ON THE GROUND: TROUBLE SHOOTING SOIL AND CROP PRODUCTIVITY

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Overview

Optimizing agricultural productivity entails the purposeful and expert manipulation of physical, chemical and biological factors in the crop-soil-atmosphere realm using sound principles of land husbandry. When the supply of soil air, water, or mineral nutrition cannot satisfy the demands of crop metabolism, yield potential is discounted generally according to the law of the minimum wherein the most limiting essential factor prevails until the final *n*th factor has been removed. Signs of deficiency may be exhibited via plant stunting, diurnal wilting, leaf discoloration, increased insect and disease pressure, and low product quality and yield. Identifying growth-limiting factors requires measuring critical soil and plant index properties. Results from such tests may reveal inherent soil limitations or indicate changes to existing cropping practices to sustain long term productivity.

Objectives

This 8-week project introduced agriculture interns at the Center for Environmental Farming Systems, Goldsboro, NC to the art and science agronomic problem solving. Working ensemble as a team, interns were given to: (1) develop an ability to observe, identify, and differentiate visual indicators of crop health and productivity; (2) acquire skill measuring soil and plant properties and interpretation; and (3) draw conclusions and make recommendations based on collective soil-plant-environmental data.

This investigation focused on several non-contiguous areas of poor crop growth in the SARE long-term cropping systems crop-animal rotation plot # 20 (Figure 1). Symptoms of stunting, yellowing, acute toxicity, or mortality had been evident in corn and cotton over the past two seasons with no explanation (Figure 2).

The team's objectives were three-fold:

- Identify growth-limiting factors in SARE crop animal rotation plot #20.
- Make specific recommendations to overcome these limitations.
- Propose soil-crop management strategies to enhance long-term productivity.

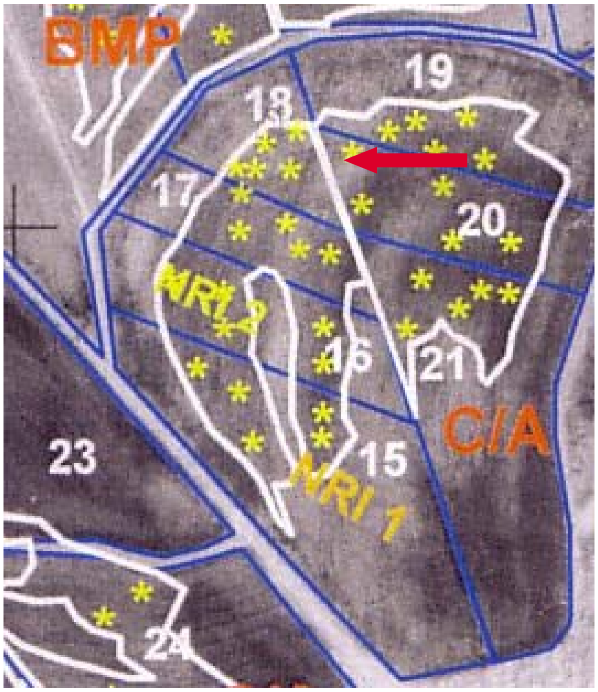

Figure 1. SARE crop/animal (C/A) plot 20. Red arrow points to approximate study location.

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Figure 2. Ground view of the problem site (Pr site) where this investigation was conducted. Photo shows a progression of crop symptoms from plant mortality (foreground), stunting and discoloration (middle), to healthy corn (background).

Methods

Site Description

Information about the site physical setting, as well as present and past agronomic practices, is essential for providing a backdrop prior to initiating an investigation. Therefore, interns were asked to retrieve information about the study site using published USDA Soil Surveys and existing farm records. This is summarized in Table 1.

Sampling

We used the method of paired sampling to troubleshoot the problem. Representative soil samples were collected in pairs from the problem site (Pr site) and from one healthy, non-problem site (non-Pr site) in SARE crop-animal rotation plot 20 (CAR-20). Within each sample site, two row positions were evaluated: (1) non-traffic, approximately 15 cm from the plant row; and (2) trafficked interrow. A total of twelve soil cores were collected from both row positions. A custom drive hammer tool fabricated to accept a standard 3.2 cm diameter steel Giddings drive tube was used to recover undisturbed soil cores down to 45 cm deep (Figure 3). Cores were sectioned in 0-15 cm, 15-30 cm, and 30-45 cm increments and composited. For each depth increment, sub-samples were reserved for chemical and biological testing. Soil physical properties were measured at both sites and at each of two row positions to 15 cm deep. Subsurface soil samples were collected manually by boring 150 cm deep using a 7.62 cm diameter steel bucket auger. The soil's surficial and subsurface physical characteristics were examined and described. In addition, twelve corn leaf samples composed of the most recently matured (MRM) leaf were harvested and submitted to the North Carolina Department of Agriculture (NCDA) for nutrient analysis.

Table 1. Site description

Location	SARE long-term crop/animal rotation treatment plot 20
Landowner	North Carolina Department of Agriculture & Consumer Services Center for Environmental Farming Systems, Cherry Farm Research Unit Goldsboro, Wayne County, NC

Physiographic Province	Coastal Plain
Physiographic Area	Neuse river basin

Topographic Orientation
Elevation: < 25 m
Slope per cent: < 1.0
Slope aspect: 317° NW
Slope shape: linear convex
Profile position: shoulder

Soil Information
Soil series: Tarboro sandy loam
Top soil depth: 20 cm
Soil depth: > 1.5 m
Drainage class: very well to excessively well drained

Agronomic Management
Present crop: corn DK 657
Rotation: corn/sweet potato/cotton
Nutrient inputs: 10-34-0 @ planting; 30% UAN @ lay by
Current season soil amendments: none
Herbicides: metolachlor + atrazine (Bicep) - pre; ametryn (Evik) - post directed
Insecticides: chlorpyrifos (Lorsban 15G) @ planting
Tillage: no-till corn/strip till cotton/conventional bedded sweet potato
Cover crop: rye

Analysis

Soil samples from the non-traffic position were submitted to the NCDA laboratory for diagnostic testing and nematode assay. Soil pH, soluble salts (EC) and mineral nitrate-nitrogen (NO_3^- -N) were determined on site using an Orion model 290A pH meter, Hanna Instruments DiST 4 dissolved solids tester, and semi-quantitative Aqua-Check colorimetric nitrate test strips, respectively (Figure 4). In addition, soil NO_3^- -N was determined quantitatively in the laboratory by extracting with 1 molar concentration potassium chloride. The extractant was then analyzed using a Lachat Quick Chem 8000 flow injection analyzer.

Soil bulk density was determined with an Uhland drive hammer, receiving tube and core assembly (Figure 5). Derived physical indicators such as porosity and water-filled pore space were obtained by standardized equations using bulk density values (Table 5).

Visual descriptors of soil physical characteristics were reported following the Munsell Soil Color Charts system (2000 edition) and the National Soil Survey Center's Field Book for Describing and Sampling Soils version 1.1 (Natural Resources Conservation Service. Lincoln, Nebraska 1998).

Figure 3. Sampling 45 cm deep using a custom drive hammer and steel tube. Obtaining a representative sample is critical for precision diagnostic inference.

Figure 4. Measurement of pH and soluble salts can be determined quickly in the field.

Figure 5. Interns learned to measure soil bulk density and interpret the results. Information derived from bulk density provides insight about physical conditions in the crop rooting zone with respect to the entry and transfer of air, moisture, and heat.

Results

Since solution pH exerts a profound influence on soil chemistry, this was one of the first tests we conducted on site. The acute acidity problem was detected immediately: measured soil reaction was pH 4.5 to 4.6 in the surface 15 cm through 30 cm deep at the Pr site (Table 2). Low base saturation, 29%, associated with high acidity, was also detected in the surface 30 cm. The target pH for mineral soils in North Carolina is 6.0. As pH drops below 5.0 the quantity of soluble trivalent aluminum (Al^{+3}) increases dramatically in the soil solution. Many agronomically important crops are sensitive to Al^{+3} even in low concentrations, while elevated Al^{+3} limits root growth as well as nutrient absorption. Available soil manganese (Mn^{+2}) was very high at both sample sites because manganese solubility also increases at low pH (Table 3). Manganese is a plant-essential micronutrient, but high Mn concentration can also induce toxicity. Given that Al^{+3} was probably present and Mn^{+2} concentration in the soil solution was also high, it is questionable how well corn roots were functioning.

Table 2. Soil chemical characterization of the untrafficked interrow.

Depth (cm)	pH (H_2O)		CEC (meq/100³)		Base saturation (%)		EC (ds/m)		NO_3^- - N (ppm)	
	Pr site	Non-Pr site	Pr site	Non-Pr site	Pr site	Non-Pr site	Pr site	Non-Pr site	Pr site	Non-Pr site
0-15	4.5	5.1	2.1	3.1	29	55	0.14	0.08	15.5	6.9
15-30	4.6	5.2	1.7	2.6	29	58	0.11	0.05	4.2	2.8
30-45	5.0	5.3	2.0	2.8	60	71	0.12	0.10	7.5	5.2

Table 3. NCDA soil nutrient analysis.

Nutrient (ppm)	Depth (cm)	Pr site	Sufficiency rating	Non-Pr site	Sufficiency rating
Phosphorus (P)	0-15	239	V. high	220	V. high
	15-30	161	V. high	113	High
	30-45	62	High	28	Low
Potassium (K)	0-15	86	Medium	152	High
	15-30	88	Medium	152	High
	30-45	149	High	152	High
Calcium (Ca)	0-15	58	Low	205	Medium
	15-30	44	Low	166	Medium
	30-45	116	Medium	224	Medium
Magnesium (Mg)	0-15	10	Low	30	Low
	15-30	7	Low	37	Medium
	30-45	26	Low	54	Medium
Sulfur (S)	0-15	1.4	Medium	1.3	Medium
	15-30	1.2	Medium	1.2	Medium
	30-45	0.84	Low	2.2	Medium
Manganese (Mn)	0-15	28	V. high	50	V. high
	15-30	48	V. high	42	V. high
	30-45	41	V. high	33	V. high
Zinc (Zn)	0-15	1.3	Medium	2.5	Medium
	15-30	1.1	Medium	1.8	Medium
	30-45	2.0	Medium	0.68	Low
Copper (Cu)	0-15	1.1	Medium	1.1	Medium
	15-30	1.1	Medium	1.0	Medium
	30-45	1.2	Medium	1.0	Medium

Cation exchange capacity (CEC: Table 2) was low, but this is normal for sandy southeastern Atlantic Coastal Plain soils.

Soluble salts and NO_3^- –N were nearly two-fold greater at the Pr site compared with the non-Pr site (Table 2). These results agree with our understanding of the relationship between fertilizer N uptake and soil acidity. Accumulation of soil mineral NO_3^- –N in the surface 15 cm provides further evidence of reduced root zone N uptake by plants growing in acid, high Mn^{+2} and Al^{+3} soil. As apparent in Table 2, soil pH and base saturation were low at the non-Pr site but these problems were less severe relative to the Pr site. Consequently, soils at both sampling sites in CAR-20 were found low in calcium (Ca) and magnesium (Mg). Sulfur (S) was also marginal at both sites (Table 3). Deficiencies of Ca, Mg, S, coupled with excessive levels of leaf tissue Mn were mainly responsible for the visual symptoms of plant stunting, yellowing, and inter-veinal chlorosis apparent at the Pr site (Figure 6).

Table 4. Comparison of the critical range for corn leaf tissue nutrient concentrations in the most recently matured (MRM) leaf.

	Critical range	MRM tissue analysis			
Nutrient	MRM leaf	Pr site	Comment	Non-Pr site	Comment
— % —					
Nitrogen	3.0 - 4.0	4.07	High	3.48	Sufficient
Phosphorus	0.30 - 0.50	0.30	Sufficient	0.21	Low
Potassium	2.0 - 3.0	2.61	Sufficient	1.57	Low
Calcium	0.25 - 0.80	0.23	Low	0.27	Sufficient
Magnesium	0.15 - 0.60	0.07*	Deficient	0.08*	Deficient
Sulfur	0.15 - 0.40	0.09*	Deficient	0.12	Low
	— ppm —				
Boron	5 - 25	8.4	Sufficient	6.8	Sufficient
Copper	5 - 25	5.6	Sufficient	8.1	Sufficient
Iron	30 - 250	83.7	Sufficient	79.5	Sufficient
Manganese	20 - 150	287 (528)**	Excessive	52.1	Sufficient
Zinc	20 - 70	60.3	Sufficient	38.8	Sufficient

* Most limiting

** Number in parentheses is corn leaf tissue Mn concentration two weeks after initial sampling

Figure 6. Corn plant showing symptoms of yellowing and inter-veinal chlorosis associated with nutrient deficiencies of Mg and S.

Plant stunting and yellowing are classic symptoms of 'acid soil infertility'. On the other hand, symptoms of acute toxicity and/or plant mortality at the Pr site were probably due to contact with the post-directed herbicide ametryn or 30% N solution, or both, applied at lay-by as corn plants were severely stunted at this point and, the foliage more susceptible to stray contact with agrochemicals. Nematode assay results were negative at both sites.

Manganese concentration in corn leaf tissue taken from the Pr site was very high and increased nearly two-fold after two weeks (Table 4). In acid soil, excessive manganese accumulation occurs through the root system which is toxic to the plant in high concentration. At first glance it may appear odd that corn leaf tissue N concentration was in the high range at the Pr site whereas test results show an accumulation of mineral NO_3^-–N in the surface 15 cm of soil. This apparent anomaly may be explained by the 'concentration effect' brought about by plant stress, particularly moisture, due to impaired root function as compared to healthy, unstressed and rapidly growing corn plants.

A comparison of semi-quantitative (Aqua-check) vs quantitative (flow injection analysis) estimates of NO_3^- –N in the surface 15 cm showed that the semi-quantitative method significantly underestimated soil NO_3^- –N at both field sites (Figure7). This points up the fact that soil test kits based on semi-quantitative tests for N, P, K and other nutrients may be useful indicators when accuracy is not critical but are inappropriate for diagnostic purposes.

Subsurface soil investigation via auger boring revealed a coarse- textured profile to 150 cm deep at the Pr site. In contrast, we found a distinct horizon of silt and clay enrichment 30-70 cm deep beneath the non-Pr site (Figures 8 and 9). Compact, fine textured soil horizons typically obstruct drainage and may explain the accelerated rate of leaching and acid pH at the Pr site compared with the non-Pr site. Furthermore, coarse textured, low organic matter soils have lower cation exchange capacity, limiting ability to capture and retain plant essential nutrient cations (Ca, Mg, K).

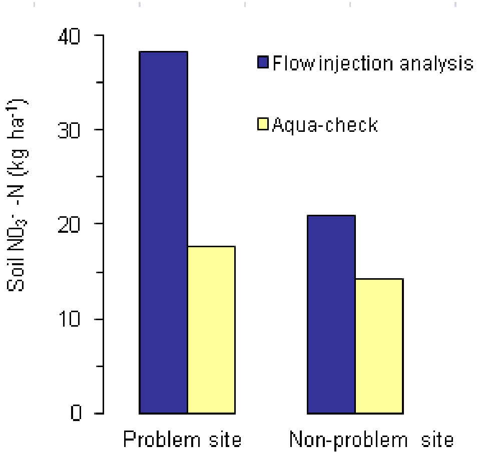

Figure 7. Comparison of quantitative (flow injection analysis) and semi-quantitative (Aqua-check) estimates of soil NO_3^- N in the surface 15 cm at two sampling sites.

Table 5. Soil physical properties.

		Pr site		Non-pr site	
Index	Depth (cm)	Non-traffic Inter-row	Trafficked Inter-row	Non-traffic Inter-row	Trafficked Inter-row
Bulk density	0 - 7.5	1.56	1.65	1.33	1.68
(g/cm^{-3})	7.5 - 15	1.67	1.69	1.84	1.66
Porosity	0 - 7.5	41.3	37.6	49.9	36.4
(%)	7.5 - 15	37.0	36.3	30.7	37.3
Water-filled pore space	0 - 7.5	38.9	53.6	44.0	68.3
(%)	7.5 - 15	47.7	54.7	14.7	57.8

Results from our subsurface investigations testify that soils can be quite variable in terms of their physical and chemical characteristics even though looking apparently identical at the surface. Abrupt changes in subsurface soil texture may occur over short distances even within the same diagnostic mapping unit. In this case, excessive leaching in a Tarboro loamy sand was the culprit leading to locally depressed pH at the Pr site. We noted several other locations within the CAR-20 unit where similar poor corn growth was apparent. We surmise that variability in subsurface texture is probably the causal factor in those areas as well.

Conclusion

Agronomic problem solving often involves consideration of many factors reaching beyond the obvious suspects of human error or natural coincidence. It would have been easy to conclude for instance, that symptoms of acute corn plant toxicity and/or mortality were the result of unintentional contact with herbicide and/or soluble fertilizer. However, we learned much more than this by digging deeper and leaving no stone unturned in our investigation. Using a multi-faceted approach gathering information about the site, soil (surface and subsurface), plant (shoots and roots) as well as prior management practices enables the investigator to troubleshoot agronomic problems with greater precision. It may also betray hidden facts about the total environment driving plant health and productivity.

Parent material: coastal plain alluvium
Moisture status: moist throughout profile
USDA taxonomic order: Entisol

Depth (cm)	Description
0 - 20	10YR 5/2 grayish brown very friable medium loamy sand (>80% sand) + few gravel (<1%); weak granular structure
20 - 38	10YR 5/6 yellowish brown very friable medium loamy sand (>80 sand) + few gravel (<1%); very weak medium granular structure
38 - 76	7.5YR 5/8 strong brown medium sand + few gravel (<2%); loose single grain structure
76 - 107	7.5YR 5/8 strong brown medium to coarse sand + gravel (~8%); loose single grain structure
107 - 150	7.5YR 5/8 strong brown to 10YR 6/6 brownish yellow medium to coarse sand + gravel (~20%); loose single grain structure

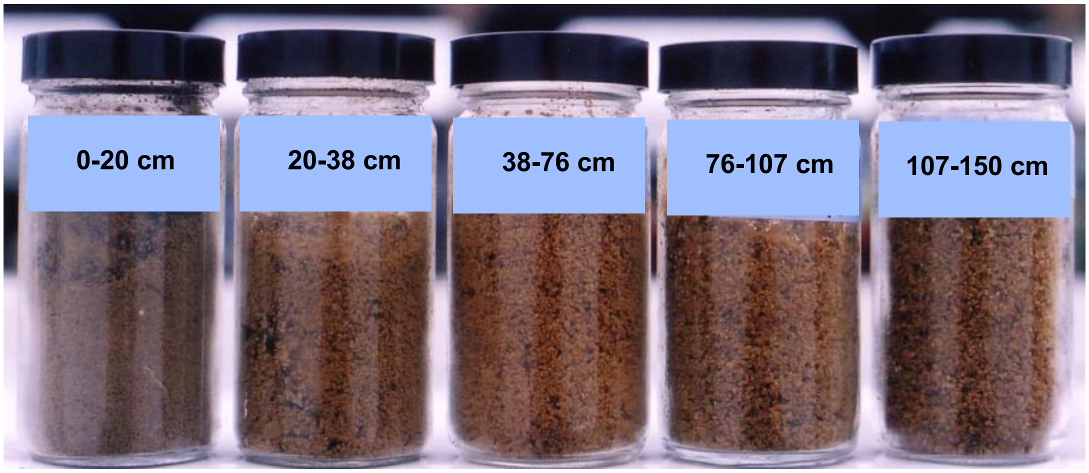

Figure 8. Soil samples recovered from 0-150 cm deep at the problem (Pr) site. Note the uniform course texture throughout the sampled profile in this Tarboro loamy sand.

Parent material: coastal plain alluvium
USDA taxonomic order: Entisol
Moisture status: moist throughout profile

Depth (cm)	Description
0 - 28	10YR 4/3 brown very friable medium to fine loamy sand; weak medium granular structure
28- 70	2.5YR 4/6 red firm silty clay loam; coarse moderate sub-angular blocky structure
70- 102	7.5YR 5/8 strong brown loose medium sand + few gravel (<1%); loose single grain structure
102-150	7.5YR 6/8 reddish yellow coarse sand + few gravel (~5%); loose single grain structure

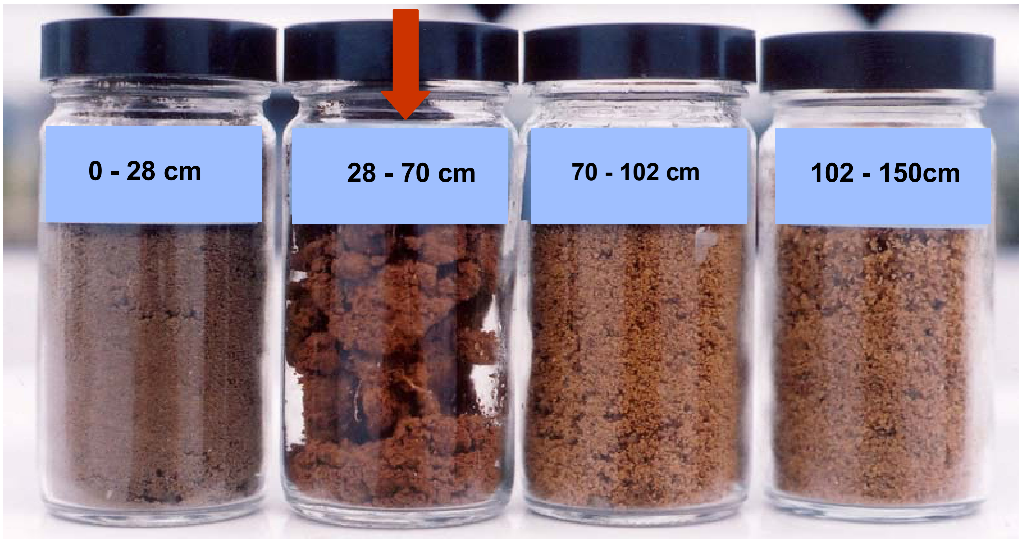

Figure 9. Soil samples recovered from 0-150 cm depth at the non-problem (non-Pr) site. Red arrow points to distinct firm silty clay loam horizon differentiating this soil from that found at the problem site. Contrasting soils in Figures 8 and 9 were proximate in the same mapping unit but have different subsurface characteristics.

Following are some recommendations and conclusions derived from this investigation.

- Overall, the soil in SARE CAR-20 unit is lime deficient. Since there would be little benefit correcting acid pH and available Ca and Mg in the current cropping season, soil samples from this plot should be submitted in fall to NCDA for recommendations aimed at improving these indicators in 2004 thereon.
- Tarboro loamy sands are very well to excessively well drained soils. Therefore, annual soil testing should be conducted to assess pH and nutrient levels. More frequent liming may be needed for Tarboro loamy sands than is presently practiced.
- Variable subsurface soil textures found in CAR-20 indicate that disjoint areas of poor growth may persist without precision management. This is the fundamental concern of variable-rate technology (VRT) emerging within the field of precision agriculture. However, precision management is not an option at this time as VRT has not been implemented on the farm. Coarse textured, very well to excessively well drained soils in the Coastal Plain of North Carolina have more limited nutrient and water holding capacity. A program integrating intensive cover crop use, returning crop residue, and increasing soil organic matter should conserve moisture while enhancing nutrient holding capacity.

Further Reading

Bennett, W.F., ed. 1993. *Nutrient Deficiencies and Toxicities in Crop Plants*. American Phytopathological Society. St Paul, Mn.
One of a series of excellent publications offered by the APS. This volume includes many photos of plant symptoms caused by biotic and abiotic factors.

Food and Agriculture Organization of the United Nations. 1984. *Fertilizer and Plant Nutrition Guide*. FAO Fertilizer and Plant Nutrition Bulletin No. 9. Food and Agriculture Organization. Rome, Italy.
Over the years the FAO has published many excellent technical bulletins that, unfortunately, have not seen a very wide distribution. This is one of them.

Sprague, P.F., ed. 1964. *Hunger Signs in Crops, 3rd ed.* David McKay and Company. New York, NY.
Originally published jointly by the American Society of Agronomy and the National Fertilizer Association in 1941, this out-of-print book is still one of the best in class.