CROP ROTATION AND STRAW RESIDUE EFFECTS ON SOIL CARBON IN THREE GRASS SEED CROPPING SYSTEMS OF WESTERN OREGON

S.M. Griffith, J.H. Davis, R.P. Dick, G.M. Banowetz and J.J. Steiner

Introduction

As grass seed crop field burning in western Oregon was phased-out, alternative non-thermal practices such as post harvest straw removal or incorporation of the residue into the soil, and crop rotations were being developed. At the time, there was little information available on the practicality and impacts of non-thermal grass seed cropping systems on soil quality. Consequently, in 1992, the multidisciplinary non-thermal cropping systems project was initiated by USDA-ARS (Corvallis, OR) and cooperating scientists from Oregon State University at three diverse locations in the Willamette Valley, Oregon (see Nelson et al., 2006; Steiner et al., 2006; 2007a; 2007b). These experimental plots provided an excellent platform to evaluate soil quality indexes to help identify early indicators of change in soil management.

The overall objectives of this study concerning soil quality were to (1) determine the effects of crop rotation and straw residue management on soil biological, chemical, and physical properties; (2) evaluate biological indexes as temporally sensitive indicators of soil quality; and (3) relate changes in soil properties to yield of temperate grass seed crops. This report will only discuss the portion of the research addressing soil carbon (C). Detailed findings of the entire study will be forth coming in a future publication.

Methods

Research was conducted from 1992 to 1998 at three Willamette Valley, Oregon locations that represented contrasting physical environments differing in soil drainage classifications, suitable for perennial grass seed production in the Pacific Northwest temperate marine ecoregion (i.e., western Oregon). At each site we compared crop rotations for each particular grass species (Table 1). The design was a split plot (four replications) with rotation as the main plot (18 m x 34 m) and residue as the subplot (9 m x 17 m) prepared in autumn 1991. The crop rotations were continuous grass seed production (G), grass/legume (GL), and grass/legume/cereal (GLC). Residue treatments consisted of post-harvest grass straw removed (raking and baling) versus residue remaining (flail chopped and returned to the field). All treatments were investigated without burning the grass straw after seed harvest. All plots were fertilized each spring with 134 kg N ha^{-1}, with urea 46-0-0-0. Site crop management was fully described in detail by Steiner et al. (2006).

Table 1. Three temperate grass species grown for seed using common crop rotation sequences found in western Oregon's Willamette Valley. Rotation sequences lasted six years (1992 to 1998). As indicated, conventional (CT) or no tillage (NT) crop establishment was used.

<u>Perennial ryegrass - Linn County</u>

Grass (G_P): perennial ryegrass; CT

Grass/Legume (GL_P): white clover/meadowfoam/perennial ryegrass; CT

Grass/Legume/Cereal (GLC_P): white clover/perennial ryegrass/wheat/meadowfoam; CT

<u>Tall fescue - Benton County</u>

Grass (G_T): tall fescue; CT

Grass/Legume (GL_T): wheat/red clover/meadowfoam/tall fescue; CT

Grass/Legume/Cereal (GLC_T): tall fescue/wheat/red clover/meadowfoam; CT

<u>Creeping red fescue - Marion County</u>

Grass (G_F): fine fescue; NT

Grass/Legume (GL_F): fine fescue/fine fescue/ red clover; CT

Grass/Legume/Cereal (GLC_F): fine fescue/wheat/red clover/fine fescue; CT

Grass stands of representative species were already being produced at each location before the start of the experiment. One grass species suited to each of the three growing conditions was used: (i) perennial ryegrass (*Lolium perenne* L.) var. Riviera on a poor drained Amity silt loam (fine-silty, mixed, mesic Argiaquic Xeric Argialbolls) in Linn County (44° 28′ 56" N, 123° 11′ 01" W; 76 m elevation), herein referred to as the Linn site; (ii) tall fescue (*Schedonorus phoenix* (Scop.) Holub var. Titan on a poor to moderate drained Woodburn silt loam (fine-silty, mixed, mesic Aquulitic Argixerolls) grown in Benton County (44° 38′ 01" N, 123° 12′ 01" W; 70 m elevation), herein referred to as the Benton site with slow permeability and a seasonally high water table; and (iii) creeping red fescue (*Festuca rubra* L.) var. Jasper on a Nekia silty clay loam 2 to 12 percent slopes of well drained soils (Clayey, mixed, mesic Xeric Haplohumults) in Marion County (44° 56′ 24" N, 123° 45′ 19" W; 236 m elevation), herein referred to as the Marion site.

All continuous perennial grass crops grown for seed were in place for three seed-years and then reestablished into grass. Rotational crops included the following, but their use was dependent upon the soil conditions at each location: white clover (*Trifolium repens* L.) var. S1 Louisiana, red clover (*Trifolium pratense* L.) var. Marathon, wheat (*Triticum aestivum* L.), and meadowfoam (*Limnanthes alba* Hartw. & Benth.) var. Floral). Clover was grown for two seed years, wheat and meadowfoam for one seed-year. These grass seed crop treatment combinations were used as examples and not meant to represent all production options available to farmers in western Oregon. At all locations, conventional tillage (CT) was used for crop establishment, except at the Marion site. At the Marion site, the continuous grass rotation (G) was established using no tillage (NT) the first seed-year and left undisturbed for a total of three seed-years and then NT established again to complete the six-year rotation. No tillage was conducted into the undisturbed soil of a previous grass seed crop of at least three years of age and CT utilized one disc plowing at 20 cm depth.

The Marion soil was representative of soils in the north Willamette Valley foothills compared to the Benton and Linn sites that represented some of the southern valley soils. At the Marion site, soil water permeability was moderately slow. All soils were non-calcareous and low pH. At the Benton site soil water permeability was moderate in the upper part of the subsoil and slow in the lower part. At the Linn site, soil water permeability was slow and some overland flow was not uncommon. These soils were chosen for the study for their extensive presence in the area and contrasting physical and chemical characteristics that are thought to influence soil C cycling.

Results

Total carbon. At the Linn site, there were no significant ($P \leq 0.05$) differences in soil total C among rotation and residue treatments at the 0-10 and 10-20 cm depths by 1998, six years from the start of the cropping sequences. Across all treatments, the mean soil total C concentration at 0-10 cm depth was 19.3 $\pm$ 1.5 g kg^{-1} in 1998, a significant ($P \leq 0.05$) decline of 18% from initial 1992 mean of 23.3 $\pm$ 0.5 g kg^{-1}. At the 10-20 cm soil depth, the 1998 soil total C concentration was 13.1 $\pm$ 0.6 g kg^{-1}, a significant ($P \leq 0.05$) decline of 35% from the initial 1992 mean of 20.2 $\pm$ 0.7 g kg^{-1}. Soil total C concentration was 28% greater at the 0-10 cm depth compared to the lower 10-20 cm depth.

At the Benton site in 1998, the G_T rotation treatment had significantly ($P \leq 0.05$) greater total C, 15.9 $\pm$ 0.9 g kg^{-1}, compared to GLC_T, 14.2 $\pm$ 0.4 g kg^{-1} and GL_T at 13.2 $\pm$ 0.1 g kg^{-1}. High straw residue significantly increased G_T total C by 10.7% from the G_T low straw treatment. There was no significant difference in total C between GLC_T and GL_T rotation and residue treatments at the 0-10 or 10-20 cm depths or G_T at the 10-20 cm depth. The soil total C mean at the 10-20 cm depth was 11.5 $\pm$ 0.4 g kg^{-1}. The total C concentration at 0-10 cm depth in 1992 was 14.9 $\pm$ 0.3 g kg^{-1} and at 10-20 cm was 14.5 $\pm$ 0.3 g kg^{-1}; these concentrations were not significantly ($P \leq 0.05$) different. From 1992 to 1998, total C concentration stayed at the same level for G_T and GLC_T rotations but significantly declined by 1998 in the GL_T residue treatment by 12.1% (13.1 + 0.14 g kg^{-1}) at the 0-10 cm depth.

At the Marion site, total C at a depth of 20 cm was not significantly ($P \leq 0.05$) affected by rotation or residue treatments, nor did total C significantly ($P \leq 0.05$) change from 1992 to 1998. However in 1998, the mean total C at 0-10 cm, 32.4 $\pm$ 0.5 g kg^{-1}, was significantly higher than the mean total C at the 10-20 cm depth, 24.3 $\pm$ 0.5 g kg^{-1}.

Location effect on total soil C was also examined. Total soil C at the 0-10 cm depth was significantly ($P \leq 0.05$) different at each location across all rotation and residue treatments. Total C means for Linn, Benton, and Marion sites were 19.3 $\pm$ 0.27, 14.0 $\pm$ 0.11, and 32.4 $\pm$ 0.73 g kg^{-1}, respectively. At the 10-20 cm depth, total C at the Marion site (24.3 $\pm$ 0.68 g kg^{-1}) was significantly ($P \leq 0.05$) different from Benton (11.6 $\pm$ 0.19 g kg^{-1}) and Linn sites (13.1 $\pm$ 0.28 g kg^{-1}). Total C at the Linn and Benton sites were not significantly different from one another at the 10-20 cm depth.

Soil organic matter (SOM). For the Benton site in 1998, the G_T rotation with high straw residue treatments had significantly higher SOM at 0-10 cm depth, but not at 10-20 cm depth, compared to the other Benton treatments. At Linn, G_T high straw treatment increased SOM over straw removed but there was no rotation effect on SOM. At the Linn site after a six-years (1992-1998), SOM at the 0-10 cm depth significantly ($P \leq 0.05$) declined from the by 10% in plots of G_P-low straw, GLC_p-low straw, GL_P high and low straw treatments. All other treatments remained unchanged from the 1992 mean of 4.65%. At the 10-20 cm depth SOM remained unchanged from the mean 1992 value of 3.81%. At Benton, SOM at the 0-10 cm depth declined 9% from the 1992 mean of 3.37% in the low straw treatments of GLC_T and GL_T receiving low straw since 1992. All other treatments remained the same. In 1998, the Benton SOM at the 10-20 cm depth in did not change since 1992.

At the Marion site, the percent SOM at a depth of 20 cm was not significantly ($P \leq 0.05$) affected by rotation or residue treatments, nor did SOM significantly ($P \leq 0.05$) change from 1992 to 1998. The Marion 1992 mean SOM at 0-10 cm and 10-20 cm was 8.10% and 5.38%, respectively.

Across all rotation and residue treatments, a location effect for SOM was evident at the Marion site. Marion site SOM at the 0-10 cm depth was 7.22 $\pm$ 0.13%, significantly different from the both the Benton and Linn sites, 3.24 $\pm$ 0.07 and 3.87$\pm$ 0.06%, respectively. At the deeper 10-20 cm depth, the Marion site SOM (5.32 + 0.14%) was also significantly higher than Benton (2.92 + 0.06%) and Linn (2.7 + 0.07%) sites. Benton and Linn sites were not significantly different from each other at the 0-10 or 10-20 cm depths.

Microbial biomass carbon (MBC). At the Linn site, MBC at the 0-10 and 10-20 cm depths was significantly ($P \leq 0.05$) affected by rotation but not residue treatment. At the 0-10 cm depth, the rotation treatment GLC_P, with high straw load, had 51% greater soil MBC, than G_P and GL_P. Microbial biomass C for rotation and residue treatments G_P and GL_P were not significantly different from each other. At the 10-20 cm depth, G_P low and high straw treatments had 45% higher MBC than GL_P and GLC_P; neither GL_P nor GLC_P were significantly different from each other. In 1998, MBC for the G_P and GL_P low and high residue treatments at the 0-10 cm depth were significantly ($P \leq 0.05$) lower from the initial MBC measurement in 1994 of 433 μg C g^{-1}, but unchanged from the GLC_P low and high straw treatments. Linn soil MBC in 1994 was 177 μg C g^{-1} at the 10-20 cm depth and not significantly different from the 1998 G_P low and high straw treatments but 998 GL_P and GLC_P rotation and residue treatments were 39% lower.

At the Benton site, the G_T rotation had 74% greater soil MBC at the 0-10 cm depth than the GL_T and GLC_T, and for all rotation treatments, high straw treatment maintained higher MBC than low straw. The GL_T and GLC_T rotations were not significantly different from one another at the 0-10 cm depth and G_T, GL_T, and GLC_T rotation and residue treatments were not significantly different at 10-20 cm depth. At the 10-20 cm depth, MBC averaged 74.6 μg C g^{-1}. The initial MBC mean in 1994 at Benton was 275 μg C g^{-1} at the 0-10 cm and not significantly different from 1998 means of similar depth. At the 10-20 cm depth, the 1994 MBC mean was 98 μg C g^{-1} and 35% higher than GL_T high straw treatment but not different from all other 1998 rotation and residue treatments.

At the Marion site in 1998, G_F rotation treatment soil MBC was 27% greater than GL_F and GLC_F treatments at the 0-10 cm soil depth but no residue effect. At the 10-20 cm depth, there was no rotation or residue effect. The 0-10 cm depth MBC mean in 1992 was 305 μg C g^{-1} but by 1998, G_F high residue treatment had 1.58-fold higher MBC, while all other 1998 treatments remained unchanged. At 10-20 cm depth, there was no significant change in MBC concentration as a function of rotation or residue treatment in 1998 and no change in MBC from 1994, 124 $\pm$ 14 μg C g^{-1}, to 1998, 133 μg C g^{-1}.

Dissolved organic carbon (DOC). There was no rotation or residue treatment effect on soil DOC from 1992 to 1998 at the Linn site. The combined mean of all treatments for DOC was 123 $\pm$ 6.0 mg C kg^{-1}. Rotation had a significant effect on soil DOC at the Benton site. The G_T rotation with high straw load significantly increased soil DOC over all other treatments. The G_T rotation and high residue treatment DOC mean was 90.3 $\pm$ 0.84 mg C kg^{-1}, while the other combined treatment mean was 62.6 $\pm$ 1.84 mg C kg^{-1}. At the Marion site, G_F plus high residue also had significantly higher soil DOC, 72.3 $\pm$ 0.30 mg C kg^{-1} then other treatments, 58.6 $\pm$ 2.7 mg C kg^{-1}.

Conclusions

- Crop rotation with different crop species or straw residue removal had little effect on total soil C in the grass seed production systems used in this study.
- Often, soil organic matter (SOM) was greater in continuous grass systems, especially where residue was chopped and unincorporated.
- SOM often increased in the upper soil layer after straw was chopped and returned to the field.
- In all cases, the greatest concentration of soil C was in the top 10 cm of soil.
- Higher soil C appeared to be linked to higher microbial biomass (MBC), and in most cases appeared to be linked to straw returned to the field.
- Soil at the Marion site had higher MBC than the other sites.
- Greater amounts of soil dissolved organic carbon (DOC) was associated with residue remaining treatments and may be related to residue decomposition processes.
- Relative to many other conventional crop systems, perennial grass seed crops in western Oregon maintain high soil C levels sequestered in organic matter and other soil fractions.
- There is some indication that tillage in well-drained soils may have little long-term effects on SOM and total soil C in perennial grass seed cropping systems.

References

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