On The Ground: Trouble shooting soil and crop productivity

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Overview

Maximizing crop productivity entails balancing the soil physical, chemical and biological environment following sound principles of land husbandry. When the supply of soil air, water, or nutrients is not in sympathy with crop metabolism the potential productivity of the soil and crop cannot be realized. Symptoms of an unbalanced soil system often are expressed visually by plant stunting, diurnal wilting, leaf discoloration, increased incidence of insects and disease and, lowered product quality and yield. Identifying growth-limiting factors requires measurement of critical soil index properties. Test results may reveal inherent soil limitations, or indicate changes needed in existing soil management practices to sustain long term productivity.

Objectives

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

The 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 death had been evident in corn and cotton over the past two seasons with no apparent explanation (Figure 2).

The team's objectives were three-fold:

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

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

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Methods

Site Description

Information about site physical aspects, as well as present and past agronomic management practices, is essential to provide a backdrop from which to initiate an investigation. Therefore, interns were asked to collect information about the study site using published USDA Soil Surveys and existing farm records, summarized in Table 1.

Sampling

We used the method of paired sampling to analyze the problem. Representative soil samples were obtained 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 site, two row positions were sampled: (1) non-traffic, approximately 15 cm from the plant row; and (2) trafficked interrow. A total of twelve soil cores were obtained from both row positions. A drive hammer adapted to a standard 3.2 cm diameter Giddings drive tube was used to recover undisturbed soil cores to a depth of 45 cm (Figure 3). Cores were sectioned in 0-15, 15-30, 30-45 cm depths and composited. For each depth increment, sub-samples were obtained for chemical analysis. Soil physical properties were measured at both sites and at each of two row positions to a depth of 15 cm. Sub-surface soil samples were obtained by boring to a depth of 150 cm using a 7.62 cm diameter bucket auger. Soil 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.

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

Table 1. Site description

Location SARE long-term crop/animal rotation treatment plot 20
Landowner NCDA-CS 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 loamy sand
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 input: 10-34-0 @ planting; 30% UAN @ lay by
Current season soil amendments: none
Herbicide input: metolachlor+atrazine (Bicep) - pre; ametryn (Evik) - post directed
Insecticide: 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. pH, soluble salts (EC) and mineral nitrogen (NO_3^- –N) were measured 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 measured quantitatively in the laboratory by extracting with 1 M potassium chloride. The extractant was then analyzed using a Lachat Quick Chem 8000 flow injection analyzer.

Soil bulk density was measured via Uhland drive hammer, tube, and core assembly (figure 5). Other physical indices such as porosity and water-filled pore space were obtained by standardized equations using bulk density values.

Soil physical characteristics were visually described using the Munsell Soil Color Chart 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 to a depth of 45 cm using a drive hammer and tube. Obtaining a representative sample is an important aspect of diagnostic testing.

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 gained from bulk density provides insight about the physical condition of the soil with respect to the ingress and transfer of air, moisture, and heat.

Results

Since pH exerts a profound influence on soil chemistry, this was one of the first tests we conducted on site. The acute acidity problem was noted immediately; soil pH at the Pr site ranged from 4.5 to 4.6 in the surface 15 cm and 30 cm depth, respectively (Table 2). Low base saturation of 29 per cent, associated with the high acidity, was observed in the upper 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. The root system of most agronomic crops is sensitive to Al^{+3} even in low concentrations, while higher levels of Al^{+3} limit root growth as well as nutrient absorption. Manganese (Mn) level at both sites was very high because Mn solubility also increases at low pH. Given the probable presence of Al^{+3} and, high Mn levels in the soil solution, it is questionable how well corn roots were functioning.

Table 2. Soil chemical characterization of the untrafficked interrow.

Depth (cm)	pH (H_20)		CEC (meq/100^3)		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) was low, but this is normal for sandy textured soil in the southeastern coastal plain region.

Soluble salts and NO_3^- –N were nearly two-fold greater at the Pr site as compared to the non-Pr site (Table 2). These results are consistent with our understanding that fertilizer N uptake is often depressed in low-pH soil due to impaired root growth and function. The accumulation of fertilizer NO_3^- –N in the surface 15 cm was further evidence of reduced root N uptake by plants growing in high Mn, low pH soil. As noted in Table 2, soil pH and base saturation were also low at the non-Pr site but the magnitude less severe. 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 soluble Mn were mainly responsible for the visual symptoms of plant stunting, yellowing, and inter-veinal chlorosis noted at the Pr site (Figure 6).

Table 4. Comparison of the critical range and leaf tissue concentration of nutrients in the most recently matured (MRM) corn leaf.

Nutrient	Critical range 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
** Concentration in parentheses of Mn in leaf 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 the classic symptoms of 'acid soil infertility'. On the other hand, symptoms of acute toxicity and death of corn plants at the Pr site were probably the result of contact with post-directed herbicide (ametryn) and/or 30% N solution 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 leaf tissue from corn plants at the Pr-site was very high and increased nearly two-fold after two weeks (Table 4). Excessive manganese accumulation through the root system can be toxic, and is usually a result of low soil pH. At first glance it may appear odd that corn leaf tissue N content was above the sufficiency level at the Pr-site whereas test results show an accumulation of fertilizer NO_3^- –N in the surface 15 cm. 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 sampling sites (Figure7). This points up that soil testing 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 testing.

Sub-surface soil investigations revealed a coarse textured profile to a depth of 150 cm at the Pr-site. In contrast, the non-Pr site had a distinct horizon of silt and clay enrichment at the 30-70 cm depth (Figure 8 and 9). Compacted, fine textured soil horizons typically impede drainage and may explain the accelerated rate of leaching and consequent lower pH in the Pr-site as compared to the non-Pr site. Furthermore, coarse textured, low organic matter soils have lower cation exchange capacity, reducing their ability to capture and retain nutrient cations (Ca, Mg, K).

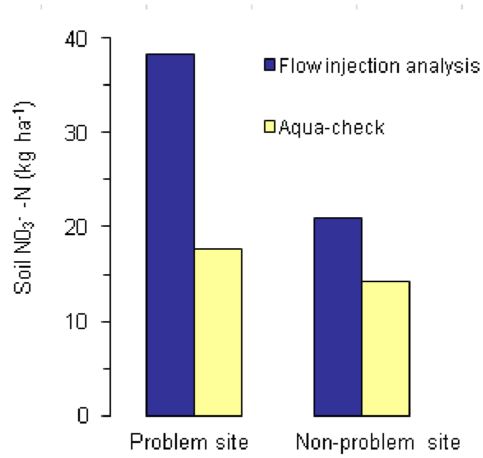

Figure 7. Comparison of quantitative (flow injection analysis) and semi-quantitative (Aqua-check) estimates of soil NO_3^- N in the surface 15 cm at two sampling sites.

Table 7. Soil physical properties.

Index	Depth (cm)	Pr site: Non traffic Inter-row	Pr site: Trafficked Inter-row	Non-pr site: Non traffic Inter-row	Non-pr site: 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 sub-surface investigation testify that soils can be quite variable in terms of their physical and chemical characteristics even though appearing identical at the surface. Abrupt changes in sub-surface soil texture can occur within a short distance and within the same diagnostic mapping unit. In this case, excessive leaching of Tarboro loamy sand was the culprit leading to a locally accelerated drop in pH at the Pr-site. Other sites scattered within CAR-20 manifested similar symptoms as the problem site in this investigation; we speculate that variability in sub-surface texture is probably the culprit in those areas as well.

Conclusion

Problem solving at the production level of agriculture often involves consideration of many factors reaching beyond the obvious suspects of human error or natural coincidence. It would have been easy to conclude in this instance that, symptoms of acute toxicity and death in corn were the result of 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 to gathering information about site, soil (surface *and* sub-surface), plant (shoots *and* roots) as well as past management practices enable the investigator to trouble shoot agronomic problems with greater precision. It may also lead to surprising new discoveries about the environment in which crops grow.

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

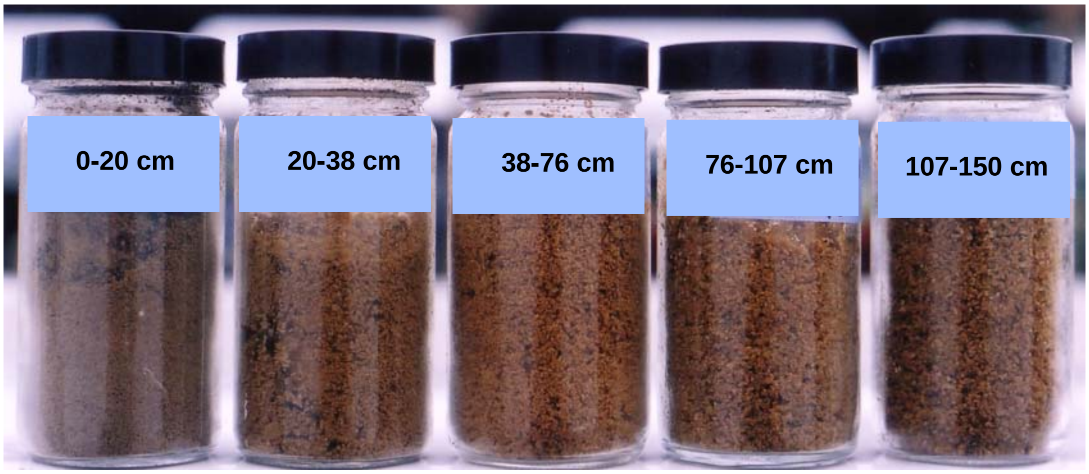

Figure 8. Soil samples recovered from the 0-150 cm depth at the problem site. Note the uniformly course texture throughout the profile of this Tarboro loamy sand.

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

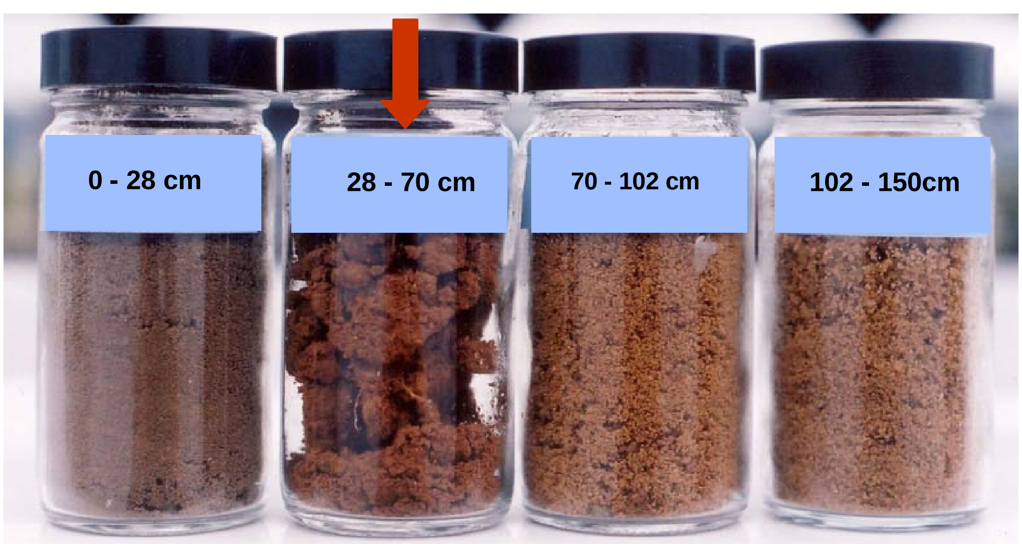

Figure 9. Soil samples recovered from the 0-150 cm depth at the non-problem site. Red arrow points to distinct firm clay loam horizon differentiating this soil from that found at the problem site. Soils in figure 8 and 9 occurred within the same mapping unit but have different sub-surface characteristics.

Following are some recommendations we submitted from this investigation.

- Overall, the soil in SARE CAR-20 is lime deficient. Since there would be little benefit of liming soil in the current season, soil samples from this plot should be submitted in fall to NCDA for recommendations aimed at correcting this problem in 2004.
- Tarboro loamy sands are very well to excessively well drained soils. Annual soil testing should be conducted to assess pH and nutrient levels. More frequent liming may be needed on Tarboro loamy sands than is presently practiced.
- The variable sub-surface soil texture evident in CAR-20 means that 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, excessively well drained soils in the coastal plain region of North Carolina have limited nutrient and water holding capacity. A program of intensive cover crop use, return of crop residue, and increasing soil organic matter content will conserve moisture and enhance nutrient holding capacity in these soils.

Further Reading

Bennett, W.F., ed. 1993. *Nutrient Deficiencies and Toxicities in Crop Plants*. American Phytopathological Society. St Paul, Mn.
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.