Long-Term Effects of Organic Amendments and Potential Carbon Sequestration in Southwest Virginia Mine Soils

Whitney Nash, W. Lee Daniels
and Jim Burger

www.landrehab.org

VirginiaTech
1872
VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY

Typical Appalachian Haul-Back Contour Mine

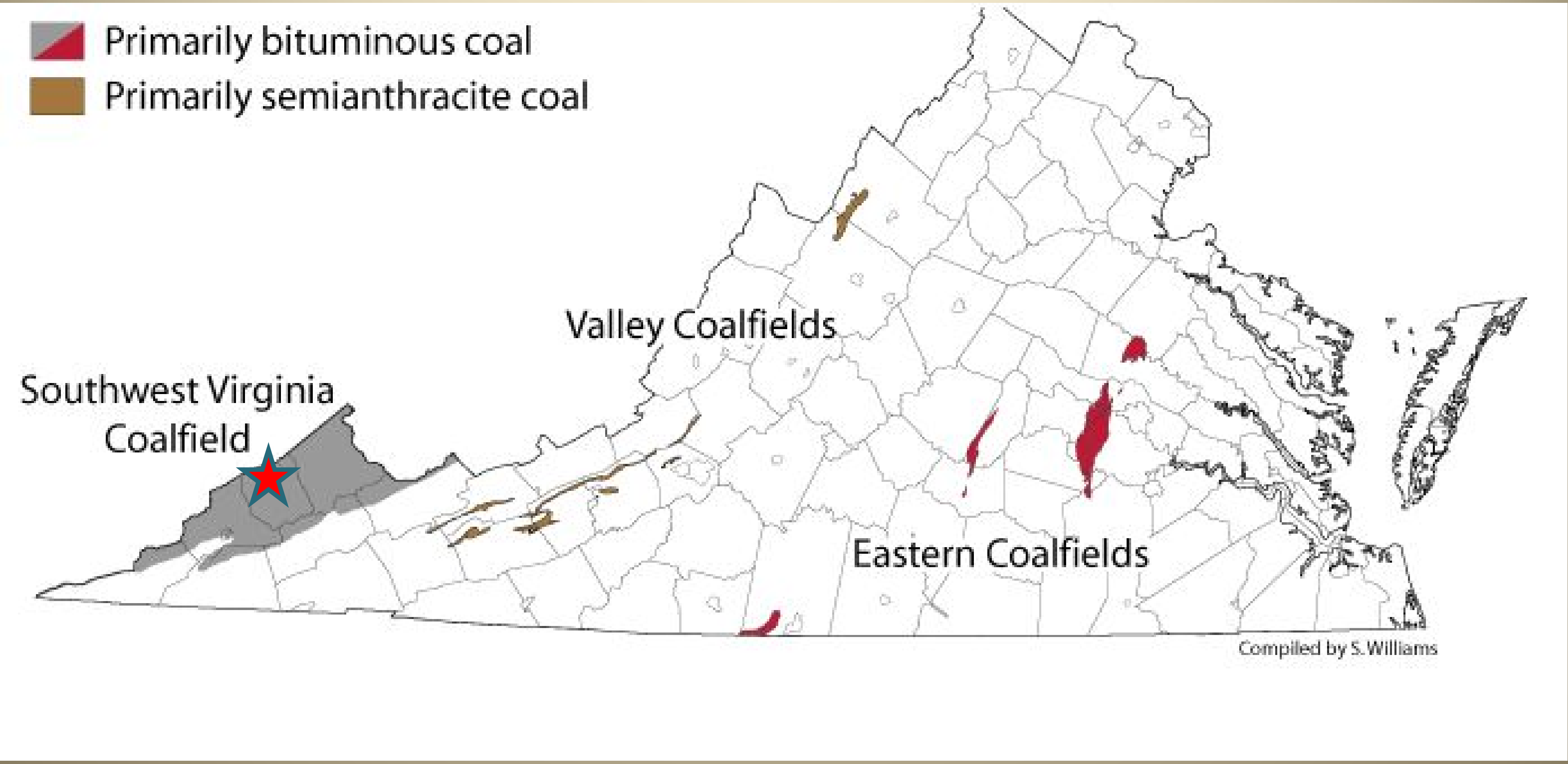
Controlled Overburden Placement

Rock Mix Experiment

Pure Sandstone (SS), 2:1 SS:SiS, 1:1 SS:SiS, 1:2 SS:SiS, Pure Siltstone (SiS)

VirginiaTech
Invent the Future

COPE Location



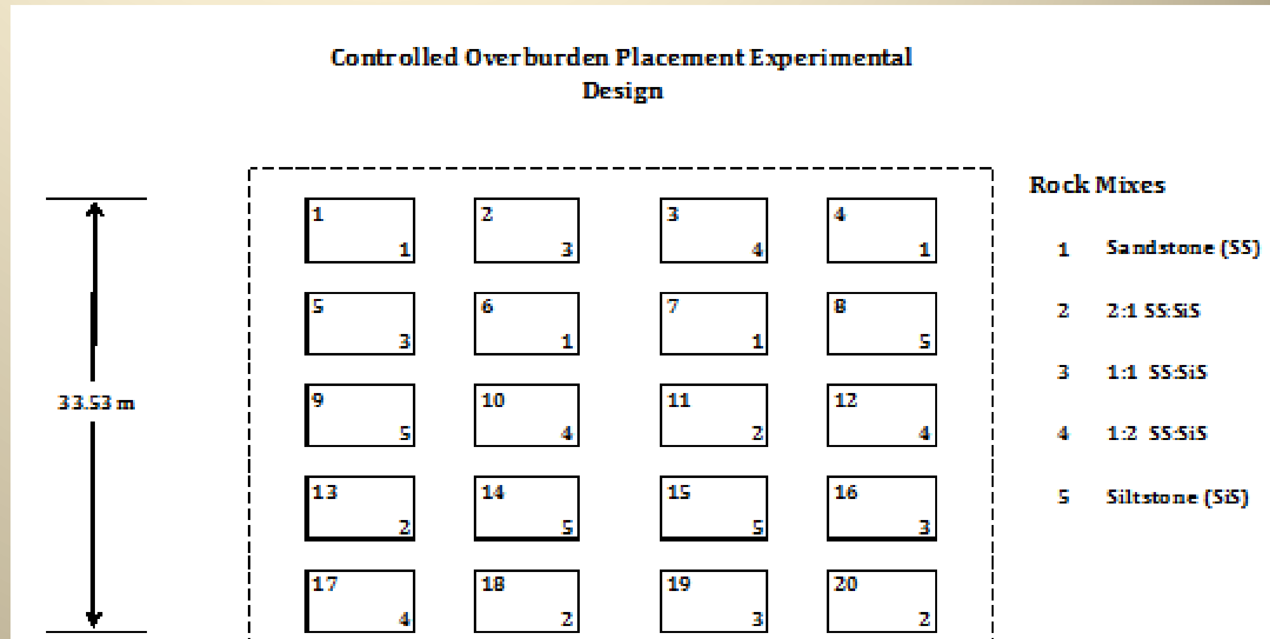
Controlled Overburden Placement Experiment

- Oldest continually monitored mine soil pedogenesis study in the world (as far as we know).
- Implemented in 1982 on the Powell River Project near Wise, Va.
- Further our understanding of mine soil genesis, mine soil nutrient dynamics and the effects of overburden rock type and surface amendments on reclamation success.
- Biomass and soils sampled 6x during the 80’s and 90’s and then again by Nash in 2008

VirginiaTech
Invent the Future

Experimental Design

- Randomized complete block design
- Each treatment replicated 4x



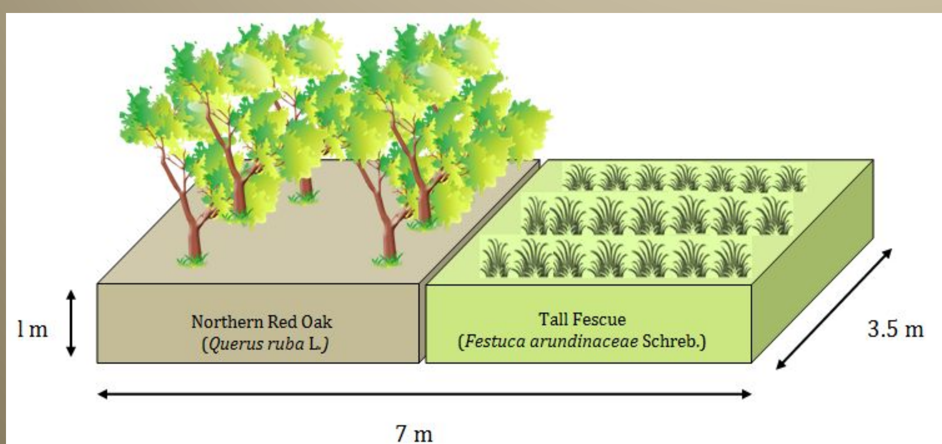


Figure 7 Vegetative Types and Split Plot Design

- Split plot design
- Tree vs. fescue

VirginiaTech
Invent the Future

March-1982

Table 1. List of treatments and abbreviations utilized for the Rock Mix and Surface Amendment Experiments.

Rock Mix Experiment	RM
Sandstone	SS
2:1 SS:SiS	2:1
1:1 SS:SiS	1:1
1:2 SS:SiS	1:2
Siltstone	SiS
Surface Amendment Experiment	SA
Control	CON
Topsoil 30cm	TS
Sawdust 112 Mg ha^{-1}	SD
Biosolids 22 Mg ha^{-1}	B-22
Biosolids 56 Mg ha^{-1}	B-56
Biosolids 112 Mg ha^{-1}	B-112
Biosolids 224 Mg ha^{-1}	B-224

History and Background

- Biosolids had been used at higher than agronomic rates on coal surface mined lands in the Appalachians since the 1970's.
- Research at Penn State, Illinois/Chicago and others had confirmed the benefits of this practice and indicated a general lack of ground- and surface-water impacts.

April-1982

June 1982

2:1 SS:SiS prior to sampling in 2008.

Volumetric Sampling Approach

- 0.09 m^2 or a ft^2
- 0-5 and 5 to 25 cm bulk sampled
- All materials sampled "straight down" including RF using a digging bar to shear where needed
- Fines separated per depth; average of 1600 g (0-5) vs. 6700 g (5 to 25)
- C, N etc. analyzed on a concentration basis on the fines
- Mass C per unit area/depth calculated as mass x conc.
- Total C taken as sum of litter + 0-5 + 5-25 in Mg/ha.
- Minimizes errors due to very high RF content and inability to accurately estimate bulk density!

Table 23. Organic matter content in the surface and subsurface depths of mine soils of the Rock Mix Experiment in 2008.

Treatment	Depth	SOM	P value
Rock Mix			
Sandstone	0-5cm	7.73b*	0.005†
	5-25cm	2.52C	
2:1SS:SiS	0-5cm	9.64ab	0.005
	5-25cm	3.07BC	
1:1SS:SiS	0-5cm	9.49b	0.003
	5-25cm	3.55AB	
1:2SS:SiS	0-5cm	9.70ab	0.008
	5-25cm	3.77AB	
Siltstone	0-5cm	11.72a	0.002
	5-25cm	4.31A	

*Column Means followed by different letters at different depths are significantly different, $P \leq 0.05$ (Fisher's LSD).

Potential Errors in C Estimation in Coal Mine Soils

Walkley-Black technique oxidizes virtually all Fe^{2+} and Mn^{2+} in the sample and reacts with silt-sized and fine coal (geogenic C). Fresh mine spoils from the COPE in 1982 generated up to 1.5% OM (Goren et al., 1983).

Most studies to date rely on estimated B.D. values in high rock fragment mine spoils. Work by Pederson et al. in the 1970's indicated that you need at least 0.5 m^3 to accurately estimate rock fragments and fine-earth B.D. in these materials. Thuys, most studies use "ballpark estimates" of rock fragment volume to predict fine-earth soil volume.

Potential Errors in C Estimation in Coal Mine Soils

Total-C (furnace) analysis burns off both carbonates and geogenic C, leading to high positive errors. See our data on this later.

Many researchers attempt to correct for the carbonate+coal error by taking a deep C horizon sample below presumed C accumulation and using this as a background subtraction. Our experience with older mine soils (pre-2000) is that the surface layers are quite often of differing spoil types and weathering/oxidation extent than deeper layers. This approach is obviously incorrect when topsoiling materials have been returned.

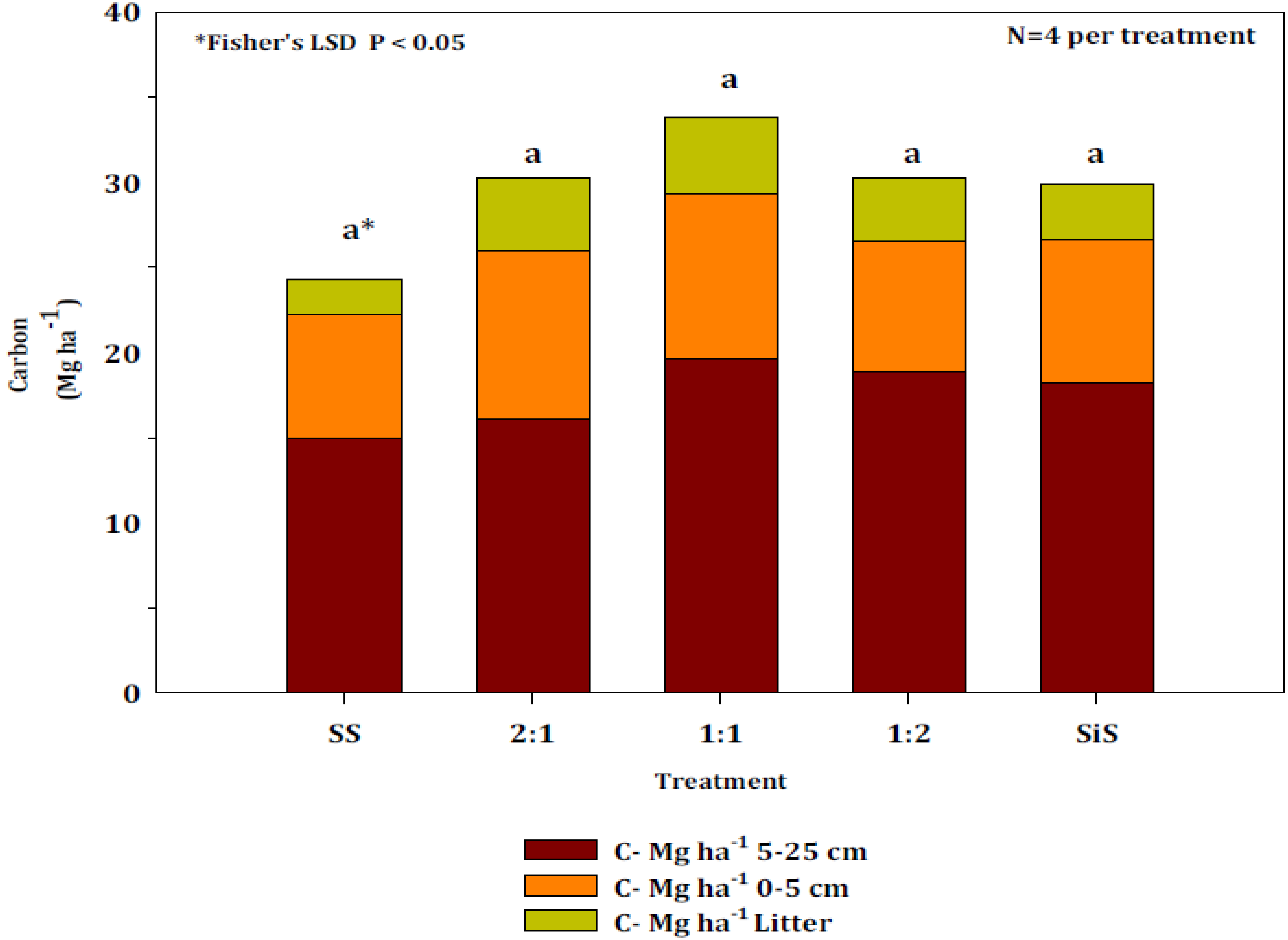


Figure 28. Total average mass C of litter layer, surface and subsurface depths of mine soils of the Rock Mix Experiment sampled in 2008.

Table 28. Estimated total mass soil C accumulation in mine soils on the fescue side of the Rock Mix Experiment.

Treatment	Carbon †					
	----------------------------Mg ha^{-1}----------------------------					
Rock Mix	0-5 cm	Annually	5-25 cm	Annually	Total C	Annually
Sandstone‡	7.30	0.28	15.00	0.58	22.30	0.86
2:1SS:SiS	9.90	0.38	16.10	0.62	26.00	1.00
1:1SS:SiS	9.80	0.38	19.60	0.75	29.40	1.13
1:2SS:SiS	7.60	0.29	18.90	0.73	26.50	1.02
Siltstone	8.40	0.32	18.30	0.70	26.70	1.03

Carbon Sequestration Corrections

- Conducted acid fumigation on pre-treatment 1982 and 2008 samples
- Determined coal and carbonate influence

Treatment	Total C 1982	Total Carbonates 1982	Total Organic C 1982	Total Organic C 2008	Total Carbonates 2008	Total C Accumulation After 26 yrs	Annually
				Mg ha^{-1}			
1:1	12.3	1.2	11.2	24.5	Minimal	13.3	0.51
SiS	20.4	3.3	17.1	25.5	Minimal	8.4	0.32

Soil samples were < pH 6.3 in 2008 and tested negative for carbonates.

It is possible (not probable?) that some of the finely divided coal or fossil-C in these materials may have oxidized/hydrolyzed to a point to be chemically reactive and somewhat similar to OM, so this approach is conservative.

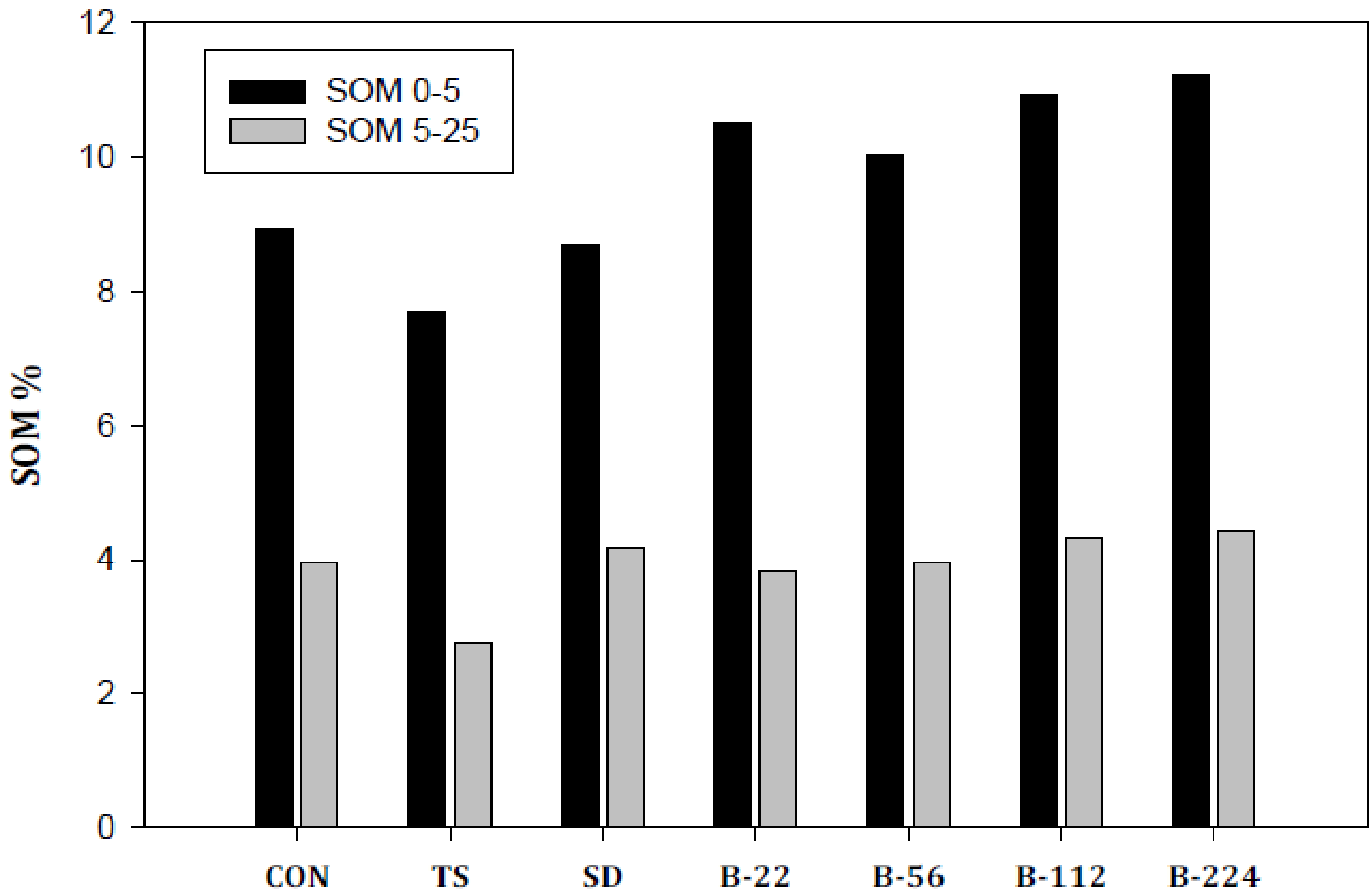


Figure 54. Soil organic matter at surface and subsurface depths of the Surface Amendment Experiment in 2008.

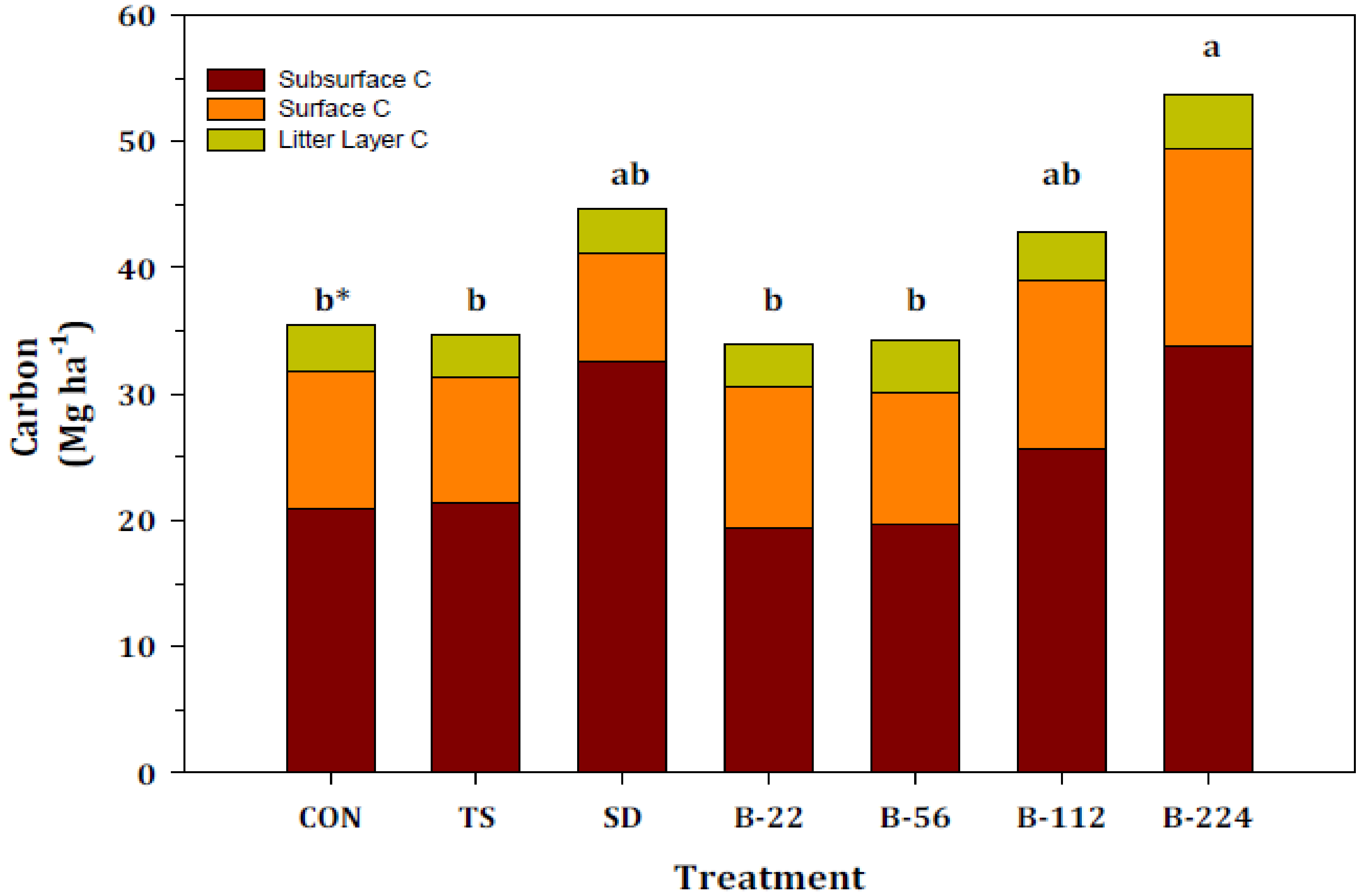


Figure 60. Whole soil mass carbon for litter layer, surface and subsurface depths of mine soils of the Surface Amendment Experiment sampled in 2008.

Table 2b. Estimated total organic C added as organic amendments on the Surface Amendment Experiment in 1982.†

Treatment†	C applied as organic amendment	Post application C to a depth of 25 cm
	C Mg ha^{-1}	
Control§	0	17.7¶
Topsoil	0	8.6 #
Sawdust 112 Mg ha^{-1}‡	50.4	68.1
Biosolids 22 Mg ha^{-1}	4.9	22.6
Biosolids 56 Mg ha^{-1}	12.3	30.0
Biosolids 112 Mg ha^{-1}	24.7	42.3
Biosolids 224 Mg ha^{-1}	49.4	67.1

† See Dewberry and Davis (Appendix C) for % OM present in biosolids. Assumed 58% of OM is C.

‡ Assumed C present in SD is 45% (Ragland et al., 1991).

§ Potential geogenic residual C influence in CON (see methods).

¶Geogenic C present in the 2:1 added to all plots.

C present in TS based on total C present in 1982. Additional C for CON not added due to the depth of the TS at application.

Table 57. Carbon accumulated at depths of 0-25 cm in the Surface Amendment Experiment between 1982 and 2008.

Treatment	Carbon		
	------------------Mg ha^{-1}------------------		
Surface Amendment			
	1982‡¶	**2008**	**Net Annual Accumulation**
Control (2:1) §	17.70	31.84	0.54
Topsoil	8.6	31.34	0.87
Sawdust (112 Mg ha^{-1})†	68.10	41.11	-1.04
Biosolids 22 Mg ha^{-1}	22.55	30.51	0.31
Biosolids 56 Mg ha^{-1}	30.04	30.17	0.01
Biosolids 112 Mg ha^{-1}	42.38	38.94	-0.13
Biosolids 224 Mg ha^{-1}	67.07	49.42	-0.68

†SD is 45% C + C present in CON in 1982. (Ragland et al, 1991).
‡See table 2b for C present in 1982.
§All plots were seeded over a 2:1 mix represented by the CON. The C present in this constant has been applied to each treatment to account for this residual C.
¶1982 is a bulk sample taken at the time of amendment application.

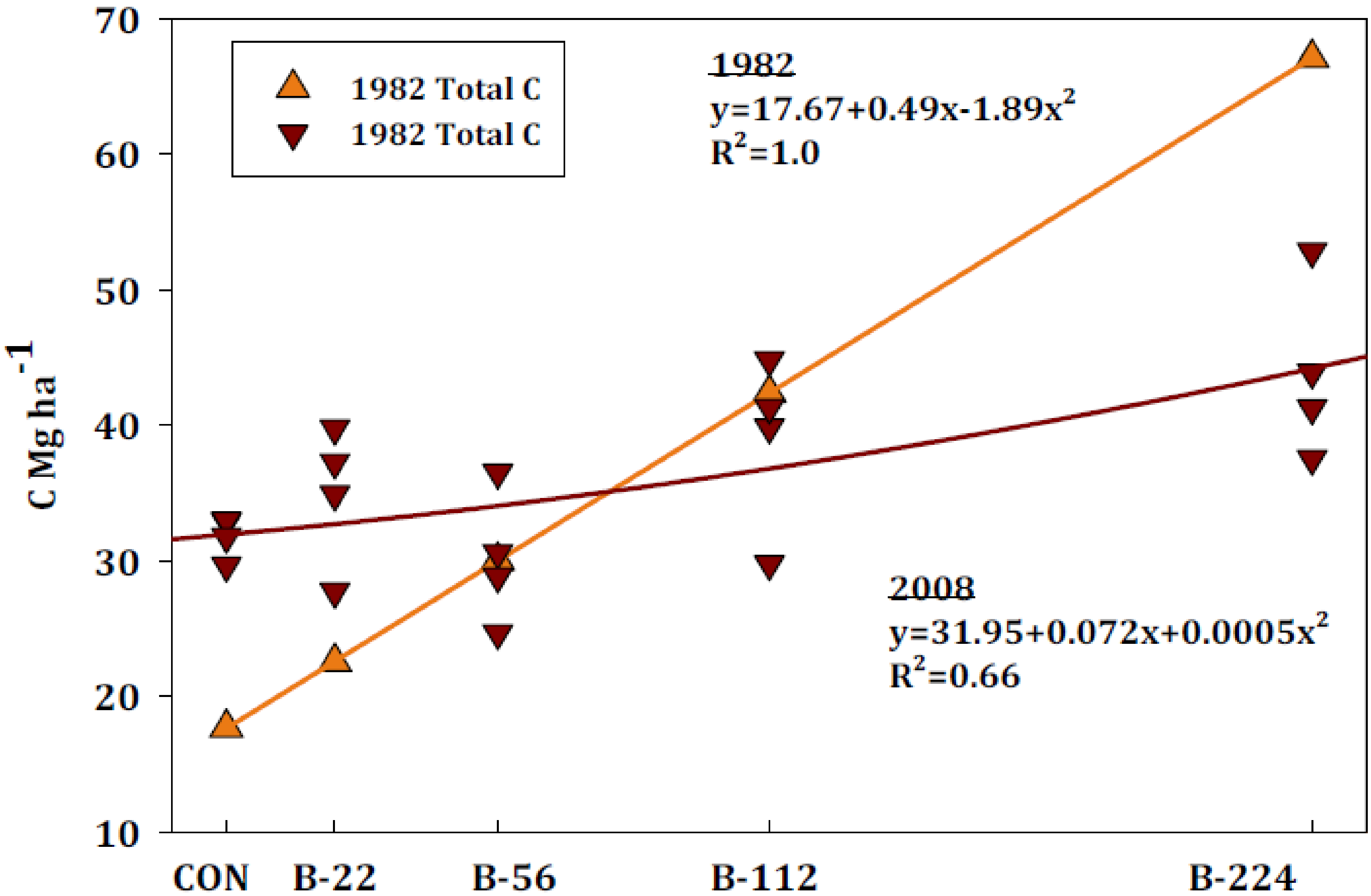


Figure 62. Total estimated C present at depth 0-25 cm in May 1982 post biosolids application vs. total C present at depth 0-25 cm in 2008 after 26 years of accumulation.

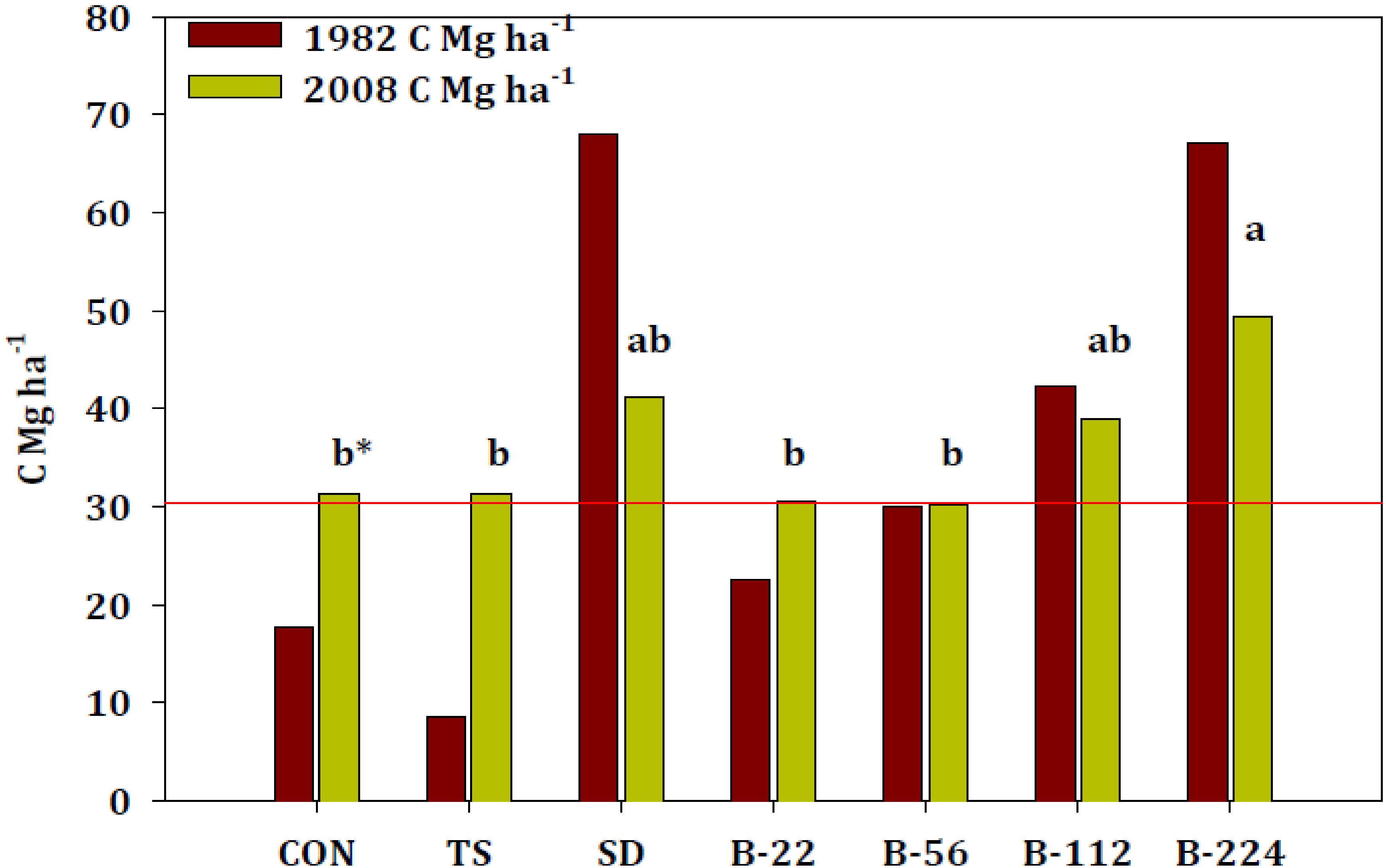


Figure 63. Comparison of estimated (1982) and measured (2008) mass soil C at 0-25 cm sampled in May 1982 vs 2008 for all treatments with prediction of total C threshold at 30-35 Mg ha^{-1}.

Table 58. Reported annual carbon sequestration rates in reclaimed mine soils based on varying reclamation techniques.

Land use	Depth	Period	Rate of C Sequestration	Reference
	cm	yr^{-1}	Mg ha^{-1}	
Grass†	0-15	11	3.1	Akala and Lal (2000)
	0-15	25	0-5 to 3.1	Akala and Lal (2001)
	0-15	47	0 to 5.3	Shukla and Lal unpublished
		45	0.13	Wali (1999)
Forest†	0-15	14	2.6	Akala and Lal (2000)
	0-15	21	0.7 to 2.3	Akala and Lal (2001)
	N/A	N/A	4	Burger (2004)
	N/A	60	2.2 to 2.8	Amichev et al (2008)
Biosolids§	0-15	34	0.54 to 3.05	Tian et al (2009)
Fertilizer	0-15	34	-0.07 to 0.17	Tian et al (2009)
Surface Amendment Experiment				
Control	0-25	26	0.54	Nash (2012)
Topsoil	0-25	26	0.87	Nash (2012)
Sawdust‡	0-25	26	-1.04	Nash (2012)
Biosolids 22‡	0-25	26	0.31	Nash (2012)
Biosolids 56‡	0-25	26	0.01	Nash (2012)
Biosolids 112‡	0-25	26	-0.13	Nash (2012)
Biosolids 224‡	0-25	26	-0.68	Nash (2012)

†As stated in Akala and Lal (2006).

‡One time application of x Mg ha^{-1}.

§ 455 to 1654 Mg ha^{-1} annually for 8 to 34 years.

What's it all mean?

- Many (most?) published C-sequestration rate estimates to date for coal mined lands may be seriously overestimated.
- Our estimates range from 0.5 to 0.9 Mg/ha/y with an apparent "equilibrium level" of around 30 Mg/ha.
- However, if up to 15 Mg/ha of the C in 2008 was "fossil coal", the actual equilibrium levels are much lower.

What's it all mean?

- C concentration values are higher than would be expected; some of this is probably due to C being concentrated into a relatively small soil volume due to high (50 to 75%) rock fragment content.

- Our estimates are specific to the early/mid successional herbaceous system studied. Forested systems ***might*** accumulate more.

What's it all mean?

- **Large amounts of organic C may be mobilized to the subsoil (> 5 cm) following heavy organic amendment applications.**

- **To be "fair" any C-sequestration estimate for mine soil systems that receive large initial applications of organics should account for (A) geogenic C errors, (B) net losses of added C over time and (C) the C-sequestration potential of similar unamended mine soils.**

19-year old mine soil that received biosolids treatment in 1989. A horizon is ~15 cm thick and exhibits well developed granular structure.

Mine soil pedon 5 m away from previous soil that did not receive biosolids. A horizon here is 5 cm thick.

Research Sponsors

- **OSM**
- **Powell River Project**
- **CSES Department**