MINERAL SANDS MINE SOILS IN SOUTHEASTERN VIRGINIA:

COMPARISON OF PHYSICAL AND CHEMICAL PROPERTIES AFTER 8 YEARS

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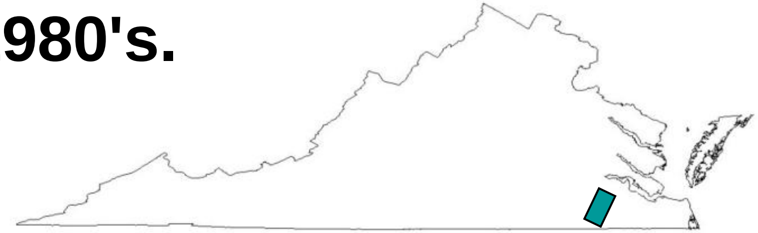
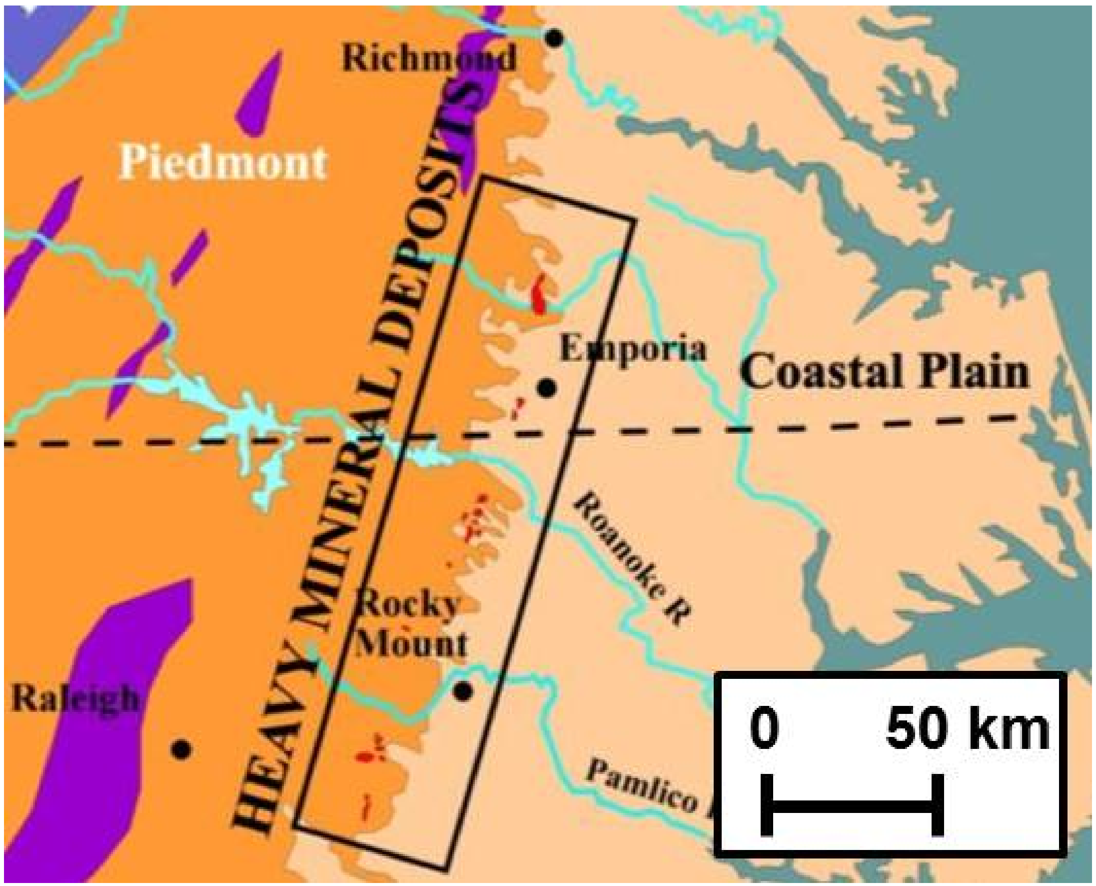
Introduction

Heavy mineral sand deposits (mainly ilmenite, rutile, and zircon) were discovered in Virginia and North Carolina in the late 1980's.





Mining of the Old Hickory deposit (the northern most deposit in VA) began in 1990's.

Location of the mineral sands ore bodies are shown in red.

Up to 7,000 ha potentially could be disturbed.

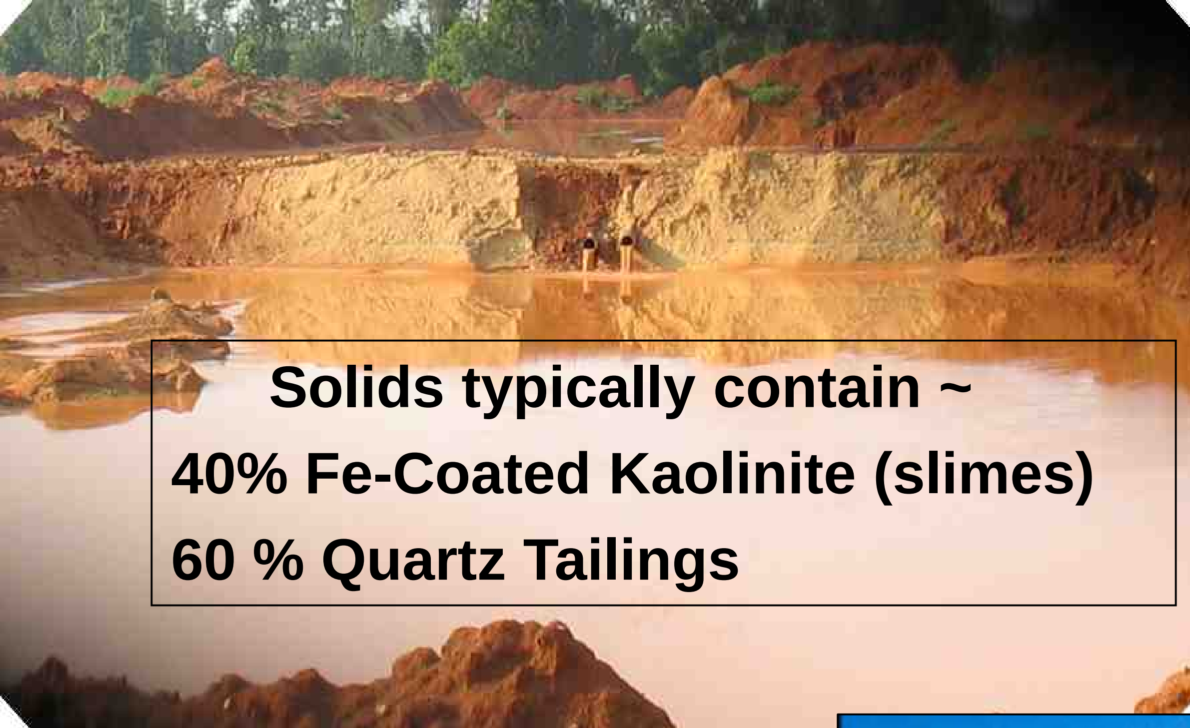
Much of the recoverable mineralized area occurs under prime farmlands – an important region for peanut, soybean, tobacco, and cotton production.

fine-loamy, kaolinitic, thermic Typic Kandiudult

Ideally the mined areas will be returned to agriculture.

The Mining Process

The deposit is mined with excavators and fed to a mobile mining unit to be sized, slurried, and pumped to the concentrator.



After processing, slimes and tails are pumped back to the reclamation pits in a water slurry (35 to 50% solids).

Final pit dewatering at Old Hickory.

Most pits take at least a year for the surface to dry enough to support machinery.

Regrading and Smoothing

Soft areas are "dipped and spread" utilizing a long-reach excavator

Dozers are used to spread the slimes to aid in drying

Smoothing gives a rolling uniform appearance, and the resulting grade is easy to work with farm equipment.

Reclamation Challenges

Dewatered tailings/slimes mixtures are highly variable laterally and vertically.

(Keys to Soil Taxonomy, 12th ed cover photo)

Objectives

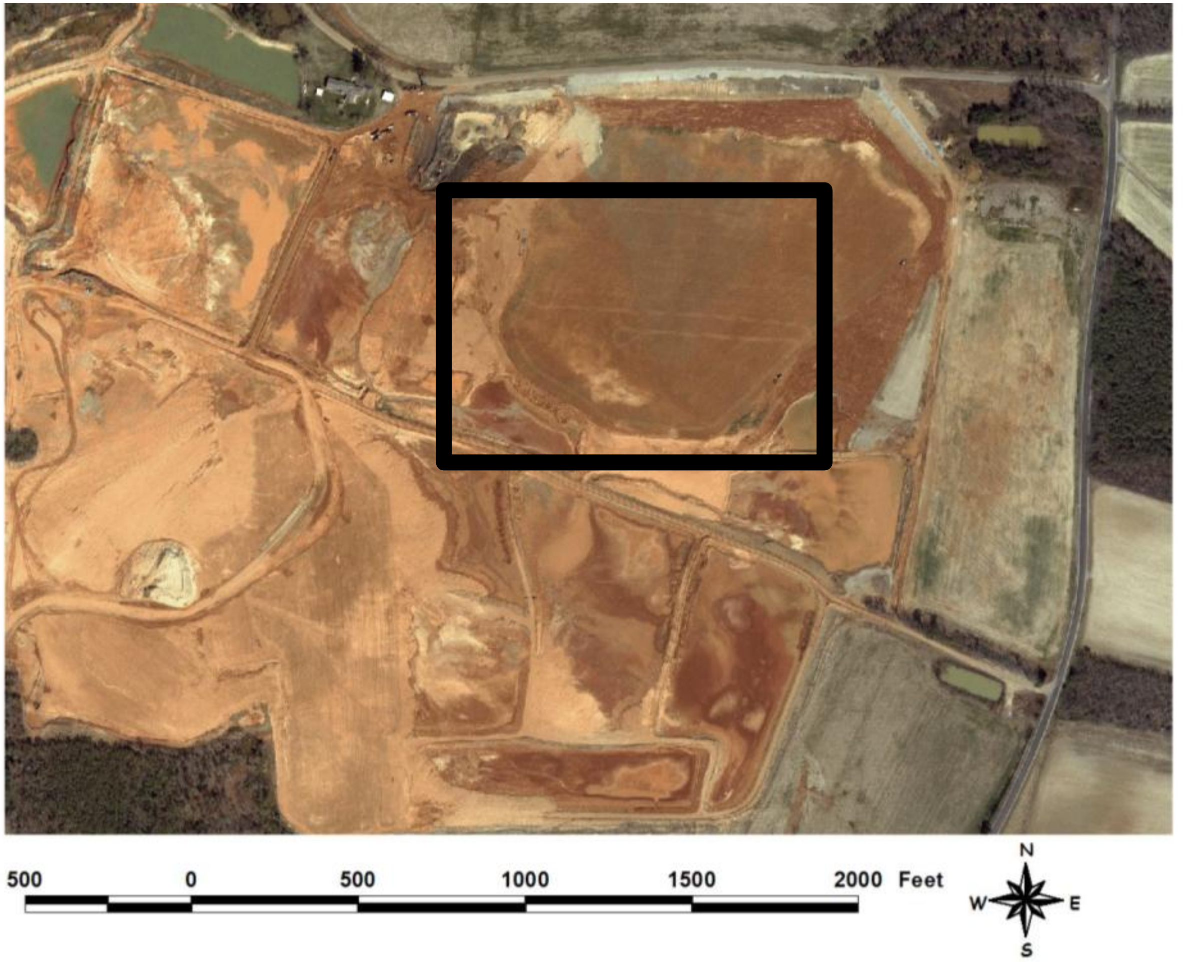
To characterize and observe changes in variably reclaimed mine soils after 8 years of management:

- Chemical – pH, extractable nutrients, C/N
- Physical and morphological – texture, structure, bulk density, diagnostic horizons
- Rooting, crop yields

Methods

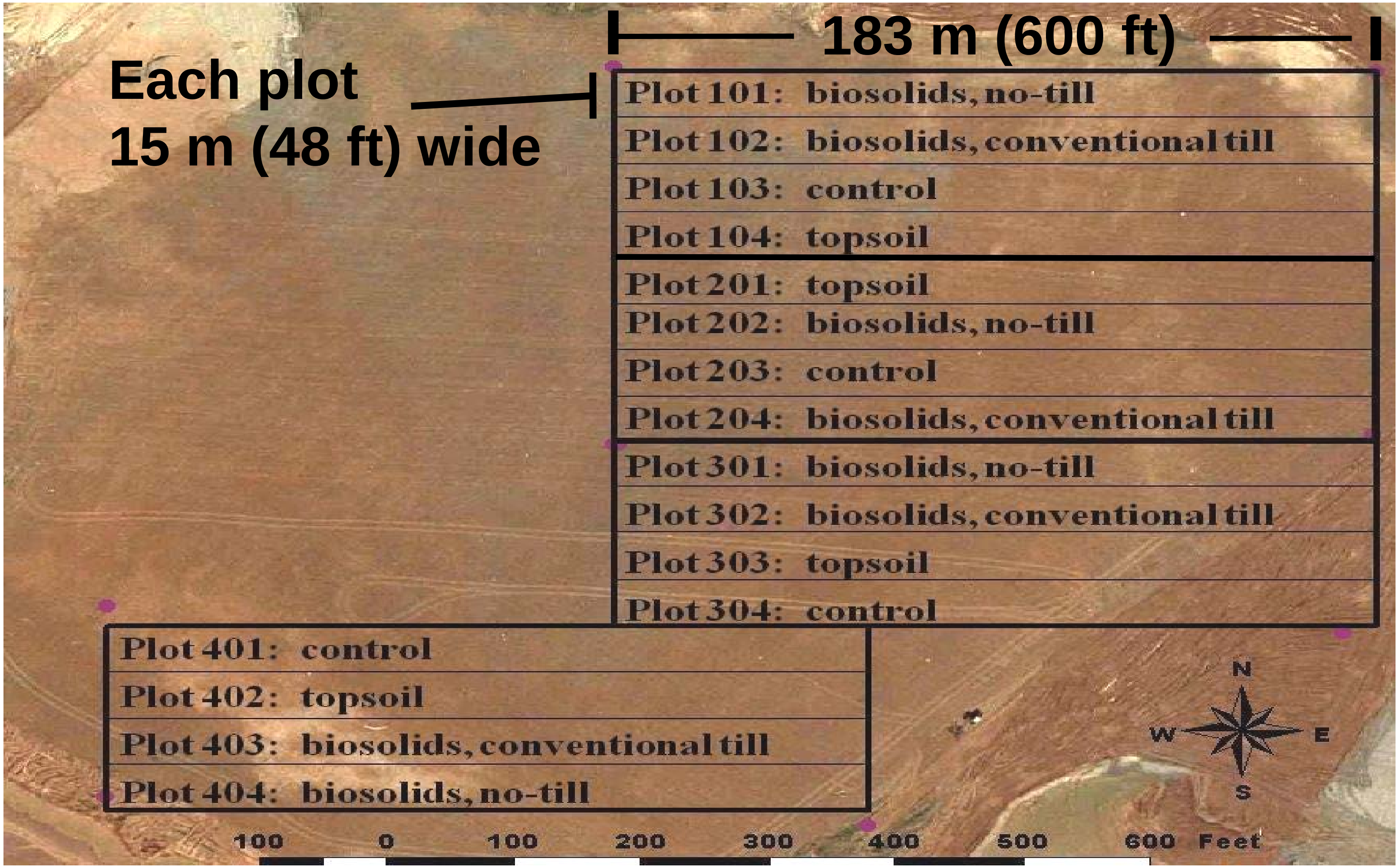
The research area was mined in 1998, reclamation practices were initiated in 2001. The standard subsoil stabilization treatment included 9.96 Mg ha^{-1} lime, 392 kg ha^{-1} P_2O_5, and a sequence of deep ripping and chisel plowing.

The area was seeded with an herbaceous cover.



Methods

- complete randomized block design (4 blocks)
- 4 treatments per block



Methods – 4 treatments

1) **LBS-CT**:
   lime-stabilized biosolids at 78 Mg/ha, conventional tillage.

2) **LBS-NT:**
   lime-stabilized biosolids at 78 Mg/ha, no-till management.

3) **TOPSOIL**:
   lime and P to subsoil, 15 cm of topsoil added, lime to topsoil

4) **CONTROL**:
   lime and P

Methods – plot establishment in 2004-2005

- Surface soil (to 15 cm) was excavated from the topsoil plots.
- All plots were ripped to 90 cm (36”) in 2 perpendicular directions, then chisel plowed to 30 cm (12”) in 2 perpendicular directions.
- Lime (8.96 Mg ha^{-1}) and P (672 kg ha^{-1}) were incorporated to 20 cm on the TOPSOIL and CONTROL plots.
- Topsoil (15 cm) was applied to the TOPSOIL plots and additional lime (6.72 Mg ha^{-1}) was incorporated to 20 cm.
- Lime stabilized biosolids (78 Mg ha^{-1}) were incorporated to 20 cm on the LBS-NT and LBS-CT plots.
- All plots were smoothed and cleared of debris with a cultivator.

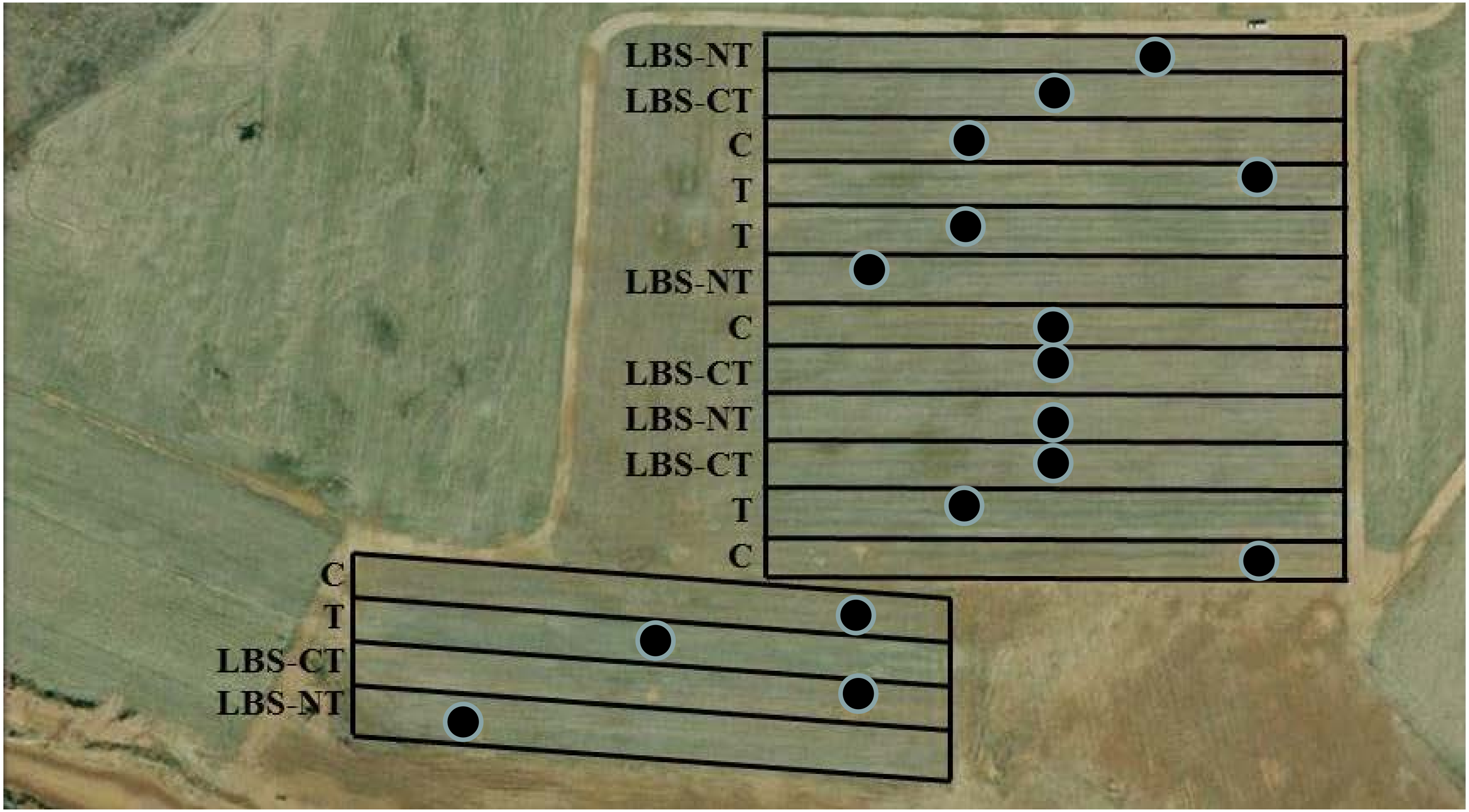
Year	Spring	Summer
2005		corn
2006	wheat	
		soybeans
2007		corn
2008	wheat	
		soybeans
2009		cotton
2010	wheat	
		soybeans
2011		corn
2012	wheat	
		soybeans
2013		corn

As necessary, all plots were irrigated and received herbicides, fungicides and pesticides.

The TOPSOIL plots received additional lime in the fall of 2005.

In most years all plots were ripped to 40 – 50 cm.

Fertilizers (N-P-K) were applied annually for optimal nutrient levels per crop based on soil test results; all plots received same fertilization except that biosolids plots did not receive N prior to fall 2007.



16 soil profile pits (1 per plot) were randomly located and described and sampled to ~1.5 m (~5 ft) in 2006 and 2014

Methods

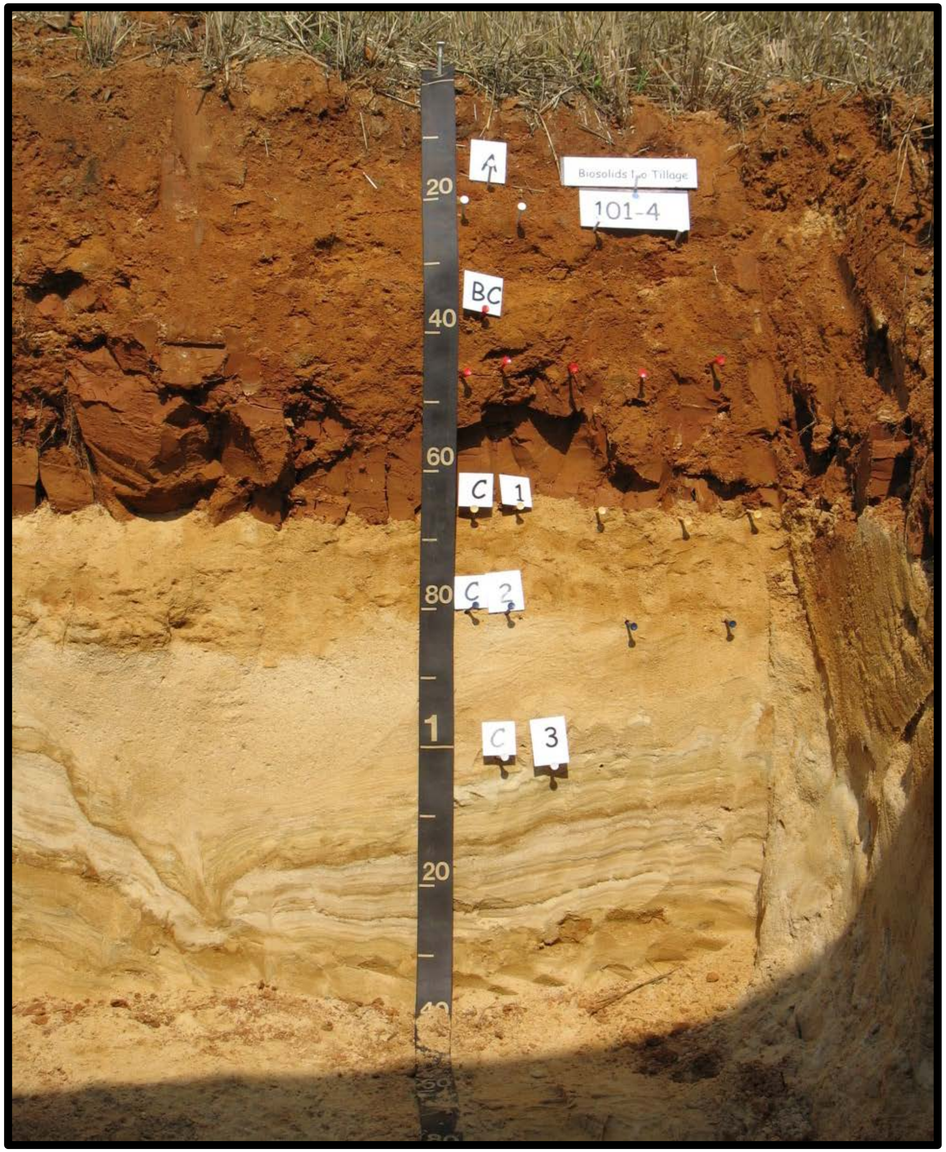
Bulk samples collected from all major horizons:

- Particle size distribution
- pH
- Extractable nutrients
- Total-C
- Total-N

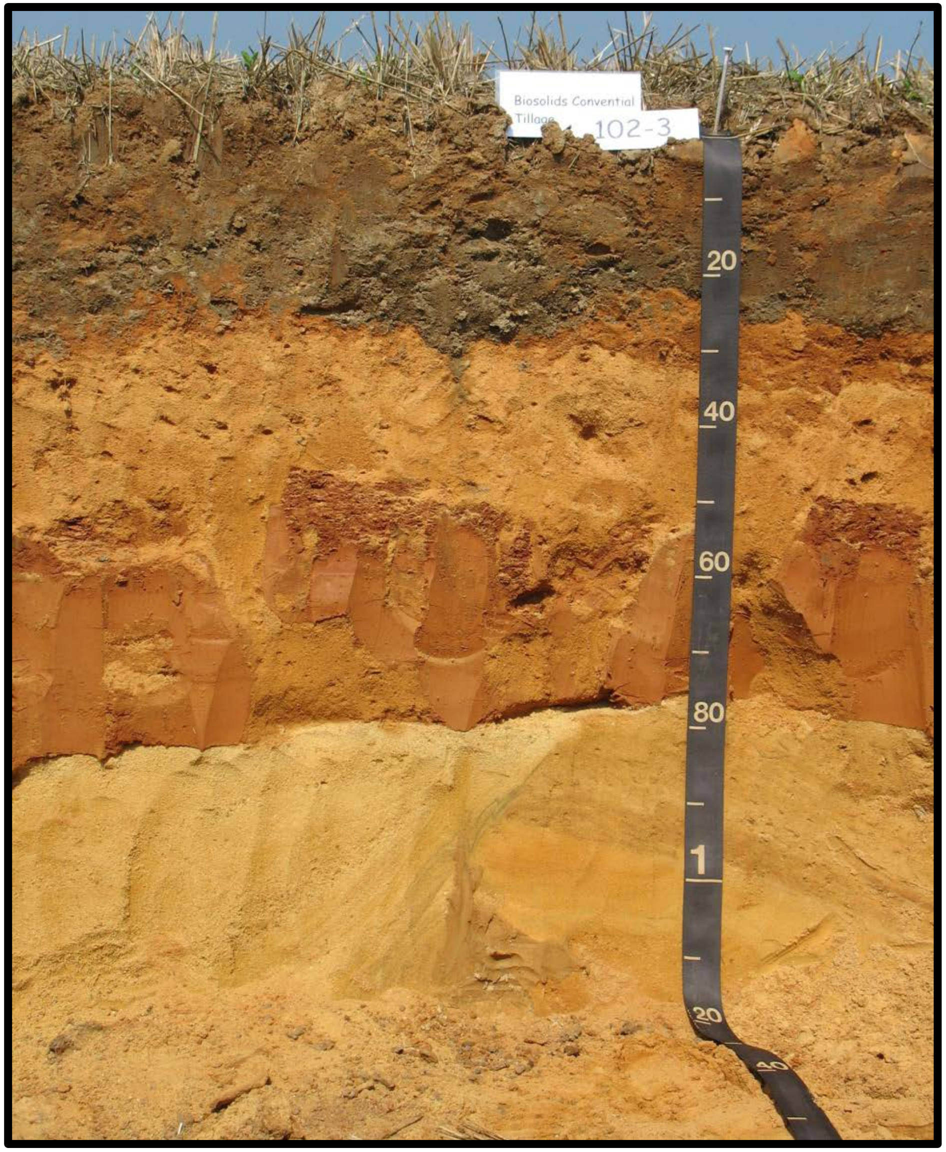
Bulk density cores, 3 reps collected from:

- Ap horizon
- directly below Ap horizon
- ~50cm

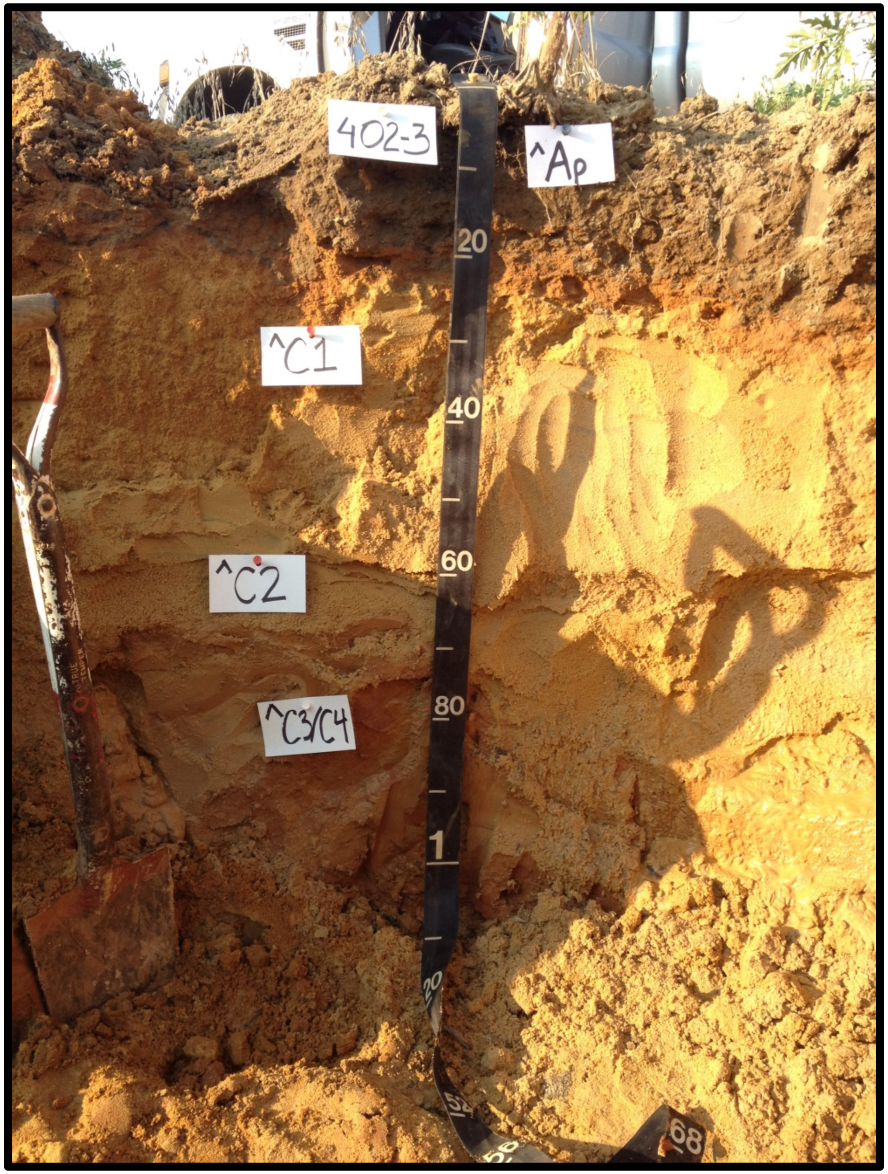
Biosolids no till: 2006 (left) vs 2014 (right)



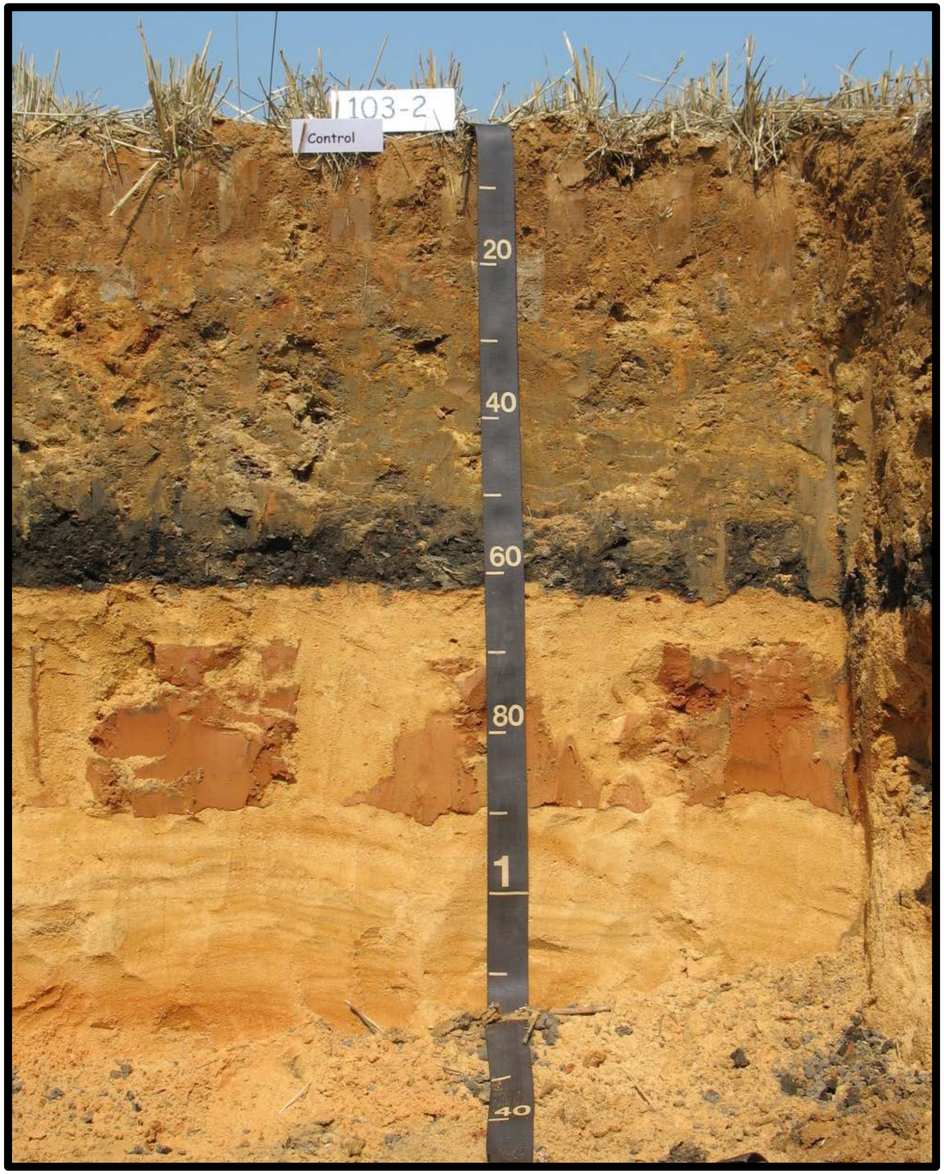
Biosolids conventional till: 2006 (left) vs 2014 (right)



Topsoil: 2006 (left) vs 2014 (right)



Control: 2006 (left) vs 2014 (right)



pH

No lime additions since 2005

pH in the Ap horizons decreased from 2006 to 2014

Treatment	2006	2014
LBS-NT	7.76[a-a]	6.78[ab-b]
LBS-CT	7.78[a-a]	7.00[a-b]
TOPSOIL	7.11[b-a]	6.49[bc-b]
CONTROL	7.20[b-a]	6.24[c-a]

Black superscript indicates significant differences among treatments per year
Red superscript indicates significant differences per treatment over time

pH in subsoil horizons did not show significant change

2006: 4.68 – 7.68 (med. = 5.21, avg = 5.50)

2014: 4.76 – 7.63 (med. = 5.42, avg = 5.75)

Bulk density – Ap

Treatment	2006	2014
LBS-NT	1.46$^{a\text{-}a}$	1.12$^{a\text{-}b}$
LBS-CT	1.65$^{a\text{-}a}$	1.35$^{a\text{-}b}$
TOPSOIL	1.71$^{a\text{-}a}$	1.25$^{a\text{-}b}$
CONTROL	1.64$^{a\text{-}a}$	1.19$^{a\text{-}b}$

Bulk density was not significantly different across treatments for either year.

All treatments had a significant decrease in bulk density over time.

<u>Bulk density – below Ap</u>

Treatment	2006	2014
LBS-NT	1.79[a-a]	1.44[a-b]
LBS-CT	1.88[a-a]	1.54[a-b]
TOPSOIL	1.94[a-a]	1.49[a-b]
CONTROL	1.81[a-a]	1.50[a-b]

Bulk density was not significantly different across treatments for either year.

All treatments had a significant decrease in bulk density over time.

Bulk density – 50cm

Treatment	2006	2014
LBS-NT	1.71[a-a]	1.31[a-b]
LBS-CT	1.74[a-a]	1.37[a-b]
TOPSOIL	1.75[a-a]	1.39[a-b]
CONTROL	1.68[a-a]	1.41[a-b]

Bulk density was not significantly different across treatments for either year.

All treatments had a significant decrease in bulk density over time.

Total-C (%) - Ap

The CONTROL treatment was significantly lower than other treatments in 2006.
Total-C increased for all treatments with time.

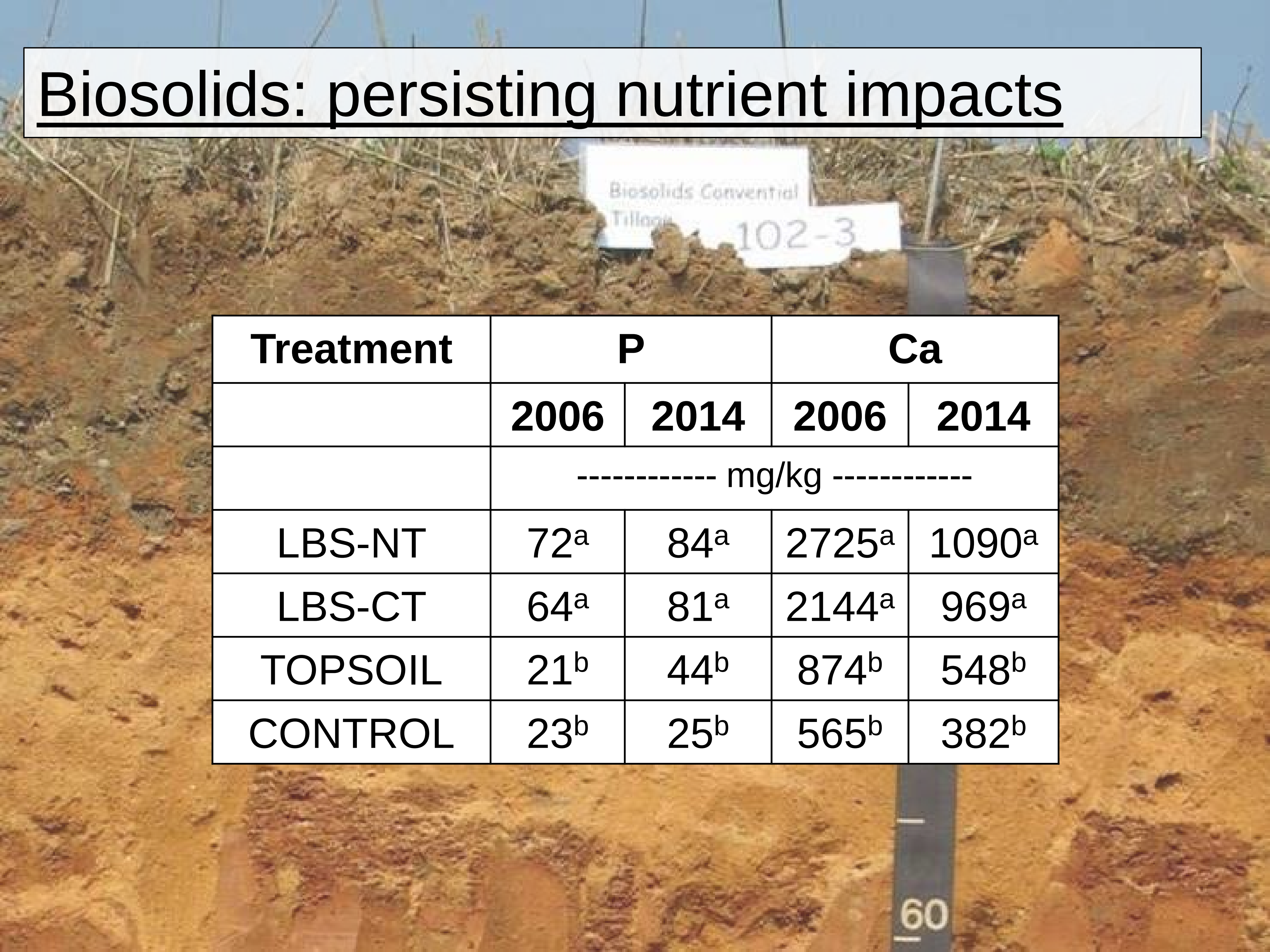
Treatment	2006	2014
LBS-NT	0.82^{a}	1.01^{a}
LBS-CT	0.66^{ab}	0.74^{a}
TOPSOIL	0.73^{ab}	0.89^{a}
CONTROL	0.39^{b}	0.72^{a}

Total-N (%)

Significant differences were not observed among treatments in a given year or over time.

Treatment	2006	2014
LBS-NT	0.12	0.09
LBS-CT	0.17	0.07
TOPSOIL	0.07	0.07
CONTROL	0.07	0.06

Biosolids: persisting nutrient impacts



Treatment	P		Ca	
	2006	**2014**	**2006**	**2014**
	------------ mg/kg ------------			
LBS-NT	72[a]	84[a]	2725[a]	1090[a]
LBS-CT	64[a]	81[a]	2144[a]	969[a]
TOPSOIL	21[b]	44[b]	874[b]	548[b]
CONTROL	23[b]	25[b]	565[b]	382[b]

Rooting

No significant differences in rooting depth across treatments for either year or over time

Depth (cm) of rooting

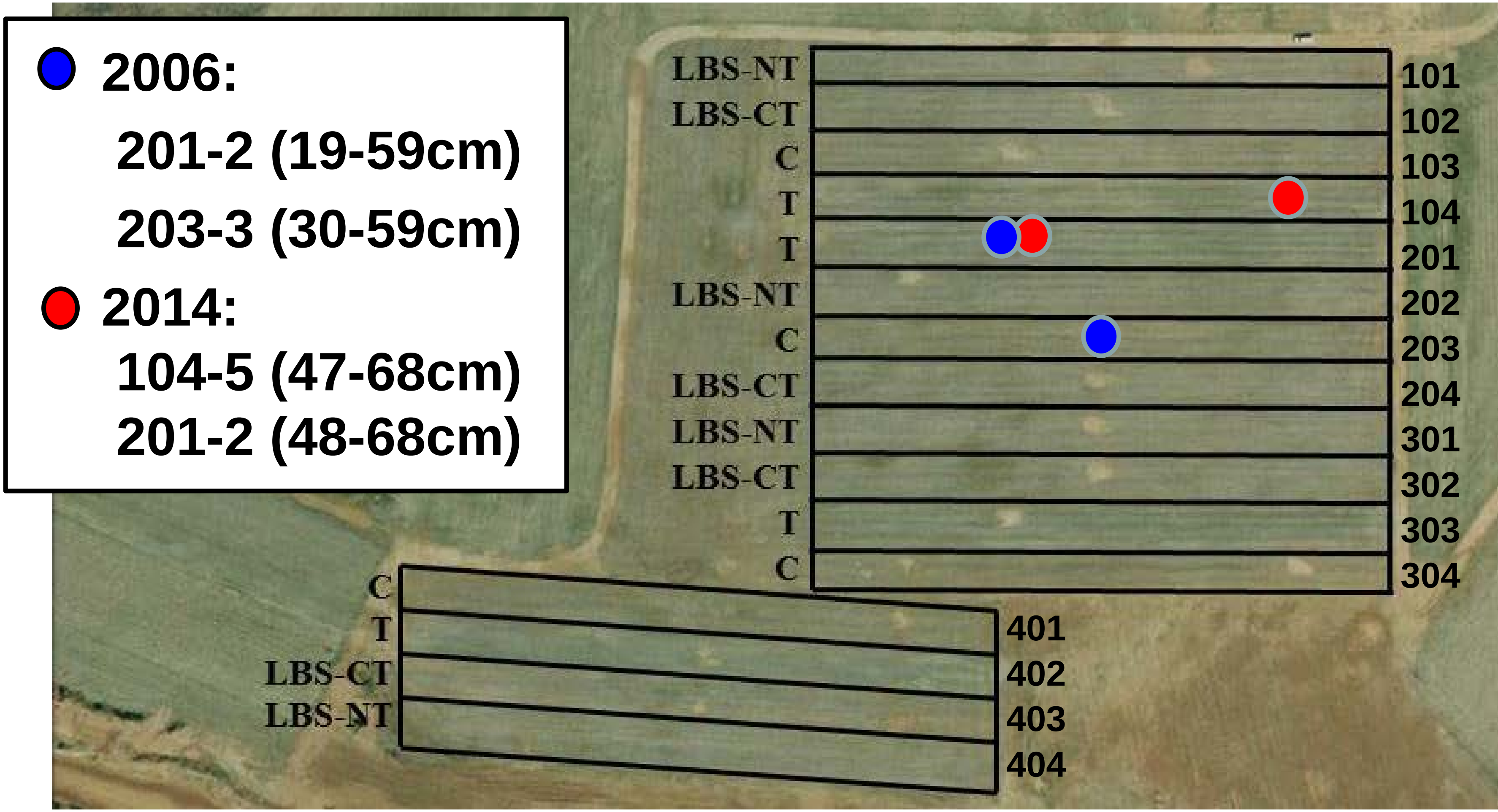
Treatment	2006	2014
LBS-NT	63	69
LBS-CT	66	59
TOPSOIL	45	64
CONTROL	57	49

Root counts increased from 2006 to 2014, particularly through the surface layers.

Root masses along desiccation cracks were commonly observed in 2006 and 2014.

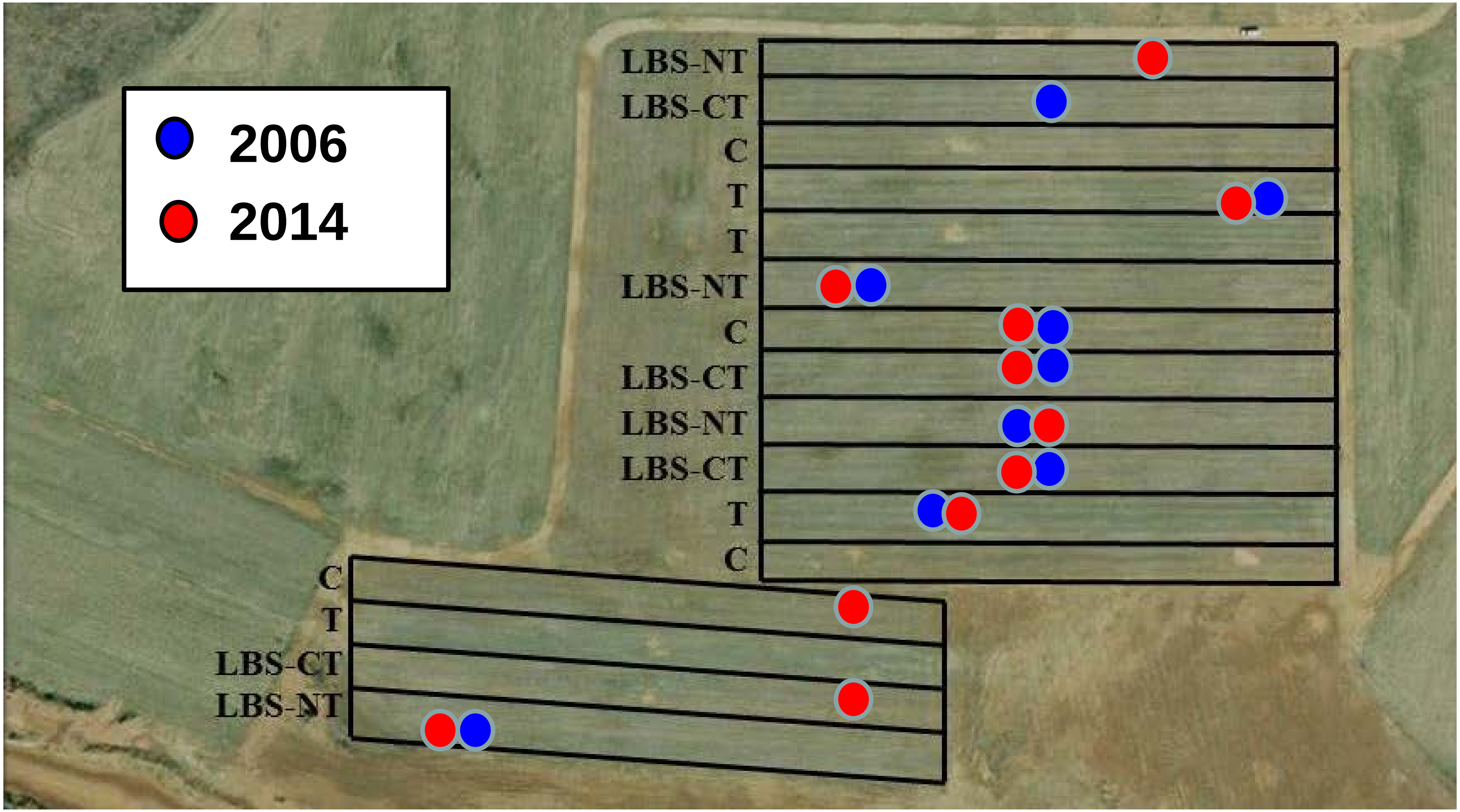
Rooting commonly stopped abruptly above sand layers.

Densic materials



No major changes in presence of densic materials from 2006 – 2014. Densic materials observed in 2006 were thicker than in 2014 (30-50cm vs 20cm), and shallower.

Bw horizons



No major changes in presence of Bw horizons from 2006 – 2014.

Corn yields

	2005	2007	2011	2013
Treatment	------------ Mg ha^{-1} ------------			
LBS-NT	10.90c	3.43a	4.75a	12.99a
LBS-CT	10.85c[†]	3.62a	4.77a	13.03a
TOPSOIL	3.79a	7.23b	4.13a	12.24a
CONTROL	8.53b	7.30b	5.30a	11.87a
UNMINED	14.30d	9.91c	12.48b	16.01b
Dinwiddie Co.	6.7	3.9	4.8	9.9

[†]Means in the same column followed by the same letter are not significantly different ($p<0.05$)

- 2005: unexpected low TOPSOIL yields were due to relatively low pH and P, crusting at surface that inhibited seedling growth, and compaction which occurred during topsoil return.
- 2007: low yields due to very hot, dry conditions AND severe N deficiency in the LBS plots (LBS plots did not receive N additions).
- 2011: low yields from mine soils due to excessive moisture and denitrification
- 2011 + 2013: no significant difference among mined treatments; CONTROL and TOPSOIL improved by chiseling and ripping

Wheat yields

	2006	2008	2010	2012
Treatment	Mg ha^{-1}			
LBS-NT	5.16b	5.65c	2.76a	3.20a
LBS-CT	5.04b	5.97c	2.74a	3.17a
TOPSOIL	4.29a	4.89b	2.68a	3.18a
CONTROL	4.10a	4.64b	2.51a	3.11a
UNMINED	6.90c	3.90a	4.72b	4.45b
Dinwiddie Co.	3.76	4.90	3.27	4.51

[†]Means in the same column followed by the same letter are not significantly different ($p<0.05$)

- 2008: low UNMINED yield due to interference of bulky corn residue with the planter.
- 2010: yields low due to very dry/hot conditions.

Soybean yields

	2008	2010	2012
Treatment	Mg ha^{-1}		
LBS-NT	2.51b	1.11a	2.45c
LBS-CT	2.24ab	0.96a	2.59c
TOPSOIL	2.20ab	1.15a	2.51c
CONTROL	2.11a	1.10a	2.34b
UNMINED	3.20c	1.73b	2.21a
Dinwiddie Co.	1.75	1.01	2.51

†Means in the same column followed by the same letter are not significantly different ($p<0.05$)

- 2010: Low yields due to hot/dry conditions and seeding problems related to recent re-grading of depressions throughout the plots.

Conclusions

- **For all treatments annual ripping and chisel plowing helped reduce compaction issues typically found in these soils.**
- **Total-C increased over time for all treatments.**
- **Improved soil conditions increased abundance of roots through the surface soil for all treatments.**
- **Persisting effects of lime-stabilized biosolids included high pH, Ca, and P.**
- **Lime-stabilized biosolids initially produced significantly higher crop yields, but over time differences among treatments became less apparent.**
- **According to the farmer “we did the right thing”.**

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