Indicators of Reclamation Success for Mineral Sands Mining in Virginia, USA

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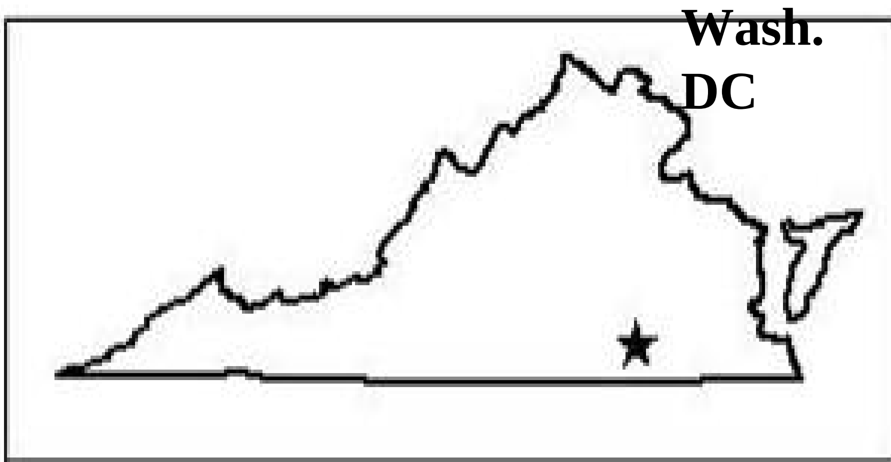
Introduction and Topics

- Background and history of Virginia mineral sands (Ti + Zr) deposits and development
- Summary of early operational challenges
- Describe the Virginia Tech & Iluka Resources mining operations and research response and development of reclamation success indicators
- Review development of topsoil substitute strategy and potential implications



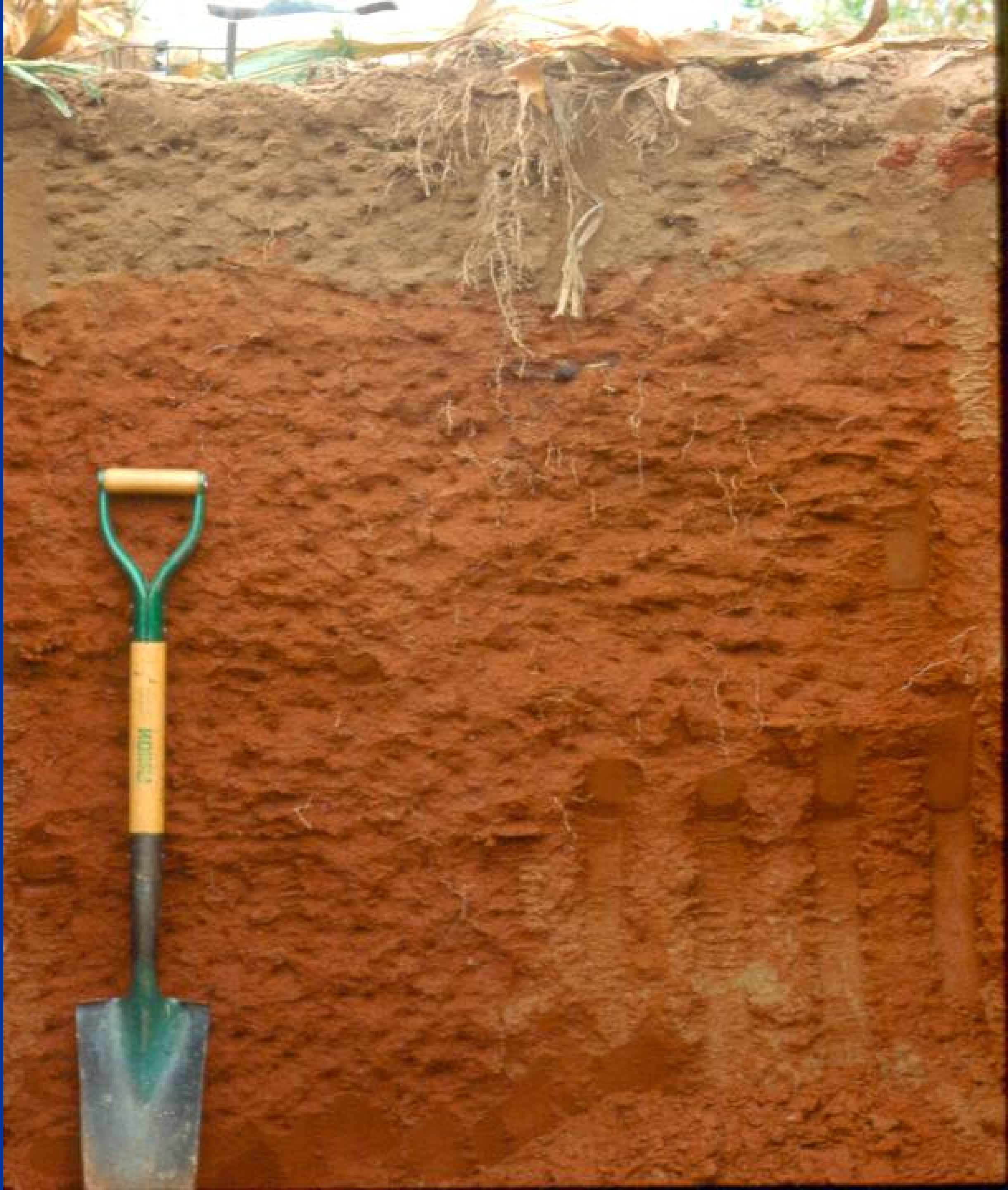
Location of mineral sands ore bodies in Virginia (in red). Similar ore bodies lie approximately 100 km south in North Carolina.

Typical prime farmland with enrichment of heavy minerals to a depth of >10 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. Mining began in 1997 after 8 years of exploration, landowner negotiations and research by Virginia Tech. Over 4000 ha in Virginia and North Carolina will be mined. 1500 ha have been mined to date.

Surface (topsoil) enrichment of ilmenite+rutile+zircon is frequently > 15% W:W. Subsoil is often > 5%.

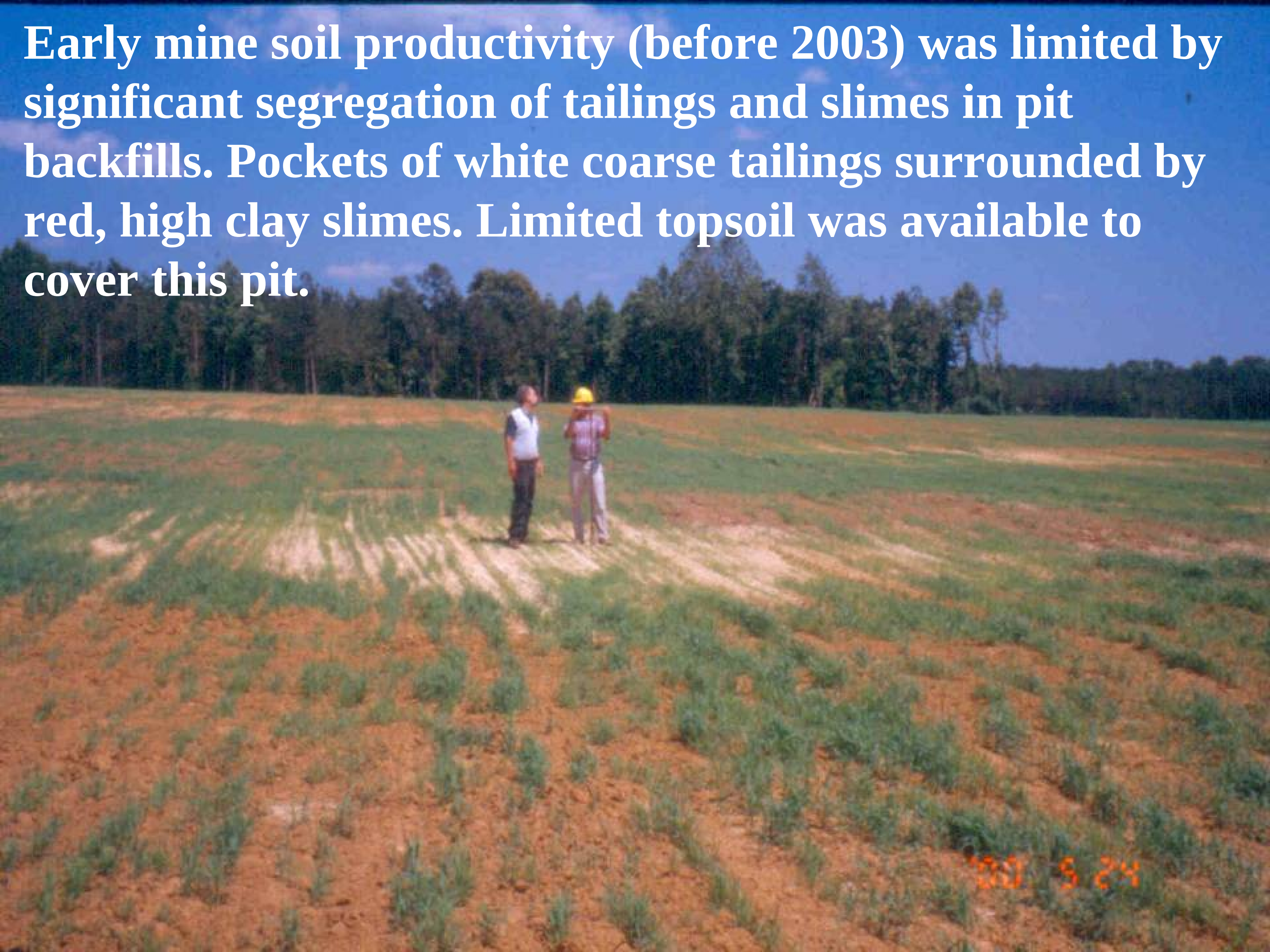
Typical highly productive soil in the Old Hickory area. The topsoil is usually 3x enriched in HM relative to subsoil.

Productivity of this soil in greatly enhanced by the low bulk density, well structured subsoil that readily allows rooting to 125 cm or more.



Active mining at Old Hickory. Over 1500 ha have been disturbed to date with approximately 750 returned to agricultural use.


Topsoil in dikes in 2001
60 % Quartz Tailings
40% Fe-Coated Kaolinite
Typical active backfill pit at Old Hickory


Early mine soil productivity (before 2003) 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.
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Topsoil Return Issues

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

- Vague state regulatory definition of “topsoil” allowed the operator and certain landowners to process topsoil for mineral return. This led to threat of litigation in 2004 and all lands received topsoil afterwards until after 2010.

Iluka's Efforts to Minimize Tails/Slimes Segregation

- Internal cross-dikes with flashboard risers
- Smaller dewatering pits with multiple discharge points
- Moving the discharge point periodically
- Reworking slimes pockets with trackhoes
- Final grading to homogenize the surface

Tailing and Consolidation

Preparation for Regrading Activities –

- **Weirs** are used to allow the ponds to further dewater over time

- **Opening Pond Walls** allows maximum drainage to occur. The tailings can self-dewater to the lowest possible level

Tailing and Consolidation

Preparation for Regrading Activities – Installing Rim Ditches

- Once the ponds have been filled with tails, they are prepared for upcoming regrading activities.
- **Rim Ditches** are used to aid dewatering

Final pit grading; usually done just as soon as dozers can walk the surface, which means it’s wet. This maximizes compactive effort on sandy materials.

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

Sequence of photos (by Chuck Stilson/Iluka) showing ripping of subsoil and application of topsoil for final reclamation. The topsoil is spread with dozers and then tilled/ripped again to loosen compaction. Ripping usually occurs below topsoil; not through it.

Lime + P are added to the subsoil before ripping and then lime + N-P-K are added to the topsoil based on soil test results.

Regulatory Issues and Sustainability Indicators

- **Threatened landowner litigation (2001-2003) revealed that local county zoning/planning permits did require full return of native topsoil (A+E horizons).**
- **State (Virginia) permit revisions required that lands returned to rowcrop agriculture (e.g. corn, wheat, soybeans) must equal the long-term county average yields for those crops.**
- **All stakeholders agreed that comparison to (A) long term (5-year) county crop yield averages and (B) local high quality farmland would be the best indicators of sustainability with respect to post-mine land use.**


VT
Carraway-Winn
Reclamation Research Farm
ILUKA
Cooperators: Iluka Resources, Virginia Tech, the Carraway-Winn Family, Virginia Health Dept., Virginia Division of Mineral Mining, Synagro Technologies Inc., and Clarke Farms, LLC
Soil reconstruction treatments
The agricultural fields behind this sign were mined for heavy minerals (titanium and zirconium oxides) several years ago. Currently, these mined lands are being returned to productive agricultural uses through a Virginia Tech research and demonstration project cooperative with Iluka Resources, the Carraway-Winn family, and others. As can be seen on the map to the left, a portion of the experimental farm is being managed for row-crops while the majority of the land is under intensive forage (hay) management. One of our major objectives is to investigate the effects of organic amendments, topsoil, and conventional lime + fertilizer + tillage treatments on crop productivity. Our second objective is to monitor changes in soil and water quality over time. Please contact us as shown below if you would like more information about this project or if you would like to arrange a tour:
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09/15/2005

Experimental Design

- Located on property of litigant with large (0.5 ha each x 4 replications) plots managed with full scale farm operations. Installed fall 2004 and cropped through 2013.

- Low quality mine soils due to pre-2001 tailing and dewatering procedures, compaction and lack of topsoil return.

Mine soil profile from research plots showing significant buried topsoil and mixing/banding of dissimilar materials in upper profile.

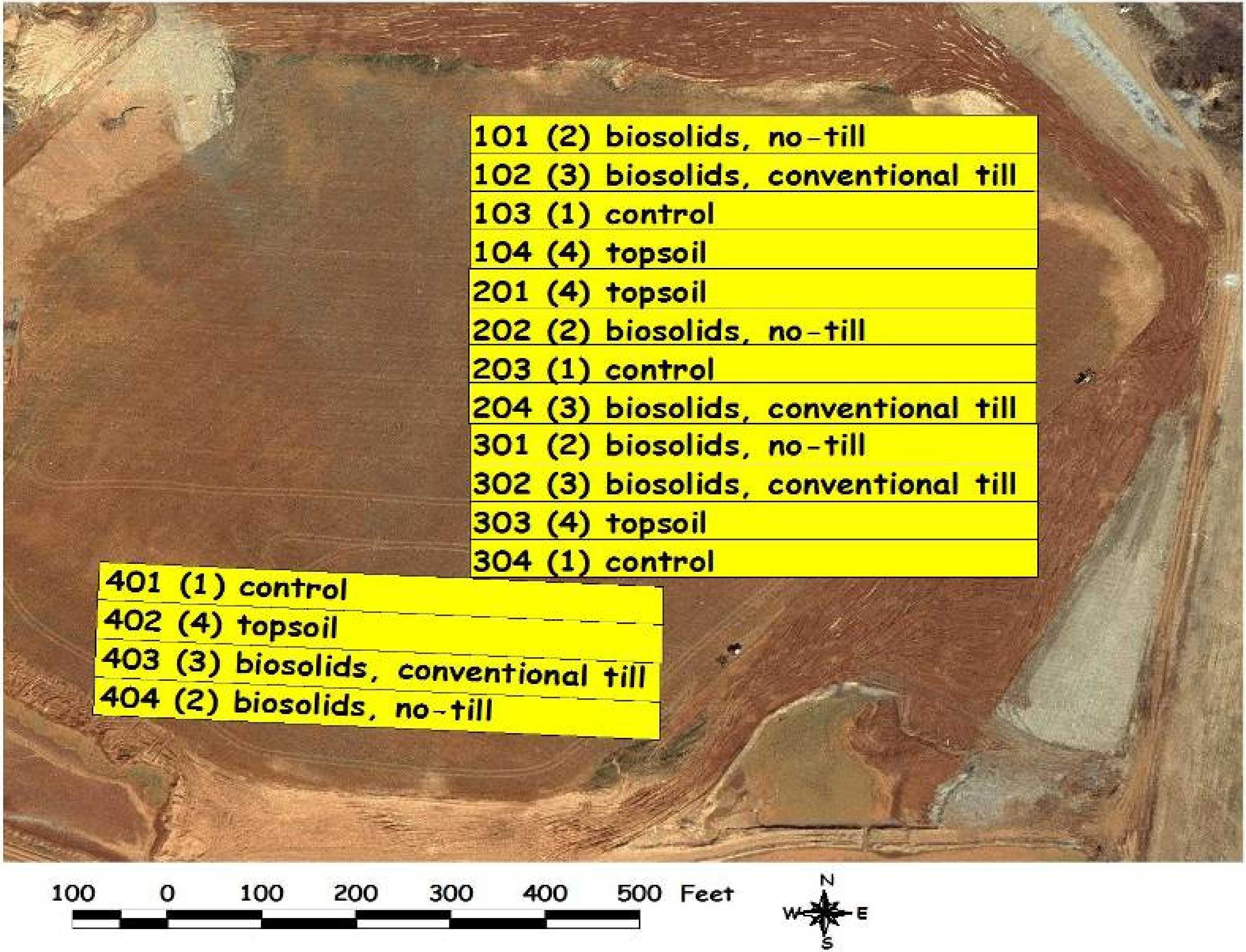
This soil was very compact with almost no rooting below 30 cm.

Experimental Design

- **(1) Topsoil -- 15 cm topsoil + P (300 kg/ha) + lime (7 Mg/ha) underlying tailings. All plots in experiment were ripped (2x) to ~75 cm.**
- **(2) Tailings Control -- N-P-K + lime directly to tailings.**
- **(3, 4) Biosolids (78 Mg/ha) + lime directly to tailings with tillage (plowing + disk) or no-tillage every year.**
- **(5; external) Non-mined prime farmland control with identical management to mined land plots**

All treatments received N-P-K and lime as needed every year.

Row crop plots with numbers and treatments




Topsoil strip after grading and disking in April 2005.
78 Mg/ha Biosolids after incorporation

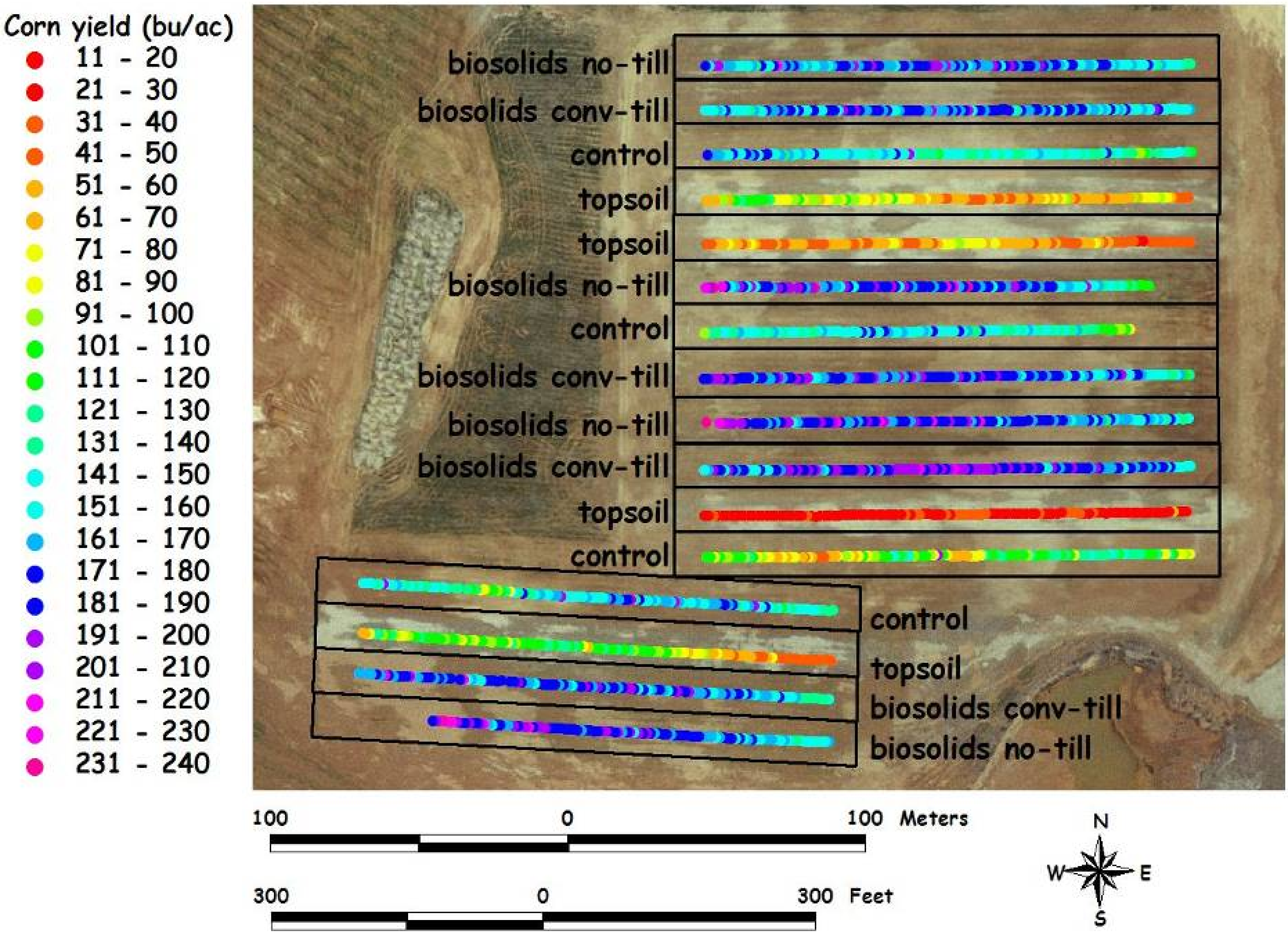

Corn yield (bu/ac)
11 - 20
21 - 30
31 - 40
41 - 50
51 - 60
61 - 70
71 - 80
81 - 90
91 - 100
101 - 110
111 - 120
121 - 130
131 - 140
141 - 150
151 - 160
161 - 170
171 - 180
181 - 190
191 - 200
201 - 210
211 - 220
221 - 230
231 - 240
biosolids no-till
biosolids conv-till
control
topsoil
topsoil
biosolids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

Table 2: Mean corn, wheat, and soybean yields (13% moisture) and cotton lint yield by treatment for the Caraway-Winn Reclamation Research Farm and the Clarke Farm unmined control with Dinwiddie County averages indicated.

Treatment	2005 Corn	2006 Wheat	2006 Soy-bean	2007 Corn	2008 Wheat	2008 Soy-bean	2009 Cotton	2010 Wheat	2010 Soy-bean	2011 Corn	2012 Wheat	2012 Soy-bean
	---------- $bu\ ac^{-1}$ ($Mg\ ha^{-1}$) ----------											
LBS-NT	173.9c[1] (10.90)	76.8b (5.16)	6.1[2] (0.41)	54.6b (3.43)	84.0c (5.64)	37.3b (2.51)	--- (1.18)	41.0a (2.76)	16.4a (1.10)	75.7 a (4.75)	47.7a (3.20)	36.4c (2.45)
LBS-CT	173.0c (10.85)	67.8ab (4.56)	6.5 (0.44)	57.6b (3.62)	93.3c (6.27)	36.0ab (2.42)	--- (1.17)	40.6a (2.73)	14.3a (0.96)	84.6a (4.77)	47.2a (3.17)	37.1c (2.49)
TS (topsoil)	60.4a (3.79)	63.9a (4.29)	7.6 (0.51)	115.3a (7.23)	72.7b (4.89)	32.8ab (2.20)	--- (1.18)	39.7a (2.67)	17.1a (1.15)	65.9a (4.13)	47.4a (3.18)	37.4c (2.51)
C (control)	136.0b (8.53)	60.9a (4.09)	5.6 (0.38)	116.3a (7.30)	69.0b (4.64)	31.5a (2.12)	--- (1.05)	37.3a (2.51)	16.3a (1.10)	76.0a (5.30)	46.3a (3.11)	34.8b (2.34)
UM – Clarke (un-mined)	224.0d (14.30)	102.7c (6.90)	37.7 (2.53)	158.1c (9.91)	58.1a (3.90)	47.7c (3.21)	--- (1.62)	70.1b (4.71)	25.7b (1.73)	199.1b (12.48)	66.2b (4.45)	32.9a (2.21)
Dinwid-die Co. Average	107 (6.7)	56 (3.76)	22 (1.47)	63 (3.9)	73 (4.90)	26 (1.75)	--- (1.18)[3]	na	15 (1.01)	131 (8.2)	72 (4.83)	44 (2.95)

[1] Values followed by different letters are significantly different ($p<0.05$).

[2] CWRRF soybean yields for 2006 were very low in part because excessive wetness prohibited an appropriately timed harvest.

[3] State average (county average not available)

2005 Corn Yields (Mg/ha)

Topsoil/Lime/NPK 3.8 c*

Tails + Biosolids: 10.9 a

Tails + Lime + NPK: 8.5 b

Unmined adjacent: 14.3

County Average: 6.7

(2000 – 2005)

Adjacent prime farmland – Orangeburg Soil with same management as plot area.

**Yields within experiment followed by different letters were different at p > 0.01*

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

2006 Wheat Yields (Mg/ha)

Topsoil/Lime/NPK	4.3
Tails + Biosolids:	4.8
Tails + Lime + NPK:	4.1

Winter Wheat on Carraway-Winn Farm in May of 2006

Unmined adjacent:	6.9
County Average: (2000 – 2005)	3.8

Adjacent prime farmland – Orangeburg Soil with same management as plot area.

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

Treatment	2011*	2012	
	Corn	Wheat	Soybeans
	-------- bu/ac	(Mg/ha) ----------	
Biosolids-NT	75.7 a (4.75)	47.7a (3.20)	36.4c (2.45)
Biosolids-CT	84.6a (4.77)	47.2a (3.17)	37.1c (2.49)
TS (+ topsoil)	65.9a (4.13)	47.4a (3.18)	37.4c (2.51)
C (tailings control)	76.0a (5.30)	46.3a (3.11)	34.8b (2.34)
UM - Clarke (unmined)	199.1b (12.48)	66.2b (4.45)	32.9a (2.21)
Dinwiddie Co. [illegible]	131 (8.20)	72 (4.83)	44 (2.95)**

*Very wet year.

*****Long term county data include ~50% full-season soybeans. Plot yields are for short season soybeans planted in June after wheat.***

Topsoil Return vs. 2010 Topsoil Substitute Amendment

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Conventional --Topsoil Return

- Topsoil stored during the land preparation process is returned
- Pull pans have been used, but trucks and dozers have proven most effective

In 2010, the state (Virginia) approved the use of tailings derived “topsoil substitutes” with landowner concurrence. This was based on C-W experiment yields. Several new mine areas have utilized this option to date.

CONCLUSIONS

With few exceptions (topsoil in early years), crop yields from the four reclamation treatments routinely exceeded local (Dinwiddie County) five-year county averages.

No improvement was seen for topsoil return vs. properly amended and managed tailings.

In comparison to native unmined land, crop yields from the reclamation plots typically were reduced by 20 to 30%.

CONCLUSIONS

In fairness, the local non-mined plots were extremely productive Virginia farmland and therefore represent a very high standard of comparison.

However, the fact that the 2012 soybean yield on the mined land actually exceeded local native prime farmlands clearly indicates that over the long term, return of 90% or more of pre-mining productivity levels may actually be possible.

CONCLUSIONS

One important outcome of this research program (in 2010) was the fact that the company was able to gain approval for a "topsoil substitute variance" from the state regulatory authority.

Once implemented, this will result in much higher mining royalty streams to landowners, higher local mineral severance tax revenues and improved profitability + long-term stability for the mining company (Iluka Resources).

CONCLUSIONS

As documented in this paper, the key to our success has been the detailed level of interaction and understanding achieved between the academic researchers from Virginia Tech and the mining engineers and professionals with Iluka.

Acknowledgments

Iluka – Matthew Blackwell, Denis Brooks, Mike Creek, Elliott Mallard, Geoff Moore, Clay Newton, Fiona Nichols, Allan Sale, Chee Saunders, Steve Potter, Steve Winkelmann, and Chris Wyatt have worked diligently with us over the years to improve mined land reclamation protocols applied at Old Hickory.

We also want to thank Carl Clarke for his management of the research farm. John Tucker and Steve Bunch for assistance with revegetation protocols, and Steve Nagle and Kelly Burdt (from VT) for help in the field.

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

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