Dynamic soil property change in response to disturbance from conventional/unconventional gas drilling infrastructure in Pennsylvania

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Introduction

Pennsylvania's landscapes have undergone extensive oil and gas development for over 150 years. The recent discovery and development of unconventional shale-gas reserves suggests extensive additional disturbance across the state is possible. Development of gas drilling infrastructure including well pads, gathering lines, frac ponds, roads, and staging areas has the potential to alter dynamic soil properties (DSP), which are soil properties documented to change with disturbance over time. Soil bulk density (BD) and penetration resistance are DSPs of interest as indicators of soil compaction after disturbance. The rocky soils often encountered in Pennsylvania's gas region make measuring BD with traditional methods difficult.

Objectives

1. Determine the effect of gas drilling disturbance on soil bulk density
2. Compare disturbance effects of conventional vs. unconventional gas infrastructure
3. Evaluate the use of nuclear density gauges to monitor soil compaction

Materials and Methods

Field Sites

- Conventional gas infrastructure
  - 12 pads with disturbance dating back to at least 1930
  - 5 pads with no disturbance prior to 1980
    - Historical aerial photography (PennPilot) used to identify approximate disturbance date (hard to verify)
- Unconventional (hydraulically fractured) shale-gas infrastructure
  - 1 pipeline constructed in 2011

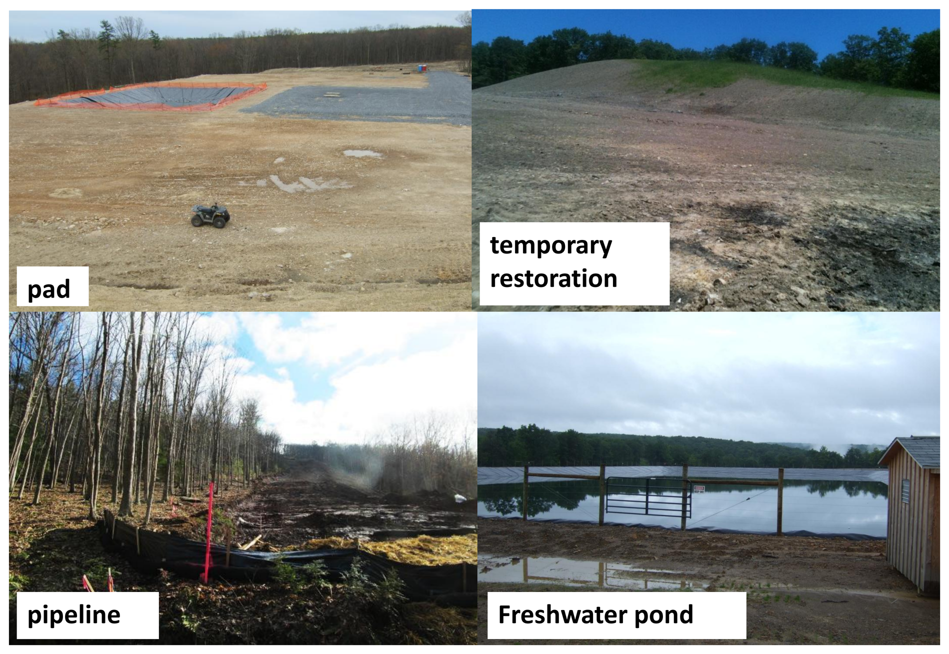


Figure 3. Unconventional shale-gas infrastructure

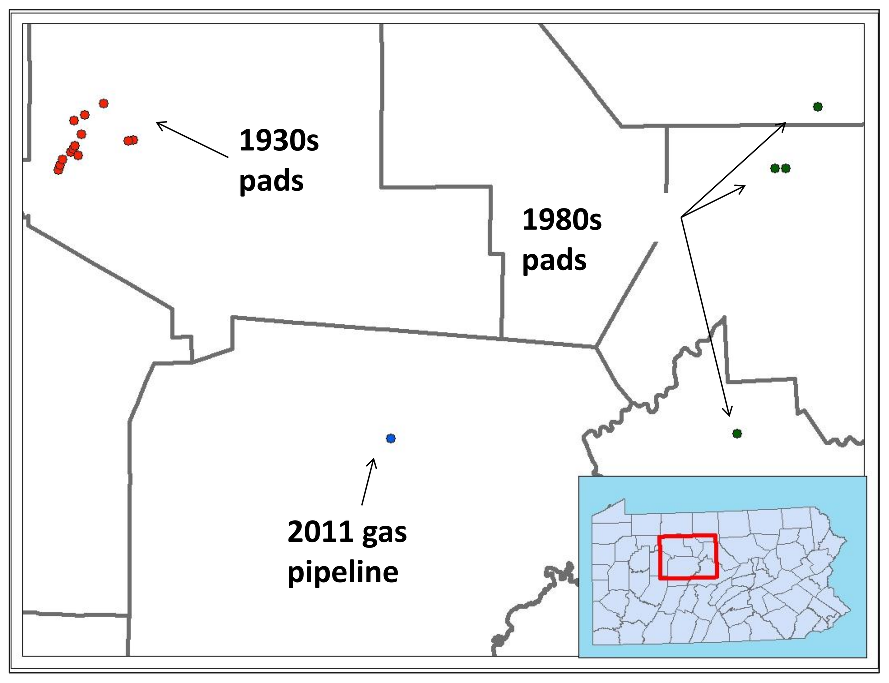


Figure 1. Location of research sites in Pennsylvania

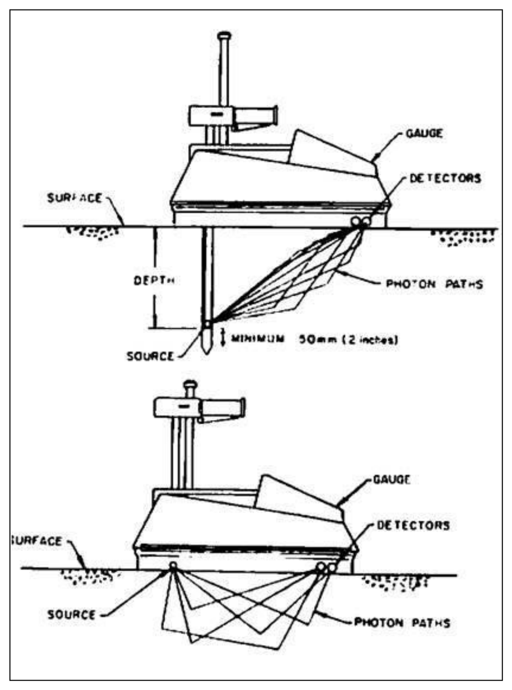


Figure 2. Direct transmission (top) and backscatter geometries (bottom) for nuclear density gauge. (Troxler Electronic Laboratories, Inc.)

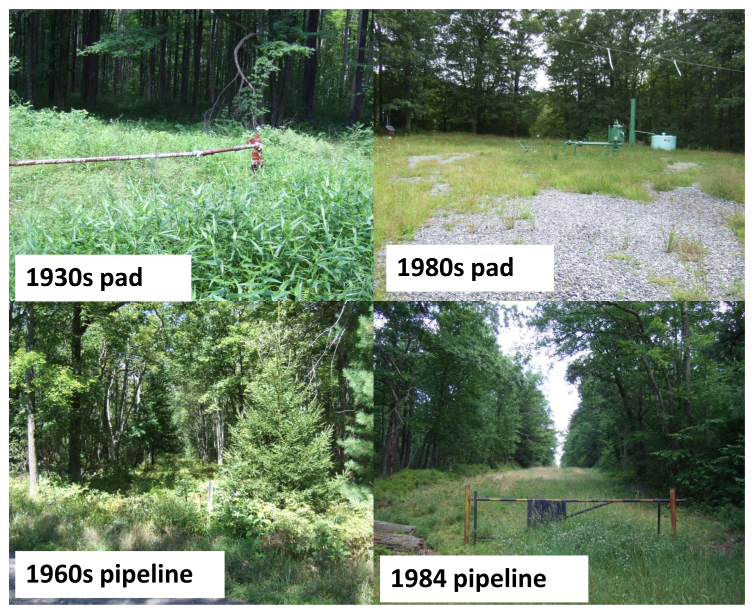


Figure 4. Conventional gas infrastructure

Data Collection

- Dry density was measured with a Troxler Moisture Density Gauge (Model 3411-B) at three random spots on the disturbed (D) and adjacent undisturbed forest (NF) soils. Readings were taken at the soil surface and 8" depth in backscatter and direct transmission modes, respectively. Dry density is reported as an average of the material between the source rod and the gauge base, including rock fragments and organic material.
- Soil bulk density values were obtained using the core method (Soil Survey Staff, 2004); a random hand excavated pit on the D and NF soils was described to 40cm and three 2"x2" core samples were taken from the 1st and 2nd master horizons.
- Penetration resistance was measured on the D and NF soils at 10 regularly spaced intervals along a 30m transect. A dynamic cone penetrometer was driven to depths of 5cm, 10cm, and 15cm; number of drops with a 2kg slide hammer was converted to total kinetic energy. Surface measurements of unconfined compressive strength were taken with a pocket penetrometer.

		Mean Dry Density (g/cm³) BS	8in
1930s pads	**Disturbed (D)**	0.94	1.34
	Forest (NF)	0.80	1.06
	p-value	0.040	<0.001
1980s pads	**Disturbed (D)**	1.10	1.52
	Forest (NF)	0.93	1.21
	p-value	0.125	0.002

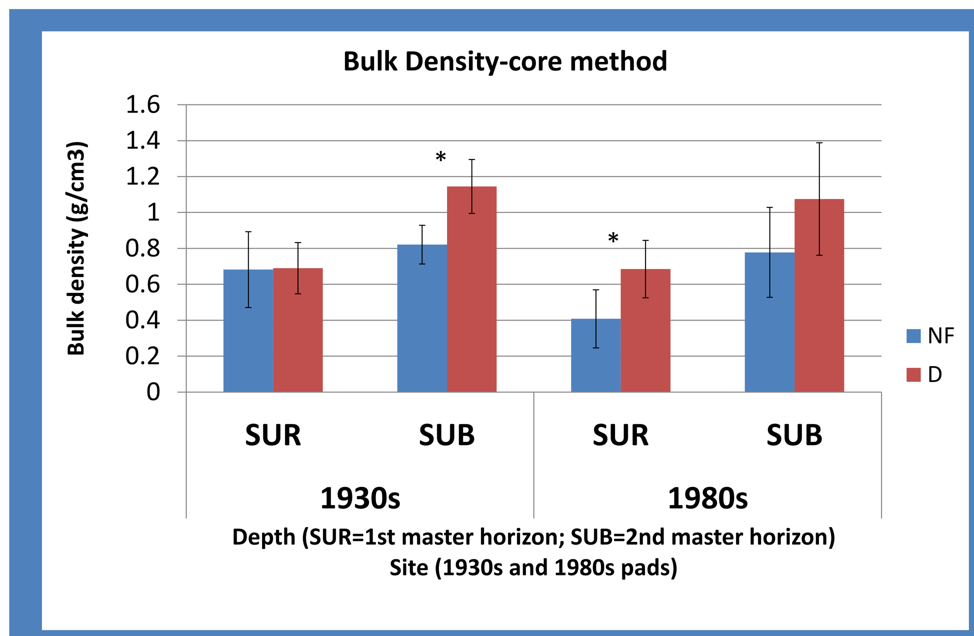
Soil Texture	Ideal Bulk densities	Bulk densities that may afffect root growth	Bulk densities that restrict root growth
	g/cm3	g/cm3	g/cm3
Sands, loamy sands	<1.60	1.69	1.8
Sandy loams, loams	<1.40	1.63	1.8
Sandy clay loams, loams, clay loams	<1.40	1.6	1.75
Slilt, silt loams	<1.30	1.6	1.75
Silt loams, silty clay loams	<1.10	1.55	1.65
Sandy clays, silty clays, some clay loams (35-45% clay)	<1.10	1.49	1.58
Clays (>45% clay)	<1.10	1.39	1.47

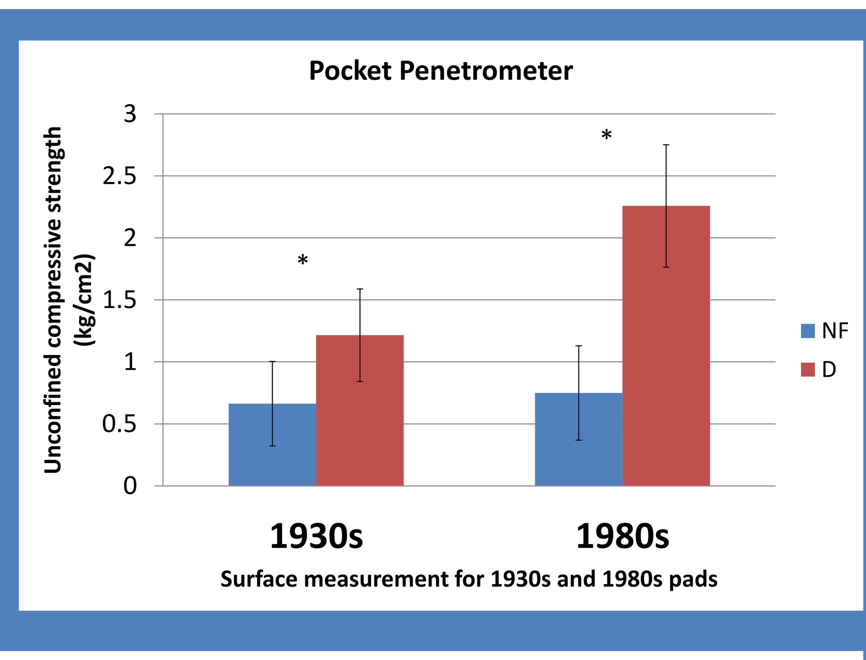
Source: Protecting Urban Soil Quality, USDA-NRCS

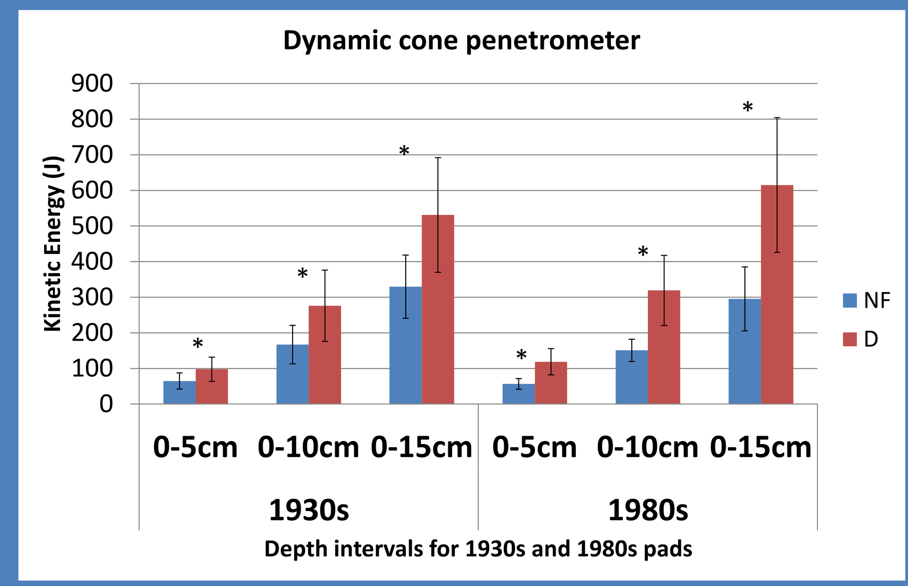
Figure 7. Pennsylvania Stormwater Best Management Practices Manual BMP 6.7.3: Soil Amendment & Restoration

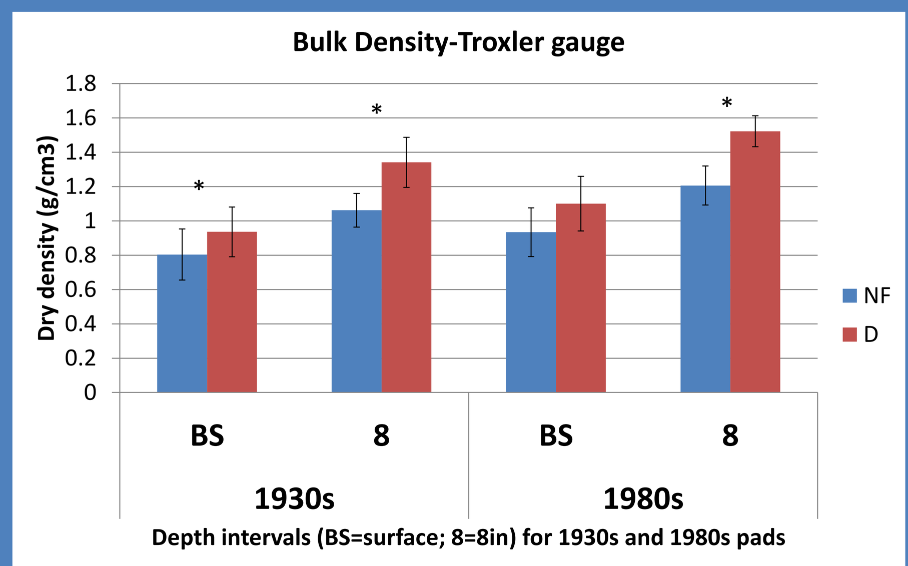
Results

Conventional gas sites



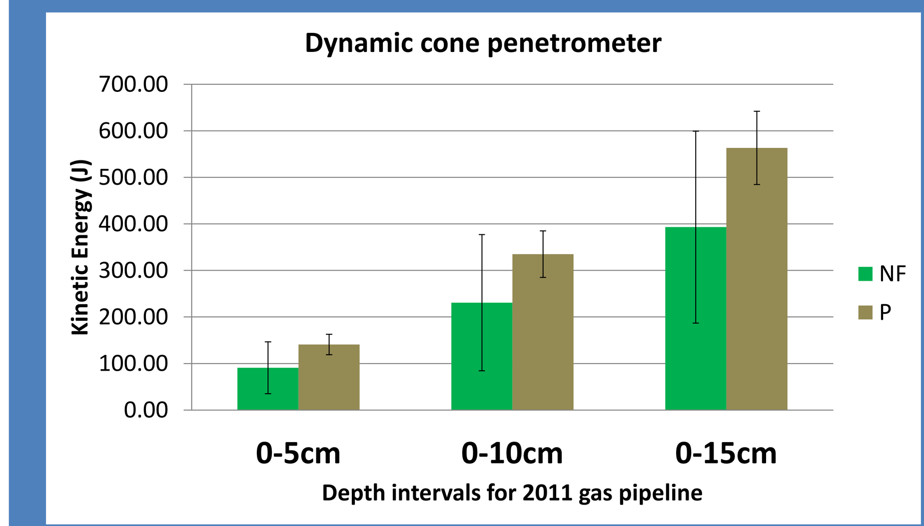


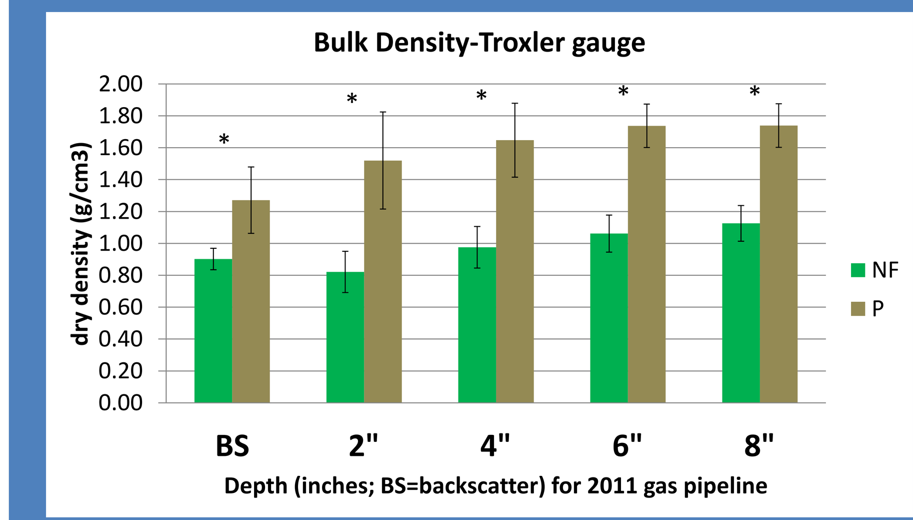




Figures 5a-5d. DSP data for conventional gas sites (* indicates significance at alpha=0.05; NF=native forest; D=disturbed) **a.)** Bulk density from core method **b.)** pocket pentrometer **c.)** dynamic cone penetrometer **d.)** dry density from Troxler gauge

Unconventional shale-gas site





Figures 6a-6b. DSP data for unconventional shale-gas site (* indicates significance at alpha=0.05; NF=native forest; P=pipline **a.)** dynamic cone penetrometer **b.)** dry density from Troxler gauge

2011 pipeline	Mean Dry Density (g/cm³) BS	2in	4in	6in	8in
Pipeline (P)	1.3	1.52	1.65	1.74	1.74
Forest (NF)	0.9	0.82	0.97	1.1	1.13
p-value	0.003	<0.001	<0.001	<0.001	<0.001

Future Work

- Measure additional DSPs (carbon, nitrogen, phosphorus, penetration resistance, and soil wetness) on gas disturbance sites
- Develop a model to predict problem soil areas for shale-gas development

Conclusions

- The BD core method proved unreliable on the rocky soils encountered. The nuclear density gauge, while only capable of reporting a depth averaged value, is an effective indicator of compaction and takes less than 5 min. per sample
- The 1930s and 1980s conventional gas sites have significantly higher dry density and penetration resistance on the disturbed compared to the forested soil.
- Dry density on the 2011 gas pipeline was significantly higher than the forested soil. Compared to the conventional pads, the pipeline had higher density values, with those at 4", 6", and 8" potentially restricting to root growth
- The differences in BD between the conventional and unconventional sites may be attributed to variances in the size of the operation and type of equipment used. Time may also influence recovery of soil BD; this factor is unclear as the exact disturbance dates of the sites in the study is hard to verify