HARDWOOD TREE GROWTH AFTER EIGHT YEARS ON BROWN AND GRAY MINE SOILS IN WEST VIRGINIA

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SURFACE MINING

- > 600,000 ha deforested in Appalachia since SMCRA (US EPA, 2010).

- Deforestation results in significant changes in aquatic communities, accelerated sediment and nutrient transport, and loss of wildlife habitat.

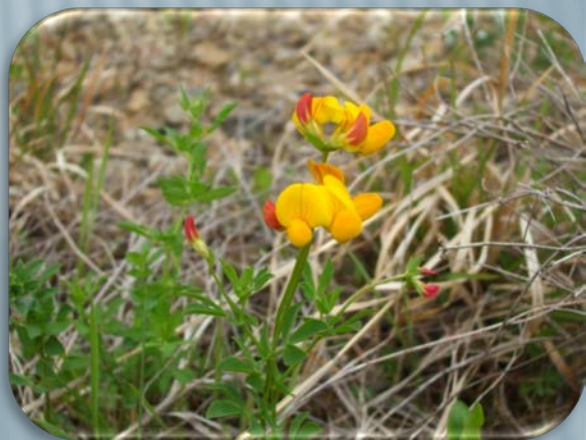
SURFACE MINING

- In the US, West Virginia ranks second in coal production.
- Currently there are 232 active surface mines in WV in 24 counties.
- In 2012, 139,424,080 tons of coal were mined!
- 48,060,579 tons from surface mining.

RECLAMATION

Post-SMCRA

- Excessive compaction
- Unsuitable rooting medium
- Encouragement of grass and legume establishment rather than trees for hayland/pastureland (Torbert and Burger, 2000).
- Aggressive herbaceous species:
  - Kentuky-31 tall fescue (*Festuca arundinacea* Schreb), red clover (*Trifolium pratense* L.), and sweetclover (*Melilotus* Mill.).



RECLAMATION

- Recent encouragement to re-establish native hardwood tree species.
- Benefits of reforestation include:
  - wildlife habitat
  - valuable and productive commercial wood production
  - improve ecosystem diversity

FORESTRY RECLAMATION APPROACH (FRA)

- Developed by Burger et al, 2005.

- FIVE TECHNIQUES:
  1. Suitable rooting medium
  2. Loosely graded and un-compacted
  3. Tree compatible groundcovers
  4. Commercially valuable crop trees and nurse trees.
  5. Proper tree planting techniques

FORESTRY RECLAMATION APPROACH (FRA)

Rooting mediums:

- Topsoil is thin and difficult to salvage.

- Soil substitute selection:

  Weathered rock: Brown sandstone.

  - pH 4.5-6.0
  - Found within first 10-30 feet.
  - Oxidized.
  - Low in soluble salts.
  - Breaks down into smaller fractions.

FORESTRY RECLAMATION APPROACH (FRA)

- FRA recommends:

  Avoid unweathered rock which contains:

  - High pH (> 7.5)
  - Pyritic materials
  - High in soluble salts (>1000 µS/cm)

RESEARCH OBJECTIVES

Determine:

1. Tree growth and survival on brown sandstone and gray sandstone, and on compacted and non-compacted mine soils.

2. Changes in soil chemical properties on the above substrates.

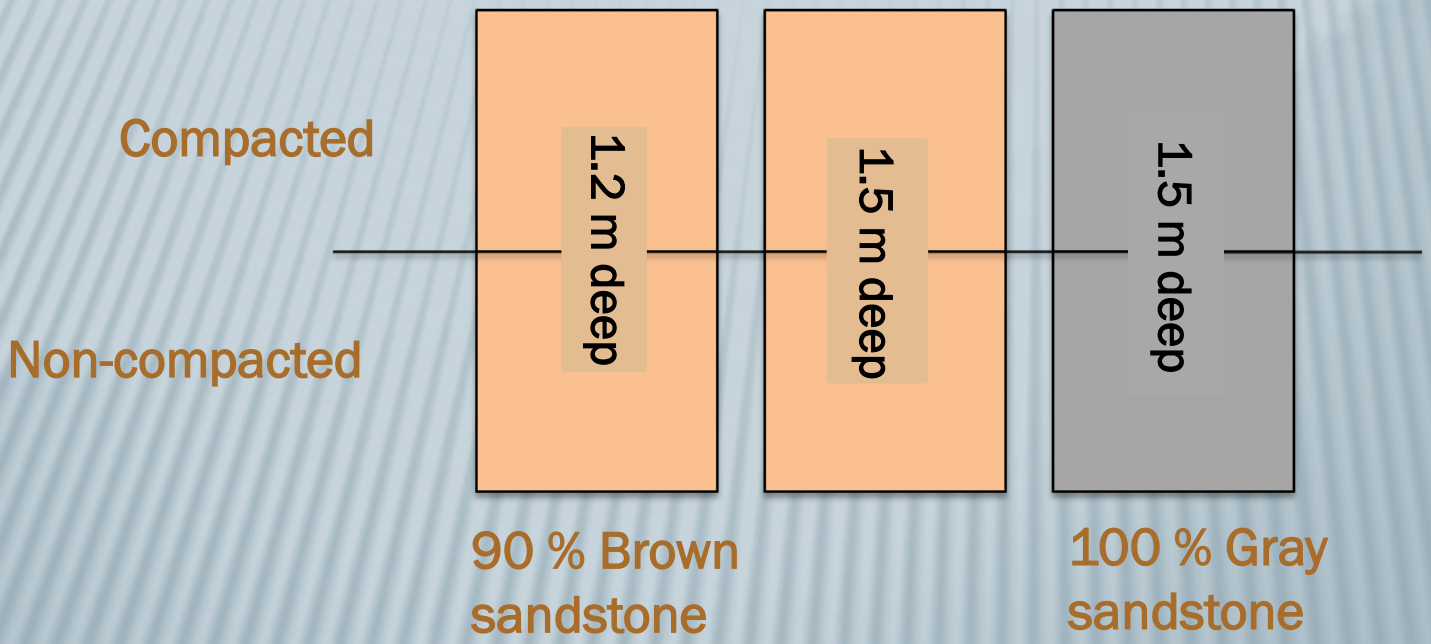
3. The establishment of herbaceous vegetation on the above substrates.

STUDY SITE

- Samples Mine- Catenary Coal
- Located approximately 50 km south of Charleston, WV.
- Spans into three counties: Kanawha, Boone, and Raleigh.

STUDY SITE

- Three 2.8-ha plots.
  - Six treatments:



Compacted

Non-compacted

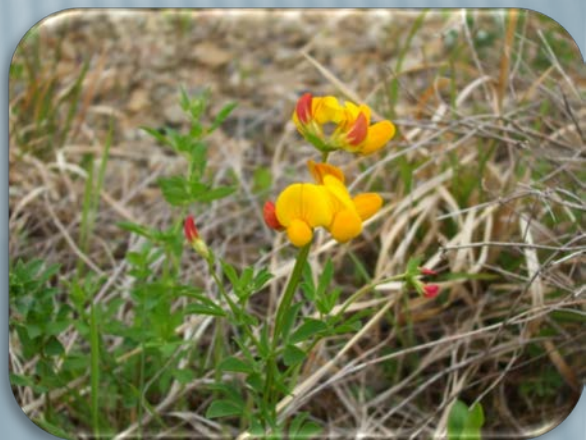
Brown Sandstone

Gray Sandstone

EXPERIMENTAL DESIGN

- Spring 2005 – 11 tree species planted on 2.3-m centers.

- Fall 2007 – hydroseeded with tree compatible ground cover at a rate of 15.4 kg/ha.



EXPERIMENTAL DESIGN

Table 1. Total number of trees planted per species.

Tree Species Planted		
Species	Total Number Planted	% of total trees planted
Red Oak	3,400	22 %
White Oak	2,500	16 %
White Ash	2,500	16 %
Sugar Maple	1,500	10 %
Chestnut Oak	1,250	8 %
Tulip-Poplar	1,250	8 %
White Pine	1,250	8 %
Black Locust	465	3 %
Black Cherry	465	3 %
Redbud	465	3 %
Dogwood	465	3 %
Total	15,510	100 %

EXPERIMENTAL DESIGN

Table 2. Hydroseeding rate by forage species.

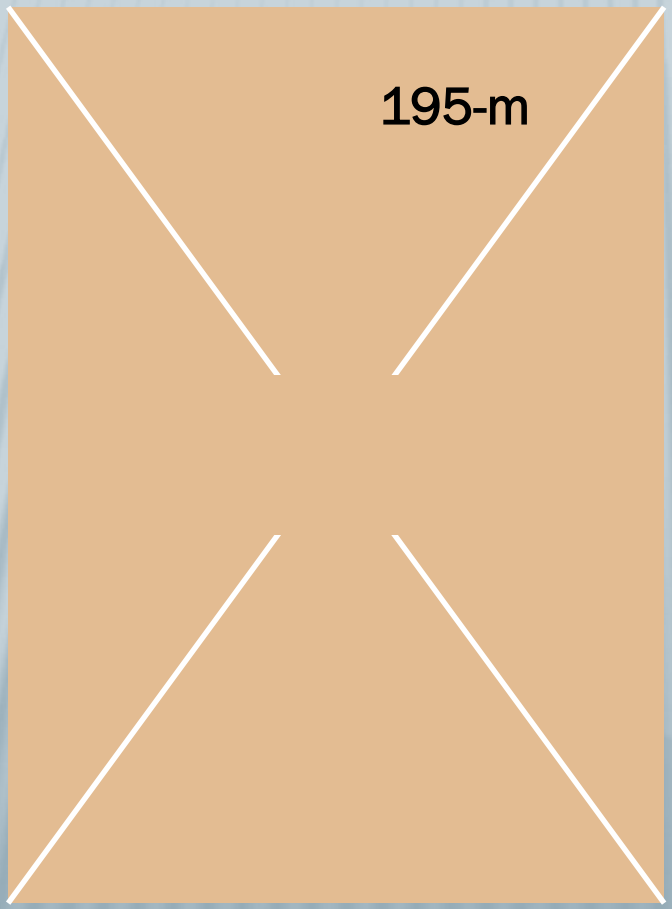
Rate of Application	
Species	**Rate**
Birdsfoot trefoil	11.0 kg/ha
Perennial ryegrass	2.2 kg/ha
Redtop	2.2 kg/ha
Total	15.4 kg/ha

EXPERIMENTAL DESIGN

- Tree sampling method:

- Two, 2.7-m wide by 195-m long transects.

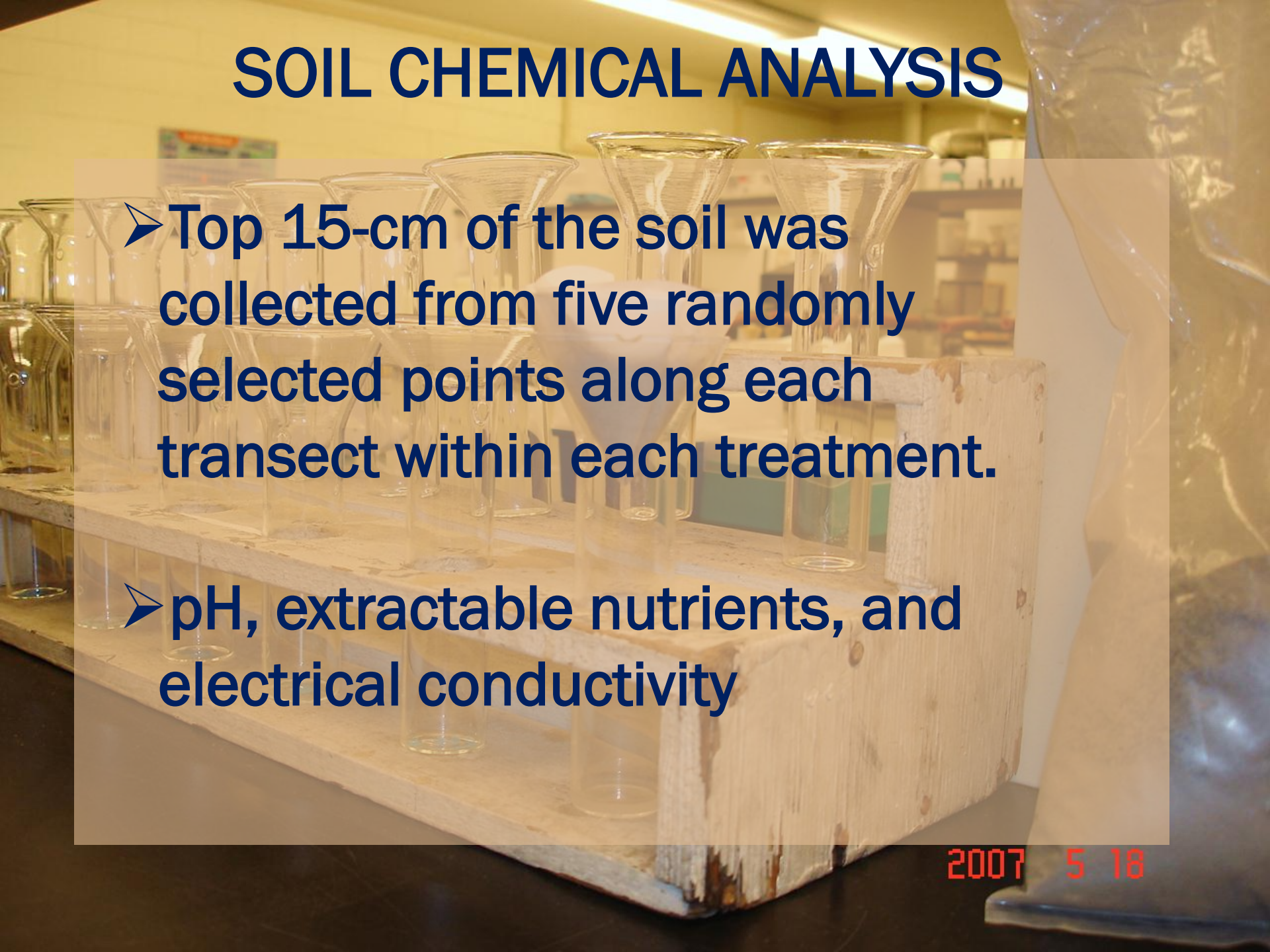
- Species, height, and diameter recorded.



SOIL CHEMICAL ANALYSIS

- Top 15-cm of the soil was collected from five randomly selected points along each transect within each treatment.

- pH, extractable nutrients, and electrical conductivity



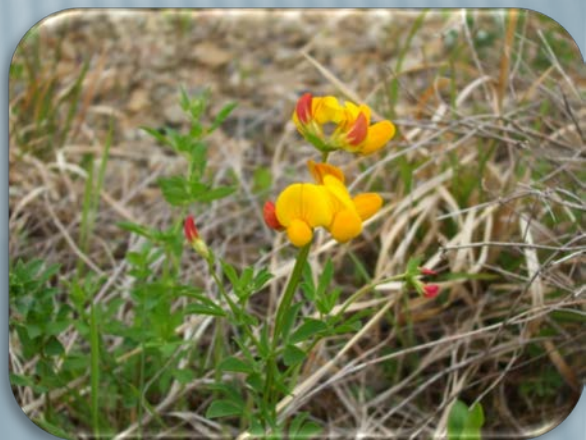
GROUND COVER

- Percent ground cover determined within a 1-m^2 quadrat.
- Quadrat placed at 20 random locations within each treatment.
- Percent herbaceous cover, litter, and bare soil/rocks estimated.

STATISTICAL ANALYSIS

- **ANOVA was used…**
  - to compare tree growth by substrate, compaction, depth, and interactions.
  - to compare soil chemical properties by year and treatment combination.
  - to compare ground cover types by soil treatment.

- **Tukey's Honest Significant Difference test used to determine significant difference at $p<0.05$ level.**



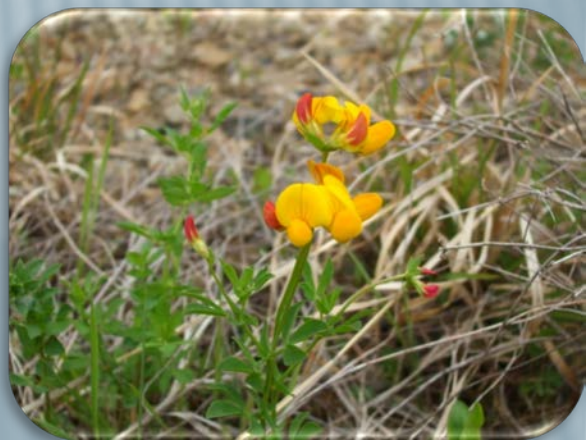
RESULTS: Trees

Table 3. Mean tree growth and survival in six treatments in 2012.

Treatment	Volume Index	Survival
	-----cm^3-----	------%------
1.2-m BC	2550	69
1.2-m BNC	3913	77
1.5-m BC	3556	84
1.5-m BNC	5182	75
GC	449	83
GNC	309	31

RESULTS: Trees

- **Sandstone type significantly affected mean tree volume index.**
  - Brown sandstone was 3853 cm^3.
  - Gray sandstone was 407 cm^3.
- **Compaction had a significant effect on mean tree volume index.**
  - Non-compacted was 3899 cm^3.
  - Compacted was 2281 cm^3.
- **Depth of brown sandstone did not significantly effect mean tree volume index.**



RESULTS: Trees

Table 4. Mean volume index and survival by tree species in 2012.

Species	Volume Index	Survival
	-----cm^3-----	-----%-----
Black cherry	1456	11
Black locust	5443	100
Dogwood	2517	44
Redbud	1390	33
Red oak	1923	60
Sugar maple	314	27
Tulip-poplar	1238	52
White ash	1166	66
White oak	3147	65
White pine	2942	51


Brown SS growth after 8 years

Gray SS growth after 8 years

DISCUSSION: Trees

- **Overall, trees grown on brown sandstone surpassed trees grown on gray sandstone.**
  - Average TVI across all species on Brown SS was nearly 10 times greater than average TVI on Gray SS.
  - These results are consistent with results reported in similar studies (Emerson et al., 2009; Torbert et al., 1990).
- **Trees growing on compacted brown treatments had a lower mean volume index than trees growing on non-compacted treatments.**
  - Soil compaction can lead to root restriction and resistance to root penetration, poor aeration, and slow movement of nutrients and water.

Black locust on brown sandstone

Black locust on gray sandstone

White oak on brown sandstone

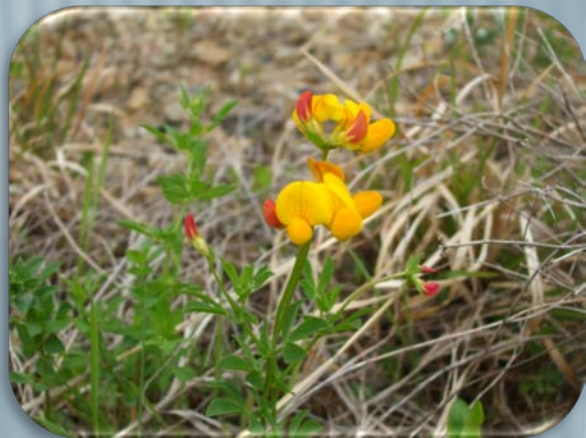
White oak on gray sandstone

Sugar maple on brown sandstone

Sugar maple on gray sandstone

DISCUSSION: Trees

- Black locust is a pioneer species which naturally grows over a wide range of soils and is easily established on disturbed sites including surface mined land.
- White oak grows on a variety of soils and sites including moderately dry slopes and ridges with shallow soils.
- Sugar maple grows on soils ranging from strongly acid (~ pH 3.7) to slightly alkaline (~ pH 7.3) but does not grow well on dry, shallow soils.



RESULTS: Soil

Table 5. Mean soil properties from six treatments in 2012.

	1.2 BC	1.2 BNC	1.5 BC	1.5 BNC	GC	GNC
Property	----------su----------					
pH	*5.23a	5.36a	5.62a	5.71a	7.93b	7.99b
	----------dS/m----------					
EC	0.04	0.04	0.05	0.03	0.04	0.06
	----------%----------					
Fines	76a	69a	69a	68a	41b	36b

*Means within row with the same letter are not significantly different at P < 0.05

RESULTS: Soil

Table 6. Mean values for extractable nutrients in six treatments in 2012.

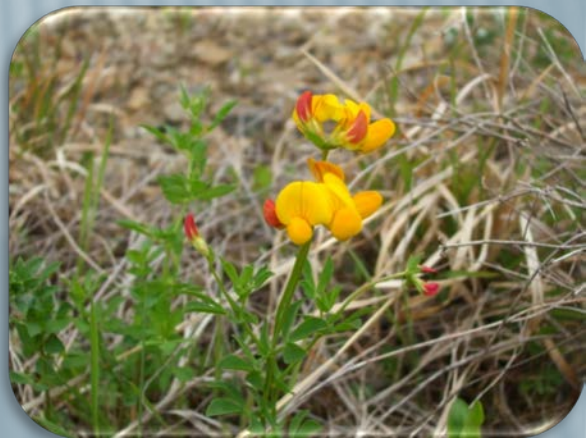
	1.2 BC	1.2 BNC	1.5 BC	1.5 BNC	GC	GNC
Element	----------cmolc kg-1----------					
Mg	4.0	4.6	4.9	5.3	6.7	6.1
K	*0.37a	0.51a	0.50a	0.42a	0.07b	0.03b
Ca	4.7	4.9	7.1	6.8	8.4	8.9
	----------mg kg-1----------					
Al	356a	289a	256a	229a	76b	81b
Fe	149	134	137	149	203	243
Mn	138	135	154	132	192	186
P	44b	39b	71b	56b	176a	191a
Zn	9ab	7b	8b	8b	16a	17a

*Means within row with the same letter are not significantly different at P < 0.05

DISCUSSION: Soil

- **Mean pH for both sandstone types fell within normal ranges for weathered and unweathered sandstones in the Appalachian coal region.**
  - pH range for brown sandstone (4.5-6).
  - pH range for gray sandstone (7.5-8).

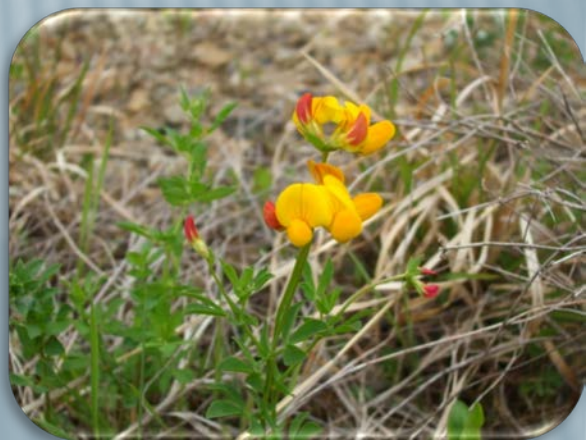
- **Al concentrations highest in brown sandstone treatments.**
  - May be due to the highly weathered nature of the brown sandstone compared to gray which experienced little weathering.



DISCUSSION: Soil

- Low levels of K in gray sandstone may be due to leaching.

- Fe and P concentrations were highest in gray sandstone treatments.
  - High levels of Fe could result in Fe-P complexes which could limit P availability.



RESULTS: Ground cover

Table 7. Mean ground cover on six treatments in 2012.

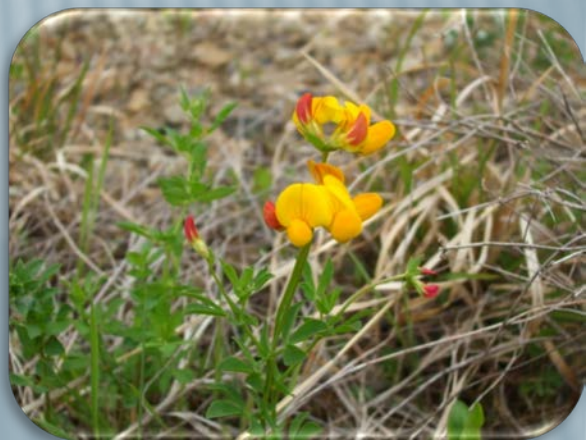
	1.2 BC	1.2 BNC	1.5 BC	1.5 BNC	GC	GNC
Cover	----------%----------					
Herbaceous	58a	52a	72a	58a	5b	9b
Litter	1b	6ab	1b	10a	0b	0b
Total Cover	65a	60a	78a	74a	11b	10b
Bare/Rock	35a	40a	22a	26a	89b	90b

*Means within row with the same letter are not significantly different at $P < 0.05$

RESULTS: Ground cover

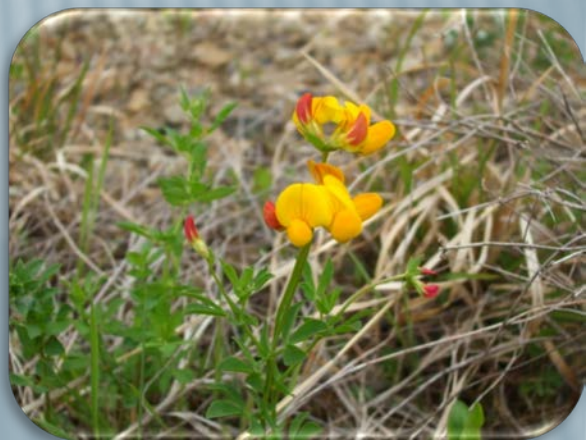
- Percent herbaceous cover, litter, and total cover were significantly greater on brown sandstone treatments than on gray sandstone treatments.

- Gray sandstone treatments had 89 to 90% bare soil and rocks.



DISCUSSION: Ground Cover

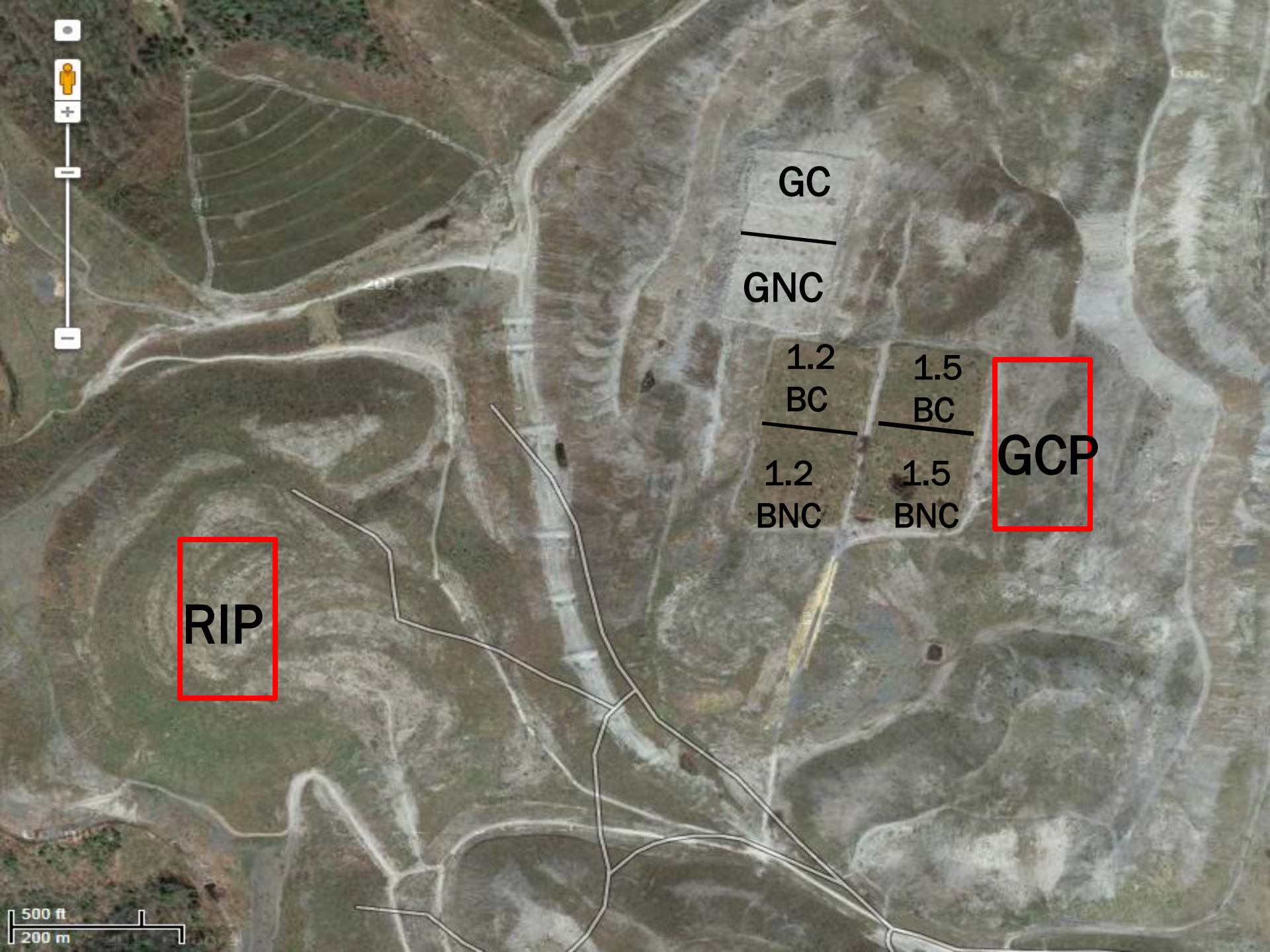
- Differences in % ground cover may be due to inadequate hydroseed application on the gray sandstone treatments.



Gray Sandstone Comparative Study

RESEARCH OBJECTIVE

- Determine tree volume index on two Gray SS areas adjacent to the original Gray SS demonstration plot.


GC
GNC
1.2
BC
1.5
BC
1.2
BNC
1.5
BNC
GCP
RIP
500 ft
200 m

RESULTS: Soil

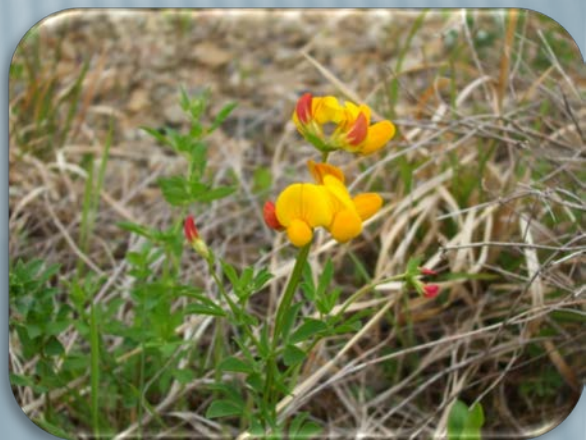
Table 8. Mean soil properties from gray sandstone treatments in 2012.

	GSS	GCP	RIP
Property	----------su----------		
pH	7.96	7.44	7.38
	----------dS m^{-1}----------		
EC	0.05	0.12	0.08
	----------%----------		
Fines	*39a	30a	76b

*Means within row with the same letter are not significantly different at $P < 0.05$

DISCUSSION: Soil

- The RIP plot may have a higher % fines due to reclamation process.
- Greater % fines in RIP may have contributed to higher water-holding capacity.



RESULTS: Ground Cover

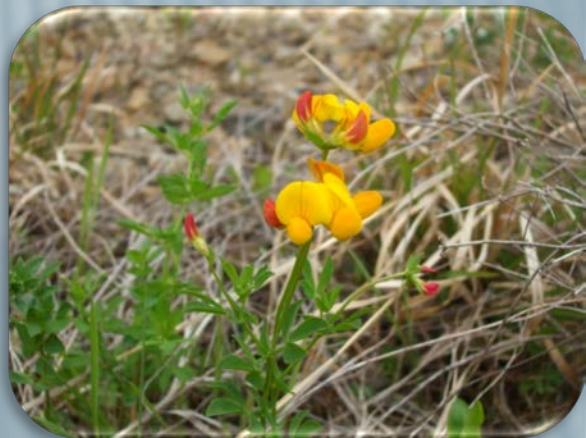
Table 10. Mean ground cover on gray sandstone treatments in 2012.

	GSS	GCP	RIP
Cover	----------%----------		
Herbaceous	*7a	32b	40b
Litter	0a	3b	5b
Total Cover	11a	36b	47b
Bare/Rock	89a	64b	53b

*Means within row with the same letter are not significantly different at P < 0.05

DISCUSSION: Ground Cover

- Differences in % ground cover may be due to inadequate hydroseed application on the original gray sandstone plot.



RESULTS: Trees

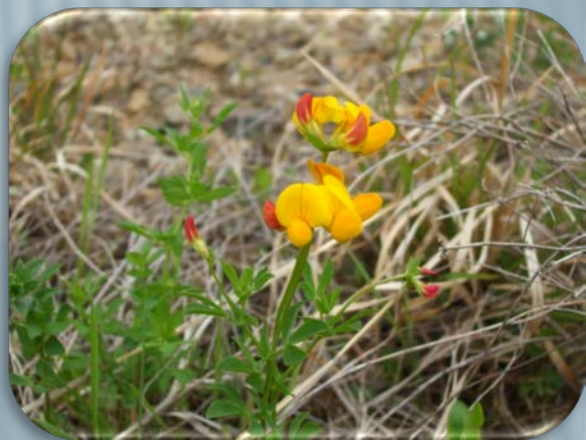
Table 9. Mean tree growth in gray sandstone treatments in 2012.

Treatment	Volume Index
	-----cm^3-----
GSS	407
GCP	909
RIP	885

RESULTS: Trees

- There were no statistically significant differences in mean volume index between gray sandstone treatments.

- Visual observations:
  - Trees growing on the new plots (GCP and RIP) appeared to be somewhat healthier.




GCP May 2013


RIP May 2013


Original Gray Sandstone Plot May 2013

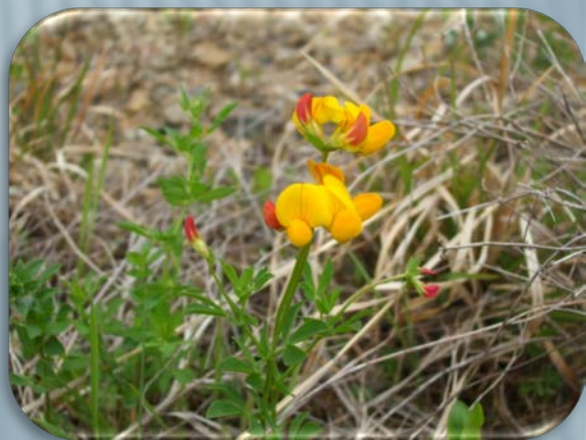
White oak on GCP

White pine and white oak on RIP

White pine and white oak on original gray sandstone plot

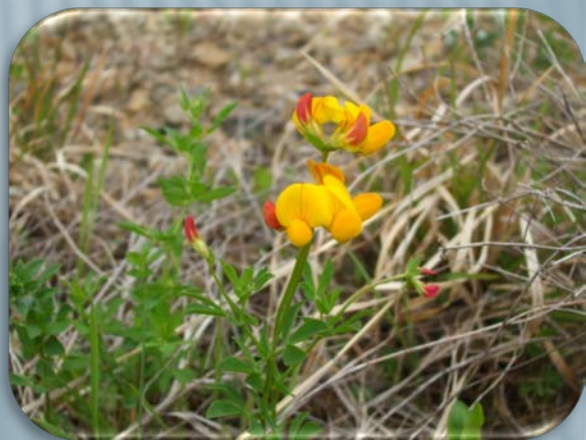
DISCUSSION: Trees

- **Explanations for visual differences:**
  - Lack of adequate herbaceous cover on GSS.
  - The higher percentage of fines on RIP could increase the soil's plant-available water which would positively influence the site's productivity.



DISCUSSION: Trees

- With time, tree growth on the ripped gray plot may surpass tree growth on the new compacted gray plot and the original gray sandstone plot (Burger and Evans, 2010).



CONCLUSIONS

- Native hardwood tree species planted on Brown SS outperformed and out-survived those planted on Gray SS.
- Compaction was a significant factor for tree volume index on Brown SS.
- Soil pH of Brown SS was more conducive to hardwood tree production.
- There was little difference in overall tree performance between the original Gray SS plot and the two adjacent Gray areas.

QUESTIONS???