Rehabilitation of Drastically Disturbed Soils

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Pb/Zn smelter slag site in Katowice Poland in 1994. Materials were 3 to 10% total-Zn, > 1000 ppm water soluble Zn, and > 90 ppm water soluble Cd.


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Three Important Principles

In order to develop appropriate reclamation protocols for any site, we must develop a detailed understanding of:

1. **Soil, biotic and water quality conditions before disturbance or in an appropriate reference area.**

Three Important Principles

2. We must thoroughly understand the nature of the mining or other disturbance process and how it impacts soil and site conditions during and after mining.

3. We must be able to predict how soil, site, and vegetation conditions will change with time after reclamation is initiated.

The Mid-Atlantics "Disturbing History"

- Land Clearing/Erosion (1600's on)
- Surface Mining (1800's on)
- Urbanization (minor before 1950's)
- Suburbanization (1940's on)
- Road Building (Expansion in 1950's)
- Utility Corridor Development


WESTERN REGION
MIDWESTERN REGION
EASTERN REGION
Pacific Coast Basin
Michigan Basin
Northern Great Plains Basin
Eastern Interior Basin
Anthracite Basin
Western Interior Basin
Rocky Mountain Basin
Appalachian Basin
Gulf Coastal Basin
Coal–bituminous and subbituminous
Lignite coal

Modern Contour Coal Mine

Coal Processing Waste Pile

Acid Mine Drainage (AMD)

Dredge Spoil Utilization

Good Silt Loam Topsoil or Black Toxic Goo?

Mineral Mining – Sand/Agg.

Road Building

Suburbanization Disturbance is Major and Highly Variable!

Four Things That Control Reclamation Success!

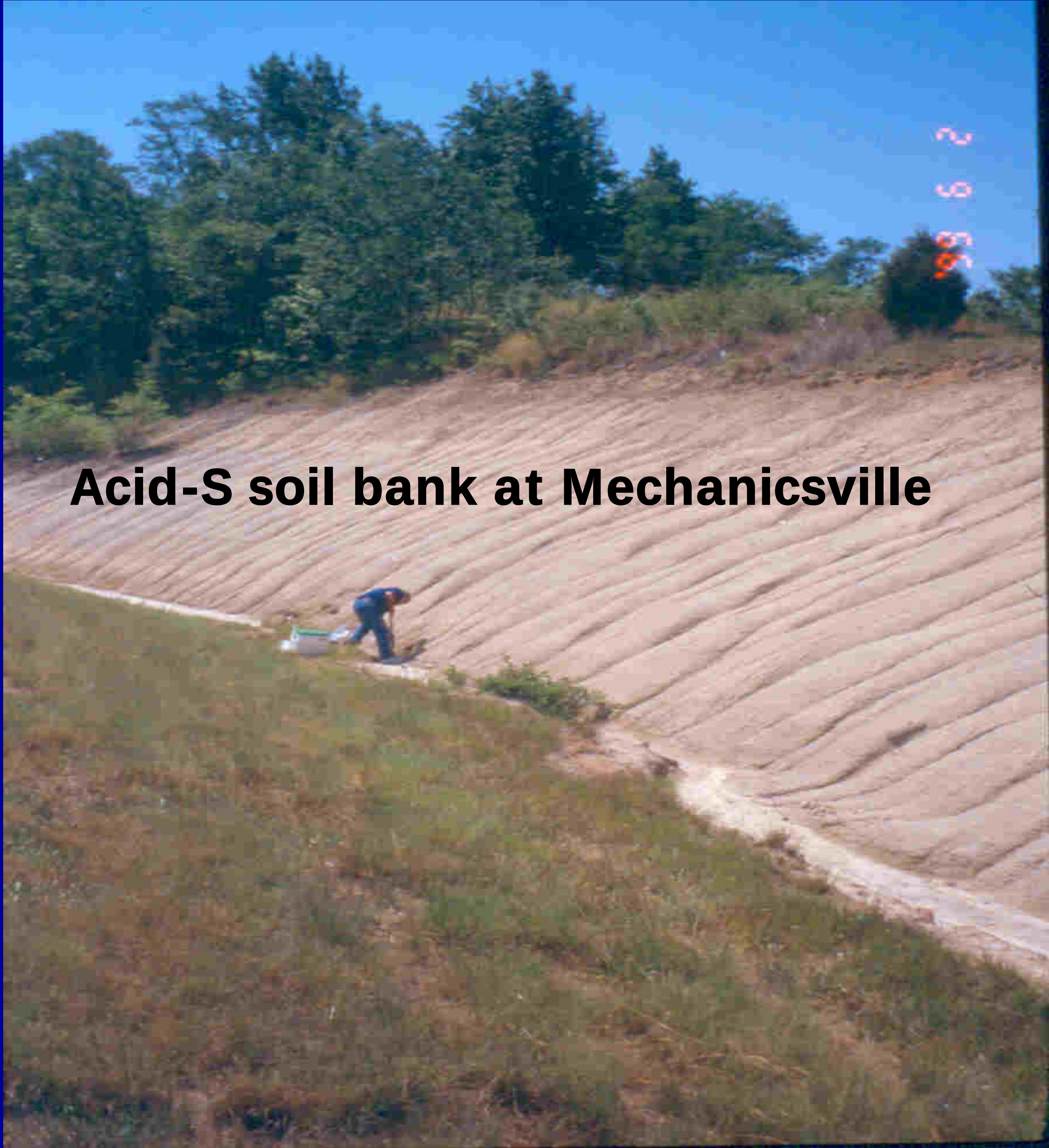
1. **Sulfidic/Pyritic acid forming materials must be avoided or neutralized for any successful stabilization project. Worldwide, there is no doubt that acid-sulfate weathering processes are the major risk to environmental quality from any drastic land disturbance.**

Active pyrite depositional environment in high C and sulfate input tidal marsh.

Acid-forming materials on 1970's "pre-SMCRA" surface mine in Virginia


AMD impact in
northern WV

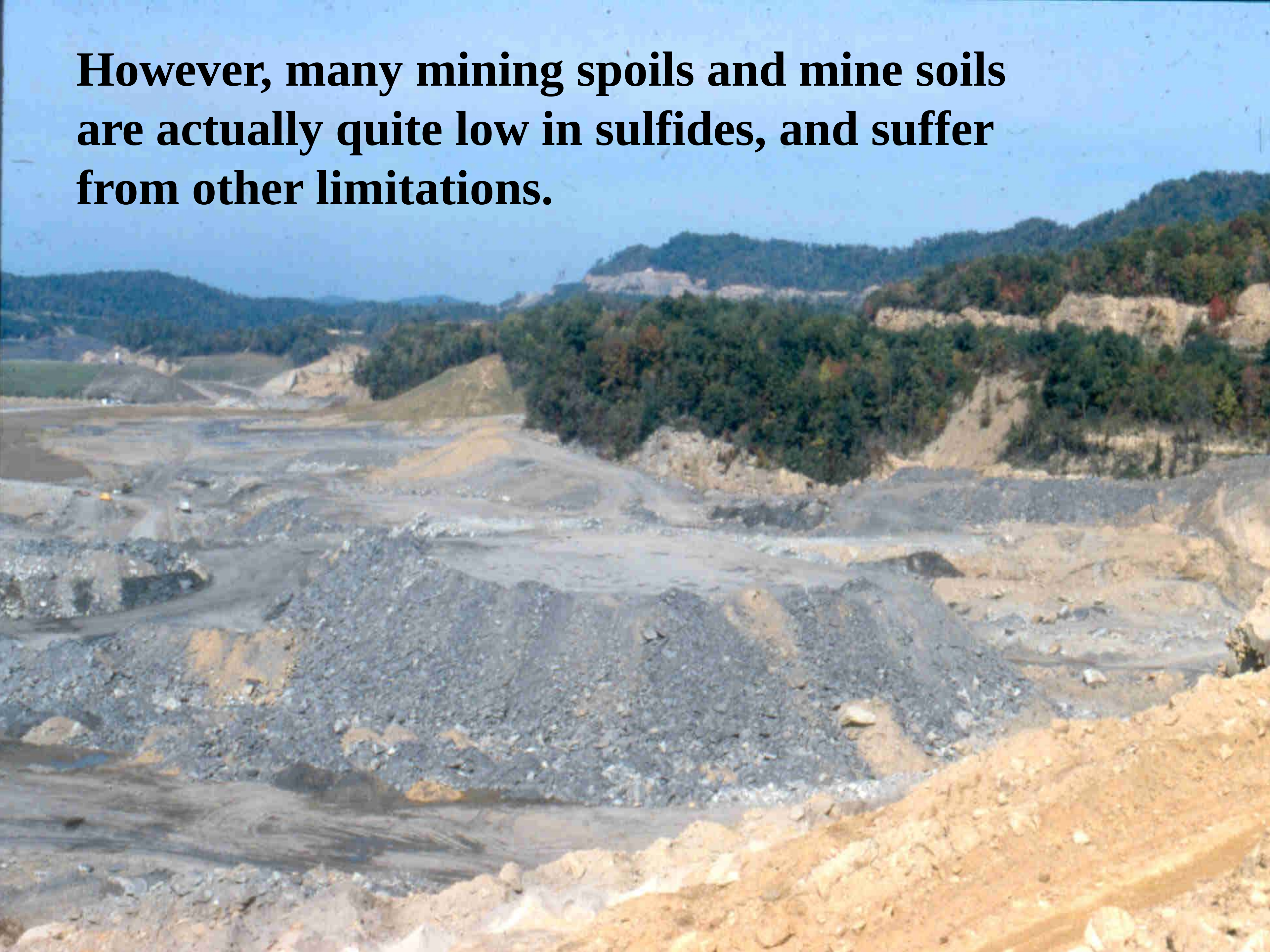
Outcrop of tertiary aged marine sediments near Richmond, VA, with soil pH's in the 1.8 to 3.0 range.



Compiling a state-wide sulfide hazard map for Virginia: Devonian black shales.

Inside the culvert at Clifton Forge.

However, many mining spoils and mine soils are actually quite low in sulfides, and suffer from other limitations.

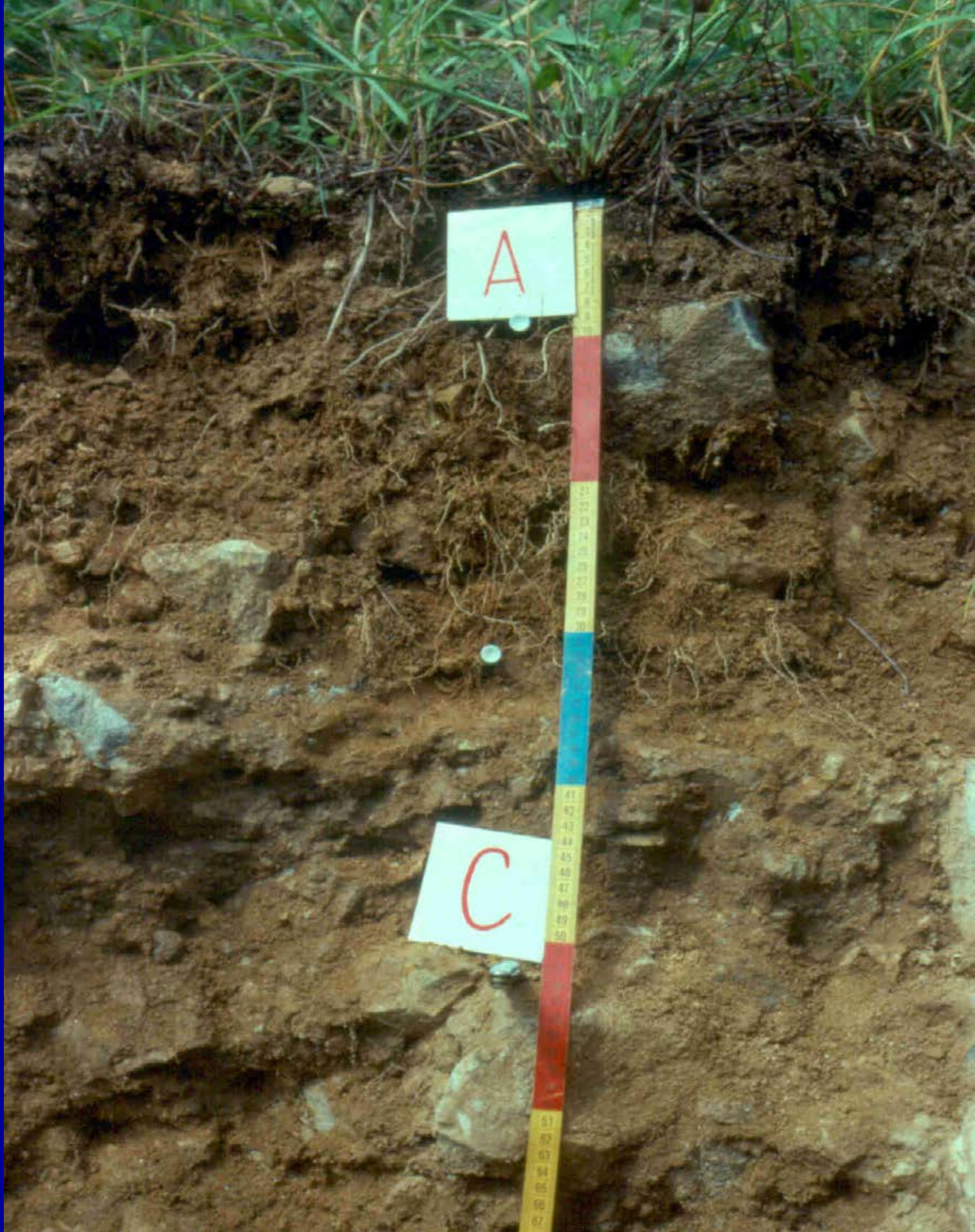


Four Things That Control Reclamation Success!

2. **Compaction is the most common limiting factor in disturbed lands worldwide.** Many mine soils with otherwise suitable chemical and physical properties are of very low quality due to severe compaction.

3. **Very coarse textures (sands) or high rock contents** limit the water holding and effective rooting volume of many disturbed land soils.

Regardless of their overall acidity and fertility status, the number one limitation to plant growth in mine soils worldwide is ***severe compaction.***




Mixed Topsoil + Weathered Overburden (A+B+C+R)
Rocky (15% fines), High pH (7.5) Sandstone Spoil

Benefits of Topsoil

Whenever it is economically feasible, native topsoils should be salvaged and re-applied to final reclamation surfaces.

In general, native soil materials will be much higher in organic matter, available N and P, and perhaps most importantly, beneficial microbial populations than any topsoil substitute materials.

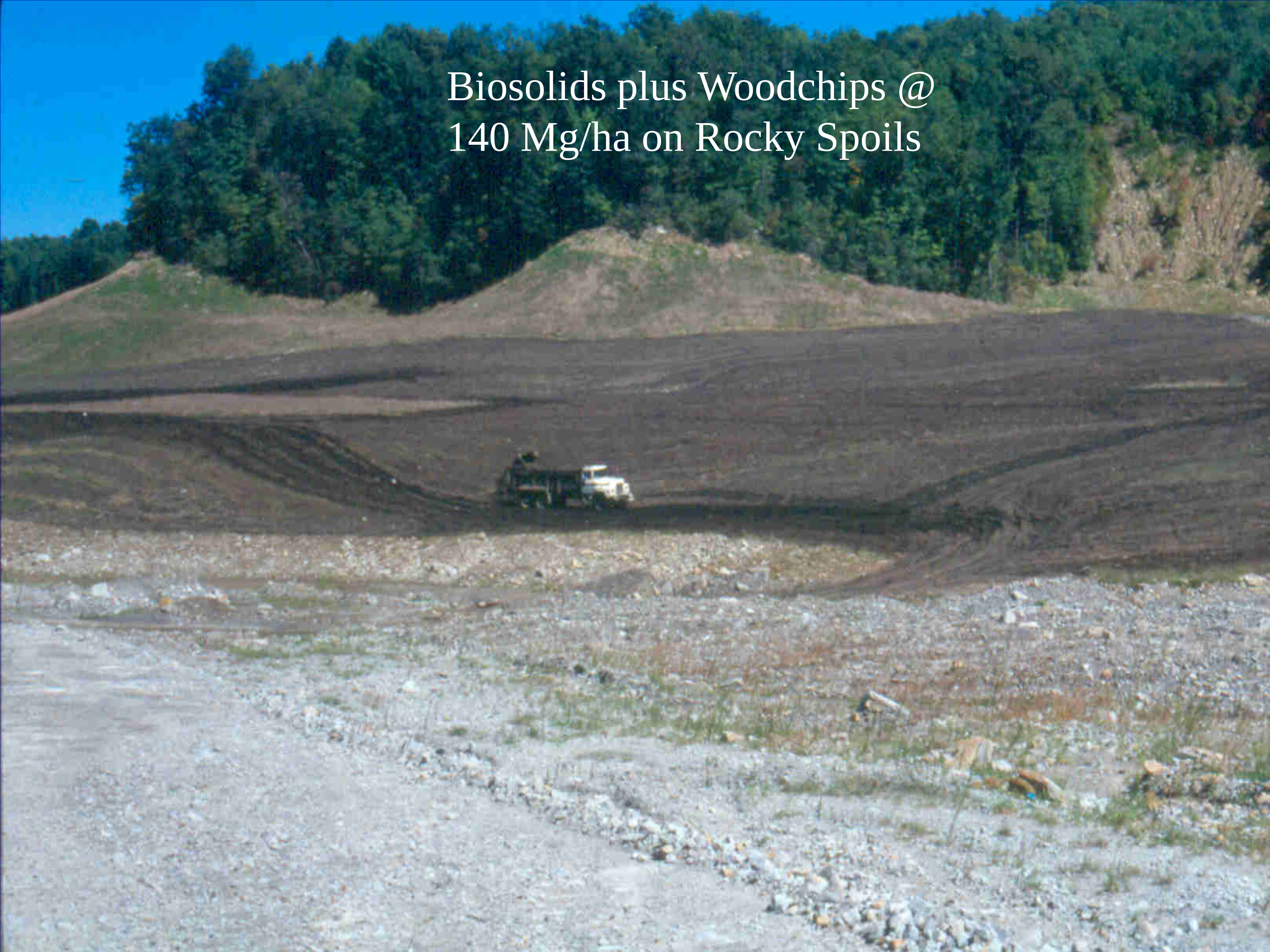
Four Things That Control Reclamation Success!

4. Assuming you've avoided acid forming materials, compaction, and excessively sandy/rocky materials, the last thing you really have to be concerned about is slope/aspect/albedo effects. For example, black coal waste on a 35% south-facing slope is going to be very, very difficult to stabilize without significant soil amendments due to heat loads and drought stress.

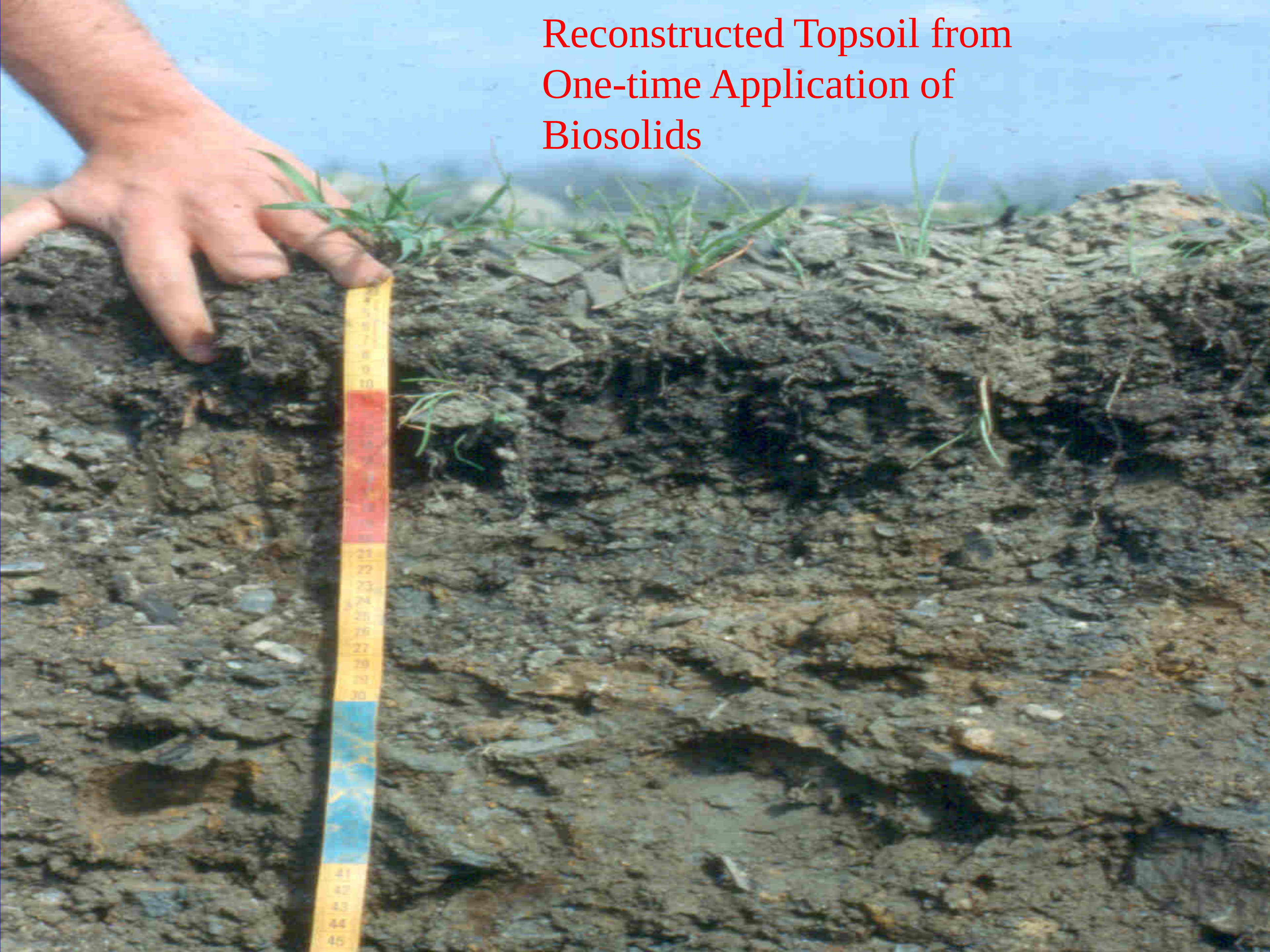

Coal Refuse
Disposal Area

Mine Soil Amendments

Once you take care of the four basic challenges pointed out earlier, you can start working towards really improving the quality of drastically disturbed soils via the addition of appropriate soil amendments such as compost, manures, biosolids, waste limes, alkaline fly ash, etc..


Biosolids plus Woodchips @
140 Mg/ha on Rocky Spoils

Reconstructed Topsoil from One-time Application of Biosolids




Incorporation of 45 Mg/ha
lime on sulfidic coal waste
materials.


Effects of 10 Mg/ha Lime plus
50 Mg/ha Papermill Sludge on
Acidic Coal Refuse

33% volumetric addition of alkaline fly ash to acidic coal refuse.

Soluble salt/B damage on soybean plants grown in sandstone mine spoil amended with 10% coal fly ash.

Most legumes are very sensitive to salt damage, so seeding should be delayed until after salts leach where possible.

Summary

- The vast majority of mine wastes, overburden material, or industrial/urban soils can be successfully reclaimed and revegetated once the appropriate suite of analyses have been conducted.

- However, it is essential that sulfidic wastes (> 0.3% pyritic-S) be isolated away from the final reclamation surface, or very high rates of suitable liming materials must be applied and incorporated, or thick covers employed.

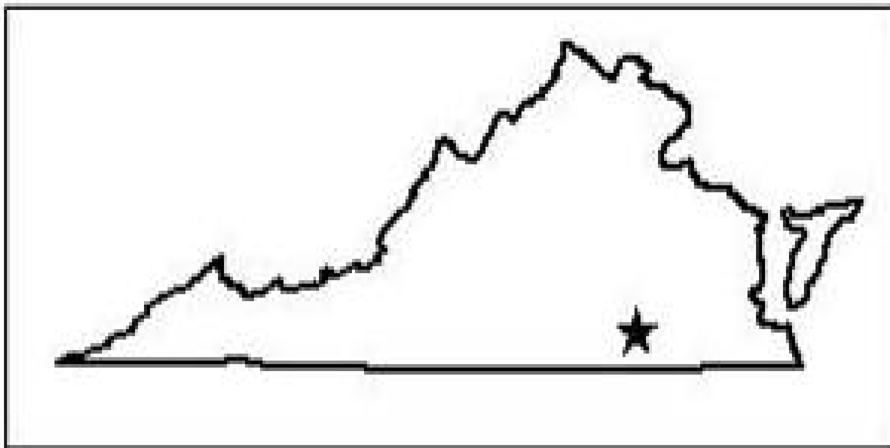
Summary

- **Assuming sulfidic materials are eliminated, long term revegetation success in mine soils is most commonly limited by compaction in most mining environments, and excessive rockiness or hot aspects in other mining/construction environments.**

- **Waste products such as biosolids and fly ash can have great utility for enhancing mine soil physical and chemical properties.**

Summary

That being said, we need to carefully balance utilization of wastes/residuals against potential for soil pollution or environmental harm from excess salts, metals, nutrients etc.



Location of mineral sands ore bodies in Virginia (in red). Similar ore bodies lie approximately 100 km south in North Carolina.

Typical prime farmland landscape at Old Hickory with significant enrichment of heavy minerals to a depth of > 8 meters. This field was the top producing peanut field in Virginia twice in the 1980’s and is used as our “unmined control” for research comparisons.


QUANTARAY

Typical highly productive soil in the Old Hickory area.

Productivity of this soil in greatly enhanced by the low bulk density, well structured subsoil that readily allows rooting to 48 inches or more.


Test pit filled with mixed slimes/tailings
from pilot plant in April, 1995.


112 Mg/ha Yardwaste Compost + Deep Ripping, + 300 kg/ha P, + 8 Mg/ha Lime applied to Tailings/Slimes
25 cm of Topsoil over Ripped/Limed + P Tailings/Slimes
10 13 '95


Cotton Crop in 1998

Treatment	1995/1996 Wheat	1996 Soybeans	1997 Corn	1998 Cotton
	Mg/ha			
Unmined control	3750 a[a]	2449 ab	8553 a	1384 a
Pit#1 topsoil	3573 a	1810 c	6587 b	1194 b
Pit#1 compost	2892 b	2386 b	7589 b	1088 b
Pit#3 topsoil	2756 bc	2684 a	4987 c	1004 b
Pit#3 compost	2375 c	2594 ab	6620 b	1130 b

a. Yields within columns followed by the same letter are not significantly different ($P < 0.05$). Data analysed via one-way ANOVA followed by pairwise contrasts (Fisher's Protected LSD).

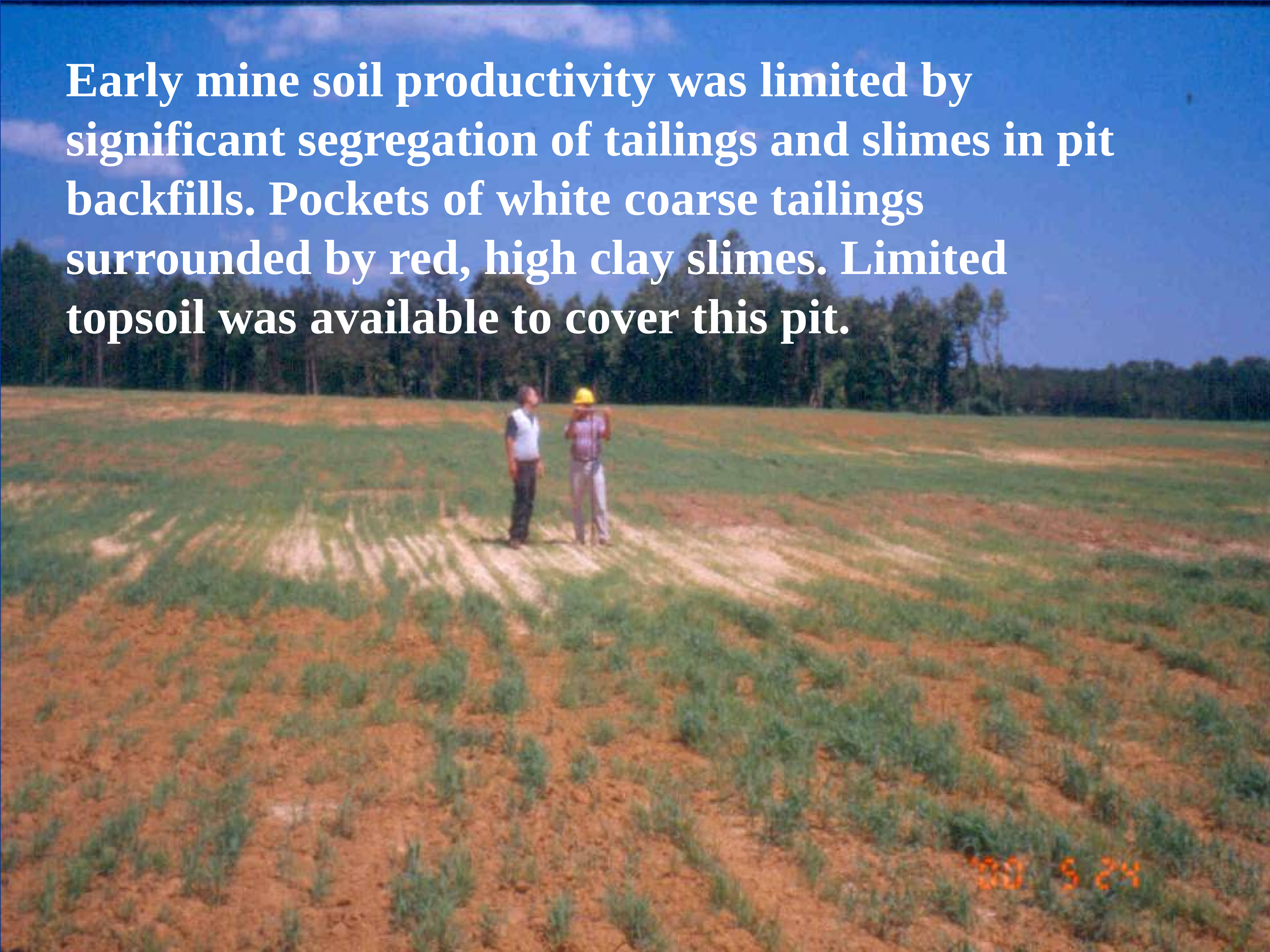
Overall crop yields were reduced approximately 20% relative to unmined control plots. Effects of topsoil return vs. compost amendment were not consistent from crop to crop.

Project History and Background

Active mining at Old Hickory commenced in the summer of 1997, and Iluka Resources acquired RGC in 2001.


60 % Quartz Tailings
40% Fe-Coated Kaolinite
Typical active backfill pit at Old Hickory
'01 1 27

Early mine soil productivity was limited by significant segregation of tailings and slimes in pit backfills. Pockets of white coarse tailings surrounded by red, high clay slimes. Limited topsoil was available to cover this pit.



Final pit dewatering at Old Hickory. Material in foreground is topsoil forming enclosing dike. Overall wet pit surface elevation is 1 to 3 m higher than original ground, but drops with dewatering and final grading.

Topsoil Return Issues

- **In many instances, topsoil was used to construct dikes before swell factor was full understood, making it impossible to return topsoil to mine pits.**

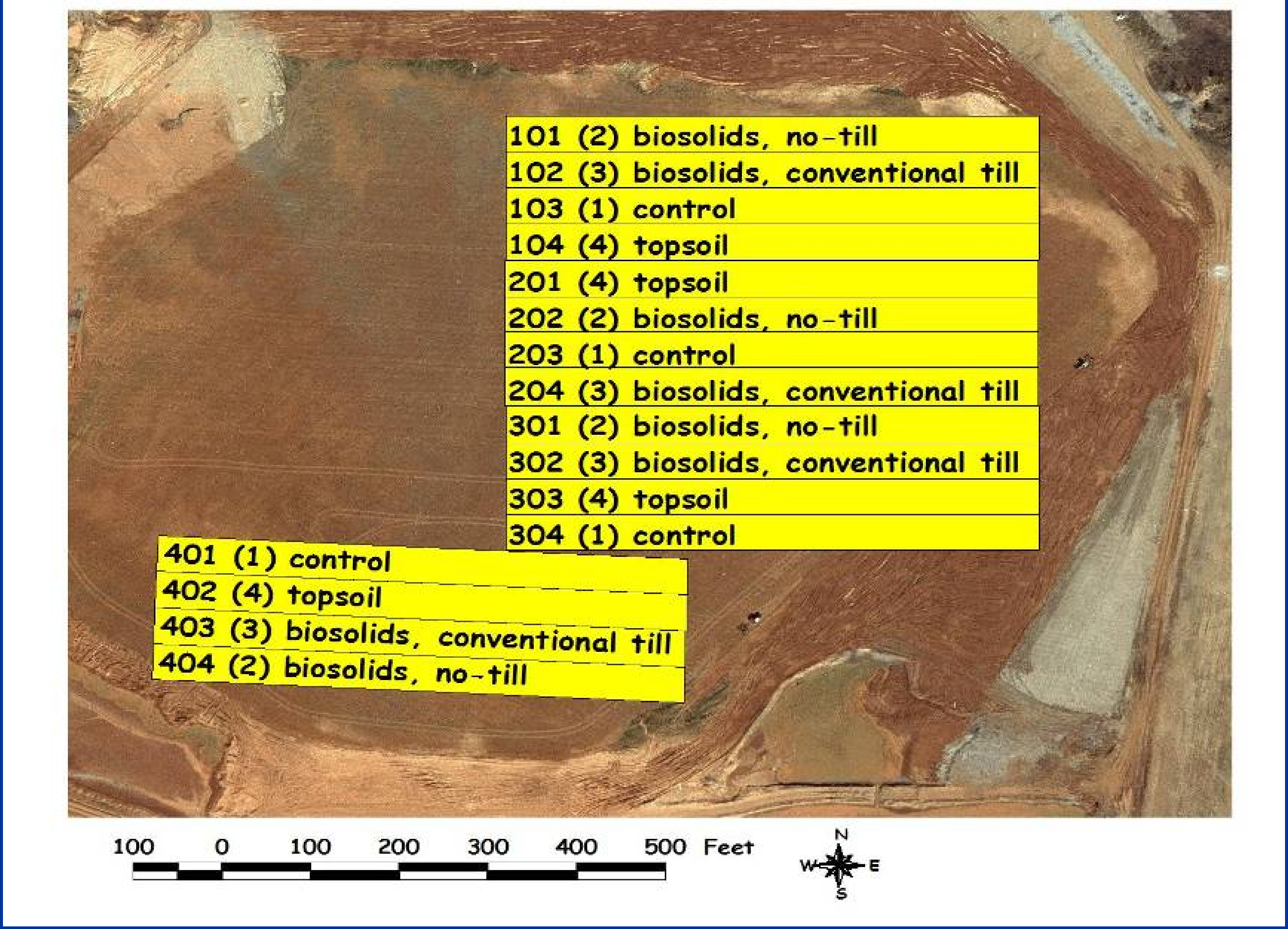
- **Vague regulatory definition of “topsoil” allowed the operator and certain landowners to process topsoil for mineral return. This was rectified via threat of litigation in 2004 and all lands received topsoil afterwards until 2011.**

Typical tails+slimes pit dewatering. Material in foreground is clayey slimes; background is sandy tailings

Compacted, platy replaced topsoil over highly compacted tails/slimes subsoil.

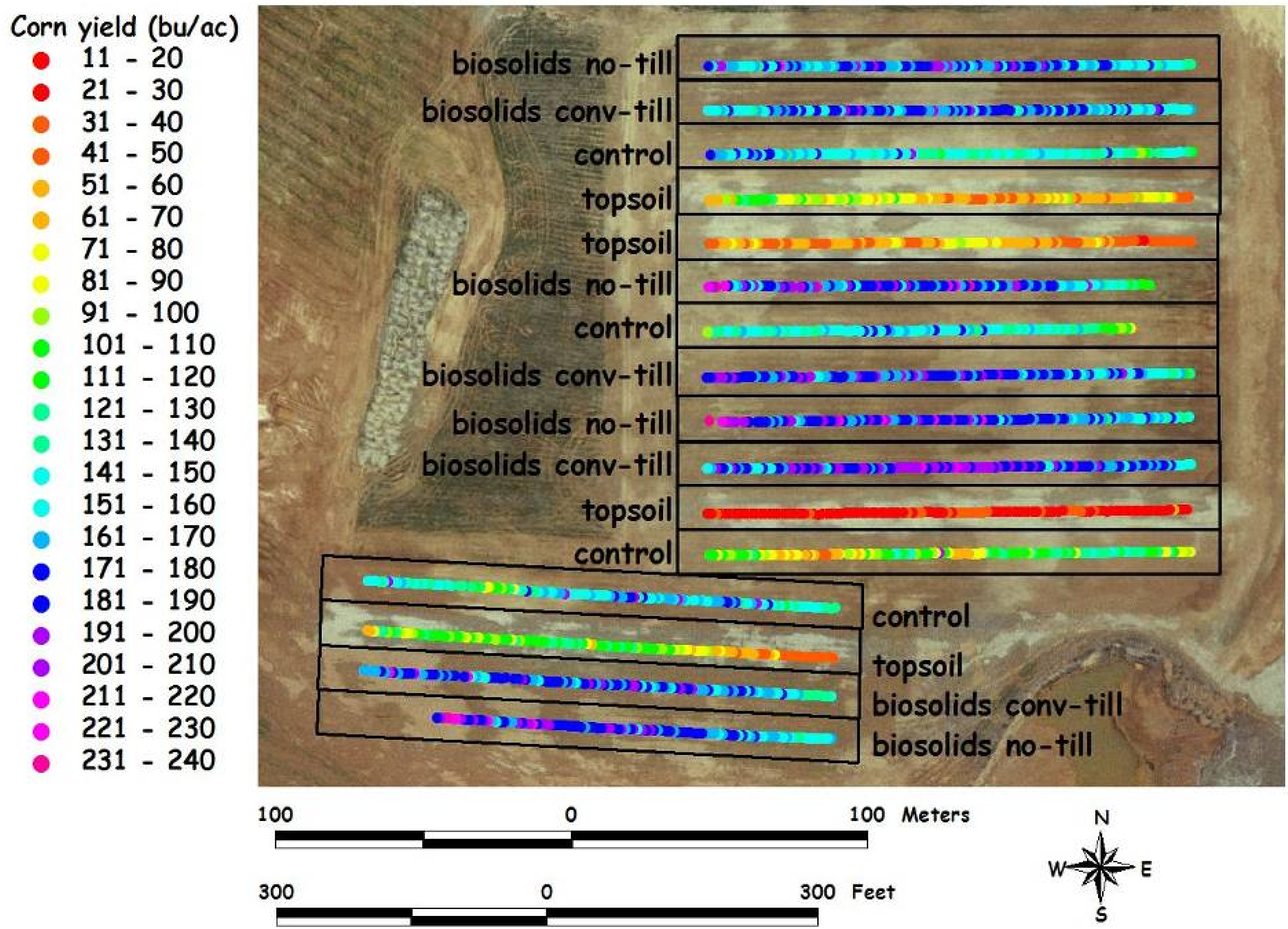
This is the "appropriate ripper" for these kinds of soil problems! Clint Zimmerman (pictured) was primarily responsible for recognizing the need and implementing routine ripping.

Row crop plots with numbers and treatments




Topsoil strip after grading and disking in April 2005.
35 T/Ac Biosolids

Topsoil yields were reduced by compaction and heavy crusting. Are these “problems” typical of the topsoil replacement process?



Corn yield (bu/ac)
11 - 20
21 - 30
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
81 - 90
91 - 100
101 - 110
111 - 120
121 - 130
131 - 140
141 - 150
151 - 160
161 - 170
171 - 180
181 - 190
191 - 200
201 - 210
211 - 220
221 - 230
231 - 240
biosolids no-till
biosolids conv-till
control
topsoil
topsoil
biosolids no-till
control
biosolids conv-till
biosolids no-till
biosolids conv-till
topsoil
control
control
topsoil
biosolids conv-till
biosolids no-till
100
0
100 Meters
300
0
300 Feet
N
W
E
S

Harvested (non-topsoiled) mined land in Fall 2005

TABLE 2

Crop yields from the Carraway-Win Reclamation Research Farm and a local unmined prime farmland soil for years 2005 - 2010 and Dinwiddie County five year crop yield averages as applicable. Crops on all areas received identical management, including irrigation as needed.

	Corn		Wheat			Soybeans		Cotton (lint)	
	2005	2007	2006	2008	2010	2008	2010	2009	
Treatment	Mg ha^{-1}								%
LBS-CT	10.85a[a]	3.62b	5.04a	5.97a	2.74a	2.24ab	0.96a	1.17a	0.424
LBS-NT	10.90a	3.43b	5.16a	5.65a	2.76a	2.51a	1.11a	1.18a	0.442
TS	3.79c	7.23a	4.29b	4.89b	2.68a	2.20ab	1.15a	1.18a	0.453
C	8.53b	7.30a	4.10b	4.64b	2.51a	2.11b	1.10a	1.05a	0.446
UM	14.36	9.91	6.9	3.9	4.72	3.2	1.73	1.62	0.4
COMP	6.07	3.18	4.33	nd	nd	1.75	nd	nd	nd
Dinwiddie Co average (2004 - 2008)	5.78								
Dinwiddie Co. Average (2006 - 2010)			4.19			1.54			

a. Means in the same column followed by the same letter are not significantly different at α = 0.05. Data analysed via one-way ANOVA followed by pairwise contrasts (Fisher's Protected LSD).
LBS = Lime stabilized biosolids @ 78 Mg/ha; TS = 15 cm topsoil return; C = Limed and fertilised control; UM = Unmined control area; COMP = Compacted, non-ripped zone.

For 9 years, row-crop yields have consistently exceeded target "county average yields" in all years and have typically been 75 to 85% of an adjacent prime farmland that is most likely the most productive row-crop field in the state of Virginia. Topsoil return has not improved productivity. In 2011, mined land yields equaled prime farmland for the first time ever.

Soybeans established in wheat stubble on Carraway-Winn farm, July 2006

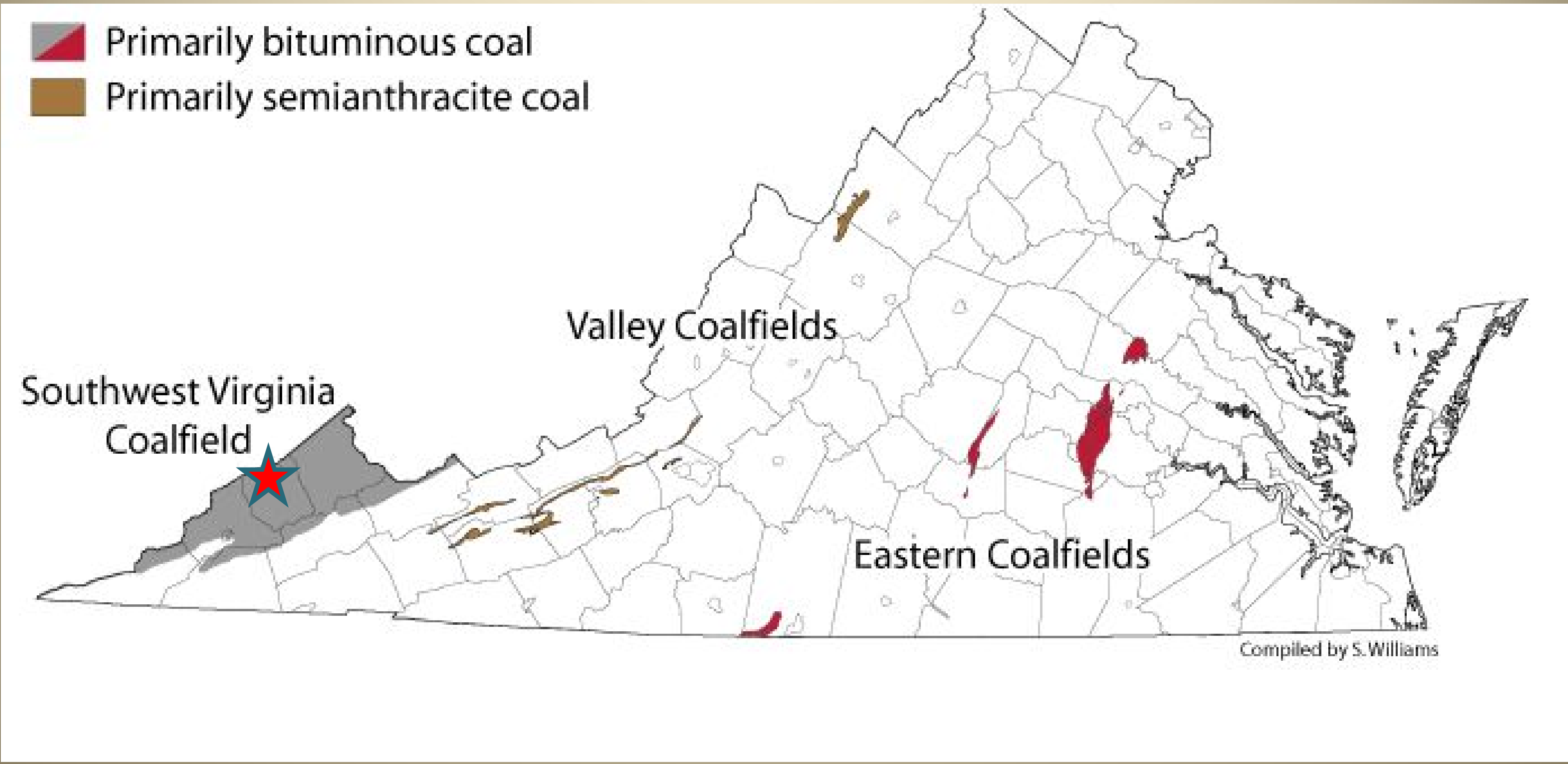
Typical profile in control plot (tailings + lime + NPK).

Light colored materials at base of trowel are pure sandy tailings.

Orange bands in lower profile are layers of high slimes 'sandwiched" between tailings.

Virginia state regulations require that a self-sustaining vegetation capable of supporting the designated post-mining land use (hayland and pasture here) be maintained for two full growing seasons before the lands are returned to their owners.

COPE Location



Controlled Overburden Placement

Rock Mix Experiment

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

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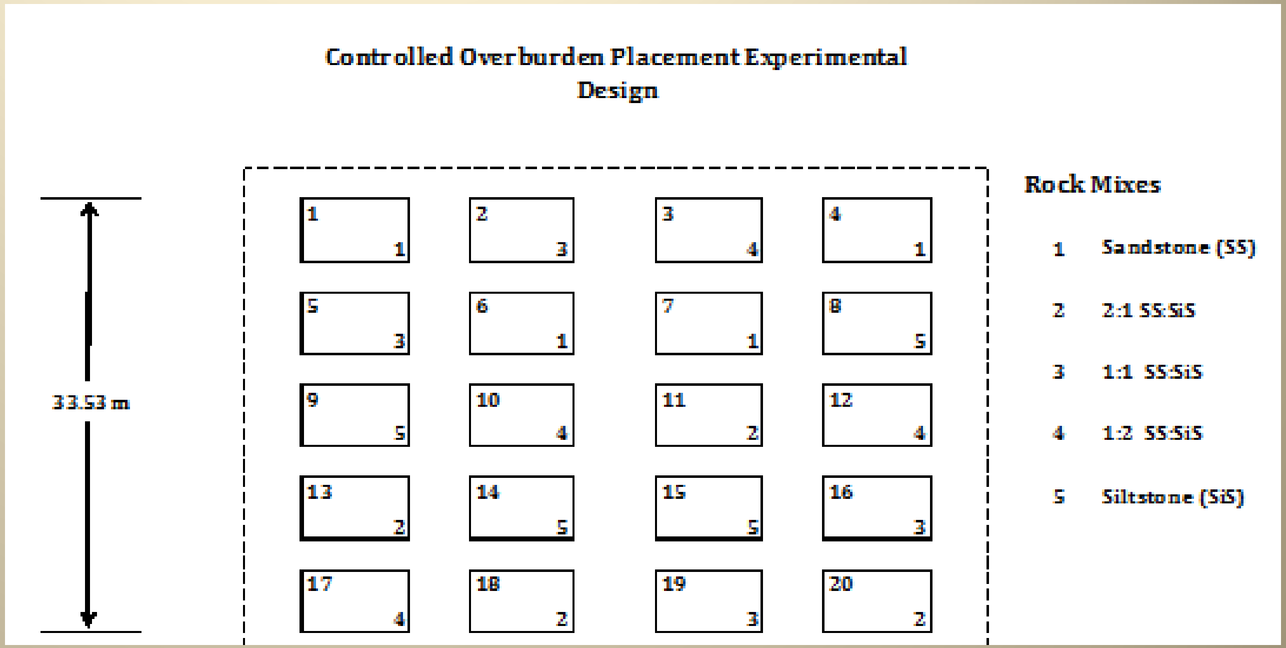
Experimental Design

- Randomized complete block design
- Each treatment replicated 4x



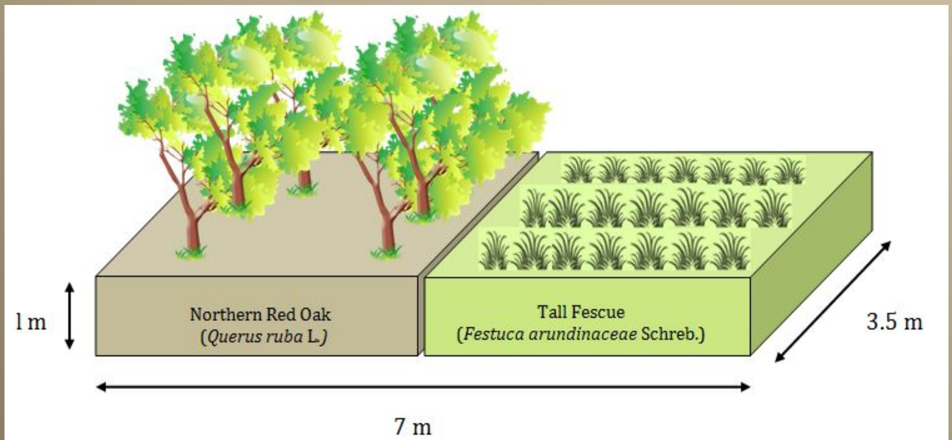


Figure 7 Vegetative Types and Split Plot Design

- Split plot design
- Tree vs. fescue

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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

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.
- Completely eliminates errors due to very high RF content and inability to accurately estimate bulk density!

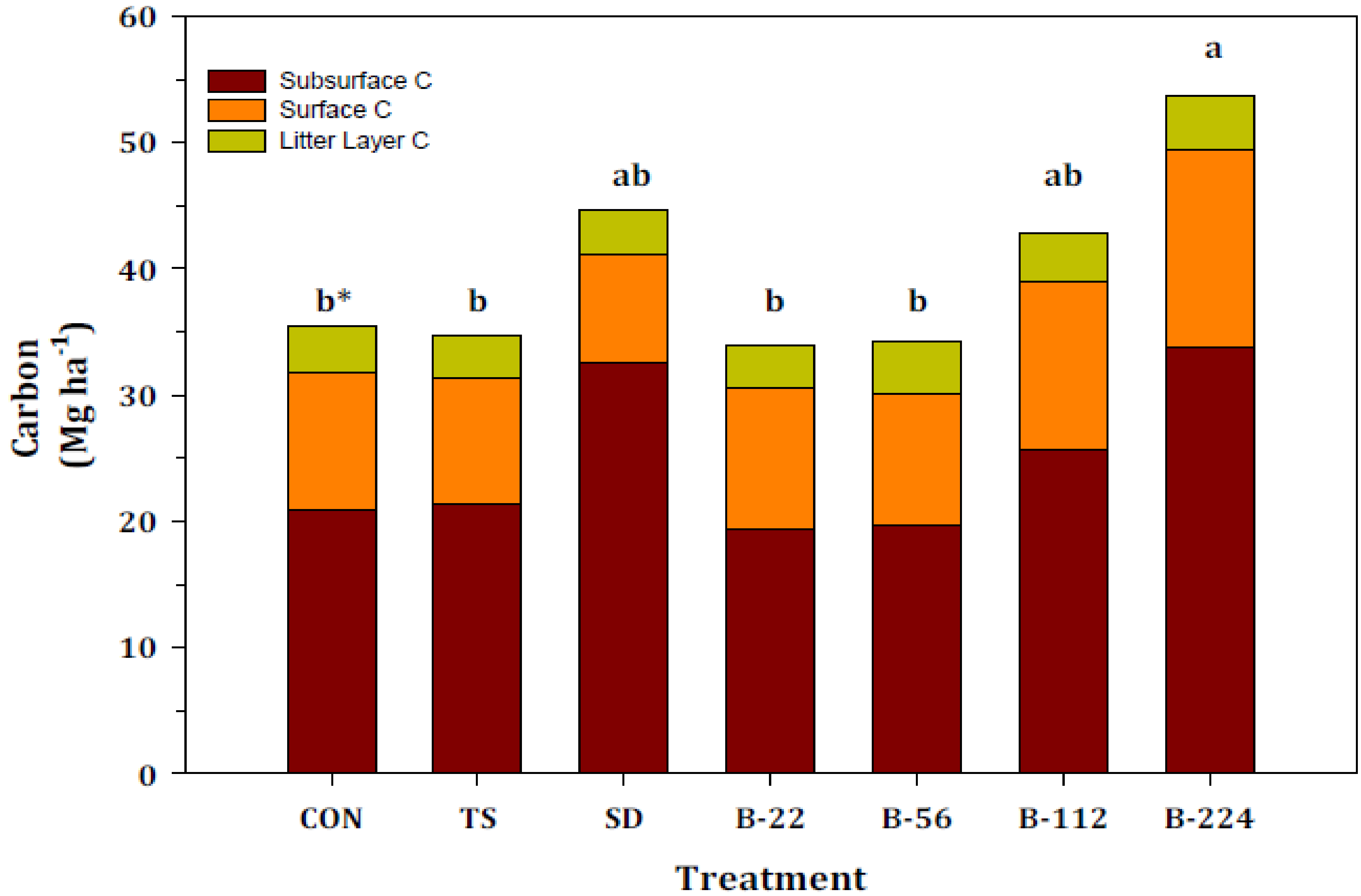

Figure 60. Whole soil mass carbon for litter layer, surface and subsurface depths of mine soils of the Surface Amendment Experiment sampled in 2008.

Table 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.

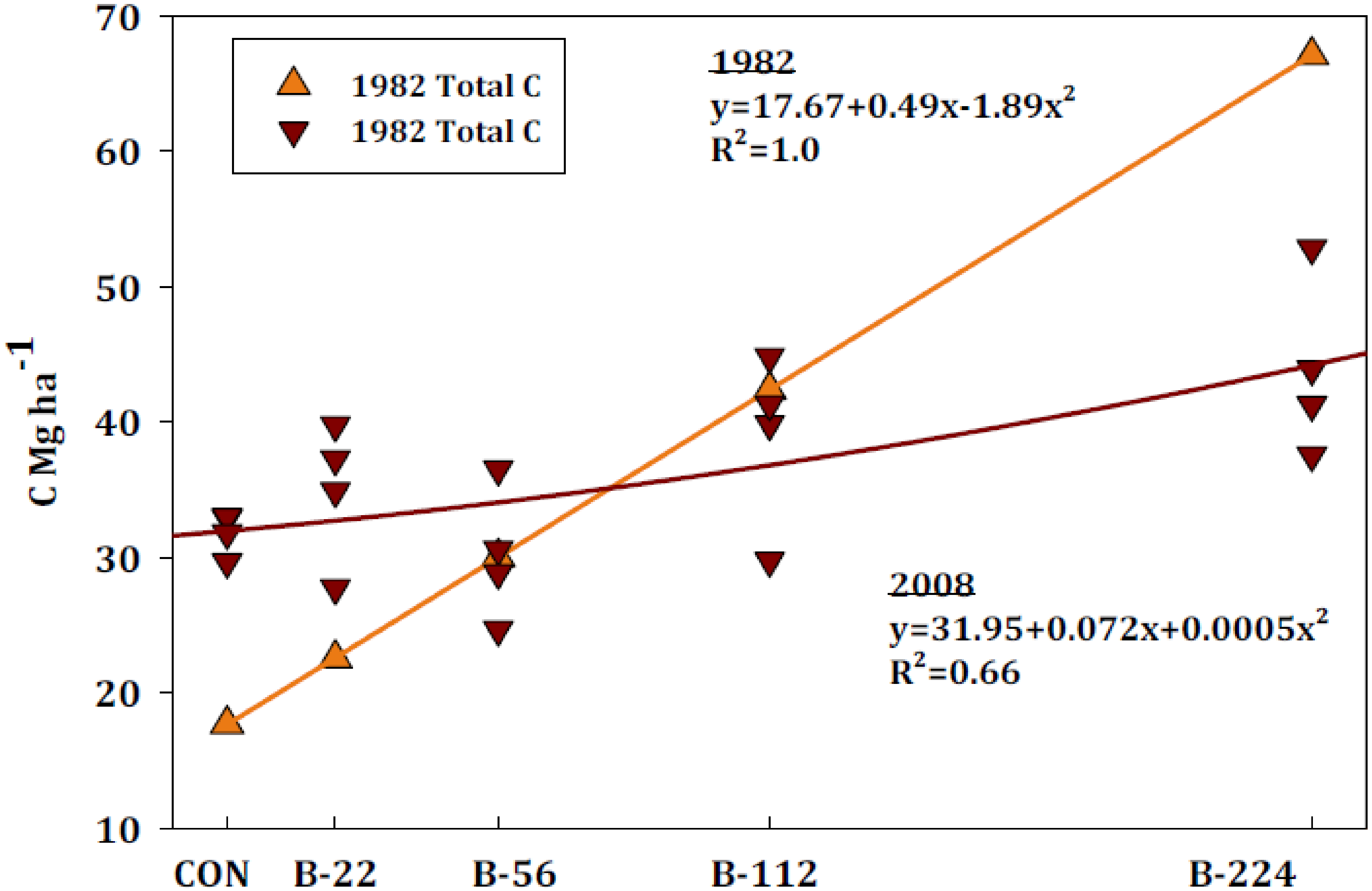

Figure 62. Total estimated C present at depth 0-25 cm in May 1982 post biosolids application vs. total C present at depth 0-25 cm in 2008 after 26 years of accumulation.

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?

- **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 5 inches thick and exhibits well developed granular structure.

Mine soil pedon 15 feet away from previous soil that did not receive biosolids.

Please contact me if you'd like copies of our papers or reports on our research results since 1990?

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