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GROWTH AND DEVELOPMENT OF SEMINAL AND CROWN ROOTS OF WHEAT SEEDLINGS AS AFFECTED BY TEMPERATURE

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HUANG B.-R., TAYLOR H. M. and MCMICHAEL B. L. *Growth and development of seminal and crown roots of wheat seedlings as affected by temperature.* ENVIRONMENTAL AND EXPERIMENTAL BOTANY **31,** 471–477, 1991. –The experiment was conducted to determine the optimum temperature for root growth of wheat seedlings (*Triticum aestivum* L.), and to evaluate the effects of temperature on growth and development of seminal and crown roots. Wheat seedlings were grown in a controlled environmental growth chamber and were harvested on alternate days for about 30 days beginning at 4 days after planting (DAP). The number of seminal and crown root axes and the length of each seminal and crown root axis, as well as the days after planting when the root axes and shoots were first observed, were recorded. Dry matter production of shoots and of seminal and crown roots was determined for air temperatures of 10, 20, 25 and 30°C. Some seminal root axes had already appeared at 4 DAP when sampling started, but their lengths were different at different temperatures. Shoots and crown roots emerged much earlier at 25 and 30°C than at 10 and 20°C. The 30°C temperature restricted formation of seminal root axes. The 10°C temperature retarded emergence and elongation of crown root axes. Lengths and dry matter production of both seminal and crown roots increased gradually to a maximum as temperature increased to 25°C, then declined at a temperature of 30°C. Root to shoot ratios were significantly greater and specific root lengths were significantly less at 10°C than those at 20, 25 and 30°C. Wheat grown at 25°C had the most extensive root system.

INTRODUCTION

PLANT root growth and development affect the total supplies of water and nutrients available to the plant and also control the rates at which these supplies are extracted from the soil profile. During early growth stages a well-developed root system is extremely important for the development of the above-ground part of wheat and for high yield.[9] Root properties are under genetic control, but are environmentally modified. Numerous studies have shown that environmental factors affect plant root growth and development.[10,12,14,15,18,23]

Temperature is an important environmental factor controlling growth and development of plants. Root growth is more sensitive to the range of temperatures occurring during the first few weeks after planting than later in the growing season.[3]

The response of root development to temperature differs greatly among species.[1,11,15] Root systems tend to have an optimum temperature for extension, which also varies greatly among species. Total root length of barley plants increased with temperature over the range of 3–25°C.[19] OWEN[20] reported that rice roots became longer but fewer at 10–20°C compared with 31°C. Maize root growth generally started at 9°C with

the optimum temperature for elongation of maize radicles being about 30°C.[3,4] The optimum temperature for cotton root elongation was 32°C.[22] Soybean root growth was retarded by 30 and 18°C root temperatures, compared with growth at 24°C.[25] DREZGIC *et al.*[9] reported that the length of the whole root system of wheat increased with temperature up to 25°C, while the weight only increased to 15°C. Wheat roots had a greater total root length when grown at a higher than at a lower temperature.[5] ABBASAL-ANI and HAY[1] studied the response of small grain cereals to temperatures of 5, 15 and 25°C and concluded that the rate of root extension was increased significantly by each 10°C increment in temperature and that the optimum temperature for cereal root extension was about 25°C.

Temperature might influence root elongation and dry matter production through affecting the rate of cell production and cell elongation in the root apical meristem. The impact of temperature on plant root growth and development tends to have an optimum, below or above which root growth is slowed. The optimum temperature for root emergence, elongation and dry matter production of wheat seedlings might be 25°C. Initial elongation of roots depends on mobilization of seed reserves.[8] The 25°C temperature may increase enzyme activity for the mobilization of seed reserves and thus enhance root emergence and elongation.[6] The number of cells per unit length of root may differ at different temperatures. This possibility could result in different root lengths per unit dry weight. Plants grown at lower temperatures might have shorter root length per unit dry weight than those grown at higher temperatures. Because lower temperatures reduced shoot growth more than root growth[6,19] due to an endogenous mechanism,[7] the plants grown at lower temperatures will have a greater root to shoot ratio than those grown at higher temperatures. Since seminal and crown root axes are developed from different origins, these two root systems might respond to temperature differently.

Very few studies have separated the seminal from crown roots when studying temperature effects on the wheat root system. The optimum temperature for root growth and development of wheat seedlings in particular has not been clearly defined. Therefore, the objectives of this experiment were (a) to determine the optimum temperature for root growth and development of wheat seedlings, and (b) to study the temperature effects on the emergence, elongation and dry matter production of seminal and of crown roots.

MATERIALS AND METHODS

The experiment was carried out in a controlled environmental growth chamber at Texas Tech. University. Winter wheat (*Triticum aestivum* L., cv. Newton) was grown in polyvinylchloride tubes at four constant air temperatures of 10, 20, 25 or 30°C with a 12-hr photoperiod controlled only by fluorescent lights (intensity 780 $\mu E/m^2 \cdot sec$). Temperature was monitored by a hygrothermograph. Tubes (5 cm diameter by 80 cm long), with a nylon screen taped over the bottom, were filled with air-dry, sterilized, coarse sand. One plant was grown at the seeding depth of 3 cm in each tube. Plants were watered with 100 ml half-strength Hoagland's solution[13] once each day.

Three plants from each temperature of 10, 20, 25 and 30°C were randomly harvested on alternate days beginning at 4 days after planting (DAP). The harvests were ended at 36, 30, 24 and 32 DAP at 10, 20, 25 and 30°C, respectively, when the roots reached the bottom of the tubes. All plants required for measurement at a particular temperature were grown in the growth chamber at one time. The procedure was then repeated at a different temperature in the same growth chamber.

At each harvest, the roots were washed from the sand. The number of seminal and crown root axes and the length of each seminal and crown root axis, as well as the days after planting when root axes and shoots were first observed on the three plant samples, were recorded. The aboveground portion was separated from the root system. The shoots and roots were oven dried at 100°C for 2 hr and then at 65°C for 24 hr. The dry weights of shoots and seminal and crown roots (including axes and lateral roots) were determined. Root to shoot ratios were derived from these dry weights. Specific root lengths (root length per unit dry weight of the roots) of seminal roots were calculated using root lengths and dry weights.

The experimental design was considered to be a series of experiments repeated over temperatures (i.e. each experiment involved a specific temperature) with three plants per datum nested within temperature as described by KEMPTHORNE.[16] Temperatures were the main plots and times of sampling were subplots. Plants designated for harvest at a particular time were completely randomized within each temperature. Differences between the treatments in terms of number, lengths, dry weights of seminal and crown roots, specific root length of seminal root axes and root to shoot ratio were determined by analysis of variance.

RESULTS

Shoot and root emergence

At 4 days after planting (DAP), shoots commenced emerging at 25 and 30°C, while 8 and 6 days were required for plants to emerge at 10 and 20°C, respectively. The seminal axes had already appeared at 4 DAP at the four temperature treatments (10, 20, 25 and 30°C), but root lengths were different at different temperatures. Crown root emergence was much later than the emergence of the seminal axes and shoot, and was delayed by lower temperatures. The crown roots began to protrude at 25, 19, 14 and 15 DAP at 10, 20, 25 and 30°C, respectively.

Number of seminal and crown root axes

At 4 DAP three seminal axes were present per plant at 10, 20 and 30°C, while five axes were present at 25°C. The mean number of seminal axes per plant increased for 18 DAP to 5.3 at 10°C, for 12 DAP to 5.7 at 20°C, for 10 DAP to 5.7 at 25°C and for 18 DAP to 5.0 at 30°C, and then remained stable (Table 1). Typically, wheat produces three to six seminal root axes per plant.[17,21] Our result implies that the seminal root axes at 20 and 25°C developed or established earlier than those at 10 or 30°C. There were significantly ($P < 0.05$) fewer seminal axes at 30 than at 10, 20 and 25°C throughout much of the experimental period. The number of seminal axes did not differ significantly ($P > 0.05$) among the plants at 10, 20 and 25°C.

The number of crown root axes increased with time. The final number of roots increased from 10 to 25°C, then decreased with further temperature increase to 30°C (Table 2). Crown root production was significantly restricted at 10°C. The plants at 10°C did not grow crown roots until 25 DAP, and produced fewer roots than the plants at 20, 25 and 30°C. There were many more crown

Table 1. Effect of temperature on the number of seminal root axes

	Temperature (°C)			
DAP	10	20	25	30
4	3.0 b* C	3.0 b D**	5.0 a C	3.0 b D
6	3.0 b C	4.3 a C	5.0 a C	3.0 b D
8	5.0 a AB	4.7 a C	5.0 a C	3.3 b DC
10	5.0 a AB	4.7 a C	5.3 a CB	3.7 b DC
12	4.3 b B	5.7 a AB	6.0 a AB	3.0 c D
14	4.7 a B	5.3 a AB	5.3 a AB	3.3 c DC
16	4.7 a B	5.7 a AB	5.3 a CB	4.3 b DC
18	5.3 ba A	5.7 ba AB	6.0 a AB	5.0 b A
20	5.3 a A	5.3 a AB	5.3 a CB	4.7 b AB
22	5.3 a A	6.0 a A	5.7 a AB	4.7 b AB
24	6.0 a A	6.0 a A	6.3 a A	4.7 b AB
26	5.3 a A	6.0 a A	—	5.0 b A
28	6.0 a A	6.0 a A	—	4.7 b AB

Means within the same row followed by the same lowercase letter* and within the same column with the same uppercase letter** are not significantly different at the 0.05 probability level based on a LSD test.

Table 2. Effect of temperature on the number of crown root axes

	Temperature (°C)			
DAP	10	20	25	30
14			3.7	—
16	—	—	6.3 a	2.5 b
18	—	—	7.3 a	3.0 b
20	—	3.0 b	9.7 a	4.3 b
22	—	5.0 b	14 a	6.0 b
24	—	11 b	19 a	9.3 b
26	2.7 c*	19 b	—	14 b
28	3.0 c	19 b	—	14 b
30	3.0 c	23 b	—	17 b

*Means within the same row followed by the same letter are not significantly different at the 0.05 probability level based on a LSD test.

axes produced by the plants grown at 25°C than those at 20 and 30°C. There was no significant ($P > 0.05$) difference in the number of crown roots at 20 and 30°C.

Elongation of the root axes

The mean axis length of seminal roots increased with time. The rate of elongation of the axes was 0.81, 1.09, 2.43 and 1.37 cm per root tip per day at 10, 20, 25 and 30°C, respectively, for 4–14 DAP, and then increased to 0.93, 1.42, 3.92 and 3.02 for 10, 20, 25 and 30°C, respectively, for 14–24 DAP. Seminal axes elongation rates increased gradually as temperature increased to 25°C, then declined at a temperature of 30°C (Fig. 1).

The mean lengths of the seminal root axes were greater at 25°C than at 10, 20 and 30°C (Fig. 1). The axes were longer at 30°C than those at 10 and 20°C, but there was no significant ($P > 0.05$) difference in length between the plants at 10 and 20°C.

Crown root length increased with time, but elongation rate decreased with time. The elongation rate of crown roots was significantly ($P < 0.05$) lower than that of seminal axes. For example, the mean elongation rate of crown roots was 0.83 cm/root tip·day at 25°C over the period of 14–24 DAP, while the elongation rate of seminal axes was 3.92 cm/root tip·day at the same temperature. Temperature response for the elongation of crown roots was similar to that of seminal root axes (Fig. 2). The average length of crown axes was greatest at 25°C, least at 10°C and intermediate at 20 and 30°C. The 10°C temperature greatly retarded root elongation.

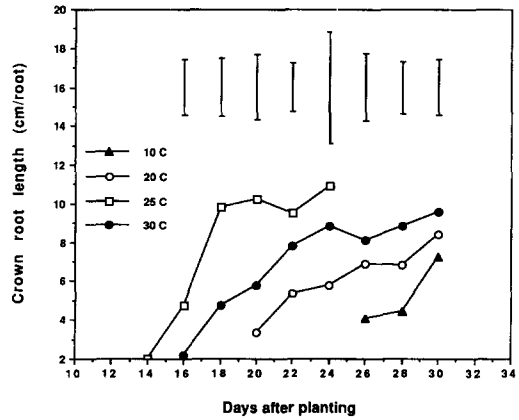

FIG. 2. Effect of temperature on the lengths of crown root axes. Vertical bars indicate LSD (0.05) for treatment comparisons at a specific time.

Root dry matter production

The dry weight of seminal roots increased with time. The rate of the incremental increase was greater at 20 and 25°C than that at 30 and 10°C (Fig. 3). The dry weight of seminal roots was significantly ($P < 0.05$) greater at 25°C than that at 10, 20 and 30°C and was greater at 20°C than

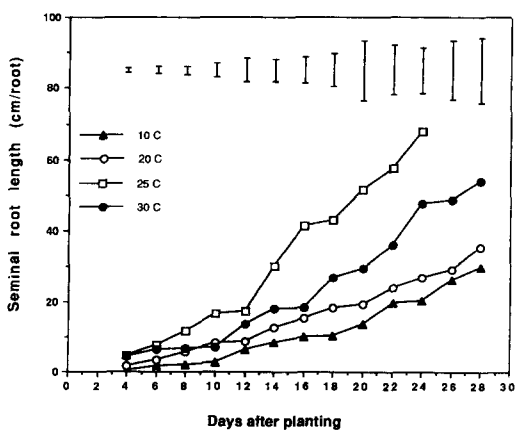

FIG. 1. Effect of temperature on the lengths of seminal root axes. Vertical bars indicate LSD (0.05) for treatment comparisons at a specific time.

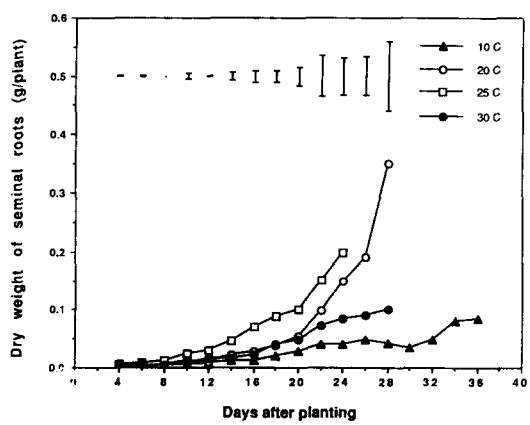

FIG. 3. Effect of temperature on the dry matter production of seminal roots. Vertical bars indicate LSD (0.05) for treatment comparisons at a specific time.

that at 10 and 30°C. The increase in temperature from 10 to 20°C doubled the daily dry matter production, while at 25°C it was more than four times greater than that at 10°C averaged over the whole sampling period. At 30°C the dry weight of the seminal roots decreased an average of 55% less than that at 25°C over the sampling period.

Dry matter production of crown roots showed a similar trend to that of seminal roots with changing temperature (Fig. 4). The dry weight of the crown roots increased with temperature to 25°C. During the first few days after root emergence, the root dry weight of the plants at 20 and 30°C did not differ significantly, but after 24 DAP the dry weight at 20°C increased faster and was significantly ($P < 0.05$) greater than that at 30°C. The dry matter production of roots was greatly ($P < 0.05$) reduced at 10°C.

Specific root lengths of seminal roots

Specific root lengths increased with temperature over the range 10–25°C (Fig. 5). The specific root lengths at 10°C were significantly less than those at 20, 25 and 30°C.

Root and shoot relationship

Root to shoot ratios (R/S) of wheat seedlings grown at 20, 25 and 30°C did not change significantly throughout much of the sampling period (Table 3). However, the R/S at 10°C increased significantly with time because the dry matter accumulation of the roots was faster than that of the shoots (Fig. 6).

The R/S at 10°C was significantly ($P < 0.05$) greater than that at 20, 25 and 30°C. There was no significant difference in the R/S among the 20, 25 and 30°C regimens.

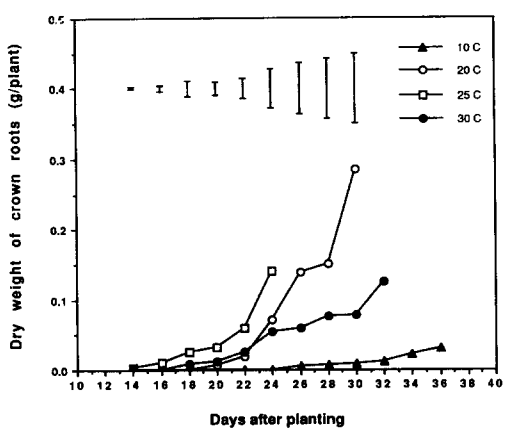

FIG. 4. Effect of temperature on the dry matter production of crown roots. Vertical bars indicate LSD (0.05) for treatment comparisons at a specific time.

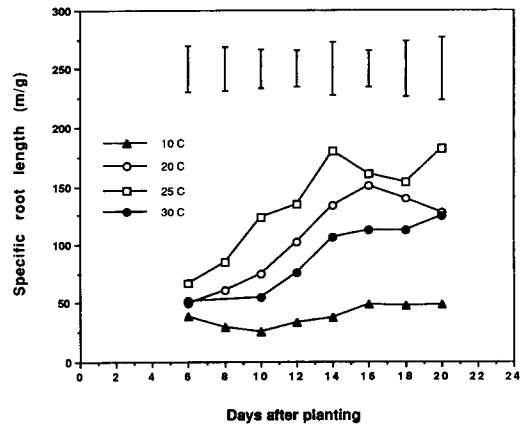

FIG. 5. Effect of temperature on the specific root length (length per unit dry weight) of seminal roots. Vertical bars indicate LSD (0.05) for treatment comparisons at a specific time.

Table 3. Effect of temperature on root/shoot ratio of wheat seedlings

	Temperature (°C)			
DAP	10	20	25	30
6	1.56 a* C	0.61 b ABC**	0.59 b B	0.95 b A
8	1.42 a CD	0.52 b C	0.56 b BC	0.62 b AB
10	0.93 a E	0.74 a A	0.80 a A	0.60 a AB
12	1.02 a E	0.72 b AB	0.73 b AB	0.82 b AB
14	1.13 a ED	0.64 b ABC	0.63 b AB	0.50 c B
16	0.97 a E	0.59 b ABC	0.59 b AB	0.54 b B
18	2.06 a B	0.57 b ABC	0.57 b B	0.58 b B
20	2.22 a AB	0.52 b C	0.57 b B	0.58 b B
22	2.67 a A	0.47 c C	0.35 c C	0.72 b AB
24	—	0.53 b BC	0.31 c C	0.64 b AB
26	2.37 a AB	0.59 b ABC	—	0.55 b B
28	2.50 a A	0.51 b ABC	—	0.58 b B

Means within the same row (*lowercase letter) or column (**uppercase letters) followed by the same letter are not significantly different at the 0.05 probability level based on a LSD test.

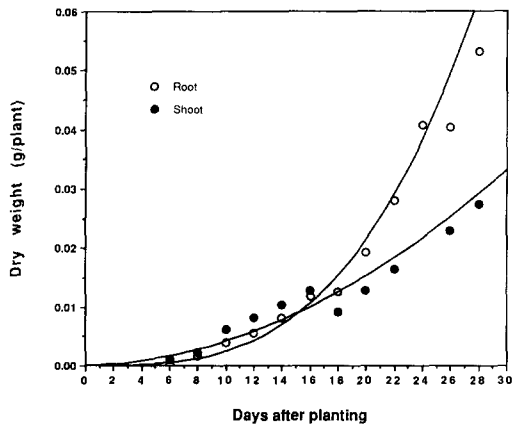

FIG. 6. Dry matter accumulation of shoots and roots at 10°C temperature.

DISCUSSION AND CONCLUSIONS

Discernible protrusion of the seminal and crown root axes occurred faster at 25°C, and also more seminal axes had emerged at 4 DAP at 25°C than at other temperatures. Temperatures above and below 25°C reduced the rate of root emergence. These results indicate that 25°C is a favorable temperature in early seedling establishment.

The plants at 10°C had no crown roots that emerged until 25 DAP and produced fewer and shorter roots than those at the higher temperatures.

The 30°C temperature limited the number of seminal root axes. The metaxylem diameter in the seminal axes has also been shown to be reduced by a 30°C temperature when compared with 10 or 20°C.[14] Before the crown roots develop, the axial resistance to water flow in wheat root depends largely on the number of seminal axes and diameter of the xylem vessel in those seminal axes. The axial resistance can be increased by decreasing the number of seminal root axes and the diameter of the main xylem vessel in these axes.[24] Therefore, the results in this study indicate that seedling wheat plants grown at 30°C should offer a larger axial resistance to water flow than those grown at 10 or 20°C.

The optimum temperature for elongation of both seminal axes and crown axes of wheat was 25°C in this experiment. Plants grown at 10°C had significantly shorter root lengths per unit dry weight than those grown at higher temperatures. Dry matter accumulation of the roots was greatest at 25°C, least at 10°C and intermediate at 20 and 30°C. Root to shoot ratios were much greater at 10°C than at the higher temperatures, because shoot growth is reduced more than root growth at lower temperatures.[6,19] DAVIS and LINGLE[7] similarly observed that a 15°C root temperature caused a higher R/S than a 25°C temperature. ATKIN *et al.*[2] measured the export of growth substances from the roots to the shoots of corn, and concluded that the depression of shoot growth by low root temperature was due to an altered production of growth substances in the root system.

In conclusion, this experiment demonstrated that temperature significantly affected root growth and development of wheat seedlings. The plants at 25°C had a well-developed root system. This research also distinguished between the growth and response of the seminal and crown root systems. Seminal and crown roots had similar responses to temperature in respect to root extension and dry matter production. However, the emergence and number of seminal and crown roots responded differently to temperature. The production of seminal axes was restricted by a higher temperature (30°C), while production of crown roots was inhibited by a lower temperature (10°C). At the same temperature, seminal axes had greater elongation rates than crown roots; crown roots emerged much later than seminal axes; the number of crown root axes continued to increase with time, while the number of seminal root axes increased for a period of time that depended on temperature and then stabilized.

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