



Fine root dynamics, coarse root biomass, root distribution, and soil respiration in a multispecies riparian buffer in Central Iowa, USA

A. TUFEKCIOGLU¹, J. W. RAICH², T. M. ISENHART¹ and R. C. SCHULTZ¹

¹Department of Forestry, 253 Bessey Hall, Iowa State University, Ames, IA 50011, USA, E-mail: atufekcl@iastate.edu; ²Department of Botany, 353 Bessey Hall, Iowa State University, Ames, IA 50011, USA

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Abstract. By influencing belowground processes, streamside vegetation affects soil processes important to surface water quality. We conducted this study to compare root distributions and dynamics, and total soil respiration among six sites comprising an agricultural buffer system: poplar (*Populus × euroamericana* 'Eugenei'), switchgrass, cool-season pasture grasses, corn (*Zea mays* L.), and soybean (*Glycine max* (L.) Merr.). The dynamics of fine (0–2 mm) and small roots (2–5 mm) were assessed by sequentially collecting 35 cm deep, 5.4 cm diameter cores from April through November. Coarse roots were described by excavating 1 × 1 × 2 m pits and collecting all roots in 20 cm depth increments. Root distributions within the soil profile were determined by counting roots that intersected the walls of the excavated pits. Soil respiration was measured monthly from July to October using the soda-lime technique. Over the sampling period, live fine-root biomass in the top 35 cm of soil averaged over 6 Mg ha⁻¹ for the cool-season grass, poplar, and switchgrass sites while root biomass in the crop fields was <2.3 Mg ha⁻¹ at its maximum. Roots of trees, cool-season grasses, and switchgrass extended to more than 1.5 m in depth, with switchgrass roots being more widely distributed in deeper horizons. Root density was significantly greater under switchgrass and cool-season grasses than under corn or soybean. Soil respiration rates, which ranged from 1.4–7.2 g C m⁻² day⁻¹, were up to twice as high under the poplar, switchgrass and cool-season grasses as in the cropped fields. Abundant fine roots, deep rooting depths, and high soil respiration rates in the multispecies riparian buffer zones suggest that these buffer systems added more organic matter to the soil profile, and therefore provided better conditions for nutrient sequestration within the riparian buffers.

1. Introduction

Roots provide detrital carbon to soil organisms and are an important variable influencing the effectiveness of riparian buffer systems in immobilizing and processing soil water pollutants and improving soil quality (Groffman et al., 1992). Fine and small roots (<5 mm), and coarse roots (>5 mm) are two major components of belowground biomass, and their vertical distributions define extent to which they modify soil physical and biological properties at depth. Fine roots represent a dynamic portion of belowground biomass, nutrient capital, and a significant part of net primary production in native and managed

ecosystems (e.g., Harris et al., 1977 and Buyanovsky et al., 1987). Nutrient inputs to the soil via fine root turnover can be as much as or more than those returned in aboveground litter (Joslin and Henderson, 1987; Hendrick and Pregitzer, 1993). Roots are also major sources of carbon dioxide within the soil, and therefore stimulate soil respiration. Soil respiration is an excellent indicator of both root system and soil microorganism activities. Hence, measurements of soil respiration provide a useful assay of differences in total soil biological activity among sites, including differences resulting from different root activities.

Few studies on belowground biomass and soil respiration have been done in riparian areas. Riparian areas differ from uplands in soil and hydrologic characteristics. Their location between upland crop fields and streams places them in a unique position to serve as sinks for sediments, nutrients, and pesticides, to protect streambanks from erosion, and to reduce excessive runoff into stream channels. While there is a considerable body of evidence confirming the ecological importance of riparian areas as sinks for nonpoint source pollution (e.g., Hill, 1996), the mechanisms controlling their effectiveness remain poorly quantified. By enhancing carbon availability to soil organisms, riparian vegetation may stimulate various biological processes within the soil.

The objectives of this study were to determine root distribution and coarse root biomass, and monthly changes in fine-small root biomass and soil respiration, in crop fields, an adjacent multispecies buffer and a cool-season grass buffer. These parameters provide important links to our larger goal of defining the mechanisms controlling the effectiveness of re-established riparian buffers in attenuating nonpoint source pollution.

2. Materials and methods

The study was conducted on a private farm along Bear Creek, in Story County, Iowa, USA (42° 11' N, 93° 30' W). A multispecies riparian buffer was established along Bear Creek in 1990 on soil that had been cultivated or grazed for more than 75 years. The basic design of the multispecies buffer consists of five rows, at 1.2 × 1.8 m spacing, of hybrid poplar (*Populus × euroamericana* 'Eugenei') planted closest to and parallel to the creek. Upslope from the trees are a row of redosier dogwood (*Cornus sericea* L.) and a row of ninebark (*Physocarpus opulifolius* L.). A 7.3 m wide strip of switchgrass (*Panicum virgatum*), a native warm-season grass, is planted upslope from the shrubs at interface with the cropped fields (Lee et al., this issue).

The study consisted of six treatments with three plots per treatment. The treatments were: poplar, switchgrass, cool-season grass I (unburned), cool-season grass II (burned in spring of 1996), soybean (*Glycine max* (L.) Merr.) and corn (*Zea mays* L.) (Figure 1). The corn and soybean fields were under an annual corn-soybean rotation. Corn planted in last week of April and har-

Soybean	Soybean	Soybean	Corn	Corn	Corn
Switchgrass	Switchgrass	Switchgrass	Cool-season grass II (burnt)	Cool-season grass II (burnt)	Cool-season grass II (burnt)
Poplar	Poplar	Poplar	Cool-season grass I	Cool-season grass I	Cool-season grass I
Bear Creek Channel					

Figure 1. Schematic representation of the experimental plot layout showing vegetation types and sampling plots.

vested at the end of October. Soybean planted at the beginning of May and harvested in the mid-September. Cool-season grass sites were part of a grazed riparian pasture prior to 1990. Dominant grass species at cool-season grass sites were brome grass (*Bromus inermis* Leysser.), timothy (*Phleum pratense* L.) and fescue (*Festuca* sp.). These same species were found in the poplar understory.

The study site is located on Coland soil (fine-loamy, mixed, mesic Cumulic Haplaquoll) which is well drained to poorly drained and formed in till or local alluvium and colluvium derived from till (DeWitt, 1984). The soils graded into Clarion soils (fine-loamy, mixed, mesic Typic Hapludolls) in the uplands distant from the stream (DeWitt, 1984). Organic carbon contents (%) of the soil (0–35 cm depth) under poplar, cool-season grass I, cool-season grass II, switchgrass, corn and soybean sites were 4.17, 3.4, 2.95, 2.83, 2.11 and 1.48, respectively (Marquez et al., in this issue). Our sampling was conducted in Coland and Coland-Clarion transitional soils.

Sequential coring was used to determine fine and small root biomass (Harris et al., 1977; Joslin and Henderson, 1987). Soil cores having a 5.4 cm diameter were removed approximately monthly from May to November from the surface 0–35 cm of soil (five cores per replicate). Cores that could not be sorted immediately were placed into a deep freeze (0 °C) until they could be. Roots were separated from the soil by soaking in water and then gently washing them over a series of sieves with mesh sizes of 2.0 and 0.5 mm, following the recommendations of Anderson and Ingram (1993). Roots were sorted into diameter classes of 0–2 mm (fine root) and 2–5 mm (small root) and were separated into live and dead fractions based on the elasticity of their tissues and the color of the cortex (Hayes and Seastedt, 1987; Joslin and Henderson, 1987). Live roots were whitish or pale-colored, elastic, and were free of decay. Dead roots were brown or black, broke easily, and were

in various stages of decay. Roots from each of these size categories were oven-dried at 65 °C and weighed.

Coarse root biomass was determined by excavating two 0.6 × 1.8 m soil pits down to rooting depth in each sampling plot for a total of six pits per vegetation type (three each in corn and soybean). Roots were separated into 2–5 mm, 5–10 mm, 10–20 mm, and >20 mm diameter classes using dry and wet sieving. A polyethylene sheet was used to record all the roots bisecting one (switchgrass and cool-season grasses) or two (poplar, soybean and corn field) walls of the excavated pits to determine root density per unit area (Anderson and Ingram, 1993). Cool-season grass I and II were considered as one treatment in this part of the study.

Soil respiration rates were measured monthly in three randomly selected locations in each of the three replicates per treatment (Figure 2) from July to November using the soda-lime method (Edwards, 1982). The soda lime method has been criticized for underestimating high respiration rates and overestimating low flux rates (Nay et al., 1994), but the method does distinguish between higher and lower flux rates and, therefore, observed differences in measured CO₂ emissions among sites reflect real differences in soil respiration. Buckets 20 cm tall and 27.5 cm in diameter were used as measurement chambers. One day prior to measurements, plastic rings with the same diameter were placed over the soil and carefully pushed about 1 cm into soil. All live grasses or crops inside the plastic rings were cut to prevent above-ground plant respiration. Carbon dioxide was absorbed with 60 g of soda-lime contained in 7.8 cm diameter by 5.1 cm tall cylindrical tins. The tins of soda-lime were oven dried at 105 °C for 24 h, weighed and covered tightly before

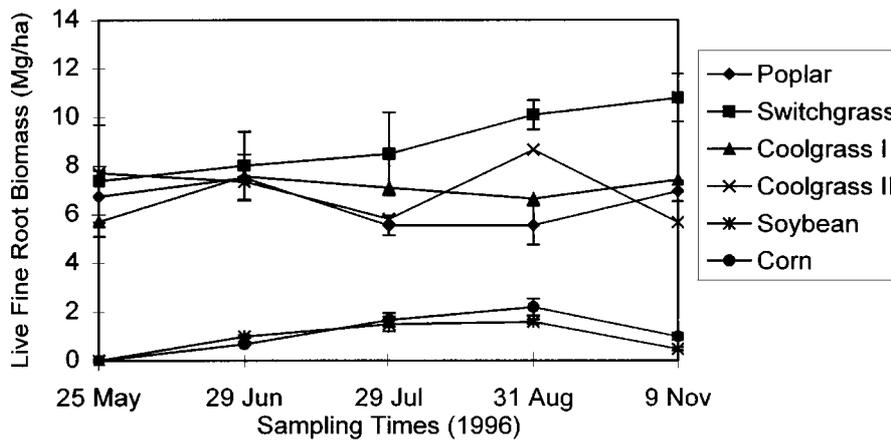


Figure 2. Mean live fine root biomass within riparian and agricultural fields in Central Iowa, USA. Each point is the mean of three sampling sites, with 5 samples per site per sampling date. Standard error bars are not shown for the cool-season grass sites to improve the clarity of the figure.

putting into field. In the field, the plastic rings were removed from the soil, and the tins were uncovered and placed on the soil or dead litter. The measurement chambers were then placed over the tins and held tightly against the soil with 3–5 kg weights placed on the top of each chamber. After 24 h, the tins were removed, oven dried at 105 °C for 24 h, and weighed. Blanks were used to account for carbon dioxide absorption during handling and drying. Soda-lime weight gain was multiplied by 1.69 to account for water loss, following Grogan (1998).

Statistical comparisons were made using the general linear models procedure of SAS (SAS Institute, 1985). We used ANOVA to compare fine root biomass and soil respiration rates among vegetation types and sampling dates using a repeated measures design. Differences between specific vegetation types and between sampling dates were determined with a least significant difference test at $\alpha = 0.05$. Root densities were compared among vegetation types and depths with the same analysis techniques, considering depth as the repeated measure.

3. Results and discussion

3.1. Belowground biomass

3.1.1. Fine root biomass (FRB) (0–2 mm)

Live FRB differed significantly among vegetation types ($P = 0.0001$) and months ($P = 0.052$). Switchgrass had significantly greater live FRB than did the cool-season grass I, poplar, corn and soybean sites. The cropfields had significantly lower live FRB than did any other vegetation type (Figure 2). Over all sites, the maximum live FRB was observed from August to October, and minimum live FRB occurred during May ($P < 0.05$). These results are in agreement with a fall maximum in live FRB in grasses and trees as observed by Hansson and Andren (1986), and Shackleton et al. (1988). However, an annual peak in FRB in spring or early summer was reported for trees by Joslin and Henderson (1987), and Farrish (1991), and for grasses by Saterson and Vitousek (1984).

In our study, live FRB of switchgrass continued to increase through time (Figure 2). This continuous increase might be due to the production of long-lived rhizomes; Hartnett (1989) reported that switchgrass maintained intact rhizome interconnections among stems up to 10 years. Increasing live FRB in switchgrass might also suggest that belowground biomass in that site has not yet reached a stable level, seven years after planting, but additional sampling is needed to test this possibility.

Dead FRB also differed significantly among vegetation types ($P = 0.0001$) and sampling dates ($P = 0.0001$). The cool-season grass sites had significantly greater dead fine root biomass than did any other sites ($P < 0.05$), and the crop fields (corn and soybean) had significantly lower dead FRB than did

any other vegetation types ($P < 0.05$). The seasonality of dead FRB was opposite that of live FRB. Maximum dead FRB occurred during May and June, when live FRB was minimal, and minimum dead FRB was observed during October, when live FRB was maximum (Figure 3). Jose et al. (1982) reported an annual peak in dead FRB in early summer, while Keyes and Grier (1981), Hansson and Andren (1986), and Hendrick and Pregitzer (1993) reported an annual peak in late summer or fall. Joslin and Henderson (1987) observed peak dead FRB values in both late spring-early summer and late summer or fall in a white oak stand.

The seasonality of live and dead roots varied among years in Kansas tall-grass prairie (Hayes and Seastedt, 1987). In that site live FRB varied from 3.2 to 6.2 Mg ha⁻¹, and dead FRB varied from 2.8 to 5.6 Mg ha⁻¹. These ranges correspond well with our ranges of 5.7 to 10.8 Mg ha⁻¹ for live fine roots and of 1.1 to 6.2 Mg ha⁻¹ for dead fine roots. An increase in dead fine root biomass after fire was reported by Jose et al. (1982) and Moya and Castro (1992). This is consistent with our finding of a large amount of dead fine root biomass under the burned cool-season grass (cool-season grass II) vegetation in May (Figure 3). On average, the poplar, switchgrass, and cool-season grass sites had two to six times more dead FRB than did soybean or corn.

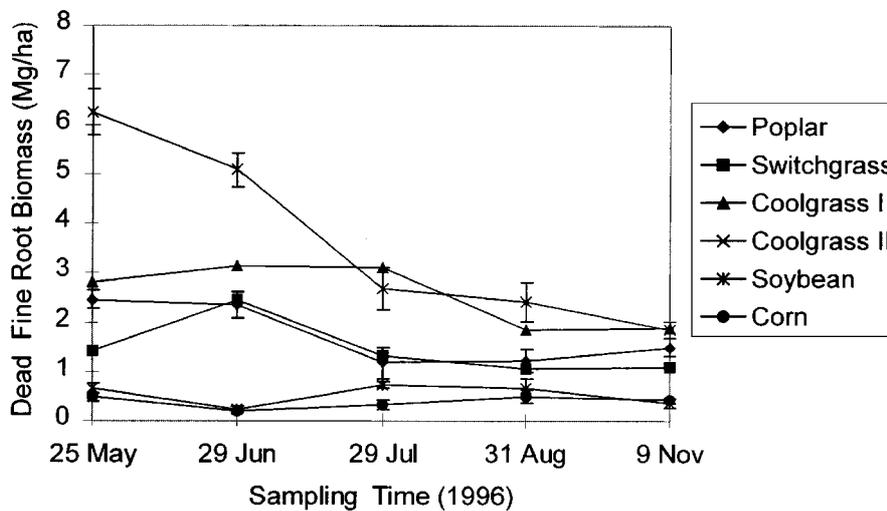


Figure 3. Mean dead fine root biomass within riparian and agricultural fields in Central Iowa, USA. Each point is the mean of three sampling sites, with 5 samples per site per sampling date. Standard error bars are not shown for the cool-season grass I or switchgrass sites to improve the clarity of the figure.

3.1.2. *Small root biomass (2–5 mm)*

Live small root biomass was substantially less than live fine root biomass in all sites. Averaged over the growing season, live small root biomasses for switchgrass, poplar, cool-season grass I, cool-season grass II, soybean and corn were 2.00, 0.38, 0.37, 0.65, 0.20, and 0.16 Mg ha⁻¹, respectively. There were no significant difference among sampling dates. Small live root biomass did vary significantly among vegetation types ($P = 0.0003$), with switchgrass having significantly greater biomass than any other vegetation type. Our live small root biomass values for switchgrass and cool-season grass II were similar to the ca. 1.3–1.7 Mg ha⁻¹ observed by Joslin and Henderson (1987) in a mature white oak stand in Missouri.

Differences in dead small root (2–5 mm) biomass were only marginally significant among vegetation types and sampling dates ($P = 0.07$). On average, the greatest biomass of dead small roots was observed under cool-season grass II vegetation (0.21 Mg ha⁻¹), and the least biomass was beneath corn (0.01 Mg ha⁻¹). The dead small roots beneath corn were those left from the soybeans that occupied that field the previous year.

3.1.3. *Coarse root biomass (> 5 mm)*

Roots with diameters larger than 5 mm were observed only under poplar, soybean and corn vegetation. Total coarse root biomass of poplar, corn and soybean were 3.9, 1.1 and 0.3 Mg ha⁻¹, respectively. Corn and soybean coarse roots extended to 20 cm depth only, while poplar coarse roots grew up to 140 cm deep. Coarse root biomass of poplar decreased with increasing depth. Total coarse root biomass of these seven-year-old poplars planted at 1.2 × 1.8 m spacing was less than that observed by Puri et al. (1994) under nine-year-old *Populus deltoides* stand planted in 2 × 2 m spacing (29.8 Mg ha⁻¹). This difference can be attributed to differences in spacing and ecological conditions.

3.2. *Root density*

Root density ranged from 0.2 to 44.2 roots per square decimeter and declined significantly ($P = 0.0001$) with increasing depth (Figure 4). Rooting density was significantly higher in the switchgrass and cool-season grass sites than in soybean or corn ($P < 0.05$). No roots were observed below 125 cm depth under corn or soybean, but roots extended to at least 180 cm under poplar. Heilman et al. (1994) reported that roots of four-year-old hybrids of *Populus trichocarpa* × *Populus deltoides* extended to depths beyond 3.2 m. Dwyer et al. (1996) reported rooting depth of corn down to 101 cm while Linscott et al. (1962) reported a rooting depth of 180 cm for corn. These differences in rooting depth of corn could be due to differences in soil properties.

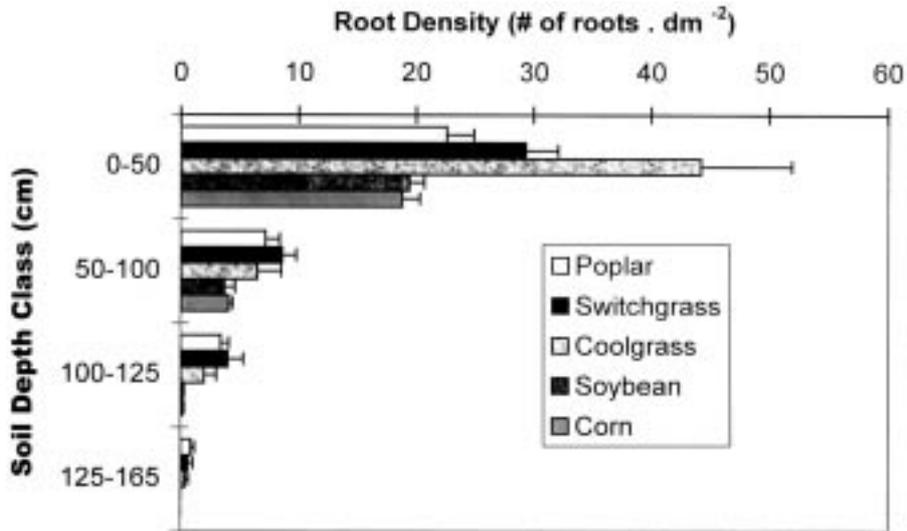


Figure 4. Average root densities of poplar, switchgrass, cool-season grass, corn and soybean sites at four depths in Central Iowa, USA. Each horizontal bar (+S.E.) represents the average of six pits for each riparian vegetation type, and the average of three soil pits for each of the crop fields.

3.3. Soil respiration

The soil respiration varied significantly among sampling dates ($P = 0.0001$), with significantly highest rates occurring in early August and the lowest rates occurring in September and October (Figure 5). Mean daily soil respiration values ranged from 1.4 to 7.2 g C m⁻² day⁻¹. From July 27 to October 28 soil respiration averaged 4.6, 4.5, 4.4, 3.7, 2.4 and 2.7 g C m⁻² day⁻¹ in the cool-season grass I, cool-season grass II, poplar, switchgrass, corn and soybean sites, respectively. Soil respiration rates in the poplar and cool-season grass sites were significantly greater ($P < 0.05$) than in the other three vegetation types. Soil respiration rates in the switchgrass sites were significantly lower than those in the cool-season grass and poplar sites, but were significantly greater than those in the crop fields ($P < 0.05$).

4. Conclusions

The poplar, switchgrass, cool-season grass I and cool-season grass II sites had higher live and dead fine root biomass than did either corn or soybean, suggesting that belowground organic matter inputs to the soil were greater in the planted riparian zones than in the crop fields. This is important because microorganisms need organic matter as a carbon source for denitrification,

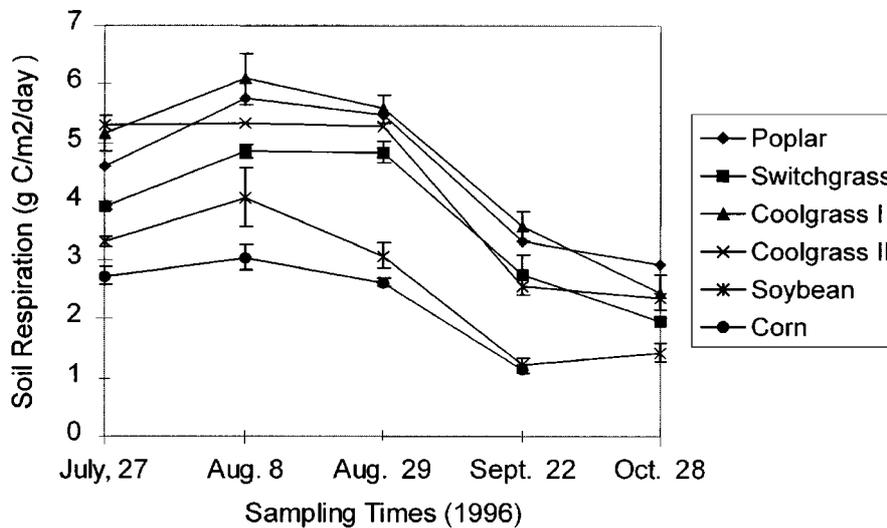


Figure 5. Mean (\pm S. E.) daily soil respiration rates in riparian and agricultural fields in Central Iowa, USA. Each mean is based on measurements in three sites with three samples per site and date. Standard error bars are not shown for the cool-season grass II site to improve the clarity of the figure.

one of the most important mechanisms of nitrate removal in riparian areas (Hill, 1996). In addition, higher root densities in switchgrass and cool-season grasses than in the crop fields, and deeper rooting depth in the poplar, provide evidence that the planted riparian vegetation types were more effective than corn or soybean in colonizing the entire soil profile. The riparian vegetation types we studied were composed of perennial plants and their roots colonized the soil for the entire year, whereas live roots were present in the annual crop fields for <5 months. The presence of abundant live fine roots in the spring and early summer (e.g., Figure 2) may be particularly important in decreasing nitrate losses from the soil at that time of year.

Plant uptake of nitrate by roots is a major nitrate retention mechanism (e.g., Groffman et al., 1993). O'Neill and Gordon (1994) showed that Carolina poplar trees were effective in lowering subsurface nitrate concentrations as soil solution migrated through the rooting zones of trees. In this study, higher live and dead root biomass, higher root densities and greater rooting depths in poplar, switchgrass and cool-season grasses than in corn or soybean suggest that some of the excess nitrate coming from adjacent crop fields through ground water flow might be taken up by the roots of the buffer strip vegetation more effectively than in corn or soybean.

Soil respiration is a good indicator of overall soil biological activity. Greater soil respiration in the planted buffer strip vegetation suggests higher rates of soil carbon turnover in the buffer strips than in the crop fields. These results

are consistent with the larger live and dead root biomass pools in the buffer strips (Figures 2 and 3), and provide supporting evidence that carbon limitations to microbes are reduced in the buffer strip in comparison with the crop fields. The differences we observed can not be attributed wholly to the different vegetation types; soil properties differ with proximity to the stream. Nevertheless, all our data are consistent in supporting the use of perennial plants in riparian zones to enhance carbon inputs to the soil and throughout the soil profile.

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