SOIL PROPERTIES IN BURNED AND UNBURNED ATLANTIC WHITE CEDAR STANDS AS A MEANS TO QUANTIFY IMPACTS FROM RECENT FIRES IN THE GREAT DISMAL SWAMP NATIONAL WILDLIFE REFUGE

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Abstract: Peatlands such as the Great Dismal Swamp National Wildlife Refuge (GDSNWR) are valuable ecosystems that filter water, sequester carbon, and support biodiversity including Atlantic white cedar, *Chamaecyparis thyoides* (L.) B.S.P., (cedar) swamps. Peatlands exhibit a positive water budget which reduces oxygen concentrations such that the rate of primary production exceeds decomposition resulting in peat accumulation, nutrient retention, and carbon sequestration. Accumulations as deep as 10 m have developed in GDSNWR since the swamp began to form approximately 10,000 years ago. However ditching during the last 200 years has caused water to drain which introduced oxygen into the soil and facilitated gradual (biological oxidation) and rapid (chemical oxidation) peat loss and influenced conditions in remaining soils. A portion of GDSNWR south of Lake Drummond has been the focus of research since 1995 and includes soil analyses prior to blowdown caused by Hurricane Isabel (2003), salvage-logging (2005 to 2008), the South One Fire (2008), and the Lateral West Fire (2011). This study was conducted to evaluate changes in nitrogen and carbon content in soils and cedar tissue to quantify fire effects. Soil samples from 1999 and 2011 were collected at a depth of 10 cm and were processed and analyzed to find bulk density, total nitrogen and total carbon content (percent dry mass). Grand mean bulk density in unburned stands was 0.14 g cc^{-1} and 0.17 g cc^{-1} (1999 and 2011, respectively); and was 0.21 g cc^{-1} in burned stands measured in 2011. Grand mean carbon in unburned stands was 47.4% (1999) and 47.9% (2011); and was 47.5% in burned stands (2011). Grand mean total nitrogen in unburned stands was 1.73% (1999) and 2.37% (2011); and was 2.10% in burned stands (2011). These results were combined with data reported elsewhere regarding depth of soil combustion and volume of unburned logs to calculate total carbon emitted by the two fires, and we estimate that up to 4,081,103,325 kg of C was emitted given a burn depth of 1.5 m. Ongoing efforts to install water control structures may reverse drainage caused by ditches and reduce the impacts of future fires.

Key Words: Atlantic white cedar, peat, fire, soil properties, carbon emissions, Great Dismal Swamp

INTRODUCTION

Peatlands are valuable wetland ecosystems that perform unique ecological functions such as accrual of peat (sequestration of carbon and nitrogen) and provision of habitat for unique species (Ornes and Hogan 2012). Temperate peatlands such as the Great Dismal Swamp have been lost at a faster rate than wetlands in general (Verhoeven and Setter 2010) resulting in rangewide decline of the Atlantic white cedar, *Chamaecyparis thyoides* (L.) B.S.P. (cedar), ecosystem with global consequences (Armentano and Menges 1986). While peat and peatland habitats may disappear slowly via decomposition, fires such as the two recent fires (2008 and 2011) in Dismal Swamp may rapidly reverse ecosystem functions, degrade ecosystem services, and affect site suitability for reestablishment of cedar.

Fire can be beneficial for peatlands, favoring regeneration of fire-dependent native species. Some peatland species, such as cedar, rely on frequent fires of low intensity to promote regeneration from a peaty seed refugium (Laderman 1989). Cedar fails to regenerate beneath mature forests (Akerman 1923, Buell and Cain 1943, Korstian 1924); however, stand-clearing fires allow sufficient light penetration to the forest floor, allowing seeds to germinate and grow with very little interspecific competition for light (Buell and Cain 1943, Little 1950, Motzkin et al. 1993, Laderman 2003).

Fire can also be harmful to peatlands, consuming peat and seeds where drainage has occurred. The primary product of fire is carbon dioxide (Yokelson et al. 1996) reversing carbon sequestration functions such that peatlands become a source for atmospheric carbon. The post fire landscape may or may not be suitable for reestablishment of cedar depending on water table position and soil nutrient availability.

Low severity, or surface fires, can increase the availability of nutrients for plant uptake and generally increases the soil temperature due to increased radiation (Neary et al. 1999). However, in drained areas, the peat is directly exposed to the fire and will combust, causing a deep and severe burn. Fire in peat soils, and the slower and biologically-mediated oxidation of peat, are among the diverse array of impacts resulting from long-term ditching in GDSNWR (Atkinson 2001). Burning peat may release nitrogen gases such as nitric oxide and nitrogen dioxide (Neary et al. 1999), and heat from fires promotes ammonia volatilization (Yokelson et al. 1996). Given the severity of fire in some of our sites, losses of nitrogen may lead to nitrogen deficiencies which could impair reestablishment of cedar. The purposes of this study were to evaluate soil changes over a 10-year period before and after the South One Fire in 2008 and to estimate carbon loss from peat burned in the Lateral West Fire in 2011.

METHODS

Site Descriptions

The Great Dismal Swamp is located in southeast Virginia and northeast North Carolina. This valuable natural resource has been disturbed by man for centuries (Atkinson et al. 2003) and has been protected by the government since the Great Dismal Swamp National Wildlife Refuge (GDSNWR) was established in 1974.

Sampling locations from both 1999 and 2011 were located in the GDSNWR south of Lake Drummond near the Virginia/North Carolina border (figure 1). The soils are classified as acidic peat, and while average pH is 3.4 (Thompson et al. 2003) it has been recorded as high as

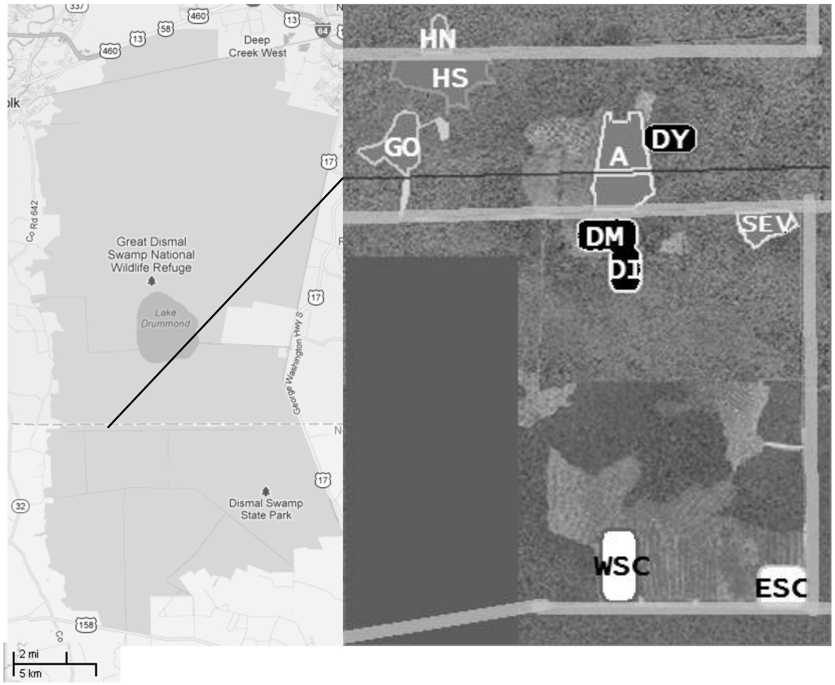
5.6. Surface texture is classified as muck, mucky peat, and woody muck, and contains a 50-60% organic surface layer (USDA Soil Survey 2012). The GDSNWR has a historic network of ditches that has lowered the water table for centuries with diverse affects (Atkinson et al. 2003).

In 1999 the canopy of the study area was dominated by cedar and secondarily by *Acer rubrum* (Red Maple). In 1999, Thompson et al. (2003) studied soil physical and biochemical properties in three stands (black rectangles in figure 1) consisting of 27 10-m x 10-m plots in three cedar stands of differing age classes including Dismal Young (DY; ~two yrs since salvage-logging had occurred), Dismal Intermediate (DI; ~25-35 yrs since commercial harvest (B. Martin, personal communication)), and Dismal Mature (DM; ~60-65 yrs since commercial harvest (B. Martin, personal communication)).

By 2003, stands studied by Thompson et al. (2003) had experienced extensive blow down from Hurricane Isabel, were salvage-logged from 2005 to 2008, and burned in the 2008 South One Fire. Following that fire, the vegetation type was mostly herbaceous, and dominant species included *Andropogon virginicus* L. *var. Virginicus* (Broomsedge) and *Woodwardia virginica* (Netted Chain Fern) (Atkinson 2010). Cedar regeneration following the fire in 2008 was reported by Wurst et al. (This Volume).

In 2011, 28 10-m x 10-m plots were sampled in seven stands that were salvage-logged in the years between 2005 and 2007 and named by GDSNWR. Of these, stands A, GO, HN, HS and SEV (dark grey in figure 1) were within the 1960-hectare (4,840-acre) area that burned in the 2008 South One Fire, and stands WSC and ESC (light grey in figure 1) were unburned. Soil conditions following the Lateral West Fire (2011) were not available.

Figure 1. Left picture shows location of study sites in the Great Dismal Swamp National Wildlife Refuge. Right picture is magnified to show plot locations for 1999 unburned (DY, DI, and DM in black) and 2011 burned (HN, HS, GO, A, and SEV in dark grey) and unburned (WSC and ESC in light grey) in GDSNWR. Horizontal black line represents the state border and thick grey lines represent ditches and roads.



Study Design

In 1999, Thompson et al. (2003) measured several soil parameters in the GDSWNR as well as two other national wildlife refuges. Soil samples were collected in 2011, prior to the Lateral West Fire, in order to determine carbon content in the soil. Soil samples collected in 2011 by the author and in 1999 as reported by Thompson et al. (2003) were compared in order to estimate carbon emissions from the Lateral West Fire in 2011.

Soils samples collected in 2011 were also evaluated in comparison to those studied in 1999 and reported by Thompson et al. (2003) in order to determine change in soil nitrogen and adequacy for reestablishment of cedar.

Soil Samples

In both 1999 and 2011, soil samples were collected from the upper 10 cm of each plot during the growing season, and compaction was avoided by using a serrated knife to cut through the soil and roots. Soils were dried at ~100°C for 24 hrs. Bulk density was determined by dividing the dry mass by the original volume, and the dry samples were ground using a mortar and pestle in order to homogenize the samples. Large sticks and roots (> 1 mm) were removed prior to nutrient analysis.

In 1999, carbon and nitrogen percent dry weight was found using Carlo Erba nitrogen-carbon analyzer on a UV-VIS spectrometer after digestion with sulfuric acid. In 2011, both soil and tissue samples were homogenized using an industrial blender and passed through a No. 20 sieve twice, any debris that remained after the second sifting was discarded. Percent carbon and nitrogen by dry weight was determined using Thermo Scientific FLASH 2000 CHNS/O analyzer with a BBOT standard (to establish a reference curve) consisting of known values of nitrogen and carbon of 6.517% and 72.529%, respectively (within 5% recovery, standards were included as an unknown to ensure accuracy and duplicates met % recovery criterion). Three subsamples were analyzed and averaged together to give values per plot.

Tree Tissue Samples

During the growing season of 2011 (and prior to the Lateral West Fire), cedar needles were collected from young, living trees by clipping the terminal 2 cm from each tree and were combined to yield one composite sample per plot. Tissue samples were dried at 75°C for 24 hours and processed as described for soils. Percent carbon and nitrogen by dry weight was determined using a Thermo Scientific FLASH 2000 CHNS/O analyzer with a BBOT standard.

Statistical Analysis

Data were initially entered and organized in Microsoft Excel (2003) before being transferred to SigmaPlot (version 11, 2008 Systat Software Inc, Chicago, IL). One way analyses of variance were used to test significant differences between soil and tissue samples at the stand level as well as between fire treatment and year (plots considered burned 2011, unburned 2011, and unburned 2003). Secondary T-tests were performed where significant differences were found; Tukey Tests were used where data exhibited equal variance and Mann-Whitney Rank Sum Tests where unequal variance was present. Tree tissue nitrogen and soil nitrogen among plots were evaluated with linear regression. A significance threshold of $p < 0.05$ was used throughout.

Carbon Emission Estimates

Carbon emissions were calculated using the formula employed by Lindsay (2010):

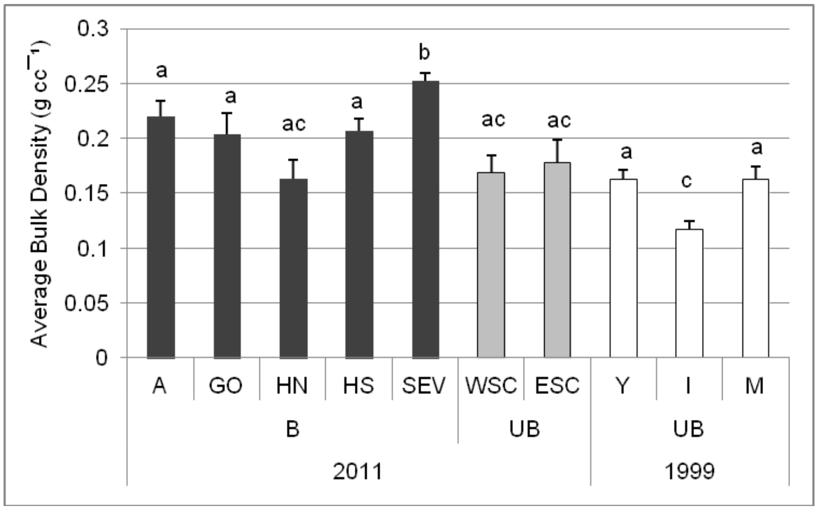
Carbon Emissions = bulk density x carbon content x area x depth

Estimates of bulk density and soil carbon content were measured in soil samples that were collected in 2011. Area and estimated depth of the burn estimates for the 2011 Lateral West Fire were obtained from Inciweb (2008).

RESULTS AND DISCUSSION

Soil Bulk Density

Figure 2. Bulk density (average g cc $^{-1}$) of soils from burned stands in 2011 (A, GO, HN, and SEV) and unburned stands in 1999 (DY, D I, and DM) and 2011 (WSC and ESC). Error bars represent +1standard error.

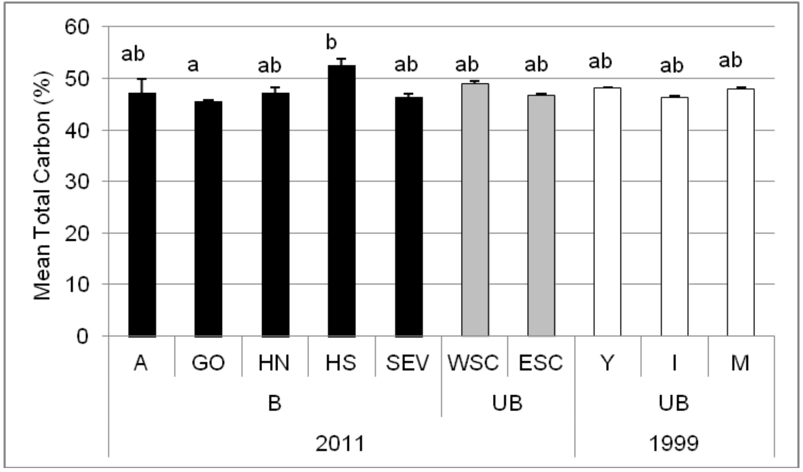


Median bulk density in burned soils in 2011 (0.207 g cc $^{-1}$ ± 0.018) was higher than for unburned soils in 1999 (0.143 g cc $^{-1}$ ± 0.015, $p < 0.001$) but did not differ from unburned soils in 2011 (0.161 g cc $^{-1}$ ± 0.004) (figure 2). Thompson et al. (2003) also reported a high bulk density value (0.244 g cc $^{-1}$) for a young cedar stand <10 years post burn in Pocosin Lakes National Wildlife Refuge in North Carolina. Smith et al. (2001) reported increased bulk density one year after a fire in shallow peat soils of the Florida Everglades.

Carbon Emissions

The amount of carbon lost in the Lateral West Fire was 0.0983 g cc $^{-1}$, which totals as 2,720,735,550 kg in the 2770 ha that burned in 2011; based on a burn depth of 1.0 m. Given a burn depth of 0.6 m, the total carbon loss would be 1,659,964,869 kg; and 4,081,103,325 kg given a burn depth of 1.5 m.

Figure 3. Carbon content (Mean percent by dry weight) in soils from burned and unburned GDSNWR in 1999 and 2011. Error bars represent +1 standard error.



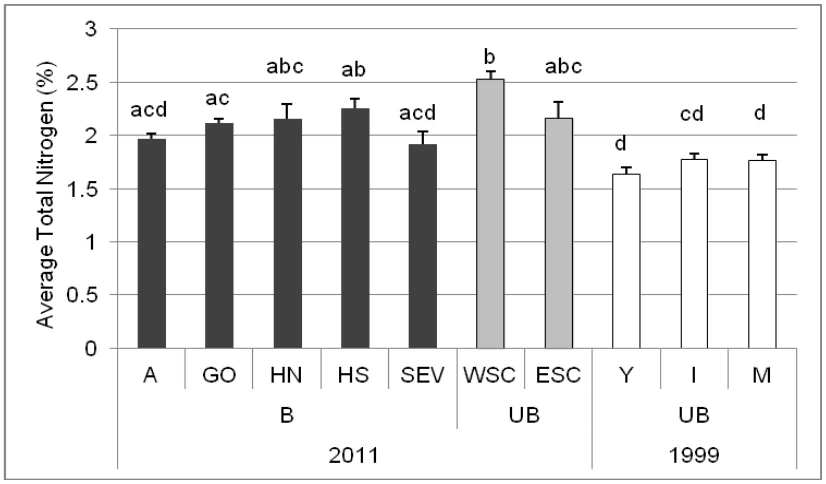
These calculations are based on the assumption that the total carbon content does not vary with depth. Hogg et al. (1992) studied decomposition and carbon emissions from drained peat samples taken from a black spruce wetland in Alberta, Canada and found that carbon content did not vary with depth. Nonetheless, that study reported significant differences between the upper and lower soil strata (0-10 and 30-40 cm, respectively) in both CO_2 emissions and mass lost, which was attributed to presumed differences in the form of organic matter with depth.

Soil Total Carbon

Fire showed no effect on soil total carbon. Mean carbon content in burned soils in 2011 (47.45% ± 1.25) did not differ from unburned soils in 1999 (47.37% ± 0.57) or in 2011 (47.85% ± 1.01). Similarly, few differences were detected between individual sites (figure 3).

Year of study showed no effect on mean total soil carbon, which was 47.55% in the seven sites studied in 2011, and 47.37% for 3 sites in 1999. No age trend was reported by Thompson et al. (2003) in a concurrent study of a young stand in Pocosin Lakes National Wildlife Refuge, NC (49.8%), and in Alligator River National Wildlife Refuge, NC at an intermediate-aged stand (47.0%) and a mature-aged stand (46.3%).

Figure 4. Soil total nitrogen (average percent by dry weight) in unburned and burned soils from GDSNWR in 1999 and 2011. Error bars represent +1 standard error.

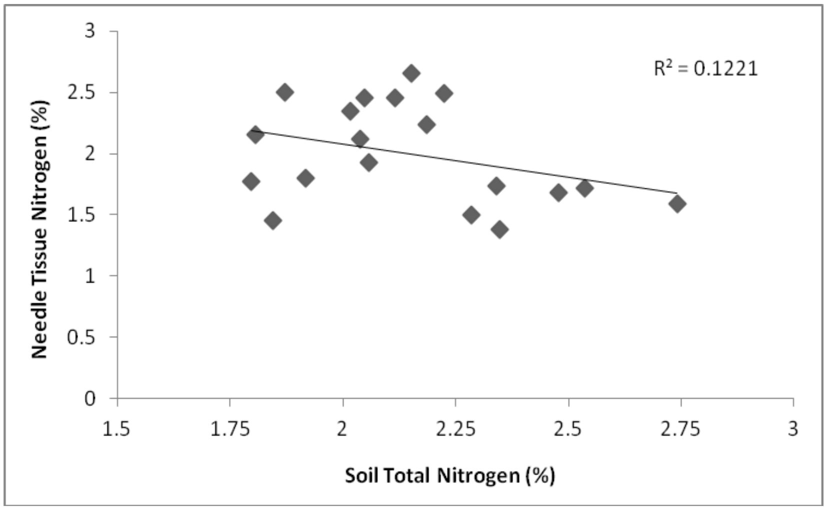


Soil Total Nitrogen

Year of sampling had the greatest effect on soil total nitrogen. Overall, soils collected in 2011 (burned and unburned) had significantly higher total nitrogen than sites in 1999 ($p < 0.001$). Unburned soils in 1999 had lower total nitrogen (1.73% 0.04) than both unburned soils in 2011 (2.37% ± 0.18) and burned soils in 2011 (2.10% ± 0.07)(figure 4).

In 2011, burned stands had significantly lower nitrogen content than unburned stands ($p = 0.011$). This trend was also reported by Smith et al. (2001), who found that soil total nitrogen content significantly decreased at 2-10 cm depth increment 1 year after peat fire. That paper also reported that low intensity (surface) fires had the reverse effect and increased soil total nitrogen. Prescribed, low intensity fires are commonly used because of their positive effects on certain soil nutrients including nitrogen (Wilburn and Christensen 1983).

Figure 5. Average soil total nitrogen (percent by dry weight) and average tree tissue total nitrogen in the 2011 study plots.



In all cases, GDSNWR had higher soil total nitrogen than other national wildlife refuges including young stands in Pocosin Lakes NWR (1.39%) and intermediate and mature-aged stands in Alligator River NWR (1.44% and 1.40%, respectively) (Thompson et al. 2003).

However, GDSNWR (unburned) stands in 1999 had significantly lower total soil nitrogen than unburned stands in 2011, which suggests that factors other than fire may influence soil nitrogen content. Zhu and Ehrenfeld (1999) suggest that differences in upstream suburban or agricultural land use can play a part in downstream nitrogen content and we note that burned and unburned plots located along two separate ditches exhibited higher soil total nitrogen than those occurring at greater distances from ditches (figure 1).

Tree Tissue

Based on cedar needle tissues collected in 2011, tissue nitrogen in burned stands (2.02%) was greater than in unburned stands (1.58%, $p = 0.011$) (Tissue nutrient content was not studied by Thompson et al. (2003)). This was higher than previous findings of 1.03% in Virginia (Gomez and Day 1982) and 1.20% in Maryland (Whigham and Richardson 1988).

A linear regression of needle tissue nitrogen and soil total nitrogen showed no relationship ($r^2 = 0.12$, $p = 0.111$)(figure 5). Plant uptake of nitrogen differs according to the form of nitrogen present (Brady and Weil 2008), which may explain the lack of a relationship between total nitrogen in soil and tissues.

Given the reservoirs of organic nitrogen as a major constituent of peat (Brady and Weil 2008, Zinke et al. 1984) nitrogen limitations may be uncommon. Another evergreen species, *Pinus serotina*, did not exhibit increased biomass (neither above nor below ground) when grown in burned peat soils compared to controlled plots (Wilbur and Christensen 1983).

SUMMARY AND CONCLUSIONS

The combination of Hurricane Isabel and recurrent peat-burning fires has drastically altered the part of the GDSNWR ecosystem and frustrated land manager attempts to restore cedar. The intensity of the fire lowered the peat surface resulting in prolonged inundation, a condition which is unsuitable for cedar for most of the 2770 ha (6845 acres) burned. Since the blowdown of cedar caused by the hurricane, pure cedar stands in GDSNWR have decreased from 1460 ha (3,600 acres) to effectively 0. The net effect is a further reduction in the extent of cedar below the estimated 2% that remained at the close of the last century (Noss et al. 1995).

According to our calculations of carbon loss of 1 m of peat in cedar stands in GDSNWR, approximately 2.7 billion kg of carbon was emitted from the peat that burned in the 2011 Lateral West Fire. Van der Wurf et al. (2010) estimates 1.5 - 2.8 Pg C annually or ~3% of global carbon emissions are derived from peat fire; therefore, our estimate for the Lateral West Fire based on 1 m of peat loss corresponded to 0.13% of the average annual global C emissions from peat fires. The Lateral West Fire emissions, given a 1-m depth of peat loss, also correspond to the amount of carbon released through burning ~1 billion (1,181,069,958) gallons of gasoline (USEPA 2011).

There was some indication that bulk density increased with fire. Total carbon in soil exhibited no significant trend with date of sample or burning. Fire generally appeared to increase soil nitrogen. Cedar needle tissue carbon was greater in burned than unburned plots even though trends in soil total nitrogen were unclear. Soil nitrogen appears unlikely to limit growth of cedar in post burn sites; furthermore Laderman (1989) suggested that cedar was tolerant of low soil nutrient concentrations.

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