POSTHARVEST RESIDUE MANAGEMENT PRACTICES DO NOT IMPACT CARBON STOCKS IN TALL FESCUE SEED CROPS

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Introduction

There is keen interest among Oregon grass seed producers to understand how crop management practices, such as tillage and residue management, influence the amount of carbon (C) stored in soils. This interest is related to our growing understanding of how organic C regulates key soil functions, including increased water- and nutrient-holding capacity, reduced mobility of pesticides, increased biological activity, and improved soil structure. As soil C is intrinsically related to soil function, improvements in function can cascade and ultimately lead to enhanced productivity, reduced environmental footprints, and improved resilience to droughts and other extreme weather events.

Interest in understanding the relationship between crop management practices and soil C is also driven by the recent emergence of voluntary C markets. Grass seed producers may have the potential to participate in C markets by implementing practices that are known to favor soil C storage. Producers could then potentially sell C offsets or receive C credits for on-farm reductions in greenhouse gas emissions.

Despite the potential agronomic and economic benefits associated with increasing soil C, our understanding of the effects of residue management practices on soil C storage in the Willamette Valley is limited. Generalizations regarding the effect of agronomic management practices on soil C in other cropping systems do not seem to extend to grass seed production in the Willamette Valley.

For example, in annual cropping systems, reduced tillage typically favors the accumulation of soil C (Nunes et al., 2020). However, in the Willamette Valley, a recent 9-year study concluded that tillage practices and establishment methods had little impact on soil C in annual ryegrass seed production (Chastain et al., 2017).

Similarly, in other cropping systems, returning crop residues to the soil generally increases C stocks. Again, in the Willamette Valley, the response of soil C to residue inputs is less predictable. For example, Griffith et al. (2011) reported that chopping and leaving the residue of tall fescue to decay increased surface soil C at only one of three Willamette Valley field sites over 6 years. Likewise, a recent survey of 28 tall fescue fields found that returning crop residue had no effect on the amount of organic matter or active C in the soil (Verhoeven et al., 2021).

While the unpredictable response of soil C to management practices may be attributed to inherent soil properties (e.g., texture and drainage class) or crop characteristics (e.g., rooting depth and perennial nature), it may also be attributed to a lack of experimental data. Most studies that have investigated soil C in grass seed production systems have measured C dynamics in the top 6–8 inches of the soil profile. To fully account for C, a comprehensive assessment of soil C that includes measurements of C in deeper soil horizons (0–39 inches) is necessary. Accounting for C inputs from above-ground (shoots) and below-ground (roots) biomass is another key aspect of C stock assessment that has not previously been included in estimates of soil C stocks in the Willamette Valley.

Therefore, the primary goal of this study was to expand our understanding of C dynamics across the soil profile by assessing the effects of stand age and postharvest residue management practices on C stocks in tall fescue (*Schedonorus arundinaceus* (Schreb.) Dumort.) seed crops. Data for grass seed systems need to be put in context with data from other Willamette Valley land-use scenarios. To this end, we also sampled a limited number of fields with more highly disturbed soils (for example, those with a history of annual tillage), as well as uncultivated natural areas.

Materials and Methods

Field selection

A total of 24 tall fescue fields were sampled across the Willamette Valley. In 12 of these fields, the postharvest straw was chopped and allowed to decompose in the field ("full straw"). In the other 12 fields, the residual straw residue was baled and removed from the field ("bale"). These residue management practices were carried out for at least 75% of the stand years. Within each management category, the fields were further subdivided by age: six fields had stands that were

2–4 years old ("young"), and six fields had stands between 5 and 20 years old ("old").

Soil and plant sampling

Soil maps from the Natural Resources Conservation Service were used to identify the dominant soil series. Soil samples (0- to 39-inch depth) were collected between February and April of 2021 using an ATV-mounted hydraulic probe with a 2-inch diameter coring tube (Giddings Machine Co., Windsor, CO) and were analyzed for total soil C and bulk density. In each field, three transects were established within the dominant soil series. Within each transect, three cores were collected for a total of nine cores per field. Following collection, soils were kept at 4°C until processed for total C, bulk density, and phospholipid fatty acid analysis.

Additional soil and root samples were collected in the spring of 2021 for microbial biomass and root C analysis. For microbial biomass, at each sampling point, a slice of soil was collected with a shovel (0–12 inches), and the three slices per transect were composited and mixed. A subsample of the composited slices was placed into a 1-gal plastic bag. Roots were collected from the center of tall fescue rows using a sharpshooter shovel, and a soil knife was used to trim the sample (2-inch x 5-inch x 12-inch slice). After collection, all samples were stored in individual 1-gal plastic bags at 4°C until processed.

In June 2021, at plant physiological maturity, above-ground tall fescue biomass was collected by harvesting a 1 ft^2 in-row quadrat using rice knives. Samples were collected across the same transects and sampling points as in the soil and root sampling (three samples/transect). Row spacing for each field was measured to convert individual plant biomass and C values to per-acre estimates.

Another set of soil samples was collected in the summer of 2021 from three annually tilled fields and three undisturbed natural areas. These fields were used to compare the soil C stocks in soils with contrasting levels of soil disturbance but similar soil types as those sampled in the tall fescue fields. The 10-year cropping history of annually disturbed fields consisted of: (1) a winter wheat/red clover rotation, (2) a winter wheat/vetch/annual ryegrass/pea rotation, and (3) a field that was in winter wheat in 2021 but had been continuously planted to corn for the previous decade. The uncultivated areas consisted of a grassy area at the edge of a field near a homestead and two local natural preserves with permanent grasslands. Soil cores from a 0- to 39-inch depth were collected as described earlier, with the exception that two samples were collected and composited from each transect.

Soil and plant processing and analysis

Soil cores were divided into two sections (0–12 and 12–39 inches) and air-dried. Soils were weighed to estimate bulk density and composited by transect to obtain three samples per field for each of the sampled depths. Samples were then sieved through a 2-mm mesh screen, and pebbles or plant fragments larger than 2 mm were discarded. Soil samples were then oven-dried at 221°F for 24 hours and weighed for total C analysis by combustion (LECO, 828 series, St. Joseph, MI).

To assess soil microbial biomass and microbial community structure, samples were shipped to Microbial ID, Inc. (Newark, DE) for phospholipid fatty acid analysis.

A subsample of 108 root samples (corresponding to 12 fields; 3 from each straw and age management combination) were washed over a 1-mm sieve to remove the soil. All plant biomass (below-ground and above-ground) was oven-dried at 149°F for 48 hours, composited by transect, ground, weighed in triplicate subsamples (0.25 g each), and analyzed for total C as above.

C stock calculation and statistical analysis

Total C stocks in the soil cores were calculated using the following equation:

$$C_{stock} = C_{content} \bullet (1 - \text{mass proportion}_{coarse}) \bullet \rho \bullet d$$

where $C_{content}$ is the mass proportion of soil C in the soil, mass $\text{proportion}_{coarse}$ is the mass proportion of the coarse soil to the whole soil sample, ρ is the bulk density of the whole soil, and d is the depth.

The effects of straw residue management and stand age on soil were evaluated using two-way ANOVAs and Tukey HSD posthoc analyses in R; data were log-transformed when assumptions of normality or homogeneity of variances were not met. Microbial biomass and community parameters were evaluated using a Kruskal-Wallis analysis.

Results and Discussion

There was no difference in soil C stocks at the 0- to 12-inch depth between postharvest residue management practices ($P = 0.11$) or between old and young stands ($P = 0.42$, Table 1). We expected that C stocks would increase with stand age; however, this was not the case, and no significant correlation was observed between the two variables (data not shown). Similar trends were observed in the deeper soil profile. Soil C stocks at the 12- to 39-inch depth were not affected by age category ($P = 0.19$) or postharvest residue management ($P = 0.37$). Average values of soil C stocks for each treatment at the different soil depths are shown in Table 1.

Immediately before harvest, above-ground biomass and corresponding above-ground C stocks were highest in young, baled fields and lower in the other treatments ($P = 0.006$, Table 1). Decreased above-ground biomass in older fields and in young, full-straw fields could be related to higher pest pressure or to limited access to sunlight during early growth stages of tall fescue in full-straw managed fields.

Below-ground biomass increased with stand age ($P < 0.001$) but was not influenced by postharvest residue management practices ($P = 0.68$). Percent C in root tissue decreased over time from an average of 37% to 32% ($P = 0.015$), but overall C stocks remained higher in old stands compared to young stands ($P = 0.008$, Table 1).

Measurements of phospholipid fatty acids are used to assess the total microbial biomass and to broadly categorize microbial community composition (i.e., fungi, bacteria, actinomycetes). Microbial biomass was not different between postharvest residue management practices in young fields ($P = 0.055$, Table 1). Microbial biomass increased with stand age in the retention fields but not in baled fields. The increase in microbial biomass in older stands with a full straw return was driven primarily by an increase in total bacterial populations ($P = 0.003$). Fungal biomass was not altered by stand age or postharvest residue management practices.

Total C stocks (soil, above- and below-ground biomass) of tall fescue stands were not different regardless of stand age or postharvest residue management practices (Table 1 and Figure 1). The overall average C stock was 75.6 ton/acre. With more than 150,000 acres planted in tall fescue in the Willamette Valley, total C stocks for this cropping system would be greater than 11.6 million tons.

In addition to understanding how C stocks respond to management practices, it is also important to understand how they respond to cropping systems. For example, we expect that annually tilled row or field crops accumulate less soil C than perennial grass seed crops. However, given that soil C does not seem to respond to repeated tillage in annual ryegrass crops (Chastain et al., 2017), this assumption could be erroneous in Willamette Valley conditions.

We also measured soil C stocks of natural undisturbed areas and annually tilled soils (Figure 2). Average soil C stocks at the 0- to 12-inch depth differed across a land disturbance gradient. Soil C stocks of tall fescue (41 ton/acre) were lower than in uncultivated natural areas (50 ton/acre) but higher than in annually tilled crops (33 ton/acre) from similar soil types in the Willamette Valley. However, at the 12- to 39-inch depth, tall fescue and annually tilled crops had similar soil C stocks (24 and 23 ton/acre, respectively), and these were significantly lower than soil C stocks of undisturbed natural areas (37 ton/acre).

Table 1. Carbon (C) stocks in soil, C stocks in above- and below-ground biomass, and microbial biomass at plant physiological maturity immediately prior to seed harvest.[1]

	----- Young (2–4 years) -----		------- Old (> 5 years) -------	
	Bale	Full straw	Bale	Full straw
Soil C stocks, 0-12 inch[2]	40.1 ± 2.4	42.0 ± 1.5	40.3 ± 2.1	45.2 ± 3.2
Soil C stocks, 12-39 inch[2]	28.7 ± 1.6	25.2 ± 1.8	30.6 ± 2.1	34.6 ± 5.8
C stocks in AG biomass[2]	3.8 ± 0.4	2.2 ± 0.2	2.9 ± 0.3	2.8 ± 0.3
C stocks in BG biomass[2]	0.9 ± 0.1	1.2 ± 0.1	1.7 ± 0.3	1.7 ± 0.2
Microbial biomass[3]	88.2 ± 9.1	79.9 ± 10.3	94.0 ± 12.2	127.4 ± 34.0

[1]Values shown are the mean ± standard error.
[2]ton/acre
[3]nmole/g soil

Conclusion

The results of our study suggest that postharvest residue management practices do not drive meaningful changes in C stocks in Willamette Valley tall fescue seed fields. These results agree with previous examinations of C dynamics in tall fescue seed crops (Griffith et al., 2011; Verhoeven et al., 2021). These results are a bit puzzling since it is estimated that straw contributes significant amounts of C per acre (Hart et al., 2012). Our results suggest that this C is not accumulating in the soil, but its fate remains unknown. One possible explanation is that data collected from on-farm measurements and surveys, including the data presented here and in previous examinations, is too variable to directly connect management practices with C outcomes. Another hypothesis is that microbial populations under full-straw retention cycle carbon rapidly, returning it to the atmosphere. Long-term studies of Willamette Valley grass seed cropping systems are needed to fully account for changes in C stocks.

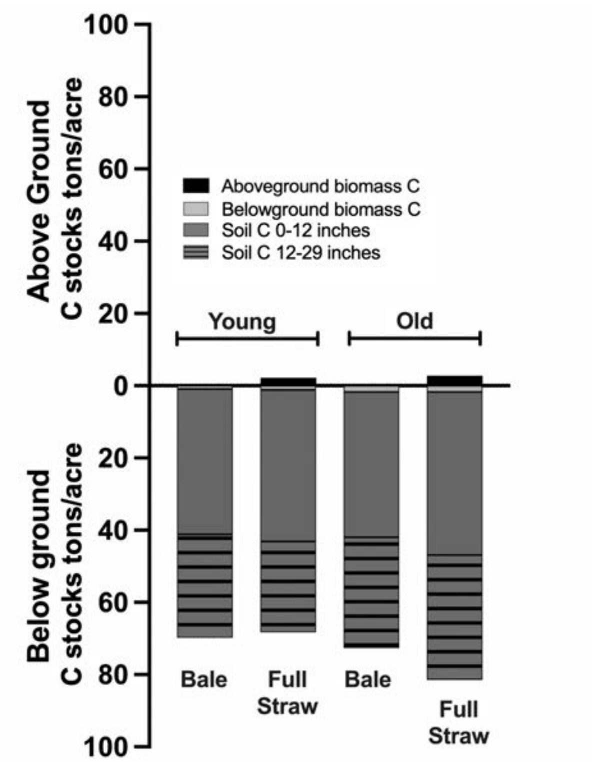

Figure 1. Carbon (C) stocks in tall fescue seed fields according to age and postharvest residue management practices. In baled fields, above-ground C contributions are assumed to be negligible because straw is removed postharvest. Upper bars represent C contributions from above-ground biomass (black). Lower bars represent contributions of root carbon (light gray), soil C in the top 0–12 inches (solid dark gray), and soil C in the 12- to 29-inch depth (striped).

While our results suggest that baling does not affect C stocks, other fertility and soil health consequences of baling should be considered in decisions regarding postharvest straw management. It is well known that baling depletes plant-available K (Hart et al., 2012), and it may reduce microbial biomass and soil aggregate stability (Table 1; Verhoeven et al., 2021). These losses need to be balanced by the reality that full straw may return lower seed yields and increase pest and pathogen pressure (Hart et al., 2012). Oregon State University Extension publications that outline the economic and agronomic trade-offs of postharvest residue management practices are available (Hart et al., 2012).

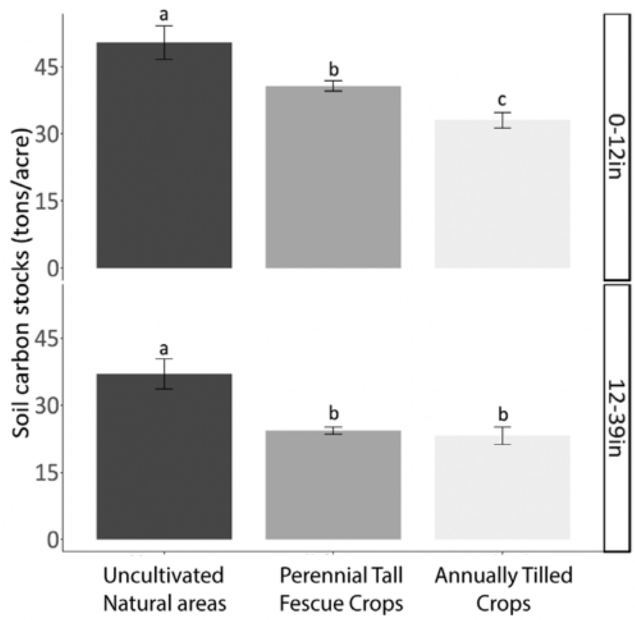

Figure 2. Average soil carbon (C) stocks in the 0- to 12-inch and 12- to 39-inch soil depths in different land uses. Error bars show standard error of the mean. Different letters indicate that average values are statistically different at the 95% confidence level.

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