THE EFFECT OF SUBSURFACE DRAINAGE IN GRASS SEED FIELDS ON SOIL CARBON STOCKS

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Introduction

Approximately 14% of U.S. cropland has subsurface tile drainage to help mitigate saturated soil conditions by lowering the water table below the crop rooting zone. As a result, growers can achieve higher yields in poorly drained soils because saturated conditions no longer limit crop performance. In Oregon's Willamette Valley, poorly drained soils, combined with long rainy seasons, lead to unique farming challenges, and tile drainage helps alleviate some of these issues.

Farmers began installing tile drainage systems in the Willamette Valley as early as the mid-1800s and continue to install tile drains today. Subsurface drainage in the region has allowed farmers to lengthen the growing season by extending access to their fields. Studies have shown that tile drainage helps warm the soil faster than untiled fields (Jin et al., 2008). Warmer soils promote plant and microbial growth, providing crops a "head start" in the growing season. Because of the extended growing season, tile drainage also allows growers to plant a more diverse selection of crops and thus provides increased economic opportunity and flexibility.

It is well established that tile drainage impacts nutrient cycling, soil chemistry, biological activity, greenhouse gas (GHG) emissions, and water quality (Blann et al., 2009; Grenon et al., 2021). However, the degree to which drainage may positively or negatively influence these essential biological processes and resources is largely dependent upon soil type, farming practices, crop selection, and climate. Most existing studies on subsurface drainage were conducted in the Midwest and provide a limited scope of research and application for Willamette Valley growers.

Although there are extensive studies on the impact of tile drainage on biogeochemical processes, almost no research explicitly examines its impact on soil carbon (C) storage dynamics, especially at lower soil depths. The Willamette Valley can serve as a model system for studying C stocks in response to drainage because its soils tend to be deep mineral soils with naturally high soil C content. Additionally, there is an age gradient of tile drainage systems across the Willamette Valley, which can provide insight into short- and long-term drainage effects on soil C. Constant saturation during the winter, followed by a long drying period in the summer, provides stable conditions for extended observation. Finally, grass seed crops that define the region's largest agricultural industry have the potential to add C inputs into the soil via deep rooting depths. Taken together, the above-mentioned regional characteristics allow us to study the impact of tile drainage on C storage dynamics and investigate potential mechanisms driving these dynamics.

Understanding C cycling dynamics in the Willamette Valley will help us determine how local agricultural management can aid in C sequestration under a changing climate. Therefore, our research aims to investigate the fate of soil C in response to tile drainage in Willamette Valley soils. We expect that soil C can respond in one of two ways: (1) tile drainage may *decrease* soil C by creating aerobic conditions and increasing microbial degradation of existing soil C, which microbes respire to the atmosphere, or (2) drained fields may facilitate crop root growth and stabilization of microbial byproducts, resulting in a net *increase* of soil C.

Materials and Methods

Soil collection

Soils were collected July through August 2022 from 15 grass seed production fields throughout the Willamette Valley between Corvallis and Eugene. We targeted Dayton silt loam soil (fine, smectitic, mesic Vertic Albaqualfs) by identifying Dayton zones within each field and then confirming the presence of Dayton soil through standard classification procedures.

Field treatments included newly tiled (< 5 years post-tile drain installation, n = 5), old tile (> 15 years post-tile drain installation, n = 5), and untiled (no history of tile drainage, n = 5). All fields have a history of grass seed crops, primarily consisting of tall fescue (*Schedonorus arundinaceus* (Schreb.) Dumort.), perennial ryegrass (*Lolium perenne* L.), and annual ryegrass (*Lolium multiflorum* L. Husnot.

Three 50-m transects were established within each Dayton soil zone within each field. We sampled soil to a depth of 1 m at the 0-, 25-, and 50-m points along each transect with an ATV-mounted hydraulic soil probe (Giddings Machine Company, Inc.) and used plastic liners within a stainless-steel soil probe (4.25 cm diameter) to extract intact soil cores. The intact soil cores were removed from the stainless-steel probe, capped on either end to prevent soil loss, and placed immediately on ice packs to keep cores cool. We stored intact soil cores at 4°C immediately after returning from the field.

Soil processing and analysis

Intact cores were removed from the plastic liners and laid out in trays for horizon delineation. A distinctive characteristic of the Dayton series is a Malpass clay layer (i.e., argillic horizon) that begins at or above 38 cm and can end as deep as 74 cm (Figure 1, Table 1). Because of variability in the depth of the Malpass clay, the abrupt textural change would likely alter the physical and chemical characteristics of the soil if standard soil depths (e.g., 0–15 cm, 15–30 cm, etc.) were used. Instead, we opted to segment the soil based on horizons, as this would maintain a consistent texture class across all samples. We identified the Ap/E (above the Malpass clay), Bt (Malpass clay), and BC (below the Malpass clay) horizons and recorded the depth and mass for each. Subsamples from each horizon from each core were analyzed for total C and nitrogen (N) (LECO CN282).

Equivalent soil mass calculations

To accurately estimate organic C stocks, we quantified the equivalent soil mass for each sample. This approach calculates the cumulative soil mass and organic C mass based on the depth, volume, and mass of different reference layers (i.e., horizons) within a soil core. Then, a cubic spline curve is fit to the cumulative soil mass and organic C down the soil profile (Wendt and Hauser, 2013). This approach provides the equivalent soil mass (ESM) C for each horizon and the cumulative soil C (i.e., summed incremental ESM-C) for the entire profile. We also used ESM calculations to determine cumulative and incremental N content within the soil profile.

Statistical analysis

To assess the overall accumulation of soil C in response to drainage, we modeled the cumulative soil C values, determined via the ESM approach, as a function of tile drainage. We used a mixed-effects model (R package lme4), with tile drainage age defined as the fixed effect and transect defined as the random effect. To determine the effect of drainage treatment on soil C within horizons, we used the mixed-effects model previously outlined within each horizon. We defined incremental soil C values as the response variable instead of cumulative soil C. For both statistical models, we excluded one of the untiled fields (n = 4) from analysis because it was determined that many of the cores obtained from that field were not of the Dayton series and thus could not be compared to the other soil samples.

We tested for Gaussian distributions for each response variable and, subsequently, examined the distribution of model residuals for normality. Response variables (except for the Bt incremental C variable) did not meet the assumptions of the model. Therefore, we performed

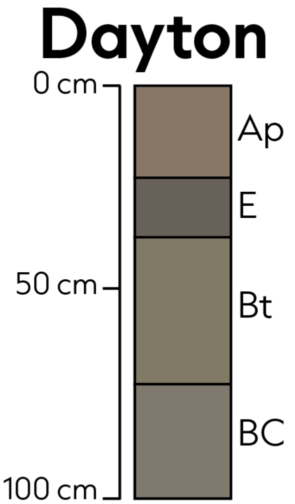

Figure 1. Illustration depicting the Dayton series soil profile up to 100 cm and the location of each horizon with respect to depth. Horizon descriptions are presented in Table 1.

Table 1. Dayton soil series horizon depths and texture.

Horizon	Description
Ap/E	0–30 cm. Silt loam texture with 15–30% clay.
Bt	38–74 cm. Clay or silty clay texture with 40–50% clay.
BC	74–100 cm. Clay or silty clay with 40–50% clay in the upper part and silty clay loam or silt loam with 20–35% clay in the lower part.

log transformations of the non-normal response variables, which allowed the data to meet the model's assumptions.

Results and Discussion

The primary objective of this study was to assess whether tile drainage encourages C storage or depletes existing C stocks. We targeted the Dayton soil series because it is poorly drained and likely to be impacted the most by subsurface drainage compared to other soil types in the Willamette Valley.

We found no differences in cumulative soil C between newly tiled, old tile, and untiled fields (Figure 2, $P = 0.35$). We also measured soil C within each horizon to determine whether this trend persisted throughout the soil profile. Consistent with known organic C values for different horizons within the Dayton series, we found that the Ap/E horizon contained the most soil C and that soil C declined with depth. Additionally, there were no differences between drainage treatments in the Ap/E horizon and the Bt horizon. However, we found the BC horizon in old tile fields contained more soil C than the newly tiled and untiled treatments (Figure 3, $P < 0.001$).

We found similar patterns in soil N concentrations across treatments and horizons. Like soil C, there were no differences in cumulative soil N (Table 2, $P = 0.24$) between newly tiled, old tile, and untiled fields. There were also no differences in soil N between treatments in the Ap/E and Bt horizons. Within the BC horizon, old tile fields had less soil N than the newly tiled and untiled fields ($P < 0.0001$).

Maintaining C:N ratios that promote biological activity is essential for regulating C and N cycling in agroecosystems, especially in the upper regions of the soil profile where roots can capture vital nutrients released from the decomposition of crop residues. Our results show that soil C:N ratios generally decreased with depth in the soil profile, meaning there were fewer parts of C to N at lower depths compared to shallower depths. Drainage affected C:N ratios within the Ap/E and Bt horizons, with old tile fields having lower C:N ratios than the newly drained and undrained fields (Ap/E, $P < 0.001$; Bt, $P < 0.01$). However, the differences in C:N ratio between drainage treatments, while statistically different, may not be meaningfully different within the larger context of agricultural processes. The C:N ratios in the Ap/E horizon were all roughly 10:1, and the C:N ratios in the Bt horizon were approximately 6:1 (Table 2). There were no differences in C:N ratios in the BC horizon between drainage treatments.

Fields with older drainage have potentially had higher diversity of crop plantings than newer fields. This extended cropping history likely has allowed more cumulative root biomass inputs. The production of new roots and death of old roots provides substrates for microbial colonization and an energy source (e.g., C) for microbial activity. Root turnover and C incorporation into microbial biomass can lead to C stabilization

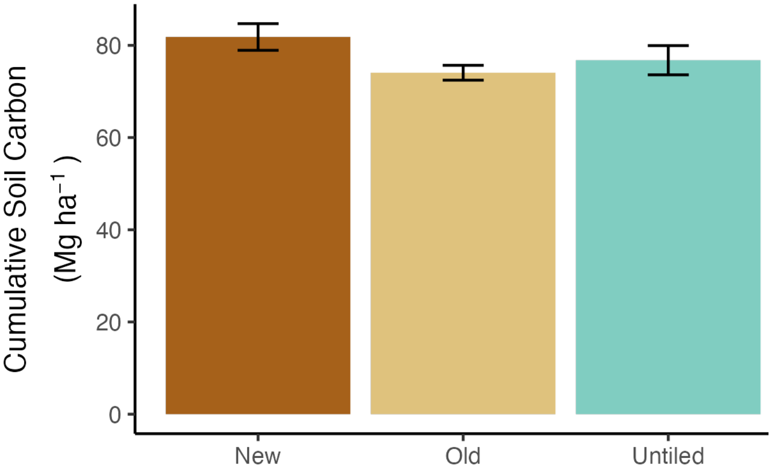

Figure 2. Cumulative soil C across drainage treatments. Differences between treatments were not significant. Bars represent standard error of the mean. Statistics are presented in Table 2.

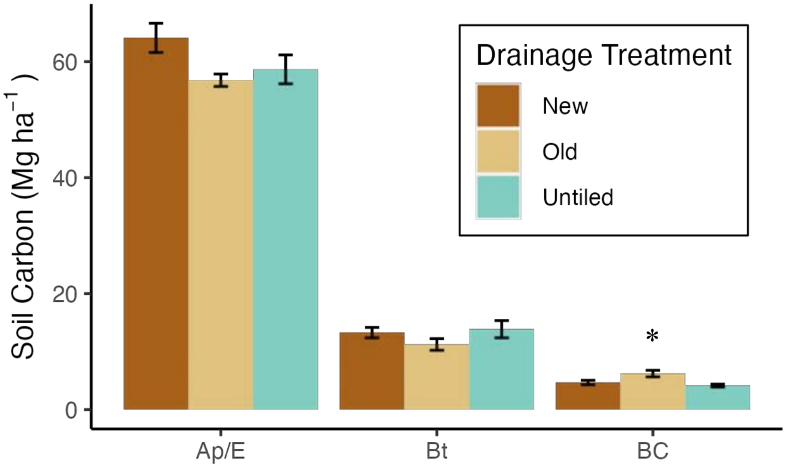

Figure 3. Incremental soil C for each horizon. Asterisk denotes differences between treatments within a soil horizon. Bars represent standard error of the mean. Statistics presented in Table 2.

Table 2. Cumulative and equivalent soil mass values for each horizon for carbon (C) and nitrogen (N) content.[1]

		Soil C			Soil N			------------ C:N ratio ------------		
		---------- (mg ha^{-1}) ----------			---------- (mg ha^{-1}) ----------					
		Mean ± SE	*F*	*P*	Mean ± SE	*F*	*P*	Mean ± SE	*F*	*P*
Cumulative	New	81.8 ± 2.9	1.86	0.16	8.5 ± 0.2	1.45	0.24	—	—	—
	Old	74.1 ± 1.6	—	—	8.6 ± 0.2	—	—	—	—	—
	Untiled	76.8 ± 3.2	—	—	8.2 ± 0.2	—	—	—	—	—
Ap/E	New	64.1 ± 2.5	2.50	0.09	5.9 ± 0.2	1.69	0.19	10.8 ± 0.2	10.48	< 0.001
	Old	56.8 ± 1.1	—	—	5.7 ± 0.1	—	—	10.0 ± 0.1	—	—
	Untiled	58.7 ± 2.5	—	—	5.5 ± 0.2	—	—	10.7 ± 0.1	—	—
Bt	New	13.3 ± 0.9	1.29	0.28	0.9 ± 0.0	0.06	0.94	7.3 ± 0.2	6.10	< 0.01
	Old	11.3 ± 1.0	—	—	1.2 ± 0.1	—	—	6.7 ± 0.2	—	—
	Untiled	13.9 ± 1.4	—	—	0.8 ± 0.0	—	—	7.6 ± 0.2	—	—
BC	New	4.7 ± 0.3	8.90	< 0.001	1.8 ± 0.1	13.36	< 0.0001	5.4 ± 0.2	0.33	0.72
	Old	6.3 ± 0.5	—	—	1.7 ± 0.1	—	—	5.2 ± 0.2	—	—
	Untiled	4.2 ± 0.2	—	—	1.8 ± 0.1	—	—	5.3 ± 0.2	—	—

[1] SE = standard error

within the soil matrix. Furthermore, the accumulation of microbial necromass can also contribute to aggregated masses of soil and organic matter. However, this aggregation process is confined to upper soil horizons and may not be the primary contributing factor of C accumulation at lower depths. Our results show that C content in the Ap/E horizon is nearly 6 times higher than that in the Bt and BC horizons, regardless of drainage treatment. The translocation of soil C as dissolved organic matter (DOM) may be a more likely avenue for deep C accumulation.

Increased subsurface drainage may aid in the movement of DOM over long durations, which may eventually become stabilized in deeper horizons via chemical bonding. When microbes decompose organic matter (e.g., crop residues) in the upper horizons of the soil profile, a portion of the organic matter is broken down into lightweight molecular structures that become soluble. These dissolved organic compounds can move freely in the soil and, because of the charged nature of these compounds, can form organomineral complexes within the soil matrix. Past research suggests that DOM derived from organic matter in the upper horizons is the primary source of DOM in percolating water in lower horizons (Rothstein et al., 2018) and thus may explain the translocation of DOM into the BC horizon within our study.

Conclusion

In summary, we did not detect differences in soil C stocks in fields with new, old, or no tile drainage, except in the deepest horizon (BC horizon). We found that old tile fields contained more soil C within the BC horizon than the newly tiled or untiled fields. As such, we can partially accept the hypothesis that drainage supports C accumulation, but only in deep horizons within old tile-drained fields.

Our early findings are promising because they indicate that in Willamette Valley soils, tile drainage does not negatively impact soil C storage and may promote soil C at lower depths in the long term. Understanding the exact mechanism for C accumulation in old tile-drained fields will be crucial for providing growers with best practice recommendations. The continuation of this work will investigate potential linkages between microbial community structure and activity and C cycling to understand further how tile drainage affects C stocks in the Willamette Valley.

References

Blann, K.L., J.L. Anderson, G.R. Sands, and B. Vondracek. 2009. Effects of agricultural drainage on aquatic ecosystems: A review. Critical Rev. in Environ. Sci. & Tech. 39:909–1001. doi:10.1080/10643380801977966.

Grenon, G., B. Singh, A. de Sena, C.A. Madramootoo, C. von Sperber, M.K. Goyal, and T. Zhang. 2021. Phosphorus fate, transport and management on subsurface drained agricultural organic soils: A review. Environ. Res. Letters 16. doi:10.1088/1748-9326/abce81.

Jin, C., G. Sands, H. Kandel, J. Wiersma, and B. Hansen. 2008. Influence of subsurface drainage on soil temperature in a cold climate. J. of Irrig. & Drainage Eng. 134. doi:10.1061/(ASCE)0733-9437(2008)134:1(83).

Rothstein, D.E., E.R. Toosi, R.J. Schaetzl, and A.S. Grandy. 2018. Translocation of carbon from surface organic horizons to the subsoil in coarse-textured spodosols: Implications for deep soil C dynamics. Soil Sci. Soc. of Amer. J. 82: 969–982. doi:10.2136/sssaj2018.01.0033.

Wendt, J.W. and S. Hauser. 2013. An equivalent soil mass procedure for monitoring soil organic carbon in multiple soil layers. Eur. J. of Soil Sci. 64:58–65. doi:10.1111/ejss.12002.

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