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Estimating Annual Root Decomposition in Grassland Systems☆

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ABSTRACT

Calculated belowground buried root bag decomposition rates may be impacted by soil disturbance and that mesh bags can exclude potential degraders. This paper explicitly compares the sequential soil sampling method to the buried root bag approach to determine if biomass degradation estimates over a season differ. The research was conducted at two eastern South Dakota grassland sites (loamy and thin upland ecological sites) in 2011 and 2012 in an area where the grassland vegetation was killed to prevent new root growth. In the sequential core technique, a composite sample consisting of three 4-cm diameter soil cores from the 0- to 15- and 15- to 30-cm depth were collected monthly from May to October, whereas five residue bags were placed 7 cm below the soil surface in spring and removed at the last soil sampling date. The sequential core (61% ± 7.2) and residue bag (58% ± 7.2) techniques had similar root decomposition amounts; however, the sequential core technique had a lower labor requirement than the residue bag technique when the increased sampling requirement was considered.

Introduction

In rangeland systems, assessing vegetation resilience and adaptability is confounded by perennial species that have root lifespans that usually exceed several years. In addition, root-to-shoot ratios are often based on live + dead roots as opposed annual growth (Mokany et al. 2005). Techniques used to assess annual root production include 1) sequential coring and subtracting the minimum biomass from the maximum biomass, 2) sampling at peak root biomass and sorting live and dead roots by inspection or by using stains, 3) using minirhizotrons to observe and calculate root growth (Cook and Stubbendieck 1986), and 4) measuring root growth into ingrowth cores (Chang et al. 2014; Hayes and Seastedt 1987; Johnson and Matchett 2001; Sims and Singh 1978; Titlyanova et al. 1999). Each technique has unique strengths and weaknesses. For example, the use of stains to separate live and dead roots has been limited by stain intensity being influenced by plant species, root age, and the storage time of the soil samples (Gregory 2006; Ward et al. 1978), whereas calculations based on sequential or annual soil coring may not integrate root degradation rates into root estimates (Weaver 1958).

Root degradation rates have been estimated using buried root bags (Chen et al. 2002; Harmon et al. 1999; Smith and Bradford 2003). This approach is quick, not labor intensive, and widely used. However, two key disadvantages are that it requires soil disturbance to bury the bags, which may introduce anomalous effects such as increased microbial activity due to the disturbance, and the root bag mesh size must be carefully chosen, as this parameter can influence biomass degradation rates (Smith and Bradford 2003). This paper explicitly compares the sequential soil sampling method to the buried root bag approach to determine if biomass degradation estimates over a season differ.

Materials and Methods

Study Sites

The research was conducted at loamy (44°20′6″N and -96°48′28″W) and thin upland (44°23′1″N and -96°57′29″W) ecological grassland sites in eastern South Dakota. The climatic conditions at both sites are characterized by cold winters and hot summers, a growing season from April to October, a frost-free period that ranges from 120 to 160 days, and an average annual temperature of 6.5oC. Rainfall in 2011 and 2012 was 380 and 383 cm, respectively.

The soil at the loamy ecological site was well drained, classified as a Barnes clay loam (fine-loamy, mixed, frigid Udic Haploborolls), and the slope ranged from 0% to 2%. At this site, big bluestem (*Andropogon gerardii* Vitman) was interseeded in 2005 and the dominant plant species were big bluestem, smooth bromegrass (*Bromus inermis* Leyss. subsp. inermis), and Kentucky bluegrass (*Poa pratensis* L.) (Smart et al. 2013).

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At the thin upland ecological site, the soil was well drained and classified as Buse-Poinsett complex (fine-loamy, mixed, frigid Udic Calciborolls). The slope ranged from 9% to 15%. The dominant plant species were green needlegrass (*Nassella viridula* [Trin.] Barkworth), porcupine grass (*Hesperostipa spartea* [Trin.] Barkworth), little bluestem (Schizachyrium scoparium [Michx.] Nash), sideoats grama (*Bouteloua curtipendula* [Michx.] Torr.), big bluestem, smooth bromegrass, Kentucky bluegrass, Canada thistle (*Cirsium arvense* [L] Scop.), musk thistle (*Carduus nutans* L.), yellow sweet clover (Melilotus officinalis [L.] Lam.), western snowberry (*Symphoricarpos occidentalis* Hook.), and prairie rose (*Rosa arkansana* Porter).

Annual Root Decomposition

Root degradation rates were measured using two techniques in a 21 m^2 area where the plants were killed. At the two study sites, glyphosate [N-(phosphonomethyl) glycine] was applied on 3 May 2011, 17 May 2011, 9 June 2011, and 28 July 2011. The experiment was repeated in 2012 at an adjacent area, and appropriate rates of acetochlor [2-Chloro-N-(2,6-diethylphenyl)-N-(methoxymethyl)acetamide] and atrazine [6-chloro-N-ethyl-N-(1methylethyl)-1-3-5-triazine-2-4-diamine] herbicides were applied on 26 April 2012, 18 May 2012, 25 May 2012, 27 June 2012, and 27 July 2012. For the sequential core technique, three soil cores from 0- to 15-cm and 15- to 30-cm soil depths were obtained and composited within a sampling date six times from May to October using a 3.97 cm diameter soil probe. Soil samples were immediately stored in a cold room (5°C) and analyzed for total roots with soil removed using a hydropneumatic elutriator (Chang et al. 2014; Smucker et al. 1982). During washing, roots and other organic materials were separated from the fine soil particles with a submerged low kinetic energy primary sieve (#925). The minimum kinetic energy of water moving across the submerged sieve permitted retention of very fine roots on a relatively coarse sieve without breaking laterals and root hairs. The primary sieved materials were transferred onto a very fine secondary sieve (#437). The roots and other organic materials were hand separated, and roots were dried at 60°C and weighed.

In the buried root bag approach, in situ root decomposition was measured in the herbicide-killed plots using techniques discussed by Harmon et al. (1999) and Chen et al. (2002). Root samples, taken from the 0- to 15-cm depth, were collected within each study site in mid-May, washed from the soil as described earlier, and oven-dried at 60°C. Root sample bags, each 20- × 20-cm and made of 1.5-mm mesh fiberglass, contained 15 g of the dried root material. The five bags were buried 7 cm deep and 1 m apart. At the end of the growing season, the bags were retrieved, residue removed, cleaned, dried, and weighed.

For the sequential core method, the first-order degradation rate was calculated using the equation:

$$\ln(y_t) = \ln(y_o) - k(t) \quad (1)$$

where *yt* was the amount of root biomass remaining in the plots at time *t*, *k* was the first order rate constant, and y_o was the hypothetical amount of dead roots in the spring (either 25%, 50%, or 100%). The half-life of the root biomass for the sequential core approach (Mamani-Pati et al. 2010) was calculated by:

$$y1/2 = \ln 2 \cdot k^{-1} \quad (2)$$

Shoot Growth and Root-to-Shoot Ratios

This experiment was previously described by Smart et al. (2013) and summarized as follows. In unfertilized plots, aboveground shoot biomass was measured in the fall following a killing frost, and root biomass from 0 — 15- and 15–30 cm was measured in the spring and fall of 2011 and 2012. Each treatment was replicated four times, the plots had the dimensions of 3 × 6 m, and the root measurements were identical to that described earlier. Annual root biomass production for three scenarios was calculated from two soil cores, one from each 0.1 m^2 plot where the aboveground biomass was sampled. The scenarios were that 25%, 50%, and 100% of the spring roots were dead. The 25% and 50% dead root values were the likely ranges of dead root biomass (Blair 1997; Hayes and Seastedt 1987; Johnson and Matchett 2001; Sims and Singh 1978; Titlyanova et al. 1999; van der Maarel and Titlyanova 1989). The equation ln (yt) = ln(yo) – k(t) was used to calculate the amount of dead roots remaining in the soil in the fall. In this calculation, time was 200 days, k was the first-order degradation rate, and y_0 was the appropriate percentage of the measured spring roots. The new annual root growth (ARG) was calculated with the equation ARG = [FR – (RDR + LSR)], where FR was measured fall roots, RDR was the hypothetical fraction (25%, 50%, or 100% of dead spring roots) that did not decompose, and LSR was the live spring roots. Vegetative biomass was measured by clipping two 0.1 m^2 quadrats, using grass shears as close to the soil surface as possible, after a killing frost from each plot. Biomass was dried at 60°C to constant weight. Annual root growth — to-shoot ratios were determined.

Statistical Analysis

The sequential core method and root residue bag methods were statistically compared using a t-test, in which it was assumed that variances were not equal. The variances of the two methods were compared using an F statistic. On the basis of sequential core root degradation rates, annual root growth and root-to-shoot ratios were

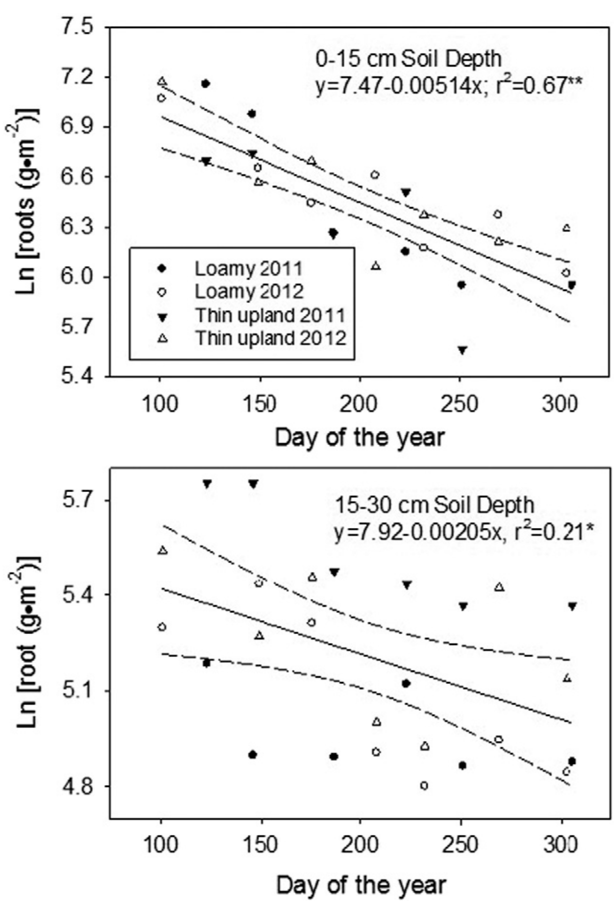

Figure 1. The relationship between natural log (ln) root in the soil and day of the year in the loamy and thin upland ecological grassland sites in 2011 and 2012 at 0- to 15-cm and 15- to 30-cm soil depths. The slope (x) is the first order rate constant for the degradation of the dead roots.

Table 1
Worksheet demonstrating the use of the root decay rate constant (k) in the calculation of annual root growth based on three hypothetical amounts of dead roots contained in the soil in the spring (25%, 50%, and 100% of the spring roots were dead). Data from the 0- to 15-cm and 15- to 30-cm soil depths are provided. The study was conducted at loamy and thin loamy ecological sites in 2011 and 2012. The annual root growth (ARG) was calculated with the equation ARG = [FR – (RDR + LSR)], where FR was measured fall roots, RDR was dead spring roots that did not decompose, and LSR was live spring roots.

			Spring	Fall	
Site	Yr	Root decay rate (k)	Total roots	Total roots	Annual root growth
0 – 15 cm		$g \cdot (g \cdot day)^{-1}$	$g \cdot m^{-2}$	----- $g \cdot m^{-2}$ -----	
25% Spring roots dead					
Loamy	2011	0.0051	1 267	1 517	453
	2012	0.0051	1 140	1 445	487
Thin upland	2011	0.0051	1 000	1 117	277
	2012	0.0051	963	1 395	586
50% Spring roots dead					
Loamy	2011	0.0051	1 267	1 517	655
	2012	0.0051	1 140	1 445	669
Thin upland	2011	0.0051	1 000	1 117	437
	2012	0.0051	963	1 395	740
100% Spring roots dead					
Loamy	2011	0.0051	1 267	1 517	1 060
	2012	0.0051	1 140	1 445	1 034
Thin upland	2011	0.0051	1 000	1 117	756
	2012	0.0051	963	1 395	1 048
15 – 30 cm					
25% Spring roots dead					
Loamy	2011	0.00205	219	237	36
	2012	0.00205	188	215	43
Thin upland	2011	0.00205	263	248	7
	2012	0.00205	259	346	109
50% Spring roots dead					
Loamy	2011	0.00205	219	237	55
	2012	0.00205	188	215	59
Thin upland	2011	0.00205	263	248	29
	2012	0.00205	259	346	131
100% Spring roots dead					
Loamy	2011	0.00205	219	237	92
	2012	0.00205	188	215	90
Thin upland	2011	0.00205	263	248	74
	2012	0.00205	259	346	174

estimated for rangeland root and shoot growth in plots described by Smart et al. (2013). Root growth rates were compared when it was assumed that 25%, 50%, and 100% of the spring roots were dead. Means and 95% confidence intervals (CIs) were calculated for each parameter.

Results and Discussion

Root Decomposition

Root decomposition in the 0-to 15-cm soil depth followed first-order kinetics, and the calculated root degradation rate (k) was 0.00514 g $(g \cdot day)^{-1}$ with the 95% CI calculated from the regression analysis ($0.00362 < k < 0.00665$) (Fig. 1). Root degradation was much slower in the 15- to 30-cm depth compared with degradation in the 0- to 15-cm soil depth. The k value for the 15- to 30-cm depth was 0.00205 g $(g \cdot day)^{-1}$ with a 95% CI ($0.00101 < k < 0.00304$). Over the 2 years of the study, dead roots in the 0- to 15-cm soil depth had a half-life of 135 days, whereas dead roots in the 15- to 30-cm soil depth had a half-life of 277 days. The lower loss rate in the 15- to 30-cm than the 0- to 15-cm soil depth was likely associated with lower O2 concentrations (Clay et al. 2015; Linn and Doran 1984). Soil depth differences in soil organic C mineralization in an annual cropped soil system were previously reported by Clay et al. (2015).

Table 2
Calculated root-to-shoot ratios based on measured shoot production, root production in the spring and fall, and root degradation rates. Root-to-shoot ratios were calculated for hypothetical amounts of dead roots contained in the soil in the spring (25%, 50%, and 100% of the spring roots were dead). The percentage of root biomass contain in the surface 30 cm was calculated.

Site	Yr	Shoot growth	Calculated annual root growth	Annual root/shoot ratio	Total root/shoot ratio	Percent current yr biomass in roots
25% Spring roots dead	$g \cdot m^{-2}$	$g \cdot m^{-2}$			%	
Loamy	2011	839	453	0.58	2.09	35.1
	2012	1 000	487	0.53	1.66	32.8
Thin upland	2011	355	277	0.8	3.85	43.8
	2012	590	586	1.18	2.95	49.8
50% Spring roots dead						
Loamy	2011	839	655	0.85	2.09	43.8
	2012	1 000	669	0.73	1.66	40.1
Thin upland	2011	355	437	1.31	3.85	55.2
	2012	590	740	1.48	2.95	55.6
100% Spring roots dead						
Loamy	2011	839	1 060	1.37	2.09	55.8
	2012	1 000	1 034	1.12	1.66	50.8
Thin upland	2011	355	756	2.34	3.85	68.0
	2012	590	1 045	2.07	2.95	63.9

The buried residue bags (58% ± 7.2) and the sequential core method (61% ± 7.7) had similar ($P > 0.10$) amounts of degraded roots in the surface soil over the growing season. Others have reported similar values (Chen et al. 2002; Gill et al. 2002; Sims and Singh 1978). However, the variances for the sequential core and residue bag approaches were 62 and 270, respectively, and on the basis of the F statistic (4.32) they were not different ($P = 0.13$).

Even though the sequential core and residue bag methods had similar amounts of root biomass decomposed, there were fundamental differences between the methods. First, the labor processing time per bag for each buried residue bag was about half the time required for the sequential core technique. Second, the sequential core method tended to have a lower variance ($P = 0.13$) than the residue bag approach. However, when the number of duplicated sampling bags is considered, the total time requirement is greater than the sequential core. In addition, the sequential core approach requires an area where the biomass was killed, whereas installing and retrieving residue requires soil disturbance.

To demonstrate the importance of considering root degradation when calculating root-to-shoot ratio, two worksheets were constructed based on hypothetical amounts of live and dead contained in the site in the spring (Tables 1 and 2). In this calculation, the first-order root degradation rate constants were used to calculate root loss from the dead roots, followed by calculated root growth and annual root growth − to-shoot ratios. This calculation is fundamentally different than Mokany et al. (2005) where all roots were included in the root-to-shoot ratios.

Annual aboveground biomass production ranged from 355 to 1000 g m^{-2} at the research sites (see Table 2), and estimated annual root growth increased with the percentage of the samples that were considered dead in the spring. For example, increasing the % dead from 25% to 100% increased the estimated annual root growth 216% (see Table 1).

Using the Mokany et al. (2005) approach, the root-to-shoot ratio was 2.63 ± 0.95. In this calculation the roots are defined by the equations, total roots = dead roots + root produced in previous years + current growth. This value cannot be used to estimate annual growth or the annual allocation of plant resources to aboveground and belowground components. The calculated amount of new root biomass was influenced by the dead root degradation rates and the amount of dead roots in the soil before growth. If 25% and 100% roots in the soil were dead before growth, then average annual root growth − to-shoot ratios were 0.77 ± 0.29 and 1.50 ± 0.56, respectively (see Table 2). On the basis of these values, the percentage of new root biomass relative to total biomass in the fall was 40.6% and 59.7% if 25% and 100% spring roots were dead. Clearly, carbon budgets need accurate accounting of root degradation and growth.

Implications

In summary, the use of a herbicide treatment to kill the vegetation provided a location to estimate root decomposition. The sequential core (61% ± 7.2) and residue bag (58% ± 7.2) techniques had similar root decomposition amounts; however, the sequential core technique had a lower labor requirement than the residue bag technique when the increased sampling requirement was considered. The residue bag technique is still a viable method to determine root degradation rates of dead roots.

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