Carbon Sequestration in Coal Ash Soils:

Estimates from Direct Measurements and Indications of Possible Errors in Estimates for Natural Soils

by

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The First Study at MCSES and HCEV

- **Objective: test rapid evaluation of carbon sequestration in coal ash soils, using**
  - **Routine, commercially available soil carbon determinations**
  - **A one-time sampling enabled by**
    - **Verifiable time since establishment of vegetation**
    - **Negligible levels of organic carbon in coal ash at time of vegetation establishment.**

- **Methods**
  - **Examination and comparison of historical documents, coal fly ash data and photographic records**
  - **Carbon analytical methods**
    - **Soils (A&L Eastern Agricultural Laboratories, Richmond, VA)**
      - **Modified Walkley-Black (wet combustion) to measure organic carbon and some portion of amorphous carbon (unburned coal residues)**
      - **Loss on Ignition (dry combustion) at 550°C to measure all carbon, including amorphous (unburned coal residues) to correct Walkley-Black if needed**
    - **Biomass**
      - **Micro-Dumas (Carlo Erba Analyzer, Agricultural Analytical Services Laboratory, Pennsylvania State University)**
- **Design**
  - **Biomass**
    - **3 Biotypes X 7 Field Replicates = 21 Samples**
  - **Soils (see Table 1.)**
    - **5 Soil Types X (7 Field + 3 Composite) Replicates X 2 Methods = 100 samples**

- **Sampling Location & Techniques**
  - **MCSES (see Figures 1. and 2.)**
    - **Above ground herbaceous biomass and surface residues: Seven 62-cm quadrats at 5.5-meter intervals along a 43-meter transect in each vegetation type (meadow, forest).**
    - **Tree biomass: Height, diameter, core (rings for age estimate) for all trees with stumps within 0.5 m of transect in forest vegetation.**
    - **Soil (in each quadrat)**
      - **Surface soil: 4.7-cm diameter core to limit of rooting depth (15 to 22 cm in MCSES meadow) or max. tool depth (36 to 60 cm)**
      - **Subsurface soil (in MCSES meadow): 4.7-cm core from bottom of rooting depth (15 to 22 cm) to max. tool depth (60 cm)**
      - **Samples processed to include all root and detrital residues, quantitatively removing, processing and restoring them to the soil sample if necessary.**
    - **Fresh Ash (bulk samples provided by MCSES)**
  - **HCEV**
    - **Seven 62-cm quadrats placed randomly in the Direct Planting Experiment area.**
    - **Above ground herbaceous biomass, surface residues and surface soils collected as at MCSES**

- **Results**
  - **History: Probable first year of effective growth**
    - **HCEV 1989 (reliable due to intentional seeding)**
    - **MCSES 1987 (less certain as records do not indicate intentional seeding)**
  - **Biomass Carbon (Mg ha^{-1})**
    - **Trees contained 49 (based on size, number and population density).**
    - **Herbaceous plants and residues contained**
      - **Forest 7.6 ± 2.3**
      - **Herbaceous Meadow 5.9 ± 0.9**
      - **Grass Meadow 3.4 ± 0.6**
  - **Soil Carbon (Mg ha^{-1})**
    - **Forest 72 ± 7.3**
    - **Herbaceous Meadow 54 ± 7.3**
    - **Grass Meadow 38 ± 7.3**
  - **Average Total Carbon Sequestration Rate (Mg ha^{-1} over first 14-16 years)**
    - **Forest 7.6**
    - **Herbaceous Meadow 3.4**
    - **Grass Meadow 2.9**
  - **Analytical Methods**
    - **Total variability (for samples collected and prepared as in this study)**
      - **Walkley-Black method 0.05 to 0.2 wt % carbon, or about 10% relative.**
      - **Dry Combustion method 0.4 to 1.25 wt%, or about 4 to 10% relative.**

  - **Selectivity**
    - **Dry Combustion method appears to detect all organic and amorphous carbon, non-selectively.**
    - **Walkley-Black measured only about 5.6% of the amorphous carbon in control samples. Field sample replicate results were consistent. Method appears to be effective, reasonably sensitive with good selectivity for organic carbon.**

Figure 1.1 South End of Martins Creek SES Ash Basin 1
(Aerial Photo 3 October 2001)

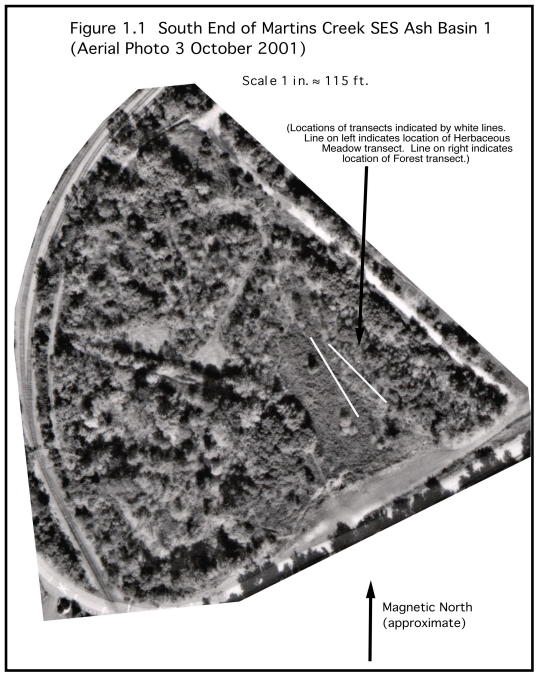

Table 1. Experimental Design Table – Soils

7 individual samples collected, prepared & analyzed for each treatment
Check and control samples run in triplicate (3 samples)
"7X Composite" indicates double-blind check samples prepared by thoroughly mixing equal volume subsamples from all 7 individual samples for each treatment
W-B indicates Walkley-Black method for organic C
LOI indicates weight "Loss on ignition" dry combustion method for total C

Source	Biotype	Soil	Sample Type	C method	Number of Samples
PPL Martins Creek Steam Electric Station	Meadow (Ash Basin 1)	Surface (rooted) (Rooted)	Individual	W-B	7
				LOI	7
			7X Composite	W-B	3
				LOI	3
		Subsurface (Unrooted)	Individual	W-B	7
				LOI	7
			7X Composite	W-B	3
				LOI	3
	Woods (Ash Basin 1)	Surface (rooted) (Rooted)	Individual	W-B	7
				LOI	7
			7X Composite	W-B	3
				LOI	3
	None	Fresh Ash	Individual	W-B	7
				LOI	7
			7X Composite	W-B	3
				LOI	3
HCEV Hunlock Creek Power Station	Meadow (Larksville Ash Site)	Surface (rooted) (Rooted)	Individual	W-B	7
				LOI	7
			7X Composite	W-B	3
				LOI	3
Totals				Total W-B Samples	50
				Total LOI Samples	50

Figure 2. Ground Level Views of the Herbaceous Meadow and Forest Sites at the PPL Martins Creek SES Ash Basin 1 South End

Northeastward view 6 May 1999
(View is roughly broadside to the sampling transects. White x's mark extreme ends of transects in this view.)

Northwestward view 17 August 1999
(View is roughly along the Herbaceous Meadow transect [indicated by white +]. The Forest transect lies just inside tree line to the right.)

Table 2. Soil Carbon Results Summary

Bio/Soil Type	Sample Source	Samples (N)	Carbon (wt %) Organic by WB Mean	Organic by WB 95% Confid. Interval	Total C by LOI Mean	Total C by LOI 95% Confid. Interval
Fly ash	power plant composite	7 3	0.66 0.66	0.51-0.82 0.60-0.71	11.5 12.0	10.3-12.8 11.6-12.3
Herbaceous Meadow Subsoil	field composite	7 3	0.77 0.89	0.68-0.86 0.83-0.95	9.5 9.7	8.7-10.2 9.57-9.73
Forest Soil	field composite	7 3	1.8 2.0	1.80-1.89 1.78-2.13	10.1 10.4	9.6-10.6 10.3-10.5
Herbaceous Meadow Soil	field composite	5 3	2.1 2.2	2.01-2.23 2.11-2.34	9.3 9.5	8.84-9.68 9.19-9.90
Grass Meadow Soil	field composite	7 3	1.8 1.6	1.66-1.99 1.46-1.85	14.7 14.8	13.6-15.9 14.7-14.9

WB = Walkley-Black (wet combustion)
LOI = Loss on Ignition (dry combustion)

Table 3. Organic Carbon in Deeper Coal Ash Soils under Trees (metric tons per ha)

Sampling Area (nearest tree)	Sampling Depth Increment 0-60 cm	60-180 cm	Total 0-180 cm
Sycamore (age ≈15 years)	56	58	114
Cottonwood (mature, age > 20 years)	67	134	201
Black Willow (mature, age > 20 years)	92	114	206
Red Oak (age ≈ 15 years, in mature stand)	103	125	228
Forested Area 2003 (age ≈ 15 years)	72	Not available	Not applicable

The Second Study at MCSES

- Observations during the first study and prior investigations indicated trees were rooting deeply.
- Lateral roots observed at 2.75-meter depth.
- For forests, carbon sequestration estimates based only on surface soil could be too low.
- In 2006 a second study was undertaken with support from PPL Generation LLC to look at greater soil depths by building on the findings from the first study.

- Objective
  - Initial assessment of organic carbon deposition by trees in deeper coal ash soils by comparison of surface and deeper depth increments

- Methods
  - Analyses
    - Organic carbon determined using Walkley-Black wet combustion method
      - Comparative data sufficient – no need to correct for amorphous carbon content (LOI total carbon determination).
  - Sampling
    - One randomly selected location in each of 4 areas in MCSES ash basin dominated by different tree species (see Table 3.)
    - Three 4.7-cm cores taken in ≈60-cm increments to total depth of ≈180 cm at each location.
    - Samples 60-120 and 120-180 cm combined to make single sample for 60-180 cm depth increment.

- Results (see Table 3.)
  - 60-180 cm depth contained at least as much carbon as the 0-60 cm depth at all 4 sampling points
  - Observations during sampling suggested these results are conservative because some coarse roots were not collected by the coring tool.
  - Surface soil results compared well to 2003 results

Even Deeper Sequestration?

- Subsequent studies collected samples to the bottom of the ash deposit, up to 10 meters deep.
- Roots decreased in number, but increased in typical size with depth.
- The deepest roots encountered were at the bottom of the ash deposit, 10 meters deep.

Conclusions

- With appropriate sampling and sample processing, routine soil carbon methods are sensitive and reliable enough to track and verify carbon sequestration.
- Carbon sequestration in coal ash soils occurs at least as rapidly as in natural soils.
- Carbon sequestration by trees occurs to considerable depths, up to 10 meters or more.
- Estimates of carbon sequestration based on conventional surface soil sampling may be substantially underestimating actual carbon sequestration under forests.