Soil Carbon Storage

Long-Term Experiments at Pendleton

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Abstract: The long-term experiments near Pendleton provide information regarding soil carbon storage rates. Specifically, a grass pasture experiment established in 1931 reveals that soil organic carbon (SOC) has been lost at about 350 lb per acre per year since cultivation began in 1880. The primary reason for the decline was the use of intensive tillage that did not replace carbon at a rate greater than SOC loss due to biological oxidation. An experiment with continuous winter wheat, no-till was established in 1982 and showed that SOC could be stored at a rate of 71 lb per acre per year. In contrast, the conventional winter wheat-summer, which relies upon intensive tillage, lost SOC at this rate. Annual cereal cropping with no-tillage appears to optimize SOC storage rates in eastern Oregon soils that are used for dryland wheat production.

Background

Six long-term experiments have been established at the Pendleton Agricultural Research Center in eastern Oregon. The earliest experiments date to 1931 and were intended to answer simple questions about the grain yield potential and nutrient requirements of dryland cereal crops. They are now the oldest long-term experiments in the western United States. The youngest were established in 1982 to study the influence of direct seeding (no-till) on wheat yields and soil properties.

In the 1970s, 80s, and 90s, Paul E. Rasmussen of the USDA-Agricultural Research Service at Pendleton led efforts to measure soil organic carbon (SOC) changes due to different cereal production practices in these experiments. After Dr. Rasmussen's retirement in 1999, Steve Machado, Oregon State University Columbia Basin Agricultural Research Center, took over the scientific leadership of the long-term experiments. These are now the most extensive studies available in Oregon and the intermountain Pacific Northwest indicating how management can change soil organic carbon (SOC) content. Because of their long-term nature, these experiments hold valuable information regarding trends in agricultural productivity and biological sustainability over time, especially if we in a changing climate.

Table 1. Long-term research experiments at the Pendleton Agricultural Research Center.

Year Initiated	Experiment Name	Treatment Variables
1931	Grass Pasture	None
1931	Continuous Cereal	None
1931	Residue Management	Nitrogen, Manure, Burning
1940	Tillage-Fertility	Tillage, Fertility
1963	Wheat-Pea	Tillage
1982	No-till Wheat	Nitrogen

Baselines and Trends

Prior to 1880 (before cultivation), the area around Pendleton was dominated by shrub grassland, or sagebrush steppe, with Idaho fescue and Sandberg bluegrass. Soils of the virgin prairie held approximately 23 tons of SOC per acre in the top 8-inches. This soil then lost 38% (8.74 tons) of its SOC in this soil depth after 50 years of continuous winter wheat cropping (1880-1930), which equals an average loss rate of about 350 lb per acre per year (Figure 1). A further 14% of the native SOC was lost after 60 years of alternate winter wheat-summer fallow (1931-1991). More than half of the native SOC (>12 tons of SOC per acre) has been lost over the 110 year period (1880-1991) since the land was converted from uncultivated shrub land to cropland. The primary reason for the SOC decline was not because of erosion of soil by wind and water, but rather use of a production system that did not replace carbon at a rate greater than carbon loss to biological oxidation.

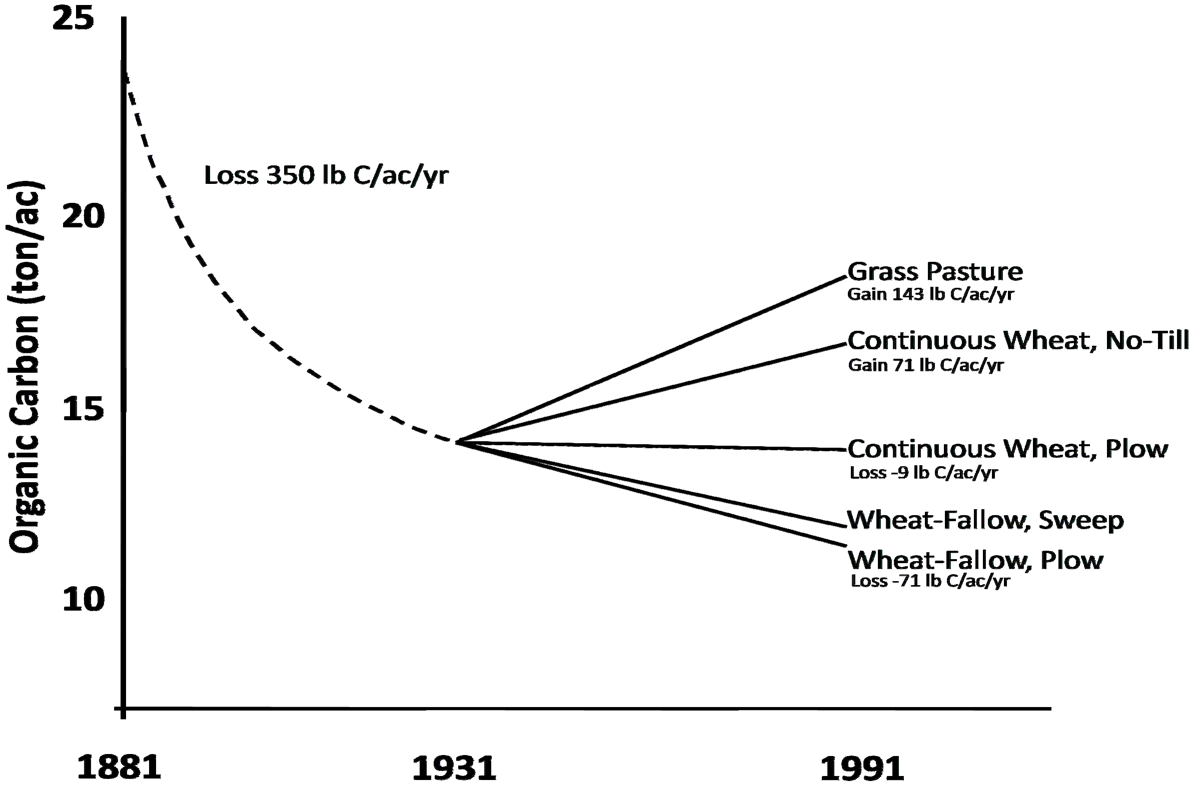

Figure 1. Change in SOC over the 50 year period (1880-1930) of annual wheat production followed by 60 year period (1931-1991) of long-term cereal/tillage experiments at the Pendleton Agricultural Research Center.

Biological Oxidation

Biological oxidation is the process by which bacteria, fungi, and other soil micro-organisms obtain energy from crop residues and other organic substances in the presence of oxygen. The decay of crop residue by micro-organisms results in the oxidation of carbon compounds in plant matter to CO_2 and water. The oxidation reaction is illustrated as follows:

$$\text{Carbon Compound} + \text{Oxygen} \rightarrow CO_2 + \text{Water} + \text{Energy}$$

About 80% of the crop residue tilled into the soil is oxidized by micro-organisms and lost as CO_2 (Figure 2). The remaining 20% of the residue is incorporated into soil organic matter consisting of microbial biomass and decomposed plant matter.

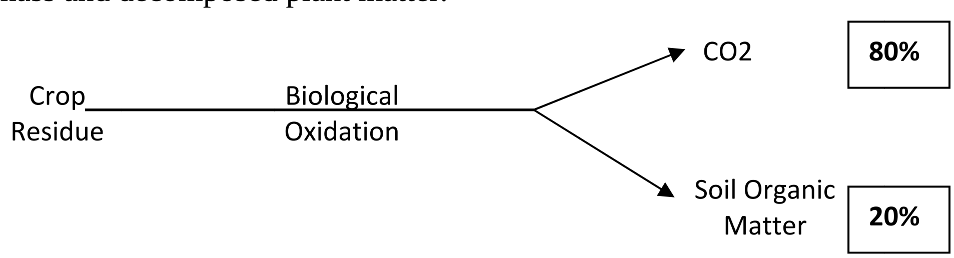

Figure 2. Pathway of carbon following biological oxidation of crop residue in one year. Percentages in boxes represent amount of carbon partitioned into CO_2 or soil organic matter.

However, the resulting soil organic matter is susceptible to further microbial decomposition. Each year, a certain amount of fresh crop residue must be input to keep pace with the rate of biological oxidation and maintain the soil's organic matter. Soil carbon is incorporated into organic substances that become increasingly resistant to loss by biological oxidation. After 20 to 40 years, this organic carbon is bound into substances that are physically and chemically protected from microbial decomposition. After hundreds of year, the resulting humus and charcoal components make up a stable soil organic carbon pool that is extremely resistant to oxidation by microbes, provided this carbon is protected from loss by appropriate soil management practices.

LONG-TERM EXPERIMENTS

Grass Pasture

Initially, SOC changes were determined within a small parcel of cultivated land that had been converted to grass pasture in 1931. Soil OC in that grass pasture has been increasing at an average rate of 143 lb per acre per year (Figure 1 and Table 2). Sixty years after conversion to grass pasture (1931-1991), the soil regained about half of the carbon lost during the first 50 years of cultivation using annual winter wheat. Thus, at least 120 years apparently may be required in a semiarid environment for the SOC to return to its pre-cultivation level. These data indicate that annual C input from grass pasture exceeds yearly biological oxidation of SOC.

Tillage Methods

In the PNW region, conventional tillage involves several tillage operations beginning with a moldboard or chisel plow and followed by up to five secondary passes with a cultivator and rod weeder. In contrast, minimum tillage involves one or two operations with a sweep plow. Soil OC storage rates became increasingly negative in order of annual cropping and alternate wheat-fallow (Rasmussen and Albrecht, 1998). For example, 60 years of conventional tillage (1931-1991) with continuous wheat yielded an average SOC storage rate of -9 lb per acre per year (Figure 1 and Table 2). In contrast, 40 years of conventional tillage with alternate wheat-fallow yielded an average SOC storage rate of -71 pounds per acre per year, which nearly equaled that of sweep tillage with alternate wheat-fallow. Apparently, the greatest negative storage rates may be attributable to alternate fallow, which does not promote the return of biomass to the soil at a rate sufficient to offset the biological oxidation of SOC.

Ten years of the no-till experiment indicate that replacing both conventional tillage and fallow with no-till and continuous winter wheat may increase the average SOC storage rate from -71 lb per acre per year to 71 lb per acre per year (Figure 1 and Table 2). Preliminary results at Pendleton clearly show that eliminating or reducing summer fallowing has improved the SOC content. At a storage rate of 71 lb per acre per year, at least 246 years would be required to restore SOC to pre-cultivation levels under no-till with annual wheat (8.74 ton ÷ 0.0355 ton per year = 246).

Nitrogen Applications and Burning

Long-term effects of N fertilization were evaluated over 55 years at Pendleton (1931-1986) (Table 2). Sources of nitrogen can be expected to increase crop residue production and thus reduce SOC loss (Rasmussen and Parton, 1994). Accordingly, high N treatments of inorganic nitrogen fertilizer decreased the rate of soil C loss. In addition, applications of manure and straw at 5 ton per acre per year yielded a slight increase in SOC over 56 years.

Burning of straw in the fall following wheat harvest over 55 years increased the rate of SOC loss whereas burning in the spring before seeding decreased the SOC loss rate. Thus, fall burning has a greater detrimental effect than spring burning. Spring burning with 40 lb of applied N per acre reduced soil C loss to -27 lb per acre per year whereas 80 lb of N per acre increased SOC by 9 lb per acre per year in the top 8 inches of soil. A combination of higher biomass, due to greater applied N, and residual charcoal from burning apparently led to the positive carbon storage rate. However, a drawback of N fertilization is that it has been found to acidify the topsoil and increase solubility and leaching of silica resulting in its concentration in a hard layer below the plow layer. By binding mobile silica, SOC prevents formation of this siliceous pan thereby promoting soil drainage and root growth (Gollany et al. 2005; 2006).

The loss of SOC in fallow negates one of the original intents of the system, which was to rest the soil and promote water conservation. In fact, the loss of SOC appears to inhibit water infiltration and exacerbate soil erosion problems (Williams, 2004, 2008; Wuest et al. 2005).

SUMMARY AND RECOMMENDATIONS

Organic carbon is naturally stored in the soil by means of biological decomposition of surface crop residues and plant roots. Soil carbon levels can be increased by adopting cultural practices that promote the production of biomass and its return to the soil at rates exceeding the rate of biological oxidation of SOC. Results of research in the Pendleton long-term experiments show that annual cereal cropping with no-tillage will optimize carbon storage rates in eastern Oregon soils that are used for dryland wheat production.

Growers near Pendleton can expect:

- Soil carbon storage rates of around 71 lb per acre per year for annual dryland wheat production with no-till.
- Negative soil carbon storage rates for a crop rotation that includes summer fallow.
- Continued loss of SOC and concomitant increase in susceptibility to erosion under conventional wheat-summer fallow.
- Decrease in rate of SOC loss with use of organic or inorganic nitrogen fertilizers.
- Increase in rate of SOC loss with use of field burning as a means to manage crop residues.

Table 2. Changes in soil organic carbon in the top 8 inches as affected by management.

Practice	Duration	Ave. Storage Rate		Reference
	year	lb C/ac/yr	ton C/ac/yr	
Continuous WW, NT	10	**+71**	**0.04**	Rasmussen and Albrecht, 1998
Continuous WW, CT	60	-9	(0.0045)	Rasmussen and Albrecht, 1998
WW-F, MT	40	-71	(0.04)	Rasmussen and Albrecht, 1998
WW-F, CT	40	-71	(0.04)	Rasmussen and Albrecht, 1998
WW-F, manure applied at 5 tons per ac per year.	56	**+18**	**(0.009)**	Rasmussen and Parton, 1994
WW-F, pea vine applied at 0.5 tons per ac per year.	55	-89	(0.0445)	Rasmussen and Parton, 1994
WW-F, not burned, no N applied	55	-170	(0.085)	Rasmussen and Parton, 1994
WW-F, fall burned, no N applied	55	-186	(0.093)	Rasmussen and Parton, 1994
WW-F, spring burned, no N applied	55	-152	(0.076)	Rasmussen and Parton, 1994
WW-F, not burned, 40 lb of N applied per acre	34	-45	(0.0225)	Rasmussen and Parton, 1994
WW-F, not burned, 80 lb of N applied per acre	34	-36	(0.018)	Rasmussen and Parton, 1994
WW-F, spring burned, 40 lb of N applied per acre	22	-27	(0.0135)	Rasmussen and Parton, 1994
WW-F, spring burned, 80 lb of N applied per acre	22	**+9**	**0.0045**	Rasmussen and Parton, 1994

REFERENCES

Gollany, H.T., R.R. Allmaras, S.M. Copeland, S.L. Albrecht, and C.L. Douglas Jr. 2005. Tillage and nitrogen fertilizer influence on carbon and soluble silica relations in a Pacific Northwest Mollisol. Soil Sci. Soc. Am. J. 69:1102-1109.

Gollany, H.T., R.R. Allmaras, S.M. Copeland, S.L. Albrecht, and C.L. Douglas, Jr. 2006. Incorporated source carbon and nitrogen fertilization effects on carbon storage and soluble silica in a Haploxeroll. Soil Sci. 171(8):585-597.

Rasmussen, P.E., and W.J. Parton. 1994. Long-term effects of residue management in wheat–fallow. I. Inputs, yield, and soil organic matter. Soil Sci. Soc. Am. J. 58, 523–530.

Rasmussen, P.E., and S.L. Albrecht. 1998. Crop management effects on organic carbon in semi-arid Pacific Northwest soils. In: Lal, R., et al. (Eds.), Management of Carbon Sequestration in Soil. CRC Press, Boca Raton, FL, pp. 209–219.

Rasmussen, P.E., S. Albrecht, and R. Smiley. 1998. Soil C and N changes under tillage and cropping systems in the PNW. Soil and Tillage Research. 47:197-205.

Williams, J.D. 2004. Effects of long-term winter wheat, summer fallow residue and nutrient management on field hydrology for a silt loam, north-central Oregon. Soil and Tillage Research 75(1): 109-119.

Williams, J.D. 2008. Soil erosion from dryland winter wheat–fallow in a long-term residue and nutrient management experiment in north-central Oregon. Journal Soil & Water Conservation 63(2): 53-59.

Wuest, S., T. Caesar-Ton, R. Wright, and J.D. Williams. 2005. Organic Matter Additions, N, and Residue Burning Effects on Infiltration, Biological, and Physical Properties of An Intensively Tilled Silt-Loam Soil. Soil & Tillage Research 84: 154-167.