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Monitoring Russian Thistle (*Salsola iberica*) Root Growth Using a Scanner-Based, Portable Mesorhizotron[1]

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Abstract: A mesorhizotron and scanning system was modified to study the development of Russian thistle root systems during the 1996 and 1997 growing seasons at Lind, WA. Our imaging equipment combined the full profile images afforded by conventional rhizotrons with the portability of cylinder-based minirhizotron systems at a fraction of the cost of either system. Root development of Russian thistle in early spring was rapid and extensive compared with shoot growth. In 1996, 30 d after planting (DAP) Russian thistle roots were at least five times as long as the corresponding plant's shoots. During the next 20 d, shoots grew a maximum of 20 cm, whereas roots grew a maximum of 120-cm deep. Maximum root elongation rate reached 2 to 3 mm/cm^2/d at the 70- to 120-cm depths 30 to 50 DAP in 1996 and 55 to 70 DAP in 1997. More than one (multiaxial grouping) Russian thistle root was often observed growing through the same soil channels. After the rapid early season growth, roots began to shrink or die back until shoots were clipped to simulate wheat harvest. Within 7 d after harvest, roots regenerated in old root channels. Our mesorhizotron system is a promising inexpensive tool for monitoring root morphological development of Russian thistle under field conditions.

Nomenclature: Russian thistle, *Salsola iberica* Sennen and Pau #[3] SASKR; wheat, *Triticum aestivum* L.
Additional index words: Root development in situ.
Abbreviations: DAP, days after planting; RER, root elongation rates.

INTRODUCTION

Russian thistle is a drought-tolerant annual broadleaf weed that flourishes in the arid and semiarid regions of the world. Many biological and ecological studies of Russian thistle have been conducted in greenhouse, laboratory, and noncropland environments (Evans and Young 1982). Other studies of interest have promoted the use of Russian thistle skeletons for postharvest residue compliance (Schillinger et al. 1999), evaluation of the plant's forage value for livestock feed (Cave et al. 1936), and identification of allelopathic chemicals from the plant's leaves (Lodhi 1979). Russian thistle is often the dominant broadleaf weed in the wheat production areas of the Pacific Northwest (Young 1986; Young and Gealy 1986) and bordering regions of Canada (Thomas and Wise 1983). In Washington, Russian thistle reduced spring wheat yield > 50% (Young 1988), used 170 L of soil water per plant during a growing season (Schillinger and Young 2000), and has impeded the adoption of no-till alternative spring crops.

Shoot growth of Russian thistle in early spring in the growing crop is normally very slow because of cool, moist conditions (Young 1986). Yet Russian thistle is extremely competitive (Young 1988); this nature may be attributed to its aggressive root system. Successful weed competitors generally establish root systems early and contain fibrous subsurface roots and deep penetrating main roots (Pavlychenko and Harrington 1934, 1935). Little research has been conducted on seasonal Russian thistle root growth and development. Information on Russian thistle root growth and productivity has been from destructive sampling of plants excavated at the end of the growing season (Pavlychenko 1937). Destructive sampling results in loss of fine roots and introduction of experimental error because of plant to plant variation in root morphology. Root imaging methods offer the capability to monitor roots of the same plant throughout the growing season, enabling researchers to more precisely characterize seasonal patterns of root development. Knowledge of seasonal root development patterns of weeds is important for understanding the biology and ecology of weed–crop interactions. Knowing the rooting

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[3] Letters following this symbol are a WSSA-approved computer code from *Composite List of Weeds*, Revised 1989. Available only on computer disk from WSSA, 810 East 10th Street, Lawrence, KS 66044-8897.

pattern and development rate of weed roots will assist growers in selecting competitive crops, as well as time of fertilizer application and fertilizer placement.

Plant roots growing through soil can be observed with transparent viewing planes of rhizotrons, minirhizotrons, and other clear-faced containers (Bohm 1974; Glinski et al. 1993). Transparent viewing planes provide researchers the opportunity to obtain qualitative pictures of root systems, as well as quantitative assessments of relative effects of genetic, environmental, and management variables. They allow us to observe the dynamics of root growth and development of the same plant through an entire growth cycle.

Rhizotrons are underground root observation laboratories costing well over $100,000 (McMichael and Taylor 1987) that allow scientists to climb underground and observe the root development of plants established next to viewing windows (Smit et al. 1994; Taylor et al. 1970). The immobility and expense of these underground laboratories have limited the widespread adoption of this root observation technique.

Minirhizotrons are portable glass tubes inserted in soil to provide a snapshot view of roots growing past the angled tube (Box et al. 1989; Upchurch and Ritchie 1983). Researchers have had mixed success at determining realistic root densities using minirhizotrons (Heeraman and Juma 1993; Majdi et al. 1992; Parker et al. 1991; Samson and Sinclair 1994). However, these instruments are useful to measure root turnover (Cheng et al. 1991). Computer-linked color line scanners, originally designed for desktop publishing purposes, offer affordable ($< \$5,000$) and superior imaging capability for generating digitized plant root images (Doty et al. 1995; Pan and Bolton 1991). A low cost, portable mesorhizotron system has been developed for in-field imaging of potato (*Solanum tuberosum* L.) roots (Pan et al. 1998). Results from the potato study concluded that seasonal patterns of digitally imaged roots were similar to patterns established with destructive sampling (Pan and Hiller 1992), and segmenting the mesorhizotron profile into zones allowed researchers to interpret the temporal and spatial distribution of roots. Previous to our Russian thistle study, this system has not been used to monitor root growth and development of weeds.

The objective of this study was to modify the potato mesorhizotron system, use it to profile two-dimensional images of field-grown Russian thistle root systems, and evaluate vertical root growth of Russian thistle over time.

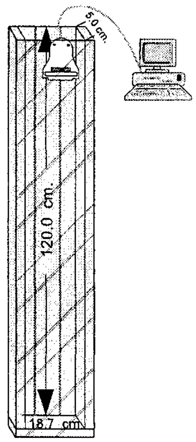

Figure 1. Diagram of modified mesorhizotron and scanning system for Russian thistle roots.

MATERIALS AND METHODS

General. The root imaging system (Figure 1) we used for studying Russian thistle roots was a modification of a mesorhizotron system designed to study potato roots (Pan et al. 1998). The basic components of the system include: (1) a glass-faced box (5 cm by 19 cm by 122 cm) buried in the soil, (2) a portable hand scanner, supporting carriage, and motorized retrieval system, and (3) a generic computer system for storing and analyzing the images. The boxes were constructed with a wooden frame and 0.5-cm-thick tempered plate glass on one side. For our mesorhizotron system, a portable scanner[4] was the image-capture device used, which produced a maximum single-scan size of 10.4 cm by 120 cm. The images were created in 24-bit RGB color at 200 dots per inch resolution. The scanner was connected to an AC/CRT P133 computer with 64 MB RAM, 5.0 GB hard drive, and 24-bit RGB color display. Pixeled images of the roots were created with a custom software program and stored on the computer's hard disk. Each glass-faced box was scanned twice vertically at each date. Mesorhizotron modifications for the Russian thistle study compared with the potato study (Pan et al. 1998) included a longer glass-faced box (Figure 1), a larger scan size, and a reduced number of scans per box. Image files from each mesorhizotron box required approximately 50 MB of disk storage space on the hard drive.

This modified system was used to monitor Russian thistle root growth in 1996 and 1997 at the Dryland Research Station at Lind, WA. The soil was a Shano silt loam (coarse-silty, mixed, mesic Xeric Haplocambids) with $< 1\%$ organic matter and a pH of 6.5. Three glass-

[4] Logitech Inc., Corporate Headquarters, 6505 Kaiser Drive, Fremont, CA 94555.

faced boxes (replicates) were buried in the soil in a late March-planted spring wheat field. Five Russian thistle seeds were planted within 1 cm of the glass face, 1.7 cm below the soil surface in front of three boxes beginning early April each year. Seedlings became established after an early May planting (frost killed several earlier plantings) in 1996 and a mid-April planting in 1997. Populations were then thinned to two plants per box. Each box was scanned at 2- to 4-wk intervals throughout the growing season and after wheat harvest until frost killed the plants.

Image Processing and Analysis. Individual scan files were stitched together to create full profile images. Twenty-four bit color depth potentially generates 16.7 million colors that can be used to discriminate the roots from soil background. Images were printed with a color ink jet printer and clear acetate was laid over the printout. The roots were traced on the acetate sheet and then the tracings were scanned with a desktop scanner (HP Scanjet 4C and IIC).[5] The tracings were analyzed with the ROOTLAW[6] software program (Pan and Bolton 1991) for determination of root length. Root lengths per unit of mesorhizotron viewing area for each sampling time were calculated as root elongation rates (RER) = $(l_2 - l_1)/(t_2 - t_1)$, where l_1 and l_2 are root lengths at sampling times t_1 and t_2, respectively. Root elongation rate data at each sampling period for a particular soil depth are subjected to analysis of variance and mean separation using Fisher's protected least significant difference at $\alpha = 0.05$.

RESULTS AND DISCUSSION

The line scanner-based mesorhizotron system was a cost effective method (< \$5,000) to examine the seasonal root dynamics of Russian thistle. In the field, each glass box was scanned in only 15 to 20 min. The high resolution of the color scanner discriminated roots from the soil.

Precipitation from March through October (crop and Russian thistle growing season) was 138 mm in 1996 and 178 mm in 1997. Long-term average precipitation for this time period is 132 mm. On May 31, 1996 (30 DAP), initial Russian thistle roots had grown to a depth of 45 cm (Table 1), whereas the plant's corresponding shoots were only 5- to 10-cm tall (data not shown). During the next 20 d, Russian thistle shoots grew 12 to 20 cm and produced 10 to 12 branches. During this same short period of time, Russian thistle produced extensive new roots ranging between 20- and 120-cm deep (Table 1, Figure 2). Multiaxial grouping of Russian thistle roots through the same soil channels (Figure 3) occurred as root densities exceeded 5 mm/cm^2 at 60- to 120-cm depths and RER that ranged from 1.44 to 2.94 mm/cm^2/d at a depth ranging from 45 to 120 cm (Table 1). The highest elongation rates occurred at the lowest depths (Table 1). Following this early development of deep root growth, Russian thistle root dieback was apparent between 50 and 86 DAP at which time negative RERs were observed (Table 1, Figure 2). This decline continued until wheat harvest (107 DAP) when Russian thistle top growth was manually cut to simulate the combine cutter bar. Whether the declining RER represents a reallocation of carbon to the shoot or to other portions of the root system not visible with the mesorhizotron is not known at this time. Similar root dynamics have been observed in potato comparing the mesorhizotron system (Pan et al. 1998) and destructive sampling (Pan and Hiller 1992). In potato, roots either disappeared or shrank in size 60 DAP (late tuber bulking).

New growth of Russian thistle roots was observed in old root channels 7 d after wheat harvest (114 DAP), particularly at the 20- to 45-cm depth. This new root growth occurs more rapidly than postharvest shoot growth, which increases measurably 14 d after harvest (Young 1986).

Russian thistle root growth in 1997 (Table 2) was not as rapid and extensive as in 1996 (Table 1). This may have been because of the warmer and drier establishment conditions in 1996. Russian thistle plants were established in May 1996 compared with April 1997. Nevertheless, roots grew extensively to a depth of 70 cm be-

Table 1. Relative root elongation rates of Russian thistle per unit viewing area, as detected by portable scanning mesorhizotrons during the 1996 growing season at Lind, WA.[a,b]

	Days after planting				
Soil depth	0–30	30–50	50–86	86–107	107–114
cm	mm/cm^2/d				
0–20	0.37 a	−0.03 ab	−0.15 b	−0.19 b	0.04 ab
20–45	0.19 ab	0.41 a	−0.13 bc	−0.22 c	0.44 a
45–70	0.04 b	1.44 a	−0.55 b	−0.23 b	0.41 ab
70–95	0.0 ab	2.94 a	−1.28 b	−0.41 ab	0.19 ab
95–120	0.0 ab	2.64 a	−1.30 b	−0.21 ab	0.37 ab

[a] Each value represents the mean of three mesorhizotrons over specified depth increments and sampling periods.

[b] Means followed by the same letters within a row (among sampling periods at each depth) do not differ at the $\alpha = 0.05$ significant level by Fisher's protected LSD.

[5] HP Scanjet 4C and IIC desktop scanner. Hewlett Packard, 3000 Hanover Street, Palo Alto, CA 94304-1185.

[6] Pan and Bolton, 1991, Washington State University Research Foundation, Pullman, WA 99164.

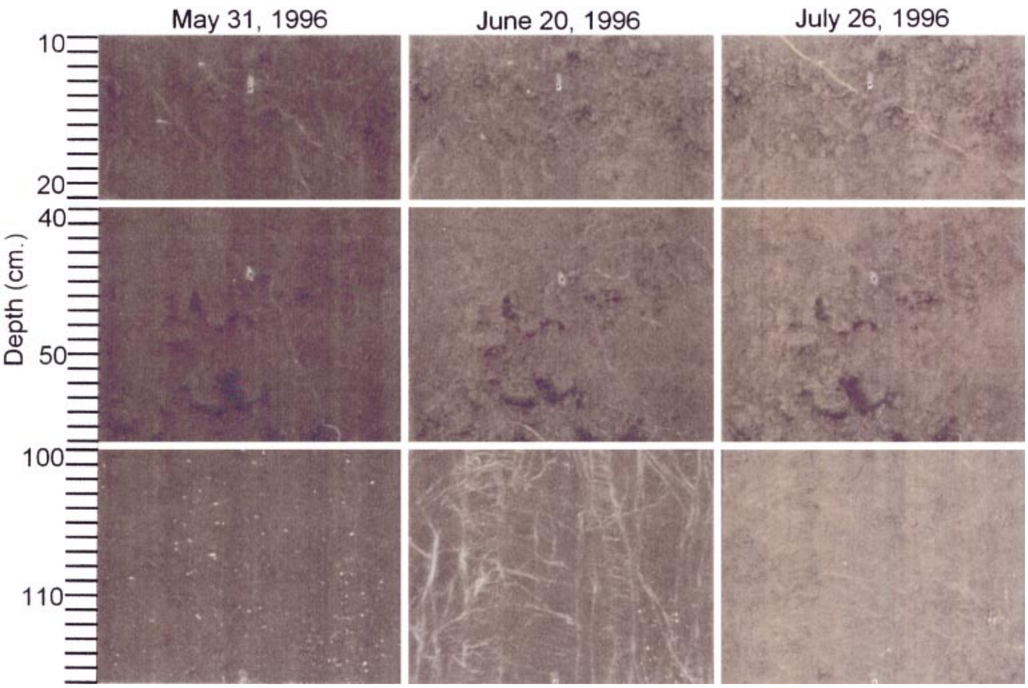

Figure 2. Sections of root profile images (10 to 21 cm, 40 to 56 cm, and 100 to 116 cm) of two Russian thistle plants scanned on May 31, June 20, and July 26, 1996. Soil color differs among depths over time caused by changes in soil water content.

Figure 3. Subsection of root image captured on June 26, 1996 at 99 to 107 cm. Image is presented as actual size to demonstrate lateral branching and multiaxial grouping of roots through the same soil channel.

tween 30 and 55 DAP in 1997. In contrast, shoots were only 8- to 12-cm tall with five to eight branches per plant (data not shown). This pattern of early root development compared to shoot development during both years partially explains depletion of soil water by Russian thistle (Schillinger and Young 2000) and the subsequent yield loss of spring wheat (Young 1988). It also demonstrates the importance of early planting and seedling establishment of spring crops in relation to Russian thistle germination and subsequent root development. When spring wheat emerged 2 wk before Russian thistle, weed competition was considerably less than when spring wheat emerged 1 wk before Russian thistle (Young 1988). Root growth in the field increased dramatically in the 45- to 120-cm depth between 55 and 70 DAP (Table 2). At this time, RER approached 2 $mm/cm^2/d$. As in 1996, roots then died back until shoots were cut at harvest. New root growth occurred after harvest in 1997 with significant increases in RER at 70 to 95 cm. Root scanning in the field continued through mid-November until killing frost each year.

Our system of tracking in situ roots of individual Russian thistle plants over time and space was cost effective and efficient. The system allowed us to observe this weed's capability to produce roots to depths of 120 cm early in the growing season, as well as the potential for new root growth after harvest. Our data on Russian this-

Table 2. Relative root elongation rates of Russian thistle per unit viewing area, as detected by portable scanning mesorhizotrons during the 1997 growing season at Lind, WA.[a,b]

Soil depth	Days after planting					
	0–30	30–55	55–70	70–91	91–118	118–126
cm	mm/cm²/d					
0–20	0.01 a	0.13 a	0.19 a	−0.21 a	0.14 a	−0.20 a
20–45	0.0 a	0.19 a	−0.19 a	0.16 a	−0.12 a	0.04 a
45–70	0.0 ab	0.25 ab	0.92 a	−0.62 b	−0.24 b	0.03 ab
70–95	0.0 bc	0.09 bc	1.97 a	−0.88 d	−0.34 cd	0.39 b
95–120	0.0 b	0.05 b	1.95 a	−0.24 bc	−0.60 c	−0.18 bc

[a] Each value represents the mean of three mesorhizotrons over specified depth increments and sampling periods.

[b] Means followed by the same letters within a row (among sampling periods at each depth) do not differ at the $\alpha = 0.05$ significance level by Fisher's protected LSD.

tle are consistent with Pavlychenko and Harrington's (1934, 1935) statements that competitive weeds are the ones that establish root systems early and deep. This information helps explain why this weed can remove up to 70 L/plant of soil moisture when growing in a crop and is very competitive with spring wheat (Young 1988). Late-season root growth allows Russian thistle to remove 100 L of soil moisture postharvest (Schillinger and Young 2000). Because Russian thistle can extract soil water from a lateral distance (base of plant) of 1.5 m and a vertical distance (soil surface) of > 1.8 m, an expanded window box size would allow researchers to fully characterize the horizontal and vertical development of the entire Russian thistle root system.

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