Forest Soil Carbon Spatial Variation and Precision Accounting on Mined Land

by
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Rationale

- Potential for sequestering C on mined lands
  - ✓ Forest biomass
  - ✓ Litter layer
  - Mine soil

  > > >

  - ✓ Grass biomass
  - Mine soil

- **Statistics**
  - 4×10^6 ha mined for coal before 1977 (U.S.D.A., 1979)
  - 1.8×10^6 ha were under coal mining permit in 2001
  - Over 600,000 ha (200,000 ha in the east) classified as "disturbed" (U.S. Office of Surface Mining , 2002)

- Carbon market incentive

[reforestation project C]
-
[business-as-usual C]

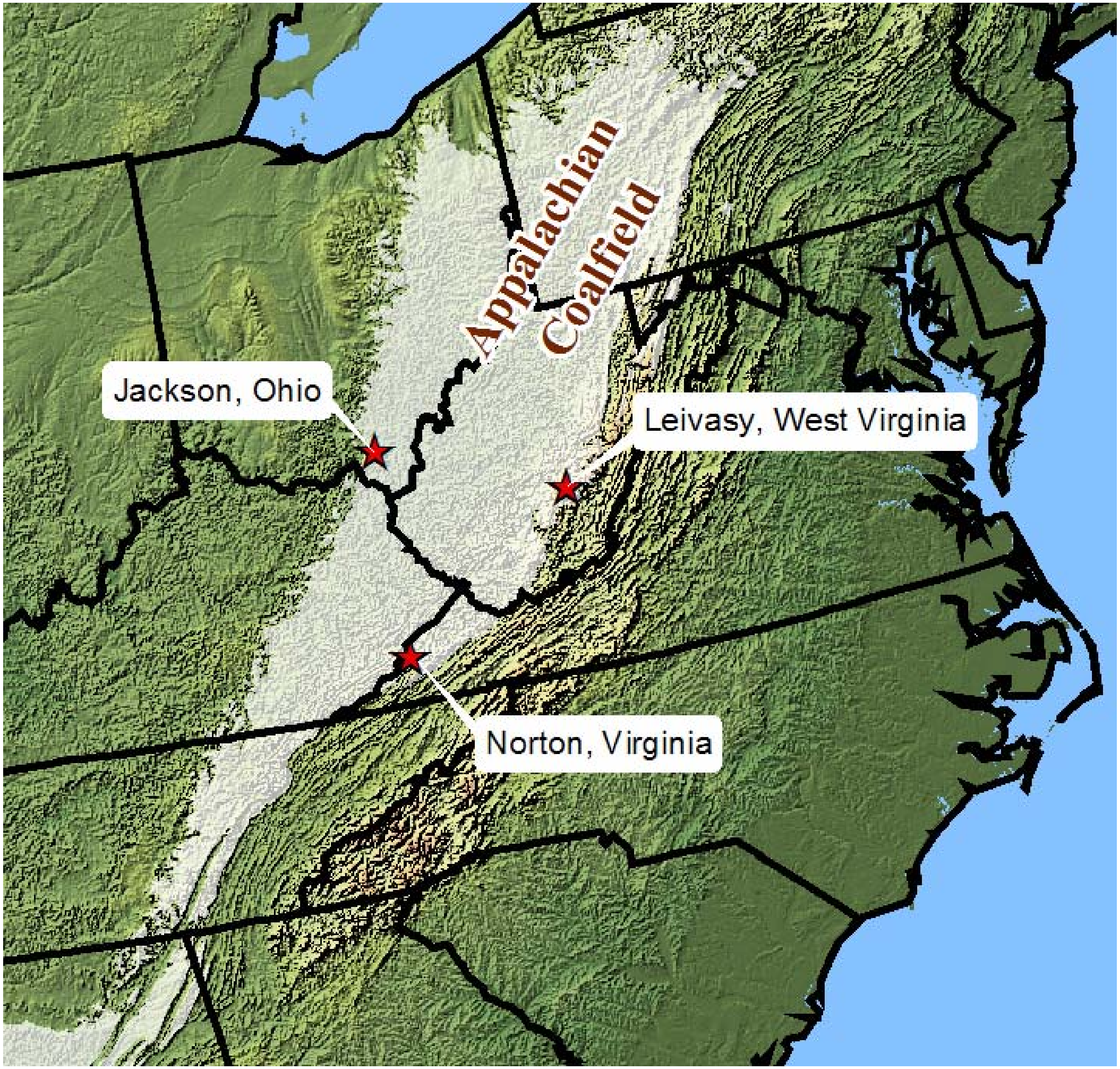
Abandoned grassland

$ Carbon credit $

Study Objectives

- To determine an accurate measure for the concentration of sequestered C on mine soils.
- To determine the spatial variation of sequestered C on reclaimed grassland/pastureland.
- To determine the baseline C sequestration on mined sites reclaimed to grassland/pastureland for C accreditation of reforestation project experiments.

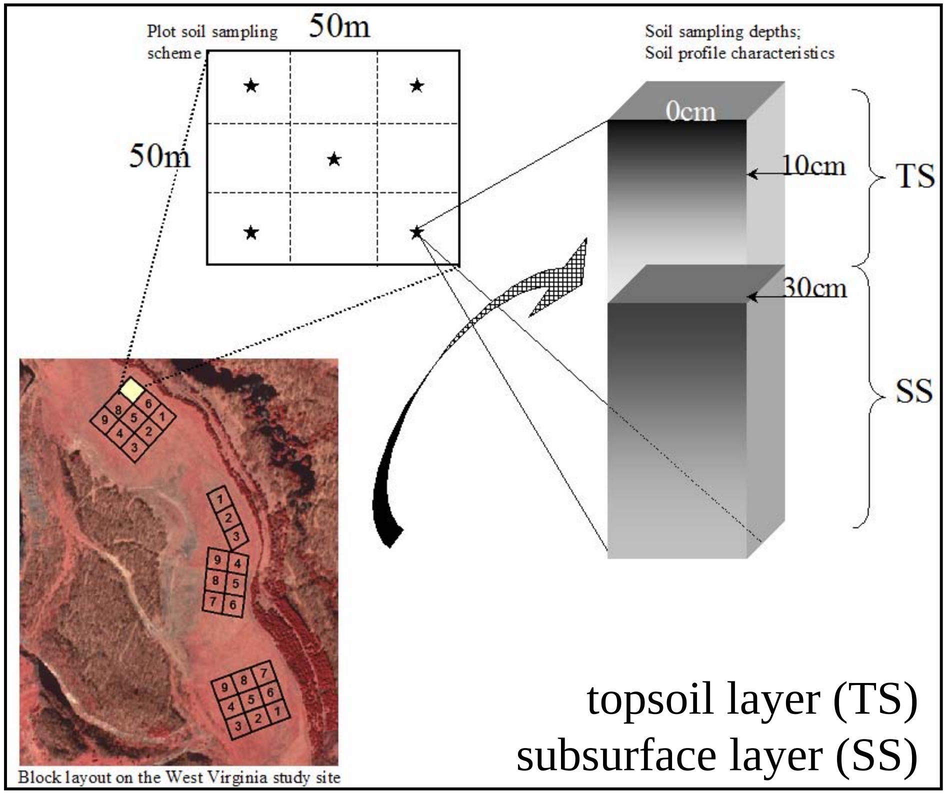
Study Sites



Site reclamation:

- West Virginia
  - -No topsoil
  - -Reclaimed in ***early*** 1980's
- Ohio
  - -Topsoil (~20cm)
  - -Reclaimed in ***late*** 1980's
- Virginia
  - -Topsoil (~20cm)
  - -Reclaimed between 2000 and 2003

Soil Sampling Procedures



Soil physical and chemical properties (3states x 27plots):

- TS/SS soil sub-sample (<2mm soil):
  - -C concentration (gram C/gram soil)
  - -CN ratio
  - -N concentration (gram N/gram soil)
  - -pH
  - -EC (mmhos cm^{-1})

- TS/SS composite sample (per 50x50m plot)
  - -CFC, percent by volume
  - -Soil texture (~%Sand; ~%Silt; ~%Clay)
  - -Sandstone (SS) and Siltstone (SiS) percent

- TS/SS soil pit (~ volume 30x30x30cm)
  - -BD (g cm^{-3}) for whole soil
  - -BD_{Fines} (g cm^{-3})

Soil Analysis procedures: *C [%] issues*

Measuring plant sequestered C in mine soils:

Methods of Analysis		Pedogenic C: Soil organic matter (SOM), oxidizable	Pedogenic C: Soil organic matter (SOM), resistant	Geogenic C: CO_3 (Inorganic C)	Geogenic C: Coal	Estimate
		---------------------- Fraction removed			----------------------	
1 Walkley-Black acid dichromate oxidation procedure.	-----STANDARD-----	all	----	----	***Unknown***	***SOC={Oxidizable SOM}*CF*** ; Assumes (1) no oxidation of coal, (2) no interference from Cl^-, MnO_2, and Fe^{2+}, and (3) {oxidizable SOM} is ~77% of total SOM.
2 Loss on ignition (375°C, 12hrs); weight difference.		all	all	----	***Unknown***	***SOC={SOM}*CF*** ; Assumes (1) no oxidation of coal and (2) no structural water loss from soil minerals.
3 C,N [%] elemental analysis (Vario MAX CNS analyzer, elementar, Hanau, Germany).		all	all	all	all	***Total C [%];*** *Represents the absolute total C [%] in the soil.*
4 Thermal oxidation (375°C, 24 hrs): C,N [%] difference; Requires sample pretreatment for inorganic C.	-EXPERIMENTAL -	all	all	----	***Unknown***	***C_{coal} [%];*** Requires correction for oxidized coal. Then *SOC=* ***Total C[%]*** *- C_{coal} [%]. Carbonates removal pretreatment.*
5 Scanning Electron Microscopy (SEM) analysis after thermal oxidation: Partitioning of ***Total C*** from C,N elemental analysis.		all	***Unknown [x]***	----	***Unknown [y]***	***[SOM:Coal] volume ratio*** . Assumes [x]:[y] ratio of captured airborne particles on filter are equal to SOM:coal in sample. Grinding, sieving through 270um sieve, and carbonates removal pretreatments.

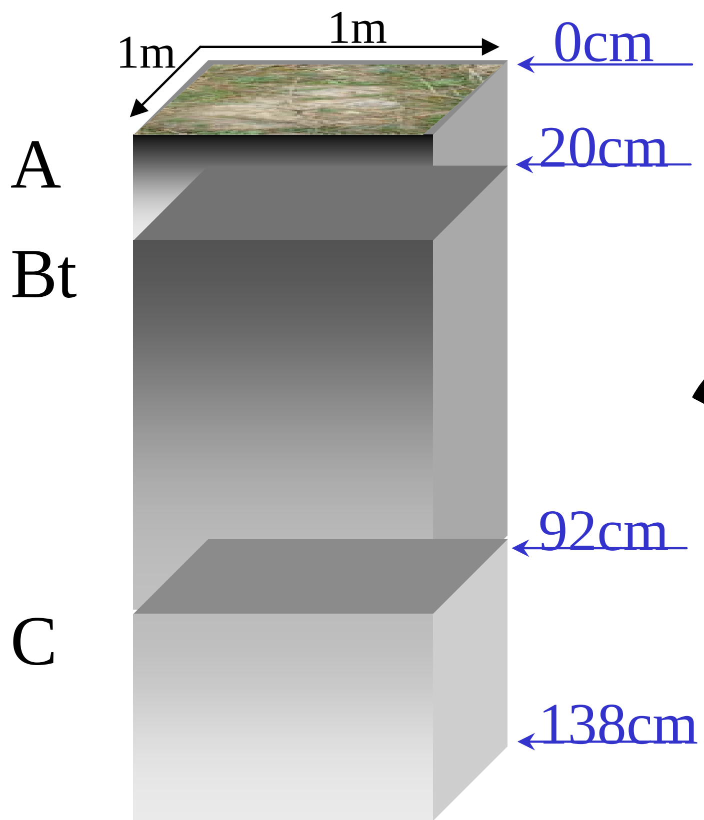
Data Analysis

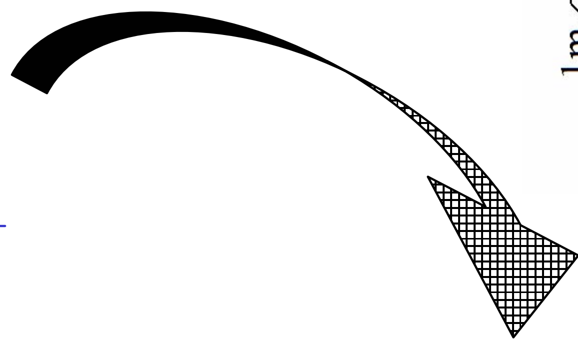
Soil carbon stock estimation:

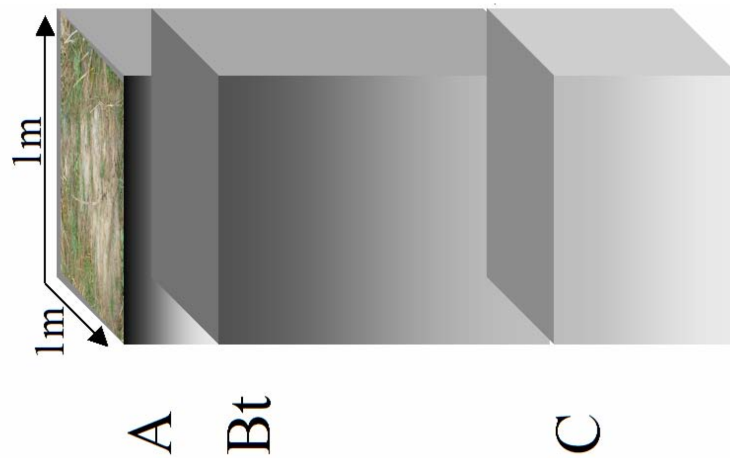
$$C(\text{kg m}^{-2}) = C(\%) * BD_{Fines}(\text{g cm}^{-3}) * \text{Volume}_{\text{Fines}}(\%) * LayerDepth(cm) * 1000^{-1}$$

Carbon stock spatial variation

- Carbon stock distribution/stratification maps using ArcGIS™ spatial analysis software
  - C stock prediction surface
  - Prediction standard error surface
  - GIS based mean carbon stock estimate





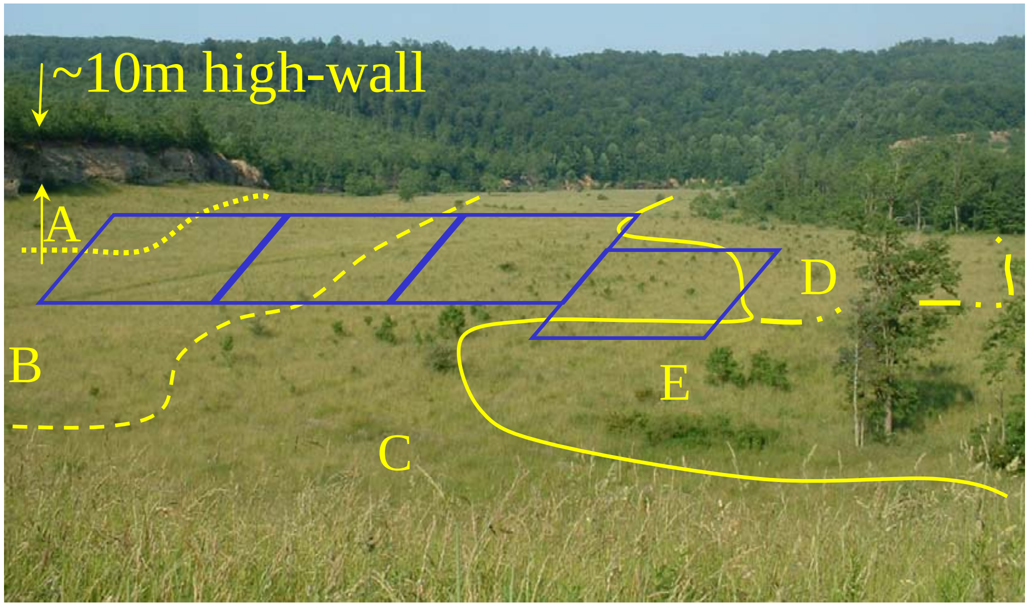


"the horizontal soil profile" ~ **mined landscape**

Per horizon (stratum) - approach

Horizon	C[%]	BD [g cm^{-3}]	Fines [volume %]	Layer Depth [cm]	C [kg m^{-2}]
A	3.520	1.10	91	20	7.047
Bt	0.103	1.35	100	72	1.001
C	0.009	1.45	95	46	0.057
					8.105

Result: {0-138cm} profile C stock = 8.105 kg m^{-2}



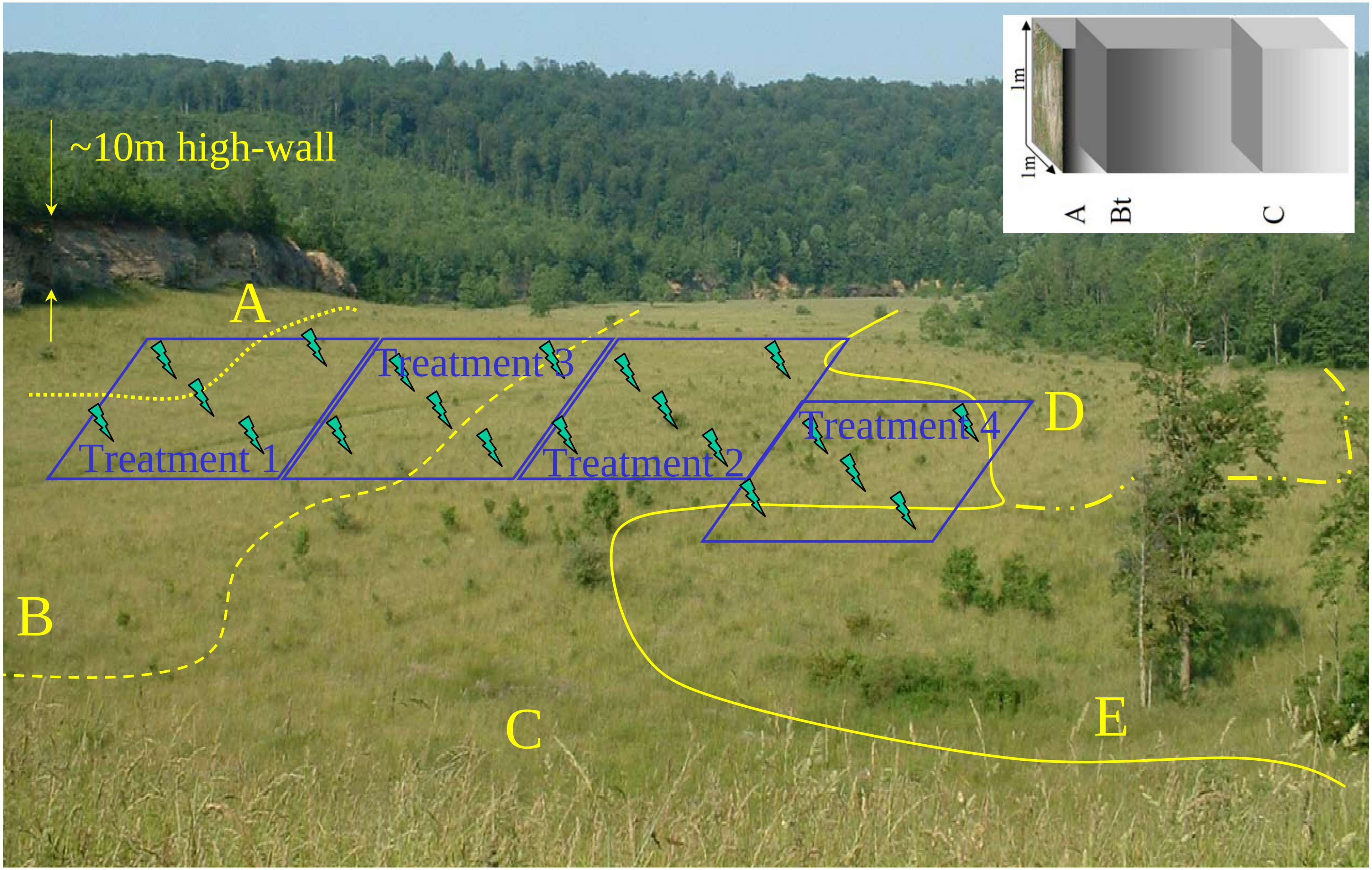
Per profile (weighted by *layer depth*) approach

Horizon	C[%]	BD [g cm^{-3}]	Fines [volume %]	Layer Depth [cm]
A	3.520	1.10	91	20
Bt	0.103	1.35	100	72
C	0.009	1.45	95	46
Weighted Avg.	0.5669	1.347	97.029	138

C [kg m^{-2}] = **10.225**

Over-estimation = 26.2 %

Data Analysis: *C stock across space*



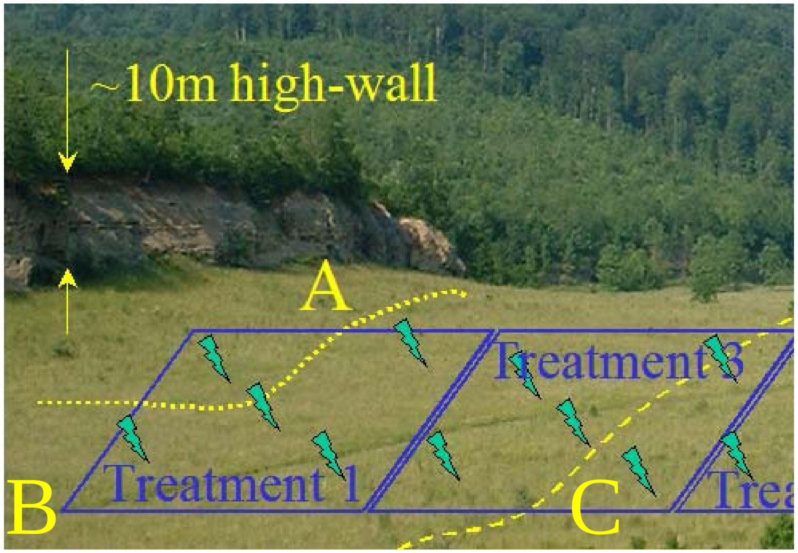
-represents mine soil sampling location (5 sub-samples per plot)

Data Analysis: *C[kg m^{-2}] issues*

Estimating C stock [kg m^{-2}] across space on mined land as:

$$C[kg\ m^{-2}] = C_{Avg}[\%] * BD_{Avg}[g\ cm^{-3}] * VolumeFines_{Avg}[\%] * LayerDepth_{Avg}[cm] * 1000^{-1}$$

Problem ?



Solution: **Site stratification!**

Methods:

1. Intensive field reconnaissance
   - Vegetation as indicator
   - Sample/feel the soil
   - Be a detective – *"How would a miner reclaim the site?"*

2. Geospatial statistics
   - Ordinary kriging in ArcGIS ™ geospatial software for surface modeling
   - Spatial distribution maps for each soil property to be used for C[kg m^{-2}] estimation

Results: *Mine soil properties*

Average values for 9 physical and chemical soil properties of topsoil and overburden spoil materials of two depth categories, 0-10cm and >10cm.

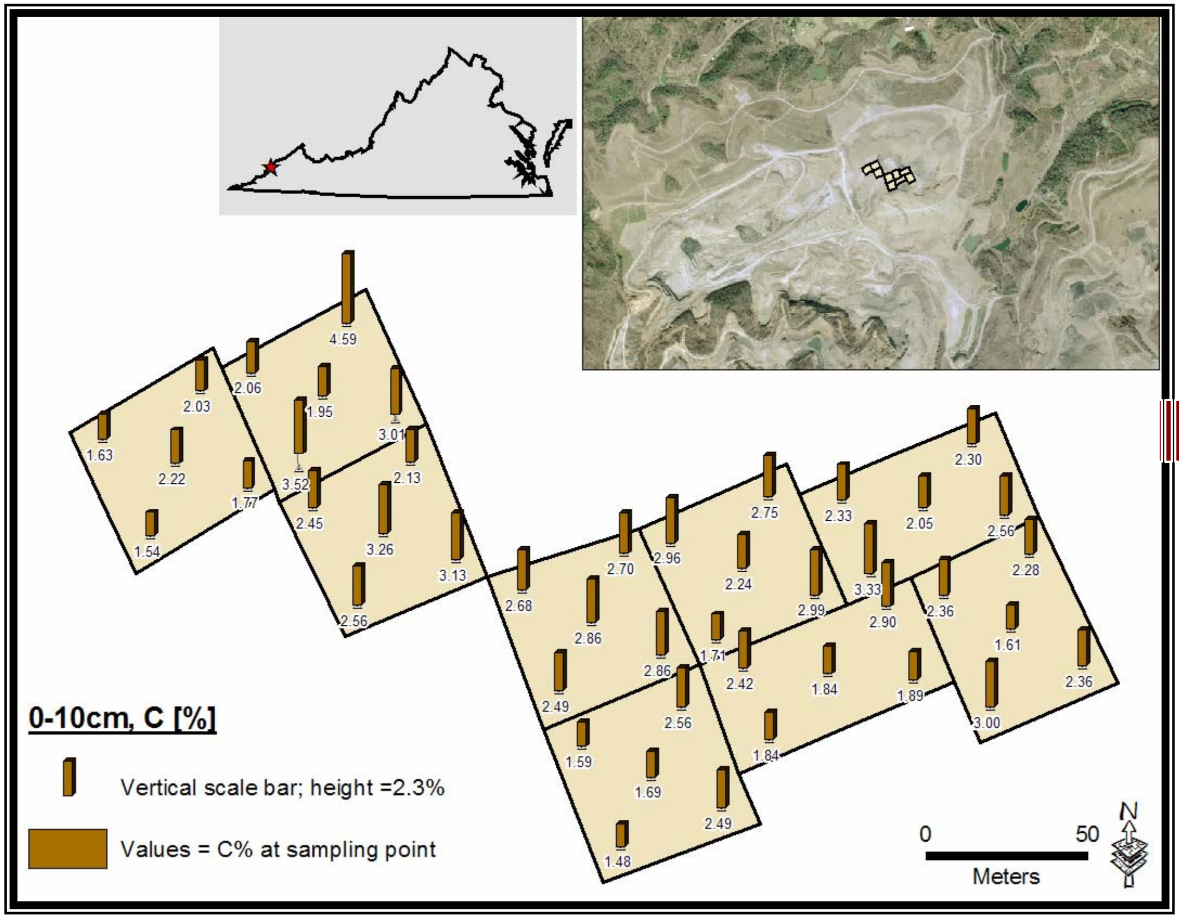
Site		OHIO			VIRGINIA				WEST VIRGINIA			
Material type		Topsoil		Spoil	Topsoil		Spoil		Spoil		--- range ---	
Variable\Depth category		0-10cm	10-[X]cm	[X]-50cm	0-10cm	10-[Y]cm	0-10cm	[Y]-30cm	0-10cm	10-30cm	min	max
C [%]	[C_g/$soil_g$*100]	*1.49 dg*	*0.38 b*	*0.66 b*	*1.92 cd*	*1.49 de*	*1.90 cefg*	*2.38 c*	*3.43 a*	*1.52 df*	*0.38*	*3.43*
CN	*[ratio]*	*12.33 c*	*8.99 c*	*13.51 c*	*23.92 b*	*25.08 b*	*27.40 b*	*33.34 a*	*12.55 c*	*13.93 c*	*8.99*	*33.34*
BD $_{Fines}$	[g cm^{-3}]	*1.46 ab*	*1.41 ace*	*1.63 a*	*1.23 cd*	*1.214 cfgh*	*1.36 bdef*	*1.37 bc*	*1.14 dg*	*1.14 dh*	*1.14*	*1.63*
CFC	*[%]*	*7.74 a*	*12.15 ab*	*19.93 b*	*40.56 c*	*41.11 c*	*56.59 de*	*57.54 df*	*51.92 d*	*57.92 ef*	*7.74*	*57.92*
pH	-	*5.88 a*	*6.31 ab*	*6.84 bc*	*5.99 a*	*5.93 a*	*6.38 acde*	*6.73 be*	*6.12 a*	*6.66 bd*	*5.88*	*6.84*
EC	*[mmho cm^{-1}]*	*0.10 a*	*0.37 bc*	*0.47 b*	*0.26 cde*	*0.36 bd*	*0.34 bce*	*0.28 cde*	*0.21 ace*	*0.11 a*	*0.10*	*0.47*
SS	*[%]*	*22.96 b*	*5.00 b*	*16.48 b*	*63.00 ac*	*83.89 a*	*61.25 ad*	*54.58 cd*	*9.07 b*	*9.81 b*	*5.00*	*83.89*
Sand	*[%]*	*41.89 a*	*33.00 ab*	*28.63 b*	*53.20 c*	*56.00 ce*	*56.00 cf*	*66.50 def*	*70.00 d*	*61.19 cd*	*28.63*	*70.00*
Topsoil	[cm]	*20.84*	*31.39*	*19.91*	*24.22*	*29.12*	*N/A*	*17.03*	*N/A*	*N/A*	*17.03*	*31.39*

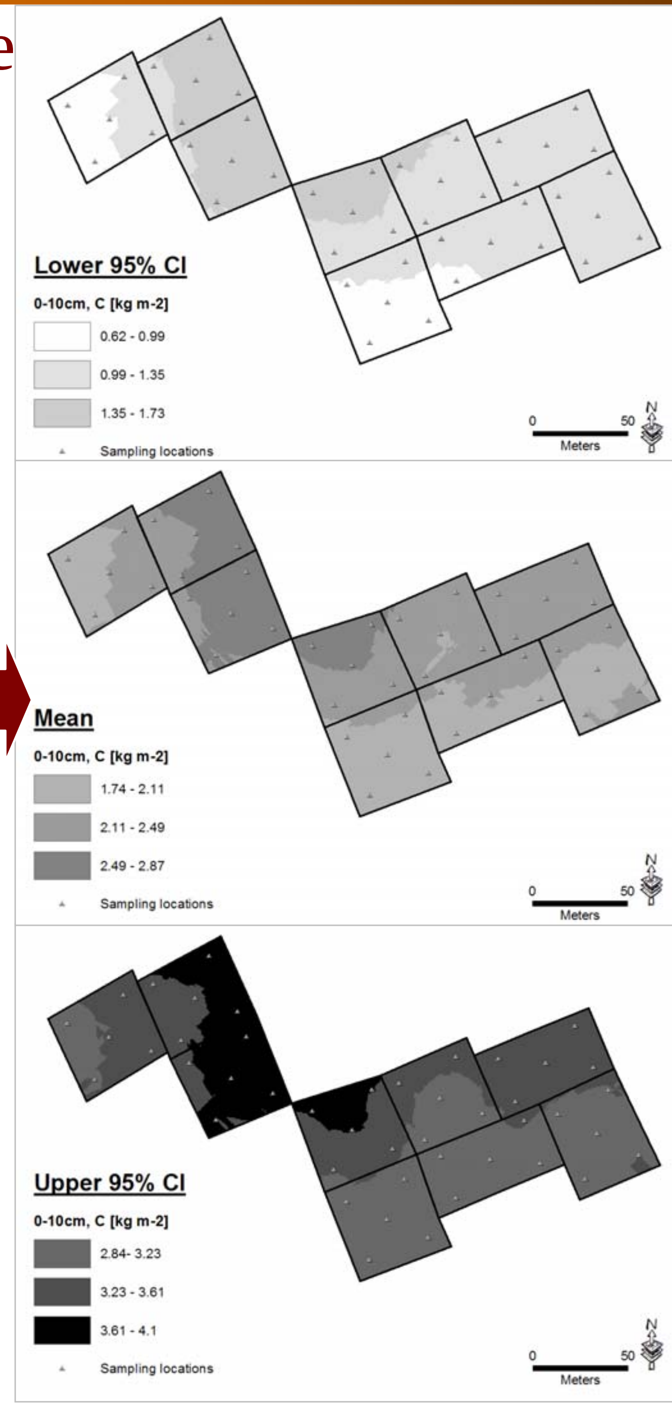
* [X] and [Y] indicate the total depth of the topsoil layer in Ohio and Virginia study sites, respectively.

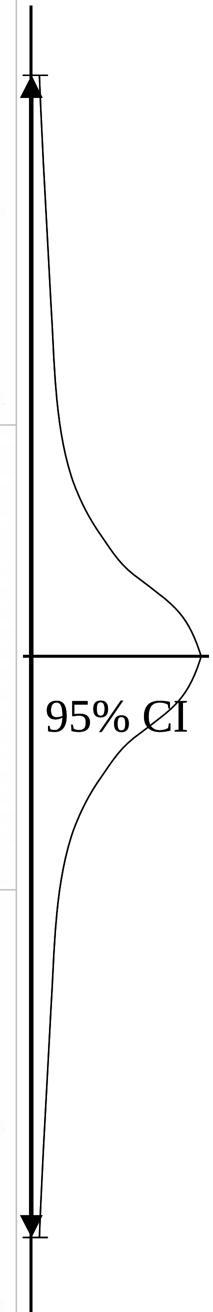
**Mean values for soil properties in Ohio, Virginia, and West Virginia followed by the same letter are not significantly different at the 0.05 alpha level (PROC GLM in (SAS®); Tukey's HSD means comparison)

Results: *Kriging example*

Carbon stock spatial variation across space





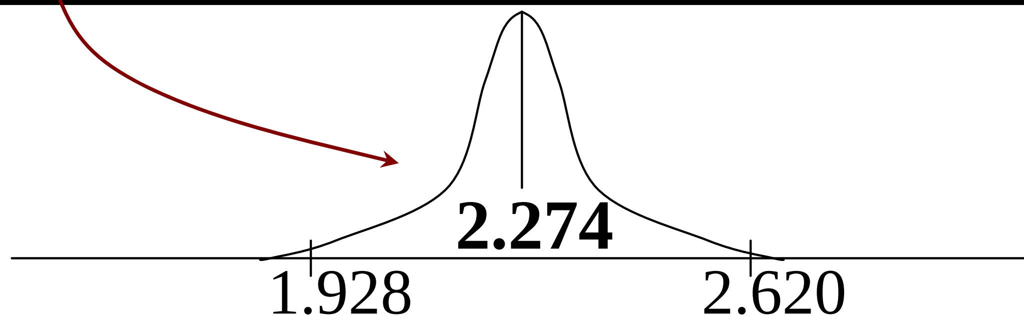


Results: *Total soil C stock [kg m^2]*

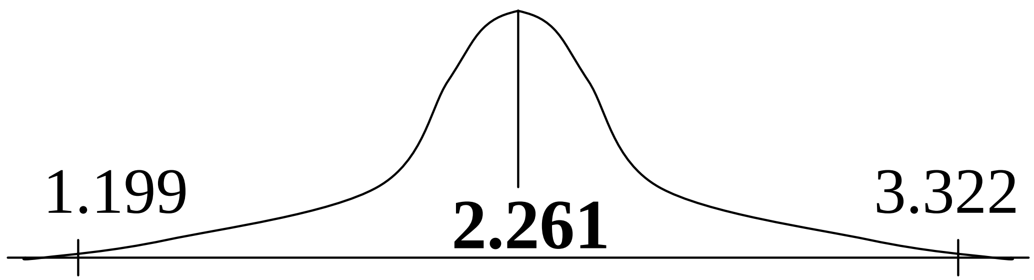
Total soil carbon stock estimates in the 0-10cm and 0-100cm mine soil profile

		0-10cm		0-100cm			
Site	**Plot**	**C** [kg m^{-2}]	Std.Err. [kg m^{-2}]	**C** [kg m^{-2}]	Std.Err. [kg m^{-2}]	# samples N	Topsoil depth [cm]
VA	1	1.153	0.1121	15.779	1.2604	9	22.0
	2	2.274	0.1728	21.717	2.4190	9	29.7
	3	1.646	0.2138	13.619	1.3508	9	8.0
Average		***1.691***	*0.131*	***17.038***	*1.1837*	*27*	*19.9*

No stratification:



With stratification:
[GIS surface modeling]



Conclusions

- Rule of thumb:

  C variation on mined grasslands does ***not*** follow the "rules" of the rest for the world, topography, aspect, etc., due to their anthropogenic origin, as opposed to pedogenic origin.

- Total C concentration varied between 1.49 and 3.43 % [C_{gram}/$Soil_{gram}$*100] within in the 0-10cm soil layer, and varied between 0.38 and 2.38 % for greater soil depths, >10cm.

- Total C stock estimates ranged from 1.69 and 2.64 kg C m^{-2} within in the 0-10cm soil layer, and between 7.68 and 17.04 kg C m^{-2} for the 0-100cm soil profile.

- GIS surface modeling software can be used with confidence for C stock spatial distribution mapping on mined land.

Additional *take-home* messages

- Mine landscape stratification is a *must*.
- GIS spatial analysis packages can be used for site stratification that will aid in reducing the costs associated with mine soil sampling.
- If properly carried out site stratification can greatly improve the accuracy of C accounting on mined land.
- Without stratification of mined lands the C stock estimates produced via soil sample properties averaging will not be representative of the sampled mine soil but rather that of a non existent, “mutant” soil.

<Summary>

- Rule of thumb:

  C variation on mined grasslands does ***not*** follow the “rules” of the rest for the world, topography, aspect, etc., due to their anthropogenic origin, as opposed to pedogenic origin.

- Total C concentration varied between 1.49 and 3.43 % [C_{gram}/$Soil_{gram}$*100] within in the 0-10cm soil layer, between 0.38 and 2.38 % for the 0-100cm soil profile.

- Total C stock varied between 1.69 and 2.64 kg C m^{-2} within in the 0-10cm soil layer, between 7.68 and 17.04 kg C m^{-2} for the 0-100cm soil profile.

- GIS surface modeling software can be used with confidence for C spatial distribution mapping.

<Ohio sites: *C% by depth*,topsoil>