Project Title:
Cornell Soil Health Assessment as a possible soil quality standard for Ontario.

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WAMQI project

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Promotion Summary: The value of Ontario's five long-term tillage system and crop rotation trials was evident by providing different production systems to evaluate soil health. This research developed a new Ontario soil health test and the framework for further refinement. Building understanding and confidence in soil health measurements is essential to advancing soil health on Ontario farms.

Introduction:
Maintaining and building soil health is an essential component of long-term sustainable agriculture production. Helping Ontario growers improve soil health will have multiple benefits such as higher crop yields, increased resiliency against severe weather events expected with climate change, and perhaps reduced water demand due to improvements in water holding capacity and water infiltration. Although maintaining and building soil health is important to growers, it is not easy to define and measure and it is difficult to interpret the meaning of results. One soil health test available to growers in the USA and Ontario is the Cornell Soil Health Assessment (CSHA). It provides one number indicating soil health (the higher the number, the better the soil health). In 2009-11, OMAFRA Soil Specialists Anne Verhallen and Adam Hayes collected soil samples from long-term research trials in Ontario to evaluate the CSHA.

Preliminary results indicate differences between treatments but the opportunity existed to analyze all data together via sophisticated statistical tools to gain meaningful knowledge. Therefore, the goals of our research were to 1: evaluate the ability of the CSHA to accurately assess soil health in Ontario and provide information to improve soil health scoring, and 2: characterize the effect of long-term land management (i.e. tillage, crop rotation, fertilization) on overall soil health. 3: Ultimately, we aimed to produce a preliminary tool ('look up table') that growers, crop consultants or Ontario certified laboratories can use to estimate soil health.

Methods:

Through a previous grant, OMAFRA soil management specialists Anne Verhallen and Adam Hayes collected soil samples from Ontario long-term tillage and crop rotation trials at 5 sites (Ridgetown (Van Eerd et al. 2014), Delhi, Elora, Ottawa Woodslee,) which were processed based on the Cornell Soil Health Assessment (Idowu et al. 2009). This is a substantial database with 2 tillage practices (conventional and no-till), 4-6 crop rotations (monoculture and rotations of cereals, legumes, forages), and 4-6 replicates. The CSHA soil parameters measured in this study were: aggregate stability (via rainfall simulator), potentially mineralizable N (PMN; 7 d anaerobic digestion), active carbon (permanganate oxidation), root health (bean assay), organic matter (%OM), pH, cation exchange capacity (CEC), P, K, Ca, Mg, Zn, Z index, Mn, Mn index, texture (% sand, silt, clay – hydrometer method). Meta-analysis using principal component analysis of the complete dataset was conducted to gain meaningful results. Site production practices are available in Congreves et al. (20xx Soil & Tillage Research *Accepted Feb 2015*).

Conclusions:

Objective #1: a) Evaluation of the CSHA to accurately assess soil health in Ontario
b) Improved Cornell Soil Health Assessment for Ontario (ON-CSHA).

Although the CSHA is a useful method for combining soil characteristics into a measure of soil health, the scoring is based on simply taking the average of all scores. This does not account for the relationship among soil attributes, and by taking the average it may over estimate soil health because 8 of the 14 indicators are nutrients. Our study showed relationships among soil attributes at four long-term experiments in Ontario. We developed a weighted scoring system to compute a new overall soil health score ON-CSHA. The ON-CSHA rankings >55% are considered good, rankings between 45 and 54 are considered fair, and rankings <44% are considered as poor soil health. This is the first soil health test for Ontario and an approach for developing soil health tests elsewhere. The ON-CSHA provides a more meaningful overall soil health score. The ON-CSHA scoring system was more sensitive than the CSHA in showing numerical differences for soil health between tillage and crop rotation systems, which may help growers to more clearly see differences in soil health under different management practices. For instance, at Ridgetown the scores were 64 vs. 68 for conventional vs. no-till for the CSHA but scores by the new ON-CSHA were 37 vs. 64 (Table 1). Although both tests showed a statistical difference there was a bigger difference between the numbers with the ON-CSHA. Thus, we recommend that growers use the ON-CSHA over the CSHA to better identify management practices which improve soil health.

Table 1. Effect of tillage system[z] on overall Cornell Soil Health Assessment (CSHA) and ON-CSHA score[Y] in 0-15 cm depth from four long-term experiments.

Site	CSHA Score			ON-CSHA Score		
	CT	NT	P value	CT	NT	P value
Ridgetown	64 (0.93) **b**	68 (0.93) **a**	**0.0470**	37 (5.2) **b**	64 (5.2) **a**	**0.0218**
Delhi	57 (1.5) **b**	64 (1.5) **a**	**<0.0001**	33 (5.0) **b**	61 (4.8) **a**	**0.0003**
Elora	69 (0.95) **b**	73 (0.95) **a**	**<0.0001**	34 (6.7) **b**	59 (6.7) **a**	**<0.0001**
Ottawa	66 (2.4)	66 (2.4)	0.8911	44 (9.5)	54 (9.6)	0.6069
Meta-analysis	64 (4.1)	68 (3.3)		36 (3.7)	61 (3.7)	

[a-b] For each site and each score, means followed by a different letter indicates a significant difference according to Tukey-Kramer means comparison ($P<0.05$).
[z] CT, conventional tillage was moldboard plough with secondary cultivation; NT, no-till had no soil disturbance except at planting.
[y] Means followed by standard error in parentheses.

Objective #2: Impact of tillage systems and crop rotation on soil health

By using the four long-term experiments in Ontario, we were able to critically evaluate how many years of production and crop management affect soil health. Generally, the ON-CSHA individual indicators (Fig. 1) and score (Table 1) were greater with long-term no-till compared to conventional tillage. There were no differences among crop rotations at Ottawa and Delhi. At Ridgetown and Elora, crop rotations which included winter wheat or 2-yr-alfalfa tended to have the highest ON-CSHA scores. In 2009 at the time of sampling, Elora was the only site where red clover was intersown into cereal crops, which had higher scores than without red clover. Therefore, to improve soil health, growers should consider adopting no-till and increasing the frequency of alfalfa, winter wheat or intersown red clover in crop rotations.

Principal component analysis (PCA) is a statistical tool that allows researchers to evaluate many different parameters at the same time, and to evaluate how they are related to each other. Our PCA used 15 soil indicators from the four long-term sites and > 300 data points to create Fig. 2 and 3. From all the data, the first two components (x and y axis of Fig. 2) accounted for 62% of the variability of the data, thus describing the majority of variation among the soil attributes. By looking at the relationship of all the data, one can see that the data variability was mostly explained by the location of the long-term trial (Fig. 3A). However, the variability among data points was not clearly related to tillage or crop rotation effects (Fig. 3B, C). Thus, this research suggests that location has a greater influence on soil health than grower production practices (tillage or crop rotation). Keep in mind that 'location' included soil texture and classification, climate, and experimental duration. This suggests a need to develop a soil health test based on soil texture. Both the CSHA and ON-CSHA are scored based on soil texture.

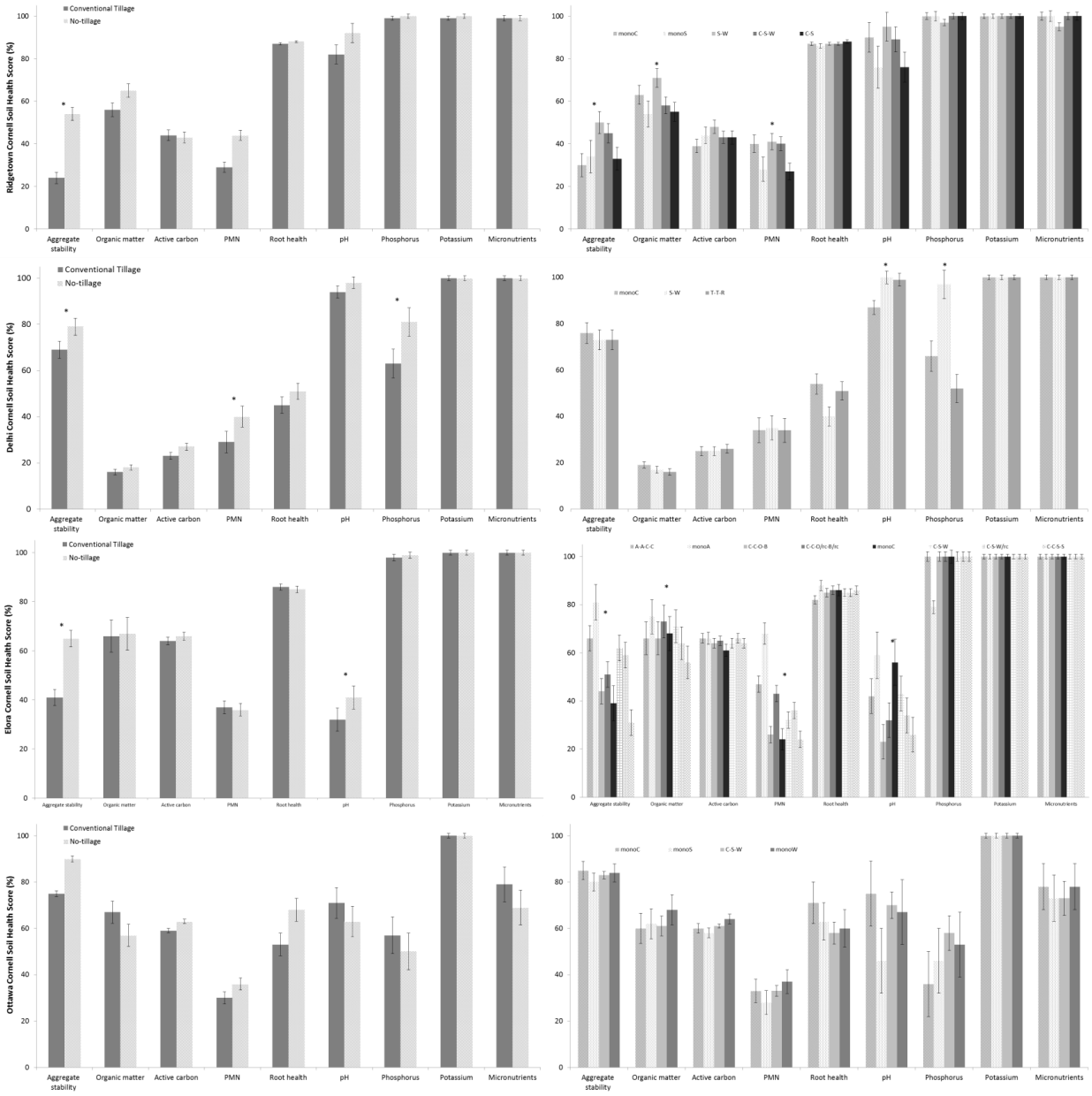


Fig. 1. Cornell Soil Health Assessment (CSHA) scores for individual soil attributes as affected by tillage system and crop rotation at Ridgetown, Delhi, Elora, and Ottawa long-term experiments. *PMN denotes potentially mineralizable N; * denotes a significant tillage system or rotation effect (P<0.05).* Brief explanation: higher scores indicate high soil quality. The overall CSHA score (Table 1) for tillage systems or crop rotation was the average of all individual scores shown here.

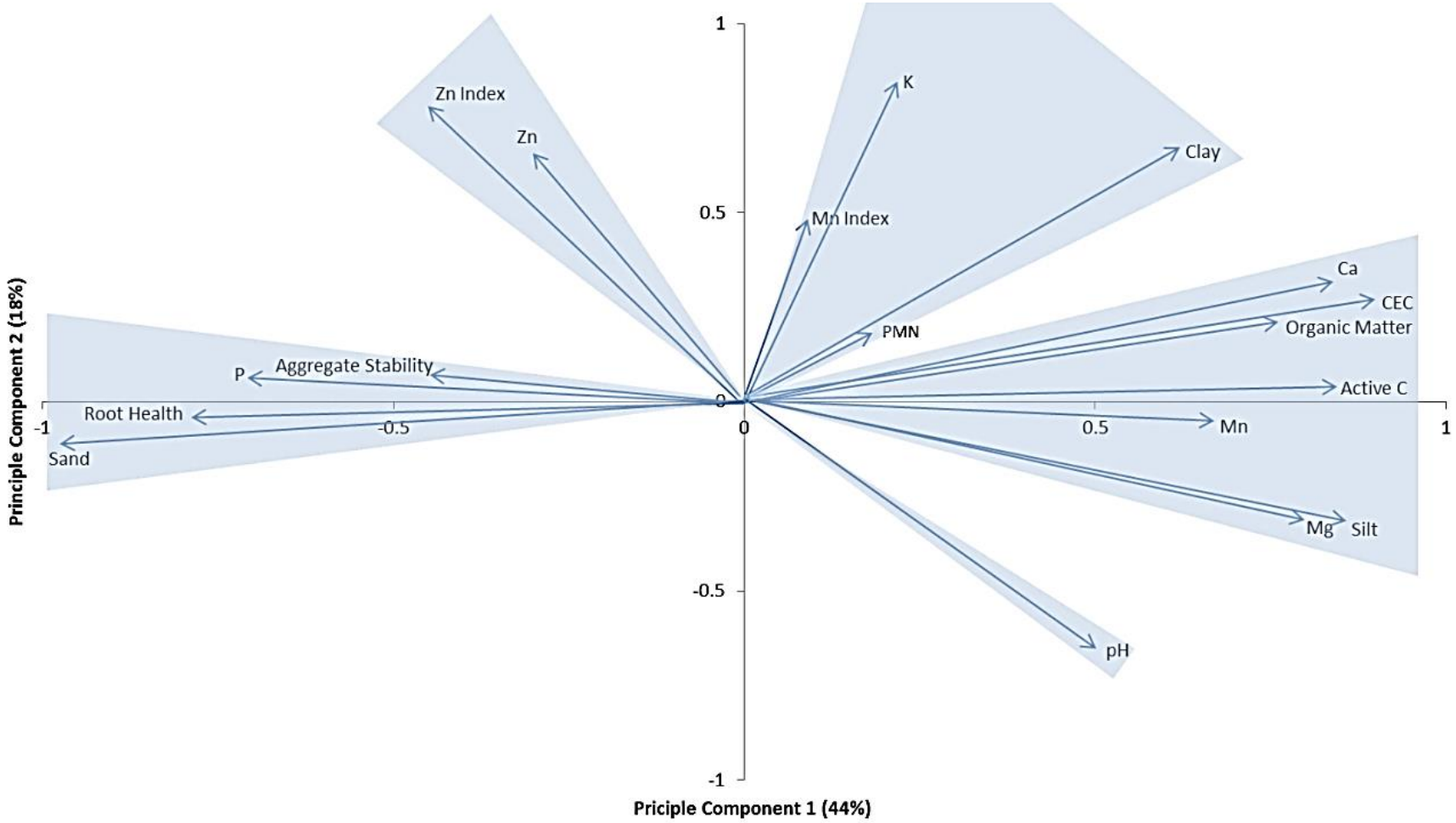
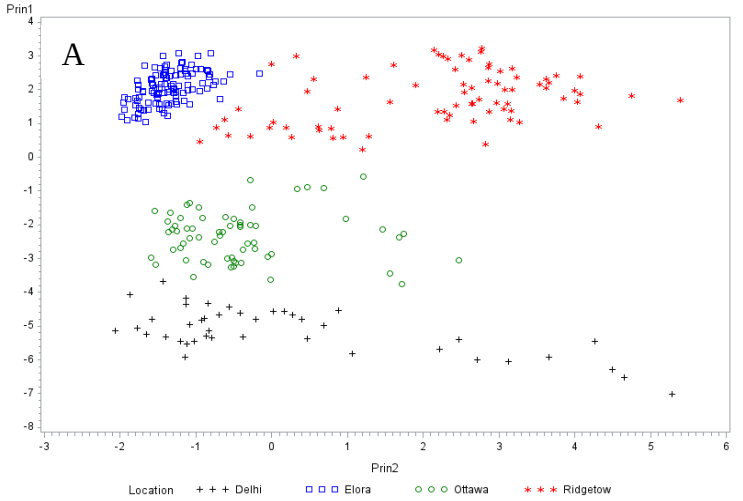
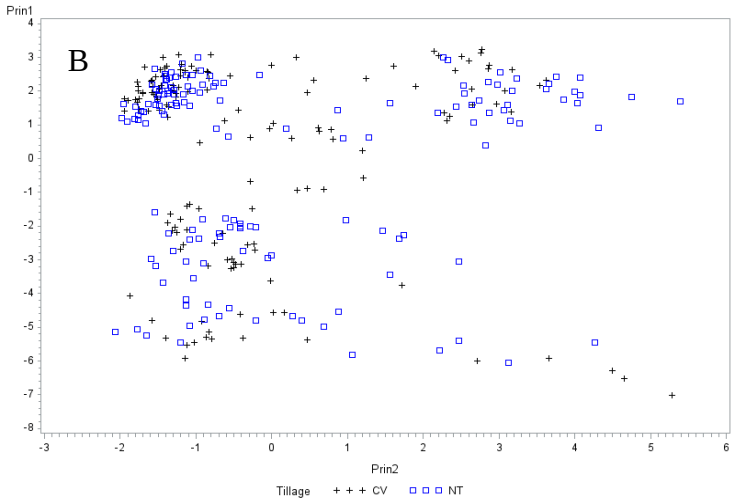


Fig. 2 Principal component analysis of soil attributes at Ridgetown, Delhi, Elora, and Ottawa long-term experiments, as influenced by long-term agricultural production under no-till, conventional tillage, and various crop rotations of grains, legumes, and forages. *PMN denotes potentially mineralizable N*. Brief explanation: this analysis takes all soil data and shows how factors were related into groups and in terms of size and direction of the arrows. This analysis explains 62% of the variability in the data.





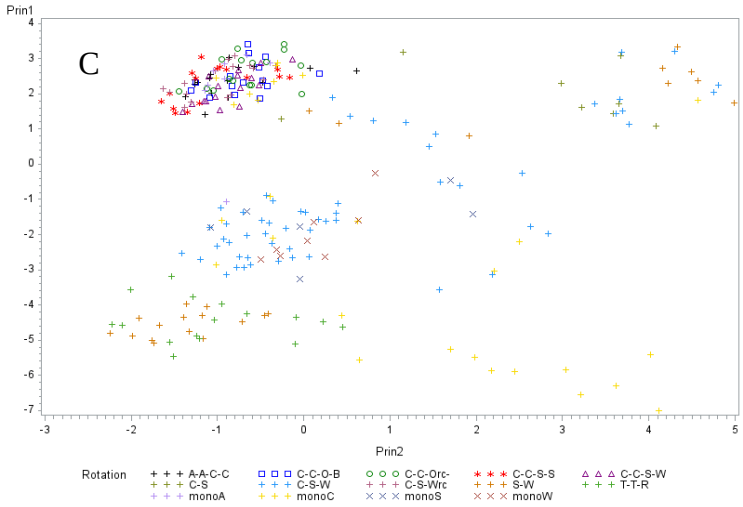


Fig. 3. Observation scores on the first two principal components for effects of location (A), tillage system (B), and crop rotation (C) on soil attributes from the long-term experiments Ridgetown, Delhi, Elora, and Ottawa. *CV and NT denotes conventional tillage and no-till systems*. Brief explanation: this analysis takes all soil data and plots them in two dimensions. Scores are grouping by location but not by tillage system or crop rotation.

Woodslee:
A trial at Woodslee, Ontario was evaluated separately because the management practices were different than at the other long-term studies. The experiment was established in 1993-96 to compare three tillage systems in a corn-soybean-winter wheat rotation, with each crop phase present each year as separate blocks. The ON-CSHA scores for no-till, zone-till, and conventional tillage were 58±8.3%, 48±7.5%, and 46±7.8%, respectively. Although this long-term experiment followed the trend of higher soil health scores with no-till, there was not a statistical difference between tillage systems. The trial at Woodslee was shorter in duration than all other long-term experiments, which reinforces the value of long-term trials, especially for evaluating indicators of soil health. Surprisingly, there was a difference between crop phases despite being in a corn-soybean-wheat rotation. The ON-CSHA score was 47±11.3% points higher in corn plots than soybean plots. One possible explanation could be in inherent differences in soil properties before the trial was established.

Objective #3:
Preliminary Soil Health Look-up Table for Growers.
This soil health look-up table is very preliminary. The table will be discussed at the soil health workshop on 2 March 2015, which we will organize and host. Results from on the CSHA and the ON-CSHA will be presented. Unfortunately the CSHA is relatively labour and equipment intensive and costly. In New York the CSHA is heavily subsidized by the state and performed at the state run lab; a situation that is not available here in Ontario. Clearly there is a need to balance affordability with reliability and sensitivity.

The goal of the 1 day soil health workshop will be to build industry consensus on which soil indicators should be part of an Ontario soil health test. This by-invitation-only workshop includes involvement of soil scientists, personnel from Accredited Soil Testing Laboratories in Ontario, and provincial and federal specialist as well as experts from Quebec and New York. This is the first step to making a recommendation to Ontario Soil Management *Research and Services* Committee (OSMRSC); the committee which approves provincial fertilizer recommendations.

The soil health indicators that showed the most differences among crop rotations and between tillage systems were: aggregate stability, percent organic matter, and potentially mineralizable nitrogen. Data were based on values from no-till and crop rotations with wheat, alfalfa, and undersown red clover. This table is based on science but is not the ‘be all and end all’ of soil quality. It is a good start and improves upon the current system.

Our principal component analysis indicated 5 groups (Fig. 2): (i) Ca, CEC (cation exchange capacity), organic matter, active C, Mn, silt content and Mg (ii) potentially mineralizable N, clay content, K, and Mn index, (iii) Zn and Zn index, (iv) aggregate stability, P, root health, and sand content, and (v) pH. These groups might be useful for new soil health test in no-till and conventional tillage system with representative crop rotations. However, other management regimes (i.e. sod, pasture, horticulture, or manure management) and heavier clay soils could have different groupings.

Table 2. Soil health look up table for growers based on long-term experiments at Ridgetown, Elora, Delhi, and Ottawa*.

Attribute	Sandy loam or lighter		Silty loam		Clay loam or heavier	
	Good soil quality	Needs improving	Good soil quality	Needs improving	Good soil quality	Needs improving
Aggregate stability (%)	≥52	≤46	≥44-40	≤32	≥46 - 40	≤35
Organic matter (%)**	≥1.7	≤1.5	≥4.2	≤3.8	≥4.8-4.6	≤4.3
Potentially mineralizable N (ppm)	≥9.5	≤8.0	≥9	≤8.7	≥11	≤8

* Data based on Congreves et al. (20xx. Soil & Tillage Research *Submitted Dec 2014*)
**Ontario labs already give recommendations for target OM%. This is not a recommendation to move away from the current practice but a presentation of data from this study.

Communication and Outreach:

Field Day Talks:

Verhallen, A. and A. Hayes. 2014. Cover Crop Coffee Break. Talk to 6growers and agronomists. 29 October 2014. Kingsville.

Verhallen, A. and A. Hayes. 2014. Cover Crop Coffee Break. Talk to 20 growers and agronomists. 31 October 2014. Lambton county.

Verhallen, A. and A. Hayes. 2014. Cover Crop Tour and Open House. Talk to 20 growers and agronomists. 30 October 2014. Thamesville & Chatham.

Van Eerd, L.L. and D.C. Hooker. 2014. Soil Health in the long-term experiment: crop rotation and tillage system. Cover Crop Tour and Open House. Ridgetown, Tour presenter to ca. 20 growers, agronomists, extension personnel and researchers. 30 October 2014. Ridgetown.

Van Eerd, L.L. 2014. Soil Health: crop rotation, tillage, N fertility and cover crops. *for*: Kent Soil and Crop Improvement Association. Tour presenter to ca. 50 growers, agronomists, extension personnel and researchers. 8 July 2014. Ridgetown.

Van Eerd, L.L. 2014. Soil health: N fertility and cover crops. *for*: Vegetable Open House. Talk to approx. 60 growers, agronomists and industry personnel. 17 July. 2014. Ridgetown.

Van Eerd, L.L. 2014. Long-term cover crop research . *for*: Quebec Farmer tour. Presentation to 44 growers and extensionists from Quebec. 22 July 2014. Ridgetown.

Van Eerd, L.L. 2014. Cover crops, soil health, and long-term research . Oxford Soil and Crop Improvement Association. Tour presenter to ca. 15 growers. 26 Aug 2014. Ridgetown.

Van Eerd, L.L. 2014. Cover crops and soil health. *for*: Communities in Bloom. Presentation to 5 participants at the research plots at Ridgetown Campus. 29 July 2014. Ridgetown.

Field Day Demonstrations:

Long-term research at these sites were highlighted as well as a demonstration of soil health (ie what is soil health, how to measure it, what to look for, etc).

Hayes, A. 2014. Long-term tillage and crop rotation on soil health. *for*: Quebec Farmer tour. Presentation to 44 growers and extentionists from Quebec. 22 July 2014. Ridgetown.

Hayes, A. and A. Verhallen. 2014. Diagnostic Days. 353 growers, agronomists and industry personnel 9-10 July 2014. Ridgetown.

Hayes, A. and B. Deen. 2014. Tillage, residue management and soil health. FarmSmart Expo. 220 growers, agronomists and industry personnel. 17-18 July 2014. Elora.

Hayes, A. and B. Cole. 2014. Crop Yield and Soil Health. Eastern Ontario Crop Diagnostic Day: 180 growers, agronomists and industry personnel. 15 July 2014. Winchester.

Hayes, A. and Verhallen, A. 2014. Crop Yield, Soil Health and Cover Crops. Blenheim 4H -17 Sept. 2014 25 People

Hayes, A. and Verhallen, A. Middlesex Soil and Crop Improvement Association. Cover Crop Field Day 80 ppl, 7 Oct. 2014. Glencoe ON.

Hayes, A. Huron Soil and Crop Improvement Association Soil Health Field Day September 3, 2014 80 people, Clinton, ON

Promotional Material:

Farm and Food Care Ontario -WAMQI promotional video. Hayes, A., Verhallen, A. and Van Eerd, L.L. 2014. Long-term research for soil health. http://youtube Produced by Farm and Food Care Ontario. Recorded 7 July 2014.

Scientific Contributions:

Congreves, K. A., Hayes, A., Verhallen, A. C., and Van Eerd, L. L. 2014. Cornell soil health assessment (CSHA) on the influence of long-term tillage and crop rotation on soil quality at four locations in Ontario. *Canadian Society of Agronomy and Canadian Society of Horticultural Science*. Annual Meeting. Lethbridge AB. 10-12 July 2014. Oral-poster Presentation

Van Eerd, L. L., Congreves, K. A., Hayes, A. and Verhallen, A. 2014. Effects of long-term tillage and crop rotation on soil quality at four locations in Ontario. *ASA/CSSA/SSSA, International Annual Meeting.* Long Beach CA. November 2014. Oral Presentation.

Congreves, K.A. A. Hayes, A.C. Verhallen, and L. L. Van Eerd Long-term impact of tillage system and crop rotation on soil health at four agroecosystem research sites in Ontario. Soil & Tillage Research *Submitted Dec 2014*.

Final Report:

Submitted to Farm and Food Care and posted online at on Dr. Van Eerd's Ridgetown Campus website
http://www.ridgetownc.on.ca/research/research_reports_profile.cfm?profile=vaneerd&name=Dr.%20Laura%20Van%20Eerd

References:

Andrews, S.S., D.L. Karlen and C.A. Cambardella. 2004. The soil management assessment framework: a quantitative soil quality evaluation method. Soil Sci. Soc. Am. J. 68:1945-1962.

Idowu, O.J, Van Es, H.M., Abawi, G.S., Wolfe, D.W., Schindelbeck, R.R., Moebius-Clune, B.N. and Gugino, B.K. 2009. Use of an integrative soil health test for evaluation of soil management impacts. Renewable Agriculture and Food Systems. 24: 214–224.

Congreves, K.A. J. Smith, D.D. Németh, D.C. Hooker, and Van Eerd, L.L. 2014. Soil Organic Carbon and Land Use: Processes and Potential in Ontario's Long-term Agro-Ecosystem Research Sites. Canadian Journal of Soil Science. 94:317-336.

Van Eerd L.L., Congreves, K.A., Hayes A., Verhallen A., Hooker D.C. 2014. Long-term tillage and crop rotation effects on soil quality, organic carbon, and total nitrogen. Canadian Journal of Soil Science. 94: 303-15.

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