0.2 | 3.0±0 | 5.0±0.5 |
| Verne | 3.0±0 | 3.2±0.2 | 3.0±0 | 4.8±0.2 |
| Clark | 3.0±0 | 3.0±0 | 3.3±0.2 | 4.9±0.2 |
| Madison | 3.0±0 | 3.5±0.2 | 3.0±0 | 4.2±0.2 |

Mean±Standard Error

Analysis of Variance

| | Cultivar | Nutrition level |
|---|---|---|
| Dec. 23 | n.s. | * |
| Dec. 28 | n.s. | *** |

*, ***: shows significant differences at 5% and 0.1% level, respectively.

Table 9. Top dry weight per plant in winter wheat.

| Cultivar | Duncan's grouping | Top dry weight per plant | | | |
|---|---|---|---|---|---|
| | | Low nutrition level | | High nutrition level | |
| | | Dec. $23_f$ | Dec. $28_e$ | Dec. $23_e$ | Dec. $28_d$ |
| B-288D | c | 16.5±1.2mg | 33.3±1.9mg | 28.8±4.7mg | 55.9±4.1mg |
| Pioneer 2548 | b | 27.0±1.4 | 44.6±3.9 | 37.8±1.7 | 73.9±4.7 |
| Cardinal | a | 31.8±1.3 | 49.7±3.0 | 42.8±2.6 | 109.3±5.5 |
| Verne | a b | 23.5±3.4 | 46.6±4.0 | 39.5±3.7 | 97.5±5.1 |
| Clark | a b | 22.3±1.7 | 48.2±3.3 | 43.3±1.8 | 81.0±1.5 |
| Madison | b c | 21.0±2.1 | 38.3±2.2 | 29.0±2.2 | 70.5±3.3 |

# Mean±Standard Error.

## Within columns, means followed by the same letter are not significantly different (a~c, d~f) at the 0.05 level of probability according to the Duncan's multiple range test.

indebted to Dr. D. Van Sanford, Dep. of Agr., University of Kentucky, for his valuable advice and offer of wheat seeds.

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