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SOIL QUALITY AND NUTRIENT LEVELS IN NEW AND ESTABLISHED HIGH TUNNELS IN MAINE

Fitzgerald, C.B. , Extension Educator and Associate Extension Professor, University Of Maine Cooperative Extension
Hutton, M., Extension Specialist and Associate Professor of Vegetable Crops, University Of Maine Cooperative Extension

ABSTRACT

In this study we report on soil nutrient levels and soil quality in 35 high tunnels on 29 Maine farms. The objective of the research was to determine soil fertility and soil health status; to identify trends in high tunnel soil nutrition management; and to identify grower practices needing additional or continued education with high tunnel farmers. Regardless of tunnel age, more careful management of pH, soluble salts, nitrate, and phosphorus are recommended in order to avoid deficiencies and excesses. This includes using less compost and more high-nitrogen fertilizer materials. Minimizing tillage and ensuring adequate moisture through improved irrigation practices are also recommended.

INTRODUCTION

High tunnel technology is being adopted by farmers to help them increase the length of the growing season, grow new crops, reduce disease incidence, increase crop quality, and improve labor options (Waterer and Bantle, 2000; Waterer, 2003; Wien, 2009; Wildung and Johnson, 2010; Wittwer, 1993; Wien and Pritts, 2009). The longer growing season and improved production capacity suggest that more nutrients will be needed in tunnels compared to open field production (Hoskins, 2013). Researchers and farmers are still learning about the best management of soils in high tunnels, with many critical questions remaining related to the relationship between organic matter management, fertility, and soil moisture management (Montri and Biernbaum, 2009).

Soil quality and soil health are two very closely-related terms used to describe the soil's capacity to function (Karlen et al., 2001). Currently, soil quality is considered to include inherent factors not subject to change, such as soil type, as well as dynamic factors that are subject to change, such as organic matter level (Moebius-Clune et al., 2016). Moebius-Clune et al. (2016) also identified the following as characteristics of healthy soils: good tilth, adequate depth for root development and crop growth, good water storage and drainage, adequate but not excess nutrients, small populations of pests, large population of beneficial organisms, low weed pressure, free of harmful chemicals and toxins, resistant to degradation, and resilient under unfavorable conditions. Methods to evaluate soil health and quality are still evolving, and the interpretation of these results is still under development (Karlen et al., 2001; Moebius-Clune et al., 2016).

Two recent studies examined soil quality in high tunnels. Knewtson et al. (2010) examined farmer opinions and observations of soil quality within their high tunnels in Missouri, Kansas, Nebraska, and Iowa. The 81 farmers surveyed reported observing clods (13%), surface crusting (16%), mineral deposition (32%), and hardpans (25%) in their tunnels. The authors also compared soil quality inside and outside 81 high tunnels to explore the assumption that soil quality in high tunnels degrades over time. They found elevated salt levels in the surface 5 cm of the soil (25% higher than 2 mmohs/cm and 3% higher than 4 mmohs/cm). Particulate organic matter as a fraction of total carbon was also higher in high tunnels. The farmer perceptions, salinity, and particulate organic matter as a fraction of total carbon were not correlated to tunnel age.

Reeve and Drost (2012) compared high tunnel soil quality under transitional organic and conventional management practices in Utah. Following use of composted poultry manure on the organically-managed soils, the authors found increases in two indicators of soil health: higher levels of organic carbon and readily mineralizable carbon in the top 15 cm of the organically-managed soils and increased activity of certain groups of soil microbes.

The objective of this study was to evaluate the nutrient status and soil quality of new (0-3 years old) and established (4+ years old) high tunnels in Maine. This was part of a larger study examining production practices, timing, and crop yield in high tunnels.

MATERIALS AND METHODS

This study evaluated soil quality and soil and plant nutrient levels in 35 high tunnels used to grow vegetables and cut flowers on 29 farms. Thirty-two tunnels were used to grow vegetables or herbs (28 included tomatoes in the rotation) and the remaining three were used for cut flower production. Non-soil characteristics of the subset of tunnels used to grow tomatoes were previously reported (Fitzgerald and Hutton, 2012). The tunnels described in this report varied in age from less than one year old to twelve years old, with 21 less than a year old. The farmers included recipients of NRCS funding for high tunnel construction. The farmers receiving conservation funds did not already have a commercially-designed high tunnel on their farms and represented many of the new high tunnels in the study. Farmers who were experienced at growing in high tunnels were selected through the researchers' contacts and by recommendation of Cooperative Extension colleagues. Soil testing and fertilization history were collected during in-person interviews between 9 June and 10 August, 2011.

The soils collected from high tunnels in this study had textures of sandy loam (59%), loam (35%), or silt loam (6%), as determined by particle size analysis (Gavlak et al., 2005) or estimated by feel by Maine Agricultural and Forest Experiment Station (MAFES) Analytical Laboratory personnel. Soil samples from all high tunnels were collected with a bulb planter between 9 June and 10 August 2011. Samples were taken to a depth of 6 inches from 10-20 locations within the crop rows of each high tunnel, combined in a pail, and mixed well. A sub-sample of approximately two quarts was taken from the pail. The sub-samples were refrigerated (4° C) for 1-2 days, air dried, and sieved to 2 mm through a roller-crusher to preserve aggregates. Soil pH, organic matter, and available nutrient content were measured using MAFES Analytical Laboratory's standard soil test protocols (*Recommended soil testing procedures for the Northeastern United States,* 2011). These methods included pH measured in distilled water at a 1:1 (w:v) ratio; all plant-available major and micronutrients extracted in modified Morgan solution at a 1:5 (w:v) ratio for 15 minutes; organic matter measurement by loss on ignition and converted to Walkley-Black equivalent organic matter using an in-house regression; and nitrate and ammonium N extracted in 1M KCl at a 1:10 (w:v) ratio.

Soil quality was measured using the MAFES Analytical Laboratory Soil Quality package, and the optimum levels were based on the guidelines in place in 2016. Total salt levels were measured by electrical conductivity in a saturated media extract (*Recommended soil testing procedures for the Northeastern United States*, 2011) and interpreted for high tunnel soils (Hoskins, 2013). Potentially mineralizable nitrogen was measured by incubating the sample for seven days at 40 C (Keeney and Nelson, 1982), extracting the mineralized NH_4 using 1M KCl (modified from Christensen et al., 1999), and correcting for initial NH_4 content. Potentially mineralizable N was interpreted based on the annual requirement of 100-200 pounds N/acre for most crops (Hoskins, personal communication, February 6, 2016). Microbial biomass/active carbon, water-stable aggregates, and plant-available water were measured and interpreted using the methods of Woods End Laboratory Inc. (n.d.), USDA NRCS Soil Quality Institute (2001), and Gavlak et al. (2005), respectively.

RESULTS AND DISCUSSION

The percentage of new and established Maine high tunnel soil samples classified as below optimum, optimum, and above optimum for key soil test parameters are presented in Table 1.Thirty-eight percent of new high tunnels and 18% of established high tunnels had soil pH below the recommended range of 6.0-7.0. Certain horticulture crops, such as tomatoes, benefit from pH above 6.5 (Dicklow and McKeag, n.d.). Most tunnels (76% of new, 45% of established) had soil pH less than 6.5. Producers did not take soil samples from 41% of the high tunnels (n=31). Another 13% (n=31) took them and did not add the lime recommended by the soil test results.

Table 1. Percentage of new and established Maine high tunnel soil samples classified as below optimum, optimum, or above optimum for key soil test parameters.

Parameter (optimum level)		New high tunnels (0-3 years) (n=24)	Established high tunnels (4 years and older) (n=11)
pH (6.0-7.0)	Below optimum	38%	18%
	Optimum	63%	73%
	Above optimum	0%	9%
Organic matter (5-8%)	Below optimum	21%	18%
	Optimum	38%	27%
	Above optimum	42%	55%
NO_3-N (100-200 ppm)	Below optimum	65%	82%
	Optimum	30%	0%
	Above optimum	4%	18%
P (40-80 lbs/acre)	Below optimum	54%	9%
	Optimum	25%	18%
	Above optimum	21%	73%
K (400-600 lbs/acre)	Below optimum	44%	55%
	Optimum	12%	9%
		44%	36%

	Above optimum		

Soil organic matter levels in Maine agricultural soils are typically in the 5-8 % range. About half of the soils in this study (42% of new tunnels and 55% of established tunnels; Table 1) had higher organic matter than is typical for open field soils, with 29% of new and 36% of established tunnel soils exceeding 10% organic matter. This included one tunnel with soil organic matter of 22.7%, which the farmer attributed to applications of large amounts of compost. Fertilizer and amendment histories were collected on 29 of the 35 tunnels, and all but one of those tunnels received compost or manure as an amendment between fall, 2010 and summer, 2011. Added organic matter, particularly compost, is often considered to be an easily-applied, long-term source of nutrients (Montri and Biernbaum, 2009). As will be seen later, the farms' nutrient applications, including compost, and did not always provide adequate nutrients to the growing crop. For farms purchasing compost, these compost applications without high nutrient content may represent an unnecessary cost.

In 2104, the Northeast regional group of soil testing laboratories agreed on new sufficiency levels for N, P, and K in high tunnels, based on estimates of crop removal by a 60 ton/acre tomato crop (B. Hoskins, personal communication, February 26, 2016). In Table 1, the current recommended soil sufficiency levels are presented along with the percentage of tunnels measured in this study that were determined to be below, at or above optimum levels. Most tunnels (65% of new, 82% of established tunnels) were below optimum in nitrogen (nitrate-N) at the time of sampling. Compost and/or manure was used in 97% of the 29 tunnels with detailed fertilization history. In 26%, compost or manure were the only source of added nitrogen. Thirty-six percent of the high tunnels received organic N-containing materials, such as kelp meal, pelleted poultry litter, or alfalfa meal. Nitrogen mineralization from compost and other organic materials depends on many factors, including original feedstocks, temperature, and soil moisture (Marshall et al., 2016; Gutiñas et al., 2012; Gonçalves and Carlyle, 1994; Gaskell and Smith, 2007). The low nitrate levels observed may have been the result of inadequate nitrogen mineralization to meet crop needs. Monitoring and adjusting soil nitrate with the addition of more readily-available N sources will help farmers avoid yield reductions due to insufficient N.

Fifty-four percent of soils in new tunnels were below optimum in plant-available phosphorus (P) (modified Morgan extract), including six extremely low (below 10 lbs/A; Table 1). In contrast, 73% of the soils from established tunnels were above optimum for plant available P. Reeve and Drost (2012) found above optimum P levels after three years of using composted poultry manure in high tunnels. They recommended reducing compost applications and adding high-N materials to minimize continued P accumulation. Since high tunnels are continuously covered, P loss from runoff will be low. However, there is potential for P losses when the tunnel is uncovered or possibly by leaching caused by flooding events, such as storms (Reeve and Drost, 2012). With continued compost and manure application in the study tunnels, levels of P in these tunnels would be expected to continue to rise.

Close to half of all tunnels (48% of new, 55% of established tunnels) were below optimum in potassium (K). Management of potassium is a difficult and complex problem critical for optimum tomato yield and quality that has had little attention in high tunnels. Use of balanced fertilizers, i.e. 20-20-20 (1:1:1), composts, or manure do not provide sufficient K in relation to P or N. Farmers should more closely monitor their soil K levels to provide adequate amounts for crop needs.

Soil quality results are shown in Table 2. A primary soil quality concern with established high tunnels is the accumulation of salts, typically from applied compost, manure and fertilizer. Since the tunnels are covered, there is not enough rainfall to leach these salts out of the soil profile. The highest recommended level for soil electrical conductivity (EC) for plant growth is 3.5 mmohs/cm. In this study, only one tunnel soil (3%) exceeded this level. This tunnel had been in production for 6 years and was primarily used for winter production. However, some crops, including bell pepper, lettuce, and carrots, all of which are commonly grown in high tunnels, can be sensitive to salt levels higher than 2.0 mmohs/cm (Bernstein, 1964). Thirteen percent of the new tunnels and 27% of established tunnels exceeded this threshold, demonstrating that moderate salt accumulations can be a concern for both established and new tunnels. Knewtson et al. (2010) found similar results for electrical conductivity in the surface 5 cm of soil. Three percent of high tunnel soils had electrical conductivity measuring greater than 4 mmohs/cm and 25% had electrical conductivity measuring greater than 2.0 mmohs/cm in this surface layer.

Table 2. Percentage of new and established Maine high tunnel soil samples classified as low, optimum or high for key soil quality parameters.

Parameter (optimum level)		**New high tunnels (0-3 years) (n=24)**	**Established high tunnels (4 years and older) (n=11)**
Salts (<3.5 mmhos/com)	Optimum	100%	91%
	Above optimum	0%	9%
Potentially mineralizable N (50-100 ppm)	Below optimum	17%	18%
	Optimum	30%	55%
	Above optimum	52%	27%
Soil biomass/active C (70-160 mg CO2-C/kg)	Below optimum	54%	73%
	Optimum	46%	27%
	Above optimum	0%	0%
Water-stable aggregates (60-70%, depending on texture)	Below optimum	74%	82%
	Optimum	26%	18%
Plant-available water (6-15%, depending on texture)	Below optimum	43%	18%
	Optimum	57%	82%

Levels of potentially mineralizable nitrogen from the study soils were high, with over 80% of new and established tunnels measuring optimum or above optimum (Table 2). However, it is important to remember that the nitrogen released under field conditions will depend on environmental factors which influence soil microbial activity such as temperature and soil moisture (Gutiñas et al., 2012; Gonçalves and Carlyle, 1994).

The soils in this study tended to have below optimum levels of soil biomass/active C (Table 2), with 54% of new tunnels and 73% of established tunnels testing below optimum. During sample collection, the researchers observed that many of the tunnel soils were quite dry. An earlier article describing the management practices used in these tunnels reported insufficient irrigation capacity on 16% of the 31 farms or lack of mulch within and between the crop rows in 26% and 28% of 41 tunnels, respectively (Fitzgerald and Hutton, 2012). Soil microbial biomass can be greatly influenced by soil moisture status, with drier soils having lower microbiological activity. The dry soils observed in these tunnels could have inhibited the development of soil microbial biomass. Greater attention to soil moisture status and using moisture conservation measures such as mulch will improve soil moisture relations and potentially increase nitrogen release by increasing soil microbe activity.

Water-stable aggregates provide added pore space in the soil and reduce soil compaction, which can reduce root growth. The amount of water-stable aggregates in this study was low in both new (74%) and established (82%) high tunnels (Table 2). Aggressive tillage, such as is done with a rototiller, can destroy soil aggregates (Magdoff and Van Es, 2009). Ninety-four percent (n=34) of the tunnels were tilled with a tractor-mounted, walk-behind, or hand-held rototiller. Reducing the amount of rototilling in the high tunnels would be expected to improve the level of water-stable aggregates and thus enhance crop growth (Magdoff and Van Es, 2009).

Plant-available water is an estimate of the amount of water that the soil can hold (Moebius-Clune et al., 2016). In this study, plant-available water was optimum in over half of the new tunnels and in 82% of the established tunnels (Table 2). The relatively high organic matter levels in many of these soils help increase the water-storage capacity (Moebius-Clune et al., 2016). Although dry soils were observed in many of these high tunnels, that is thought to be the result of insufficient irrigation, and not from inadequate water-holding capacity.

SUMMARY

Although this project was limited in scope, with data collected once during a single year, it highlights some potential management gaps in Maine high tunnel production. We recommend the following guidance for Maine farmers growing crops in high tunnels:

- Take soil tests regularly to monitor pH and nutrient levels
- Low pH may be a problem in any tunnel where native soils have low pH, regardless of age
- Monitor soil nitrate levels and supplement with easily-available N to ensure adequate levels
- Monitor for elevated salt levels in all tunnels, regardless of age. This is particularly important if growing crops sensitive to high salt concentrations
- Keep organic matter and phosphorus levels closer to optimum by using moderate but not excessive amounts of compost.
- Minimize tillage in the tunnel to increase the formation and maintenance of soil aggregates
- Ensure adequate moisture in the tunnels to optimize crop growth and potentially enhance soil microbial activity

LITERATURE CITED

Bernstein, L. (1964). Salt tolerance of plants. U.S. Department of Agriculture Agriculture Information Bulletin No. 283. Washington, D.C.: U.S. Government Printing Office.

Christensen, N.W., Qureshi, M.H., Baloch, D.M., and Karow, R.S. (1999). Assessing nitrogen mineralization in a moist xeric environment. *In:* Proceedings, Western Nutrient Management Conference, 3:83-90. Potash & Phosphate Institute, Norcross, GA.

Dicklow, M.B. and McKeag, L., eds. (n.d.) 2016-2017 New England Vegetable Management Guide. University of Massachusetts Extension Vegetable Program, Amherst, MA.

Fitzgerald, C.B. and Hutton, M. (2012). Production practices and challenges with high tunnel systems in Maine. Journal of the NACAA, 5(2). Retrieved from: http://www.nacaa.com/journal/index.php?jid=170

Gaskell, M. and Smith, R. (2007). Nitrogen sources for organic vegetable crops. HortTechnology, 17(4), 431-441.

Gavlak, R., Horneck, D., and Miller, R.O. (2005). Western States Soil and Plant Analytical Methods. WREP-125. 3rd edition. Method S-1.00. Retrieved from: www.naptprogram.org/files/napt/**western-states**-method-manual-2005.pdf

Gonçalves, J.L.M. and Carlyle, J.C. (1994). Modelling the influence of moisture and temperature on net nitrogen mineralization in a forested sandy soil. Soil Biology and Biochemistry, 26(11), 1557-1564.

Gutiñas, M.E., Leirós, M.C., Trasar-Cepeda, C. and Gil-Sotres, F. (2012). Effects of moisture and temperatures on net soil nitrogen mineralization: A laboratory study. European Journal of Soil Biology, 48, 73-80.

Hoskins, B. 2013. Soil testing options for high tunnel production. *In:* Proceedings of the 2013 New England Vegetable and Fruit Conference. Retrieved from: http://www.newenglandvfc.org/2013_conference/proceedings2013/Hoskins%20High%20Tunnel.pdf

Karlen, D.L., Andrews,S.S., and Doran, J.W. (2001). Soil quality: Current concepts and applications. Advances in Agronomy, 70, 1-40.

Keeney, D. R. and Nelson, D.W. (1982). Methods of Soil Analysis, Part 2. 2nd edition. Agronomy Monograph 9. Madison, WI. Agronomy Society of America.

Knewtson, S.J.B., Janke, R., Kirkham, M.B., Williams, K.A., and Carey E.E. (2010). Trends in soil quality under high tunnels. HortScience, 45(10), 1534-1538.

Magdoff, F. and Van Es, H. (2009). Building Soils for Better Crops: Sustainable Soil Management. Handbook Series Book 10. Sustainable Agriculture Research and Education Program.

Marshall, K., Erich, S., Hutton, M., Hutchinson, M., and Mallory E. (2016). Nitrogen availability from compost in high tunnel tomato production. Compost Science & Utilization, 24(3), 147-158.

Moebius-Clune, B.N., Moebius-Clune, D.J., Gugino, B.K., Idowu, O.J., Schindelbeck, R.R., Ristow A.J., van Es, H.M., Thies J.E., Shayler H.A., McBride, M.B., Wolfe, D.W., and Abawi, G.S. (2016). Comprehensive Assessment of Soil Health—The Cornell Framework Manual, Edition 3.1. Cornell

University, Geneva, NY.

Montri, A. and Biernbaum, J.A. (2009). Management of the soil environment in high tunnels. HortTechnology, 19(1), 34-36.

Recommended soil testing procedures for the Northeastern United States. (2011). Northeastern Regional Bulletin No. 493 (3rd ed.). Retrieved from: http://extension.udel.edu/lawngarden/soil-health-composting/recommended-soil-testing-procedures-for-the-northeastern-united-states/

Reeve, J. and Drost, D. (2012). Yields and soil quality under transitional organic high tunnel tomatoes. HortScience, 47(1), 38-44.

USDA NRCS Soil Quality Institute. (2001). Soil Quality Test Kit Guide. United States Department of Agriculture. Retrieved from: http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs142p2_050956.pdf

Waterer, D. (2003). Yields and economics of high tunnels for production of warm-season vegetable crops. HortTechnology, 13, 339-343.

Waterer, D. and Bantle, J. (2000). High tunnel temperature observations. University of Saskatchewan. Retrieved from: http://www.usask.ca/agriculture/plantsci/vegetable/resources/veg/ht_temp.pdf

Wien, H.C. (2009). Microenvironmental variations within the high tunnel. HortScience, 44, 235-238.

Wien, H.C. and Pritts, M.P. (2009). Use of high tunnels in the Northeastern USA: Adaptation to cold climates. Acta Horticulturae, 807, 55-59.

Wildung, D. and Johnson, P. (2012). Managing risk: Production comparisons between high tunnels and the field. *In:* Nennich, T. and S. Wold-Burkness (eds.), Minnesota high tunnel production manual for commercial growers (2nd ed.). University of Minnesota. Retrieved from: http://hightunnels.cfans.umn.edu/files/2012/11/4-Risk-Mgmt.pdf

Wittwer, S.H. (1993). Worldwide use of plastics in horticultural production. HortTechnology, 3, 6-19.

Woods End Laboratories Inc. (n.d.) Soil CO_2 Respiration Test. Official Solvita Guideline. Version 2013/2. Mount Vernon, Maine: Author.

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