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Article

Long-Term Soil Productivity in Christmas Tree Farms of Oregon and Washington: A Comparative Analysis between First- and Multi-Rotation Plantations

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Abstract: Christmas tree production removes organic matter and associated nutrients from a site and can change soil physical properties, reduce mycorrhizal populations, and result in pesticide over-use/accumulation. These impacts have been implicated in potential field productivity declines. Assessing Christmas tree productivity is complicated by genetics, management, and market forces. We approached the perceived or possible productivity decline by examining soil properties on 22 pairs of sites. Each pair was comprised of an early rotation and late rotation plot with 1 and 3 or more rotations of Christmas trees, respectively. All sites were located on commercial Christmas tree plantations from the major production areas in Washington and Oregon. Chemical properties assessed to 45cm included pH, total C and N, and extractable P, K, Ca, and Mg. Soil physical properties assessed included aggregate stability and soil resistance. In general, we found little impact on soil resources that would impact long term production of Christmas trees. These impacts may have been mitigated by farmers following extension service recommendations. Nitrogen, K, and Ca appeared to be primarily affected by harvesting, but replacement by fertilizer application was probably adequate.

Keywords: soil carbon; soil nutrients; long-term soil productivity; soil compaction; Christmas tree; soil calcium

1. Introduction

Continued Christmas tree production on plantation sites is important to both Oregon and Washington's agriculture economy. Oregon ranks as the nation's largest Christmas tree producing state, with a production of 6.4 million trees in 2012 [1]. Oregon has held this position now for over 3 decades. Washington ranks at the sixth largest producer in the United States. Maintaining the site productivity of this important crop is vital for the continued success of this industry in both states.

Frequently, sites are used for multiple rotations of Christmas trees. Rotation lengths will vary from 6 to 12 years depending on species, site, markets and other factors. Depending on market demand, species may change from one rotation to the next. Growers employ a wide variety of production methods that frequently change as species, knowledge, and conditions alter from one rotation to the next. The common species grown in the region are Douglas-fir (*Pseudotsuga menziesii* (Mirib) Franco.), noble fir (*Abies procera* Rehd.) and grand fir (*Abies grandis* (Dougl.) Lindl.).

Some growers have commented that trees grown in fields with several rotations of Christmas trees seem to be of lower quality than those on first rotation sites. These comments raised concern that field productivity may decline after multiple rotations. If true, the trend leads to increased costs, lower returns, and longer rotations.

A generalized definition for Christmas tree productivity would be stated as the time to harvest quality 1.8–2.1 m (6–7 ft) trees on any given site. Measuring the productivity of a Christmas tree farm is less straightforward than a natural or managed forest due to extensive trimming, changing species between rotations, and market conditions. Furthermore, detecting a decline in productivity between rotations in systems dominated by perennial species (*i.e.*, forests or Christmas tree farms) is challenging due to the effects of tree genotype, management practices, plasticity of trees to adapt to a site, and changes in state factors (e.g., climate) at potentially masking any trends in productivity [2,3]. One suggestion for detecting changes in the ability of a site or soil to grow trees is to use soil indicators [3,4].

Numerous causal candidates have been implicated in potential field productivity declines. Candidates commonly mentioned include changes in soil physical properties such as aggregate stability, compaction/resistance to penetration [5–7], loss of organic matter, mycorrhizal decline [8], pesticide over-use/accumulation [9], removal of limiting nutrients, and changes in soil chemical properties [10] which can affect nutrient availability and uptake as well as water uptake and holding capacity.

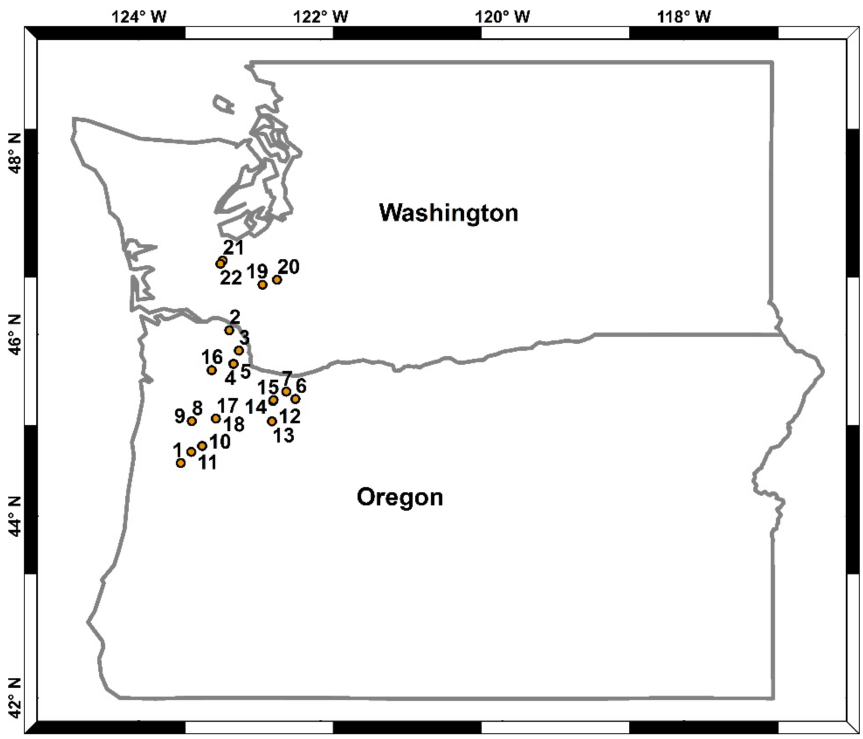
We hypothesized that nutrient capital was reduced as a result of harvesting which could lead to the perceived reduction in Christmas tree production. Since measuring productivity is complicated by genetics and management, we approached the perceived or possible productivity decline by utilizing paired test sites to compare selected site productivity properties commonly implicated as potential reasons for the decline. All sites were located on commercial Christmas tree plantations from the major production areas in Washington and Oregon.

2. Experimental Section

2.1. Site Description

We analyzed Christmas tree farms from a wide range of sites in Oregon and Washington (Figure 1). Soils ranged from clay loam to gravelly silt loams and sandy loams. Using downscaled PRISM data [11] we found that these sites span a relatively narrow range of mean annual temperature (9.6 to 11.7 °C) and precipitation (1213 to 1853 mm; MAT and MAP, respectively; Table 1); however, they represent a majority of the region utilized for Christmas tree production. While MAP increases and MAT typically decreases with latitude we did not find latitude to be correlated with MAT or MAP ($R^2 < 0.14$) among our study sites, suggesting that climate may not be a significant covariate in the response at each site. The sites are situated in a Mediterranean environment with 80%–90% of their precipitation falling between October and April (2%–6% as snow). As a result of the annual distribution of precipitation water can limit production.

Figure 1. Map of Christmas tree farms in Oregon and Washington.



Soil properties were measured in field pairs which were proximate and as similar as possible with respect to species, soil type, slope, aspect, management, and usage prior to being planted to Christmas trees. Twenty-two pairs, a total of 44 fields were selected at 18 locations in western Oregon and 4 locations in southwest Washington (Figure 1 and Table 1). One of the pairs was a first rotation field; the other was a matched site that had undergone at least 3 rotations of Christmas trees with an average of 25+ years of continuous tree production (range 22–43 years; Table 1).

Table 1. Site and climate variables; na = not available; [1] Rot. = Rotations; [2] Prod. = Production.

Pair	Elev. (m)	MAT (°C)	MAP (mm)	USDA Subgroup Soil Classification	USDA Soil Texture	# of Rot. [1]	Years in Prod. [2]	Years Since Liming	Years Since Tillage
1	201	11	1853	Typic Humult	clay loam	1	3	na	3
					silty clay loam	4	28	2	2
2	251	10	1506	Andic Fragiudepts	gravelly silt loam	1	9	1	na
					silt loam	4	31	na	na
3	97	11	1251	Aquic Haploxerepts	silt loam	1	0	na	na
					silt loam	3	15	na	16
4	342	10	1590	Andic Fragiudepts	silt loam	1	9	na	36
					silt loam	6	35	1.5	39
5	382	10	1599	Andic Fragiudepts	silt loam	1	3	1.5	26
					silt loam	4	25	1.5	3
6	348	11	1545	Typic Paleudults	silt loam	1	3	na	3
					loam	3	20	na	2
7	94	12	1213	Ultic Argixerolls	silty clay loam	1	4	na	na
					loam	4	20	na	22
8	175	11	1227	Xeric Palehumults	silty clay loam	1	2	na	2
					silty clay loam	3	27	na	9
9	175	11	1227	Xeric Haplohumults	silty clay loam	1	2	na	2
					silty clay loam	3	28	na	5
10	118	11	1406	Ultic Haploxerolls	loam	1	12	1.5	6
					loam	4	22	na	na
11	156	11	1675	Xeric Haplohumults	silty clay loam	1	9	0	10
					silty clay loam	5	38	2	na
12	475	10	1755	Xeric Palehumults	clay loam	1	1	na	1
					clay loam & silt loam	4	43	6	6
13	475	10	1755	Xeric Palehumults	clay loam	1	1	na	
					clay loam & silt loam	3	23	na	6
14	245	11	1343	Xeric Palehumults	silt loam & clay loam	1	1	na	1
					silt loam	3	na	na	na
15	232	11	1340	Xeric Palehumults	silt loam	1	2	na	3
					clay loam & loam	4	na	na	na
16	150	11	1249	Ultic Haploxeralfs	silt loam	1	6	na	7
					silt loam	5	36	1	1
17	326	10	1320	Xeric Haplohumults	silty clay loam	1	6	0	1
					silty clay loam	4	31	na	na
18	326	10	1320	Xeric Haplohumults	silt loam	1	5	na	na
					silt loam	3	30	na	19
19	231	10	1381	Humic Haploxerands	silt loam	1	1	na	1
					loam & sandy loam	3	20	na	5
20	327	10	1713	Humic Haploxerands	silt loam	1	6	na	8
					silt loam	4	na	na	na
21	71	10	1342	Xeric Palehumults	loam	1	3	na	4
					silt & silt loam	3	na	na	4
22	147	10	1359	Xeric Palehumults	silt loam	1	1	na	1
					silt loam	3	21	na	na

Although with the exception of rotation age, conditions between pairs of fields were as similar as possible, soil, climatic and management conditions among locations were very dissimilar. Conditions at each of the locations were in the range typical for Christmas tree sites in western Oregon and Washington. Management practices such as site preparation, tillage, sub-soiling, liming, pesticide use, and fertilizing varied among locations. Furthermore, the land use prior to becoming a Christmas tree farm (early or late rotation) on these sites varied and included second growth forest, pasture, and field crops. In general, the prior land use and management practices tended to be similar between pairs, but large variations in the parameters among locations are to be expected.

2.2. Soil Sample Collection and Analysis

Using a 3 cm diameter probe, soil samples were collected from: (1) the surface to 7.5 cm; (2) 7.5 to 30 cm; and (3) 30 cm to 45 cm at 15 to 20 randomly selected locations in each field with no pattern with regard to placement of samples within rows or near trees. The samples for each depth were combined and analyzed as a single sample per site. Soil samples were air dried and sieved to 2 mm.

Soil pH was measured on air dried and sieved soil with a combination electrode in a 2:1 (v/v) water:soil suspension [12]. Carbon and N were determined by combustion in a LECO CNS analyzer [13]. Extractable K, Ca, and Mg were measured by ICP after extraction with 1 N neutral ammonium acetate [14]. A dilute acid-fluoride extraction (Bray P1) for P was followed by measurement with an Alpkem rapid flow auto-analyzer using the molybdenum blue method [15].

Aggregate stability and particle size analysis (PSA), were determined on samples from the 0 to 7.5 cm depth. The pipette method was used to determine the size distribution of sand (50–2000 μm), silt (2–50 μm), and clay (<2 μm) after organic matter removal using hydrogen peroxide [16]. Aggregate stability was determined on air dry samples gently broken and passing a 2 mm sieve and collected on a 1mm sieve. Aggregates were subjected to repeated (35 cycles minute) insertion and removal from water for 3 min followed by an additional 5 min after addition of dispersing solution.

2.3. Soil Resistance

Soil resistance above 2000–2500 kPa restricts root growth [5,6] and root growth ceases when soil resistance is above 3000 kPa [7]. Soil resistance was measured with a recording penetrometer at 25 mm increments to 600 mm in 30 locations. At each location, soil resistance was further divided into measurements of three sub-areas (within tractor tire tracks, tree drip line and mid-row) where we anticipated differing levels of resistance. At the site level, we reduced these data to an average for each location (25 mm depth increment). From these composited data we determined an average and maximum across the range of depths corresponding to our soil sampling protocol (0–7.5, 7.5–30, and 30–45 cm). Means and standard deviations across the treatments were calculated from these site level averages and maximums.

2.4 Statistical Analysis

We performed a Wilcoxon Signed Rank test to test the null hypothesis that the median difference (absolute and early rotation normalized) between the early and late (early-late) rotation Christmas tree farms is equal to zero. We hypothesized that the response of a site's nutrient or carbon capital may be influenced by their initial state. To examine this effect, we performed a Wicoxon Signed Rank test on normalized differences. Normalized values were determined by dividing the differences (early–late) in each variable by the value of the corresponding early rotation site (*i.e.*, initial). Spearman correlations among selected variables were used to help explain the trends in the data. We used a tolerable type I error rate of 0.1 for all statistical tests.

The data set has been viewed and analyzed in its aggregate, as intended in the original experimental design. Making comparisons between individual pairs must be done with caution. Without replicated observations at each location, it is very difficult to judge whether differences between pairs are the result of natural variation or the result of prolonged cropping to Christmas trees. Future analysis of data subsets is planned. These analyses may provide additional insights on the impact of continuous cropping to Christmas trees on site productivity; however, it is not expected that these analyses will substantially alter the conclusions reported here.

3. Results and Discussion

The sites had a wide range of soil chemical characteristics (Table 2). In general pH, Ca, and Mg increased with depth while C, N, P, and K decreased with depth. We found that the concentration of Ca was lower in the late rotation relative to the early rotation at all depths (Table 3). The only other nutrient that decreased between early and late rotations was N at the 0–7.5 cm depth. Potassium has been shown to be a nutrient that is removed at a high rate and may need replacement through fertilization [10]. Potassium was lower in the late rotation relative to the early rotation, but the result was not statistically significant.

Table 2. Summary of soil chemical data.

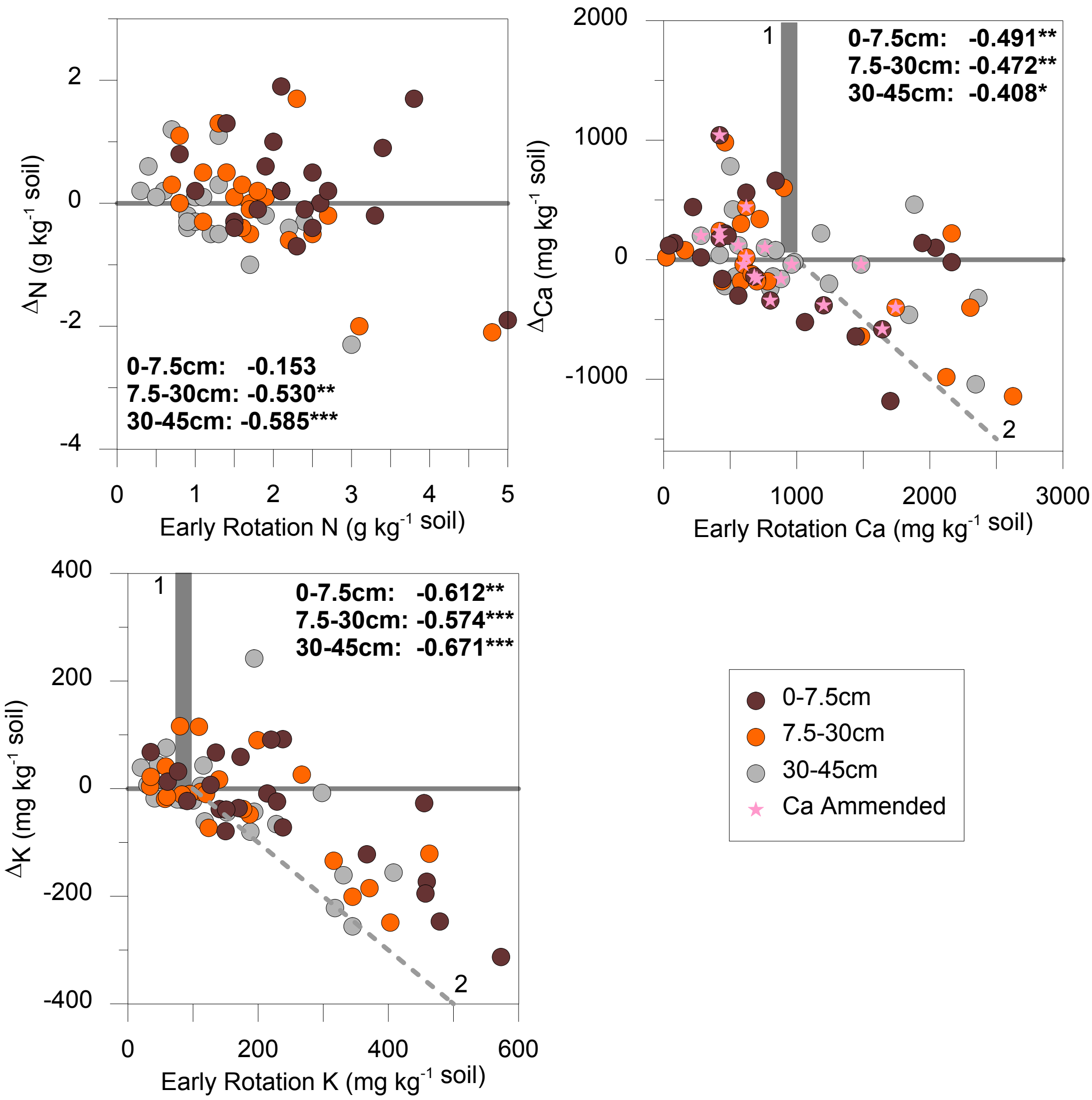
Parameter	Depth (cm)	First Rotation		Late Rotation	
		Average	Range	Average	Range
pH	0 to 7.5	5.4	4.5 to 6.3	5.5	4.8 to 7.0
	7.5 to 30	5.6	4.8 to 6.2	5.5	4.8 to 6.2
	30 to 45	5.6	5.0 to 6.1	5.7	5.1 to 6.0
P (mg kg^{-1})	0 to 7.5	28	10 to 76	28	6 to 103
	7.5 to 30	21	9 to 68	21	5 to 81
	30 to 45	14	6 to 34	14	4 to 43
K (mg kg^{-1})	0 to 7.5	235	35 to 573	196	74 to 428
	7.5 to 30	177	34 to 463	139	38 to 342
	30 to 45	154	20 to 408	130	37 to 436
Ca (mg kg^{-1})	0 to 7.5	932	40 to 2160	822	80 to 2140
	7.5 to 30	1080	20 to 2620	800	40 to 2380
	30 to 45	1030	20 to 2360	914	40 to 2340
Mg (mg kg^{-1})	0 to 7.5	143	12 to 411	150	12 to 496
	7.5 to 30	156	12 to 593	148	12 to 557
	30 to 45	184	12 to 629	200	12 to 750
C (g kg^{-1})	0 to 7.5	37.9	11.9 to 76.9	36.4	13.9 to 107
	7.5 to 30	30	11.6 to 72.0	27.5	8.9 to 75
	30 to 45	27.5	5.0 to 43.8	17.4	5.5 to 45.8
N (g kg^{-1})	0 to 7.5	2.6	0.8 to 5.0	2.3	1.0 to 5.5
	7.5 to 30	1.9	1.0 to 4.8	1.8	0.7 to 4.0
	30 to 45	1.2	0.3 to 3.0	1.1	0.4 to 2.4
C:N	0 to 7.5	18.4	13.3 to 25.5	17.3	8.1 to 23.0
	7.5 to 30	18.6	13.2 to 24.9	18.2	12.4 to 23.6
	30 to 45	18.4	11.7 to 24.5	18.6	11.7 to 24.6
AS (%)	0 to 7.5	94.3	64.6 to 99.7	91.2	48.7 to 99.2

Table 3. Median and standard deviation of differences (Δ) between early and late rotation pairs. p_{diff} and p_{norm} represent the results from a Wilcoxon Signed Rank test testing the null hypothesis that the median difference (absolute) and normalized difference are equal to zero, respectively; nm = not measured.

Depth		**ΔpH**	**ΔP**	**ΔK**	**ΔCa**	**ΔMg**	**ΔC**	**ΔN**	**ΔC:N**	**ΔAS**
			mg kg^{-1}				**g kg^{-1}**			**%**
0 to 7.5 cm	median	0.1	−5.5	−25.5	60.12	36.46	−1.750	0.200	−0.7	−1.8
	stdev	0.4	17.1	108.5	489.14	296.63	11.295	0.834	3.3	10.2
	p_{diff}	0.861	0.648	0.110	0.062	0.483	0.247	0.056	0.421	0.011
	p_{norm}	0.935	0.615	0.560	0.273	0.273	0.334	0.124	0.367	0.011
7.5 to 30 cm	median	0.1	−2.0	−10.5	−80.16	−48.61	−1.250	0.050	−1.0	nm
	stdev	0.3	9.8	96.5	484.46	293.80	11.721	0.876	2.7	nm
	p_{diff}	0.178	0.753	0.252	0.005	0.475	0.187	0.329	0.626	nm
	p_{norm}	0.140	0.790	0.695	0.025	0.025	0.317	0.475	0.649	nm
30 to 45 cm	median	0.0	−0.5	−20.5	−30.06	−18.23	−3.100	−0.200	−0.6	nm
	stdev	0.3	4.7	104.7	360.09	218.37	11.032	0.705	3.2	nm
	p_{diff}	0.373	0.742	0.318	0.092	0.331	0.963	0.987	0.725	nm
	p_{norm}	0.242	0.647	0.814	0.367	0.367	0.458	0.448	0.700	nm

Several parameters showed decreases between the early and late rotation plots, while normalized values showed little result. This suggests that the absolute response of a site is related to its initial level of nutrients. To explore these trends we examined the relationships among the site and soil characteristics. Indeed, we found significant negative correlations between early rotation K, Ca, and N from all depths and the change in these parameters from early to late rotation (Figure 2).

Figure 2. Relationship of early rotation N (upper left), Ca (upper right), and K (lower left) concentrations and change in nutrient soil concentration; Line #1 represents the soil Ca concentration that the OSU Extension service recommends application of Ca or K amendment; Line #2 represents the threshold for fields that declined below the Ca or K concentration that is recommended to be fertilized; spearman correlation coefficients are presented for each depth (*, **, and *** represent statistically significant correlations with $p < 0.1$, 0.05, and 0.001, respectively).



Early rotation N had a weak relationship with the decline in N from early to late (Figure 2). This may be partly a result of the common practice of N fertilization at mid- to late-rotation in Christmas tree farms. Both Ca and K had relatively strong correlations between the early rotation value and difference between early and late rotation soils. We plotted the threshold values at which OSU extension recommends Ca and K fertilization (Line #1 in Figure 2). Additionally, we plotted the threshold for fields that may have declined below the threshold from early to late rotation (Line #2 in Figure 2). In the case of both Ca and K all soils fall above or quite near these threshold values, which suggests that the recommendations of the extension service are being followed by this group of farmers. Indeed 7 of the 11 sites that were below the Ca threshold of 1000 mg kg^{-1} in at least one of the three sampled depths had been limed. It also suggests that these farms are in a good position to maintain site productivity between rotations.

Reductions in nutrient capital as a result of Christmas tree harvesting could be a result of removal from harvesting, increased leaching, translocation, or erosion rates. Harvesting has been shown to remove 140–336 kg ha^{-1} (125–300 lb ac^{-1}), 56–168 kg ha^{-1} (50–150 lb ac^{-1}), and 84–140 kg ha^{-1} (75–125 lb ac^{-1}) of N, K, and Ca, respectively [10]. To determine if the trends in nutrient concentration are a result of harvesting, or some other process, we needed to calculate the mass of nutrients in the early and late rotation fields. Bulk density data were not measured on these soils, but we assumed that bulk density increased with depth and the 0–7.5, 7.5–30, and 30–45cm soil depths had bulk densities of 1, 1.3 and 1.5 g cm^{-3}, respectively, which allowed us to estimate differences in mass of these nutrients between the whole soil profiles (0–45 cm) in the early and late rotation fields.

We found that N removal was negligible across the study, but ranged from −5.5 to 5.5 kg ha^{-1} difference between the early and late rotation fields. Nitrogen fertilization is a common practice in Christmas tree production, and is probably buffering any effect that harvesting may have on the site (and farmers are maintaining N levels).

Potassium was reduced by an average of 127 kg ha^{-1}, within the rate of loss that can be attributed to harvesting (56–168 kg ha^{-1}). Those sites that had removal rates greater than 168 kg K ha^{-1} had significantly higher early rotation K levels (averaged across all depths) than those that had lower removal rates ($p < 0.005$ from Mann-Whitney test). These high K loss sites lost an average of 497 kg ha^{-1} over an average of about 4 rotations, which is within the rate of loss caused by the harvesting of four rotations of trees. These results do suggest that soil K status should be monitored on Christmas tree farms and amended as needed, as suggested by extension recommendations [10].

Calcium was reduced by about 58 kg ha^{-1} on average across the sites, which is less than removal rates that can be attributed to harvesting one rotation of Christmas trees (84–140 kg ha^{-1}). Those sites that had removal rates greater than 140 kg Ca ha^{-1} had higher early rotation Ca levels (averaged across all depths) than those that had lower removal rates but the result was not significant ($p = 0.355$ from Mann-Whitney Test).

We suggested in the introduction that soils may be a better predictor of long-term productivity of a site due to problems with measuring productivity in perennial species, changes in cultural practices, *etc.* However, a change in soil does not necessarily imply that site productivity was affected. The soil could be approaching a new threshold that is stable with regard to its disturbance regime [17]. Furthermore, with the appropriate monitoring of nutrients as suggested by the extension service, nutrient deficiencies may be avoided.

Overall, we found little indication that late rotation stands would have lower productivity relative to early rotation stands. In two pilot studies we examined mycorrhizae and triazine herbicides. The ability of Christmas trees to acquire nutrients is influenced by mycorrhizae. Mycorrhizal colonization and counts on noble fir (the most commonly planted species) was observed as similar between early and late rotation sites [18]. Furthermore, an accumulation of commonly applied triazine herbicides has also been implicated in productivity declines as a result of indirect impacts to the mycorrhizal and microbial communities or as direct growth reduction. We found that atrazine, Velpar™, the commonly applied triazine products, and their decomposition products were higher in the later rotation sites measured but were more closely associated with time since application. Results suggest that changes in the fungal or microbial communities are not significant and not associated with herbicide applications. Further, residual triazine levels were frequently below those needed to control triazine sensitive grasses.

Aggregate stability is a commonly measured soil quality parameter. Soil with stable aggregates should allow water infiltration and retention, be disposed to minimal erosion, and not restrict root elongation [19]. We found that aggregate stability in the top 7.5 cm was lower in the late rotation relative to the early rotation (Tables 2 and 3). This could have some implication on long-term sustainability. Likewise, this finding has implications to growers regarding the methods of field preparation and subsequent erosion losses.

Neither early nor late rotation fields had a mean soil resistance that would restrict root growth (Table 4). However, at the 7.5–30 cm depth we found an average maximum soil resistance greater than 3000 kPa in the mid-row location, suggesting that root penetration may be hampered in this area. However, with one exception, we did not find a difference between the early and late rotation soil resistance (Table 5). This suggests that repeated management and harvesting has little effect on soil resistance.

We did find that mid-row locations had high soil resistance at the 7.5–30 cm depth, but no difference between early and late rotation (Table 5). We suggest that this effect is a result of management practices that occur at crop establishment. Farmers commonly use a planting apparatus with a ripping shank set to about 30+ cm. This tractor would have had its wheels in the mid-row location, where resistance was highest, where it could have compacted these locations. This effect appears to have remained after many years. Depending on the site preparation techniques this compacted area could impact the next crop's productivity.

Table 4. Summary of soil penetrometer data collected within the drip line, first tire track and mid-row; all units in kpa.

Depth	Rotation	22	Drip Line		Tire Tracks		Mid-Row	
			Mean	Max	Mean	Max	Mean	Max
0 to 7.5 cm	Early	median	670	1021	882	1317	757	1284
		stdev	389	620	385	585	393	579
	Late	median	537	860	754	1073	733	1112
		stdev	382	655	327	573	345	649
7.5 to 30 cm	Early	median	1926	2339	2072	2420	2122	3746
		stdev	382	368	342	354	331	640
	Late	median	1918	2325	2067	2388	2116	3878
		stdev	466	473	429	445	426	744
30 to 45 cm	Early	median	2308	2455	2309	2525	2387	2616
		stdev	383	423	410	395	405	435
	Late	median	2213	2412	2260	2461	2320	2442
		stdev	406	473	395	443	411	439

Table 5. Median and standard deviation of differences (Δ) between early and late rotation pairs; p_{diff} represent the results from a Wilcoxon Signed Rank test testing the null hypothesis that the median difference (absolute) is equal to zero; all units in kpa.

Depth	Rotation	Drip Line		Tire Tracks		Mid-Row	
		Mean	Max	Mean	Max	Mean	Max
0 to 7.5 cm	median	−91	−120	−80	−63	−159	−174
	stdev	490	811	477	786	490	855
	p_{diff}	0.478	0.518	0.458	0.498	0.384	0.582
7.5 to 30 cm	median	−21	−39	−59	−80	15	−186
	stdev	408	377	370	343	370	811
	p_{diff}	0.718	0.350	0.539	0.245	0.478	0.439
30 to 45 cm	median	−76	−36	−83	−66	−59	−122
	stdev	335	339	389	410	379	388
	p_{diff}	0.070	0.245	0.478	0.814	0.439	0.334

Compaction can create root restrictive layers in the soil that can limit the ability of trees to obtain water and nutrients. Compaction can also increase bulk density which can have a small effect on the water holding capacity of the soil. Resistance to penetration has been shown to be positively related to soil bulk density [7] and much more sensitive to compaction than bulk density [20]. Since we found no difference among most locations and depths' soil resistance, we surmise that bulk density and therefore water holding capacity were not affected. The higher degree of compaction at the 7.5–30 cm depth in the mid-row location may limit root growth and the amount of soil volume tree roots can utilize and therefore may affect uptake of water and nutrients. Since this compacted area is beyond the crowns of the trees, and the spread of most of the roots, it may have little effect on site productivity.

4. Conclusions

We analyzed 22 pairs of early and late rotation Christmas tree plantations from a major Christmas tree growing region and found little impact on soil resources that would impact long term production of Christmas trees, if extension service recommendations are followed by Christmas tree farmers. We found that N, K, and Ca were affected by the treatments but replacement by regular fertilizer application was probably adequate. We also suggest that planting methods or other practices that potentially compact soil, increase resistance, and reduce aggregate stability should be investigated. The ripping operation at planting should be shifted to fall when the soil is dry.

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Author Contributions

Jeff Hatten, analyzed the data and wrote the paper; Chal Landgren and John Hart designed the study, performed the research, and contributed to interpreting the results and writing the paper.

Conflicts of Interest

The authors declare no conflict of interest.

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