Ontario Topsoil Sampling Project

Soil Health Baseline Study

2024

Ministry of Agriculture,
Food and Agribusiness

Ontario

Contents

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Executive Summary

The Ontario Topsoil Sampling Project involved comprehensive sampling of topsoil and documentation of a variety of land-use management trends related to soil health at targeted locations throughout southern Ontario. This report provides baseline information about indicators of soil health in Ontario.

Results from the project data showed land management risks and best management practices are used to mitigate risks.

Land Management Risks

- Soil compaction is a widespread issue on a high proportion of fine-textured (clay-rich) soils, as well as on approximately 50% of medium-textured (loam) and coarse-textured (sand-rich) soils.
- Soil texture impacts a soils inherent ability to store organic matter and impacts Soil Health Test values. Coarse-textured (sand-rich) soils have a lower inherent ability to store organic matter compared to fine-textured (clay-rich) soils.
- Tillage and water erosion was identified as a significant risk on hill-top locations in the field, where the depth of topsoil was thinnest.
- Cropping systems that rely on intensive tillage for crop production showed lower soil health test values.

Best Management Practices of Project Participants

- **Crop rotation:** 91% indicated they incorporate crop rotation (two or more annual crops), 63% indicated they incorporate three or more annual crops in their rotation, while 5% did not use crop rotation.
- **Perennial crops:** 27% indicated that they use a perennial crop in their cropping system. The most common perennial was a forage crop (e.g., hay).
- **Cover crops during non-growing season:** 43% indicated they incorporate at least one cover crop into annual cropping systems. 29% of respondents use a single species cover crop.
- **Organic amendments:** 51% indicated they use organic amendments and manure was most common (46%). Compost and biosolids account for between 1%–2% in various combinations.
- **Tillage:** 13% indicated they use low disturbance tillage practices. 29% indicated moderate disturbance tillage practices. 40% indicated high disturbance tillage practices. No disturbance was classified as land not disturbed at all (e.g., pasture) and accounted for 13% of all responses.

1. Introduction

In 2019, the Ontario Ministry of Agriculture, Food and Agribusiness (OMAFA) launched the Ontario Topsoil Sampling Project (OTSP). The aim of the OTSP was to better understand the variability and range of agricultural topsoil properties and soil health indicators by collecting up-to-date soil information throughout the province. A key goal was to establish baseline information for indicators of soil health in Ontario. This information will help modernize provincial soil maps, inform best management practices (BMPs) and develop soil health and stewardship related initiatives.

The OTSP involved comprehensive sampling of topsoil and documenting of a variety of land-use management trends related to soil health at targeted locations throughout southern Ontario. Land-use management trends also help to:

- understand the interactions between field-scale environmental variability (e.g., landscape position) of topsoil properties and soil health indicators.
- understand provincial-scale variability of topsoil properties and soil health indicators.
- quantify current land management practices related to soil health.
- support the development of OMAFA's *Soil Health Assessment and Plan (SHAP) Guidebook* by generating a soil health indicator baseline database to be leveraged in developing an assessment framework for soil health in Ontario.

1.1 Soil Health Basics

The United States Department of Agriculture (USDA) defines soil health as the continued capacity of soil to function as a vital living ecosystem that sustains plants, animals and humans (USDA-NRCS 2023). Other researchers expand upon this definition to consider the capacity of a soil to function within ecosystems and land-use boundaries to sustain:

- biological productivity
- environmental quality
- plant and animal (including human) health.

Overall, there is agreement that soil health should be evaluated by examining chemical, physical and biological soil properties (Figure 1).

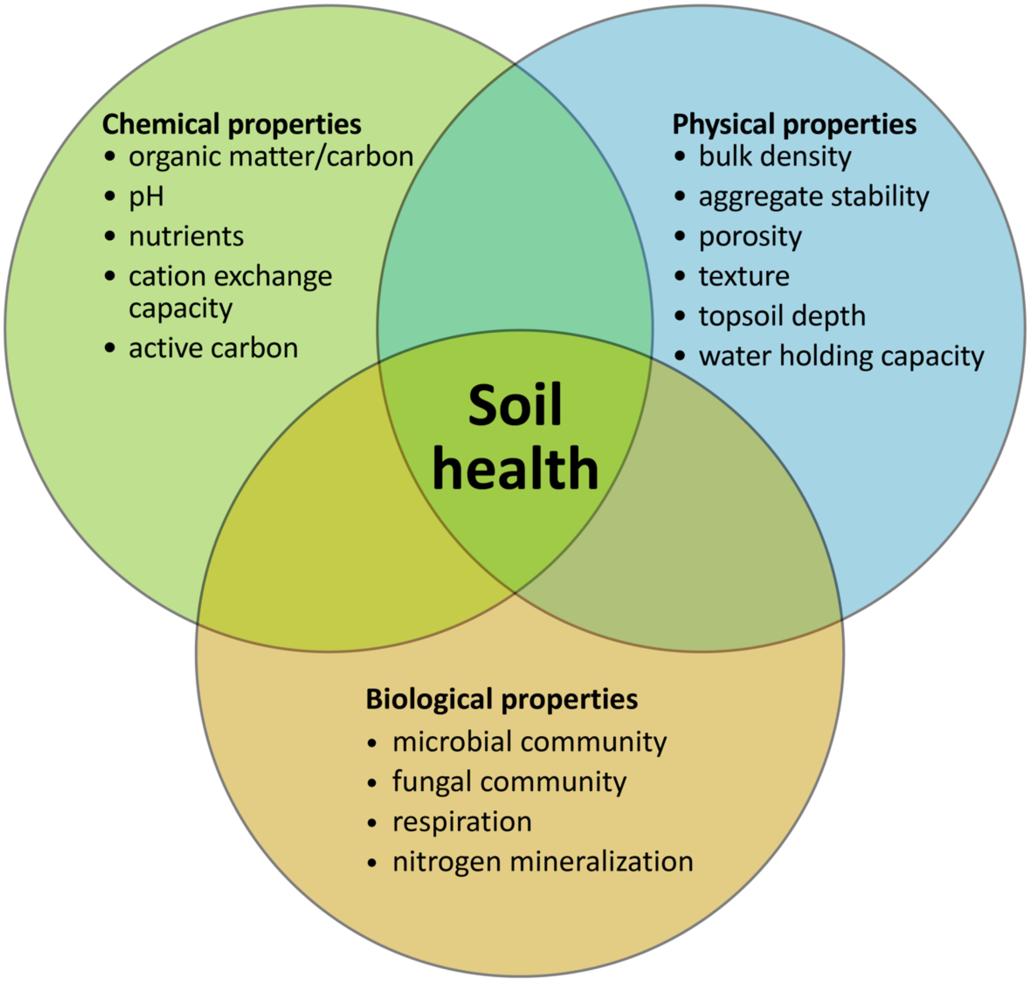

Figure 1. *Chemical, physical, and biological soil properties are used as indicators for assessing soil health.*

2. Methods

2.1 Selecting Sampling Locations

In total, 504 farms (Figure 2) were selected for the OTSP based on available baseline environmental information and geographic location. These are referred to as “seed points.” For each seed point, typically three samples were collected within the same field along a slope gradient to represent upper, mid and lower slope positions. In level landscapes, three samples were collected with a minimum 50-metre separation. In total, 1,511 soil samples were collected across the 504 seed locations (farms).

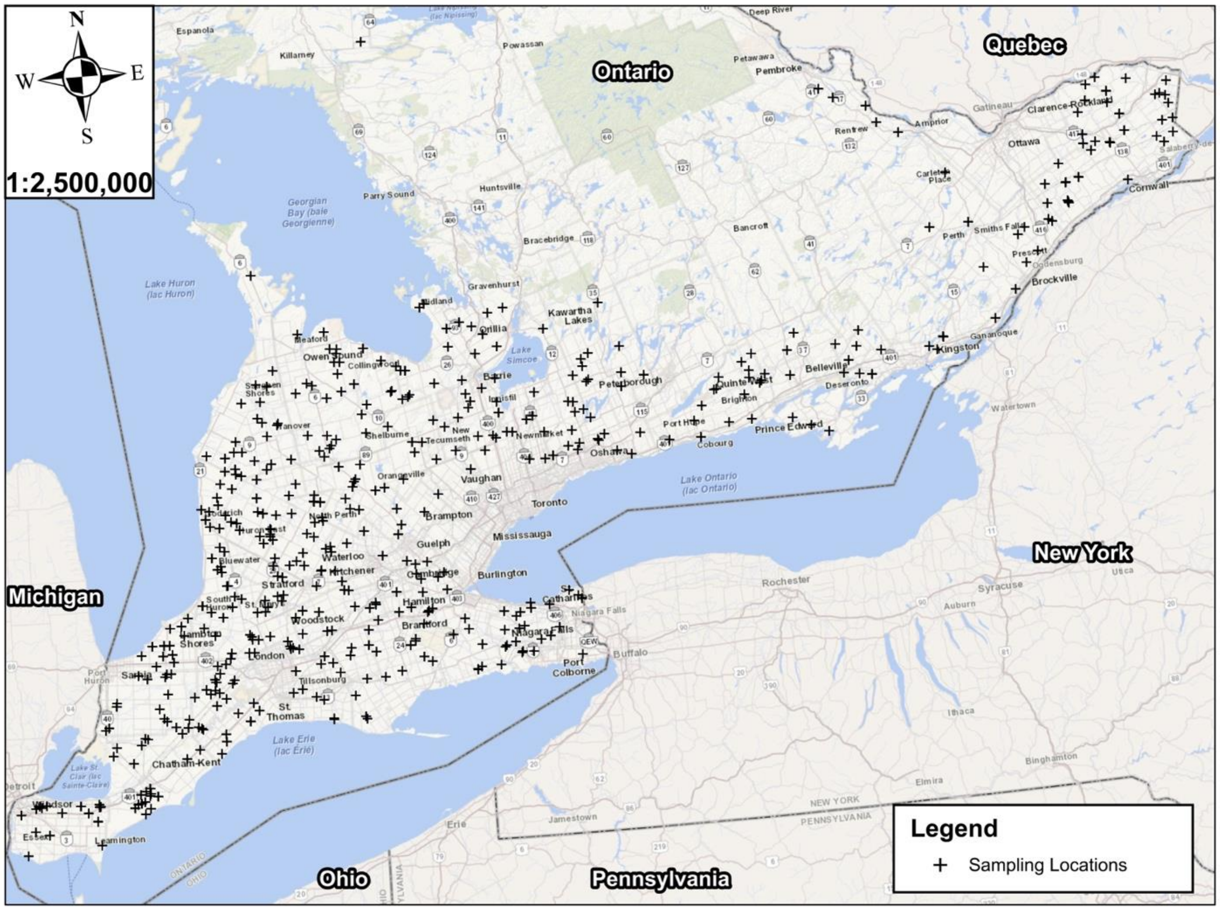

Figure 2. *Soil sampling locations across southern Ontario for the Ontario Topsoil Sampling Project.*

2.2 Project Components

The OTSP comprises three major components:

1. Land management information
2. Landscape description and soil sampling
3. Laboratory analyses of soil samples

The following sections provide a detailed description of each component.

2.2.1 Land Management Information

At each participating farm, land management information was collected to gather general information about ownership, crop rotations, use of cover crops, tillage practices and use of organic amendments (e.g., manure or biosolids).

2.2.2 Soil Sampling

Samples were collected by excavating a small soil pit to the base of the topsoil horizon and sampling to a maximum depth of 30 cm (Figures 3 and 4). In addition to the "grab" samples (samples taken by hand) for analytical work, bulk density samples were also collected from each soil pit using soil cores.

Figure 3. *Example soil pit excavation between rows of soybeans.*

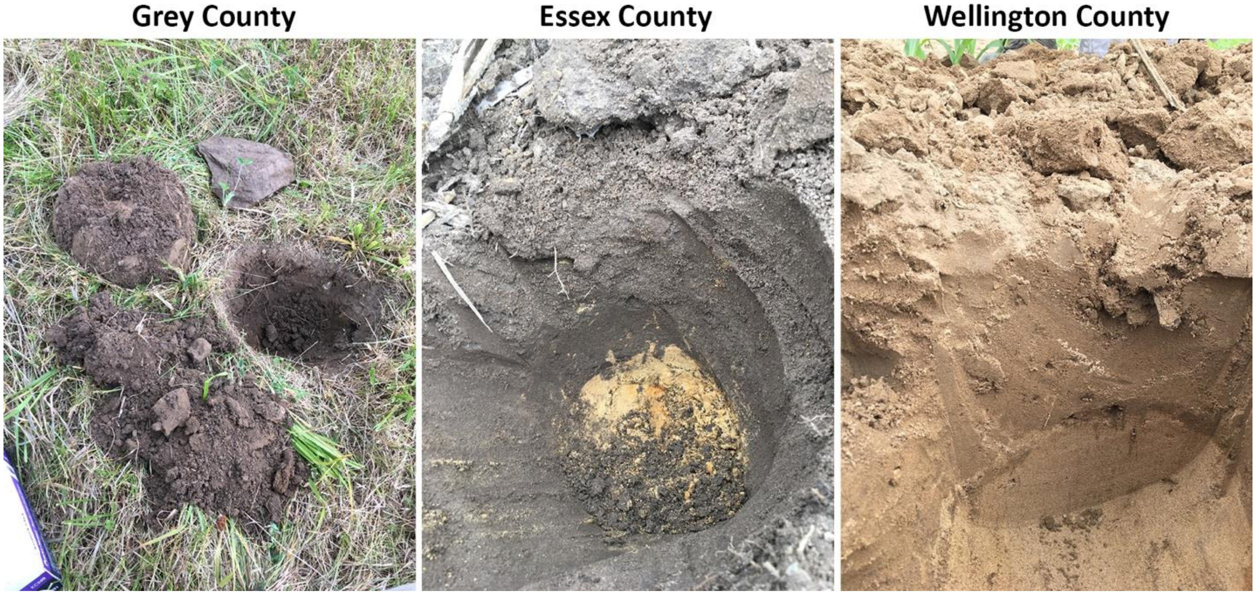

Figure 4. *Topsoil sampling pits from different counties showing variation in soil colour attributed to differences in organic matter content.*

2.2.3 Laboratory Analyses

Key soil attributes and laboratory analytical tests were completed on the soil samples collected through the OTSP, including soil health indicators selected for SHAP.

The key soil properties are:

- soil organic matter
- active carbon
- respiration
- potentially mineralizable nitrogen
- aggregate stability
- bulk density
- soil texture (sand, silt and clay)

3. Soil Health Properties

3.1 Soil Organic Matter

Soil organic matter (SOM) is the sum of all the organic materials present in the soil and is expressed as a percentage by weight. It has an important influence on many processes in the soil. Soils with higher SOM content have better structure, supply more nutrients to crops and support greater soil biological populations, all of which make soils more resilient to weather extremes.

3.2 Active Carbon

Active carbon represents a fraction of soil organic carbon (SOC) that is not the most microbially available (labile), but rather moderately stable and slightly processed. Active carbon responds to management changes more quickly than SOC, therefore it can be interpreted as a leading indicator of future changes in SOC. Higher levels of active carbon are associated with soil management practices that tend to stabilize SOC and increase aggregate stability.

3.3 Respiration

Soil respiration is a measure of potential carbon mineralization and an indicator of biological activity. Soil microorganisms feed on SOM, releasing nutrients and other compounds that benefit plants and influence other soil processes.

3.4 Potentially Mineralizable Nitrogen

Potentially mineralizable nitrogen (PMN) measures how much of the nitrogen tied up in organic matter is converted (mineralized) into plant-available ammonium nitrogen under certain temperature and moisture conditions with time.

3.5 Aggregate Stability

Aggregate stability refers to the resistance of soil aggregates to disintegration following disturbance. It indicates how well soil aggregates can resist impacts of tillage, raindrops and water erosion.

3.6 Bulk Density

Bulk density (BD) is a measure of the dry weight of soil per unit volume and is an indicator of soil compaction. Soil bulk density is usually expressed in units of g/cm^3 or $tonnes/m^3$ ranging from about 1.0 to 2.0 g/cm^3. Lower bulk density values are preferable as values approaching 2.0 g/cm^3 restrict root growth. Bulk density increases with soil depth and depends on soil texture.

3.7 Particle Size Analysis

Soil texture, the relative amount of sand, silt and clay in a soil, is an important soil property and is naturally linked to other soil properties including certain soil health indicators. Texture class was considered when interpreting soil health indicators. The individual soil texture classes were grouped into three broader groups to aid in the interpretation (Figure 5).

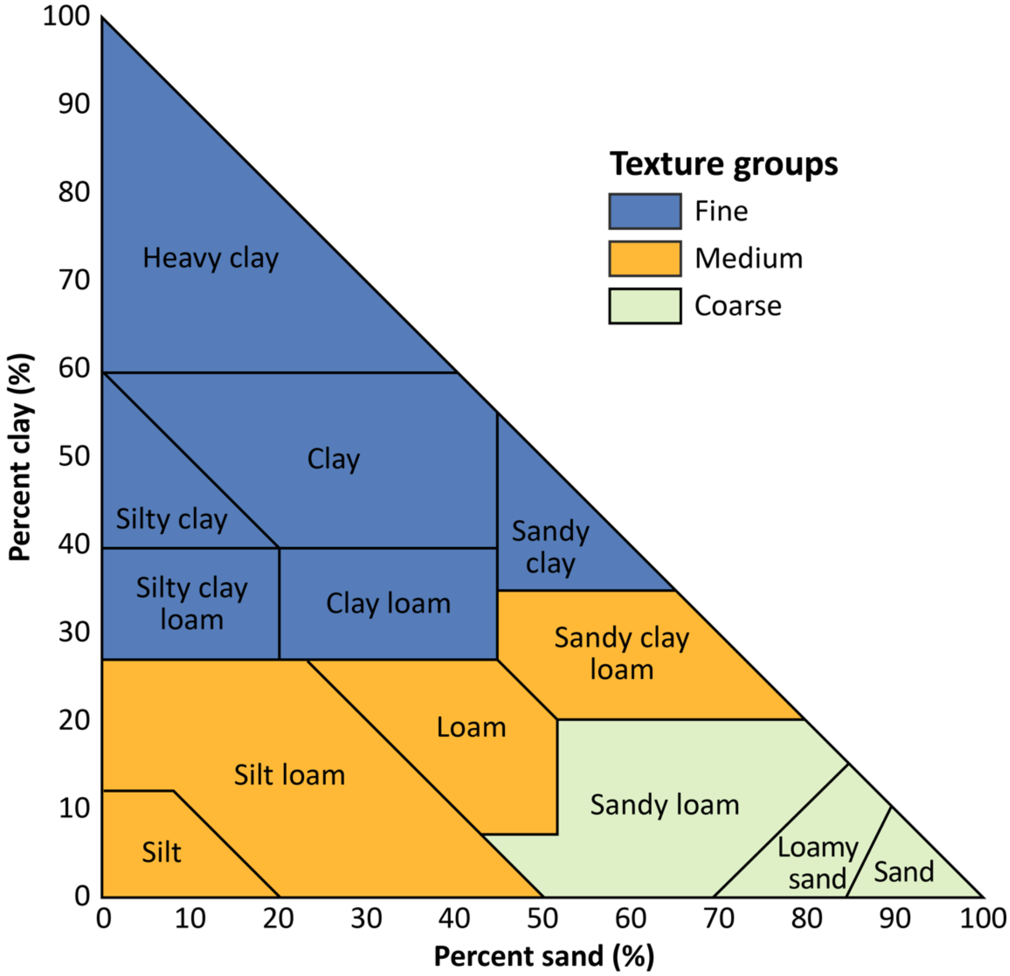

Figure 5. *Texture triangle showing the 13 texture classes and how they were grouped to aid in the interpretation of soil health.*

4. Results and Discussion

4.1 Land Management

4.1.1 Property Ownership

Land parcels sampled were owned by 77% of participants, while 22% indicated the land parcel was rented (Figure 6).

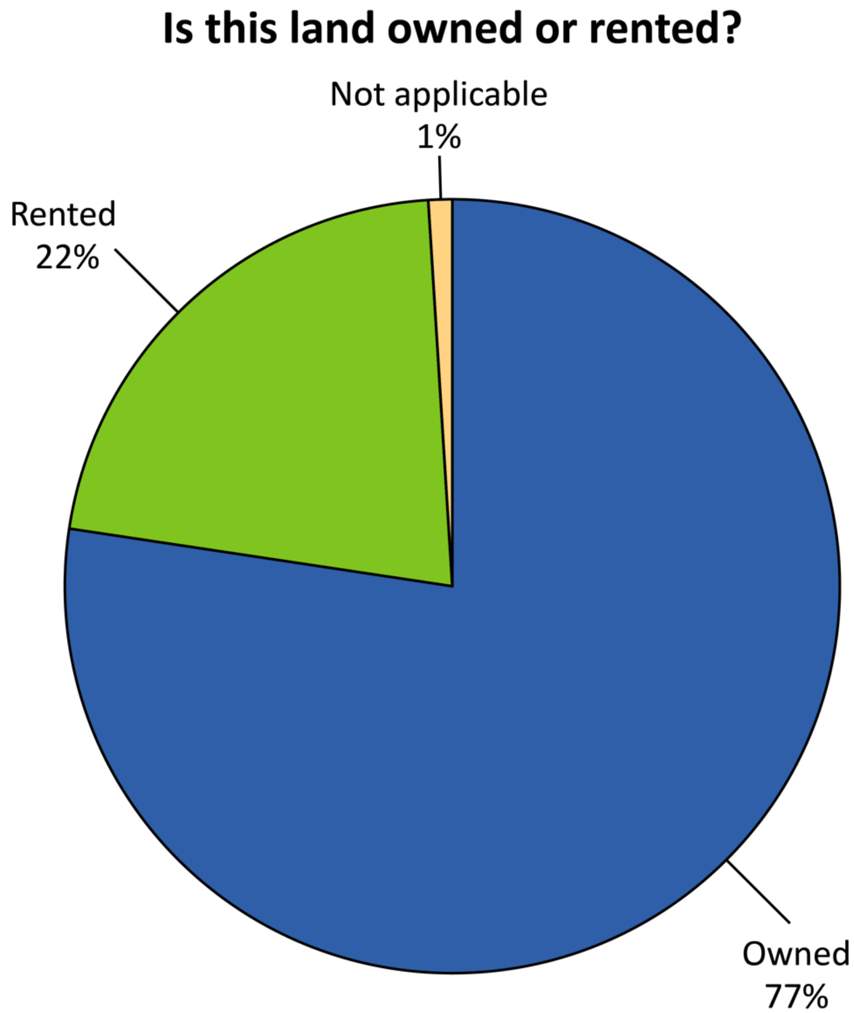

Figure 6. *Distribution of land ownership based on the land management questionnaire responses.*

4.1.2 Crop Types

The distribution of crops recorded during the sampling showed soybeans and corn as the two most commonly grown crops (Figure 7).

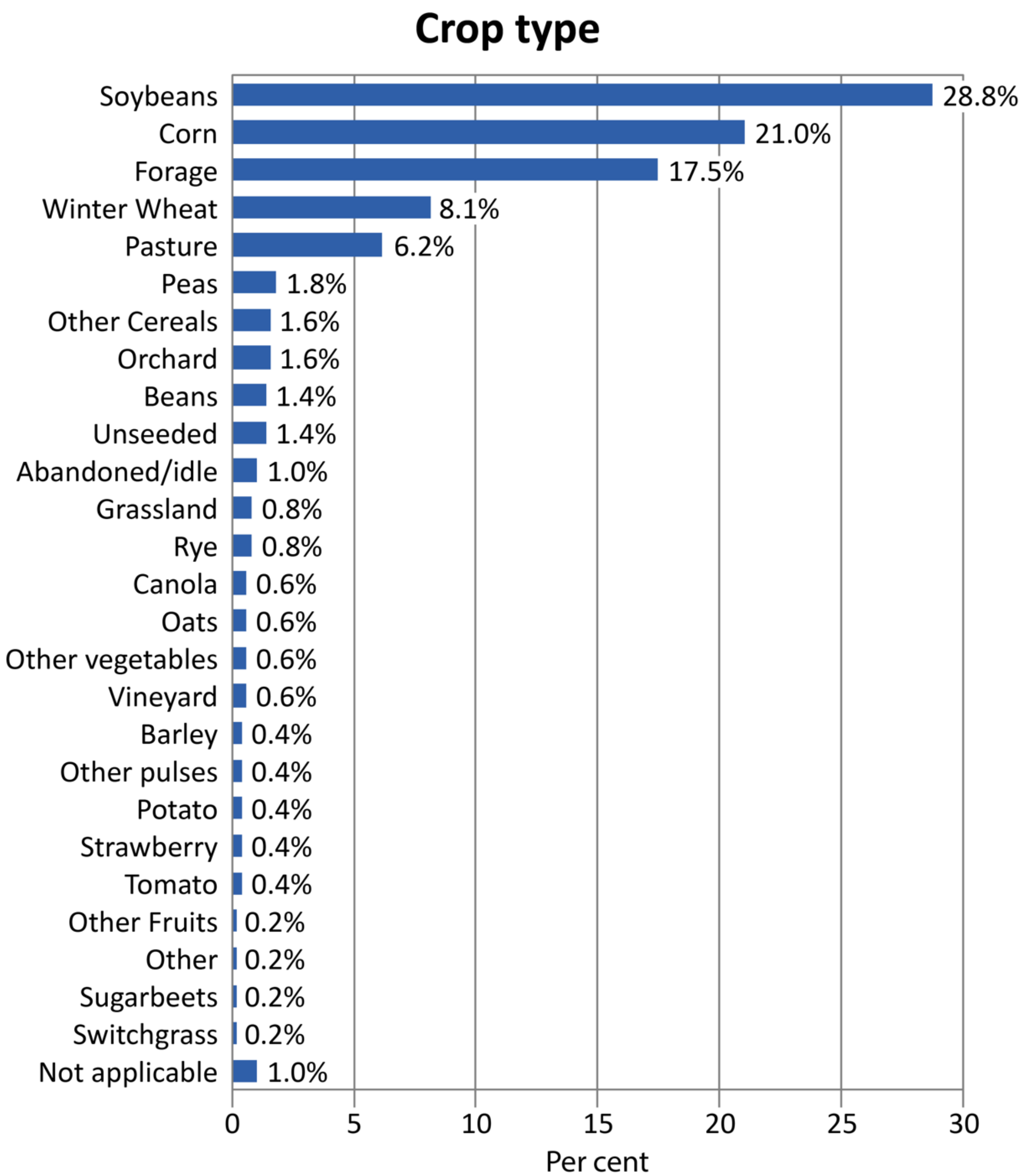

Figure 7. *Occurrence of crop types within the sampled fields.*

4.1.3 Crop Rotation and Cover Crops

Crop rotation with two or more crops was integrated into annual cropping systems by 91% of participants (Figure 8), and 63% of respondents indicated they used three or more annual crops in rotation (Figure 9).

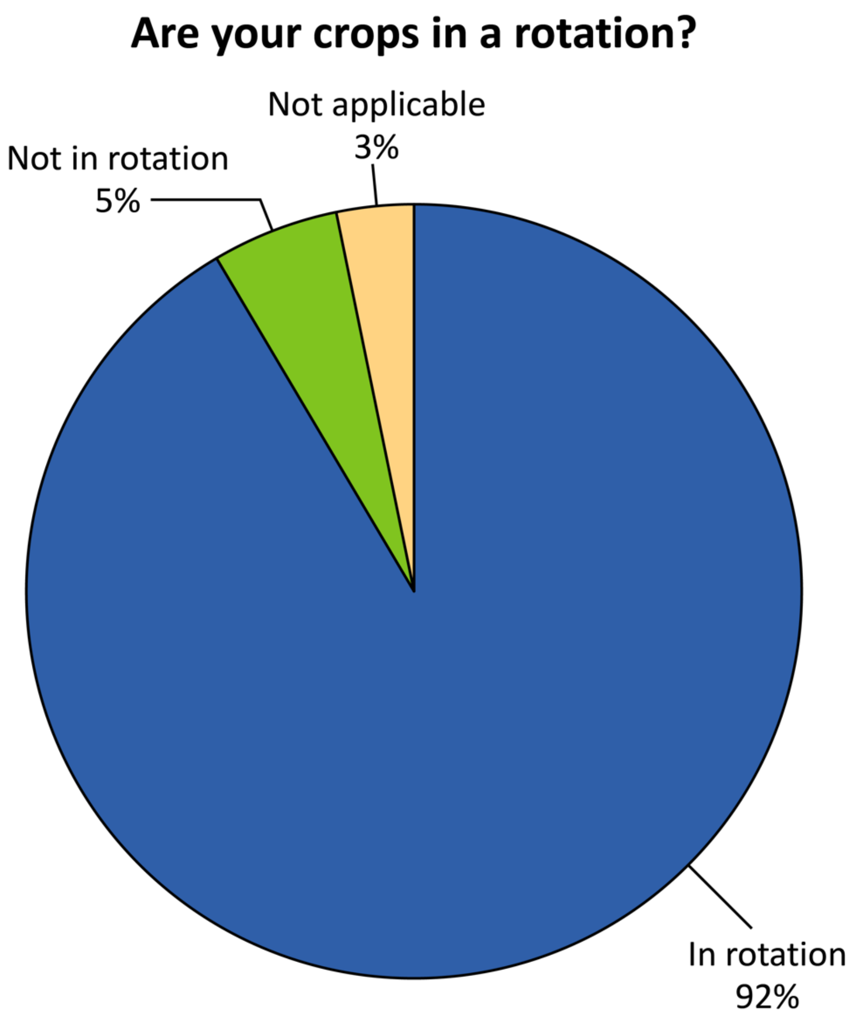

Figure 8. *Proportion of respondents using crop rotation as part of their farm management.*

For more information on how to incorporate crop rotation into your production system, refer to *Best Management Practices – Rotation of Agronomic Crops* and *Agronomy Guide for Field Crops*.

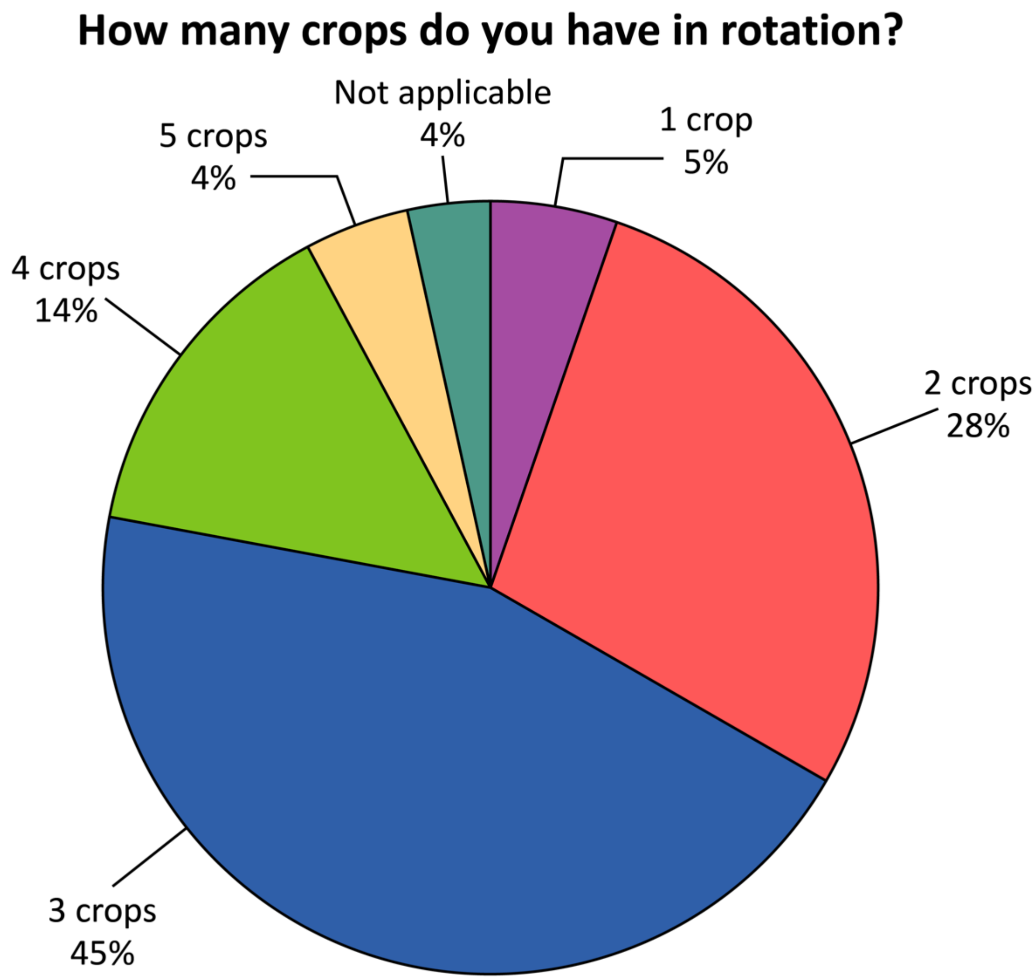

Figure 9. *Number of crops used in rotation based on project participant responses.*

A perennial crop (e.g., forage, hay) was not included in the annual cropping system of 69% of participants, while 27% indicated they do use a perennial in the rotation (Figure 10). The most common perennial used in an annual cropping system was a forage crop (e.g., hay).

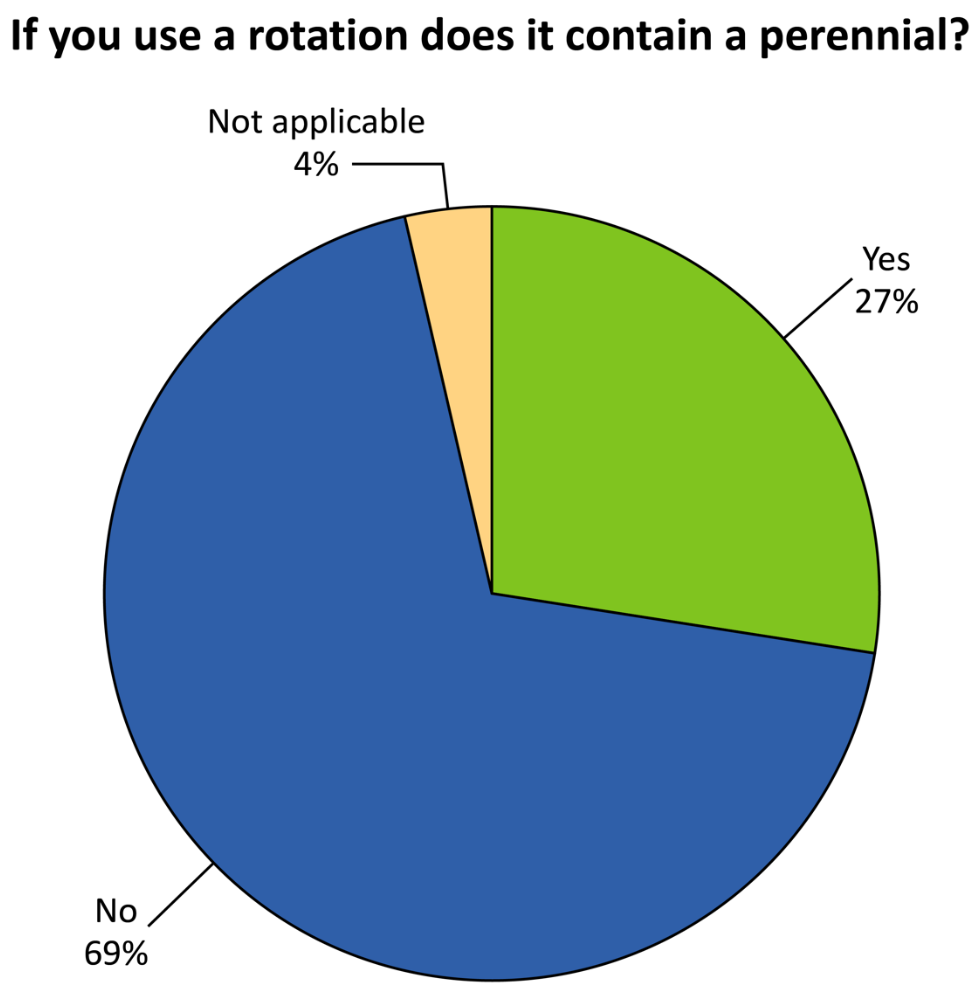

Figure 10. *Proportion of respondents using a perennial crop as part of the crop rotation.*

For more information, refer to *Best Management Practices – Perennial Systems*.

At least one cover crop was incorporated into annual cropping systems by 43% of participants. Further investigation of cover crop species within annual cropping systems indicated single species cover crops were most common at 29% (Figure 11).

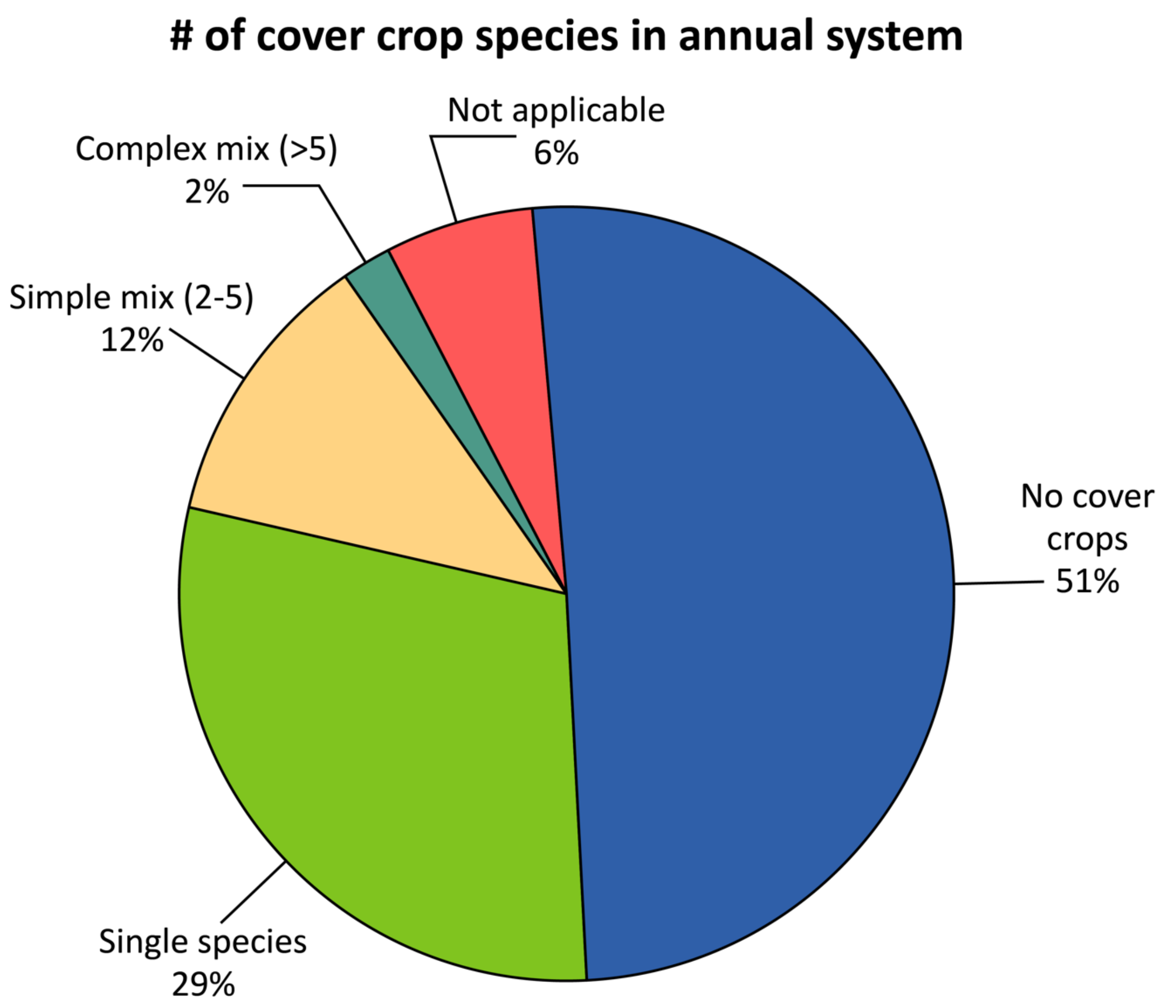

Figure 11. *Cover crop species mix for respondents in an annual cropping system.*

For more information, refer to *Best Management Practices – Winter Cover Crops* or the Midwest Cover Crop Council.

4.1.4 Organic Amendments

Organic amendments were not used by 42% of participants (Figure 12). Of those that used organic amendments, manure was the most commonly used type of organic amendment (46%). Use of biosolids and/or compost was relatively low (<5%).

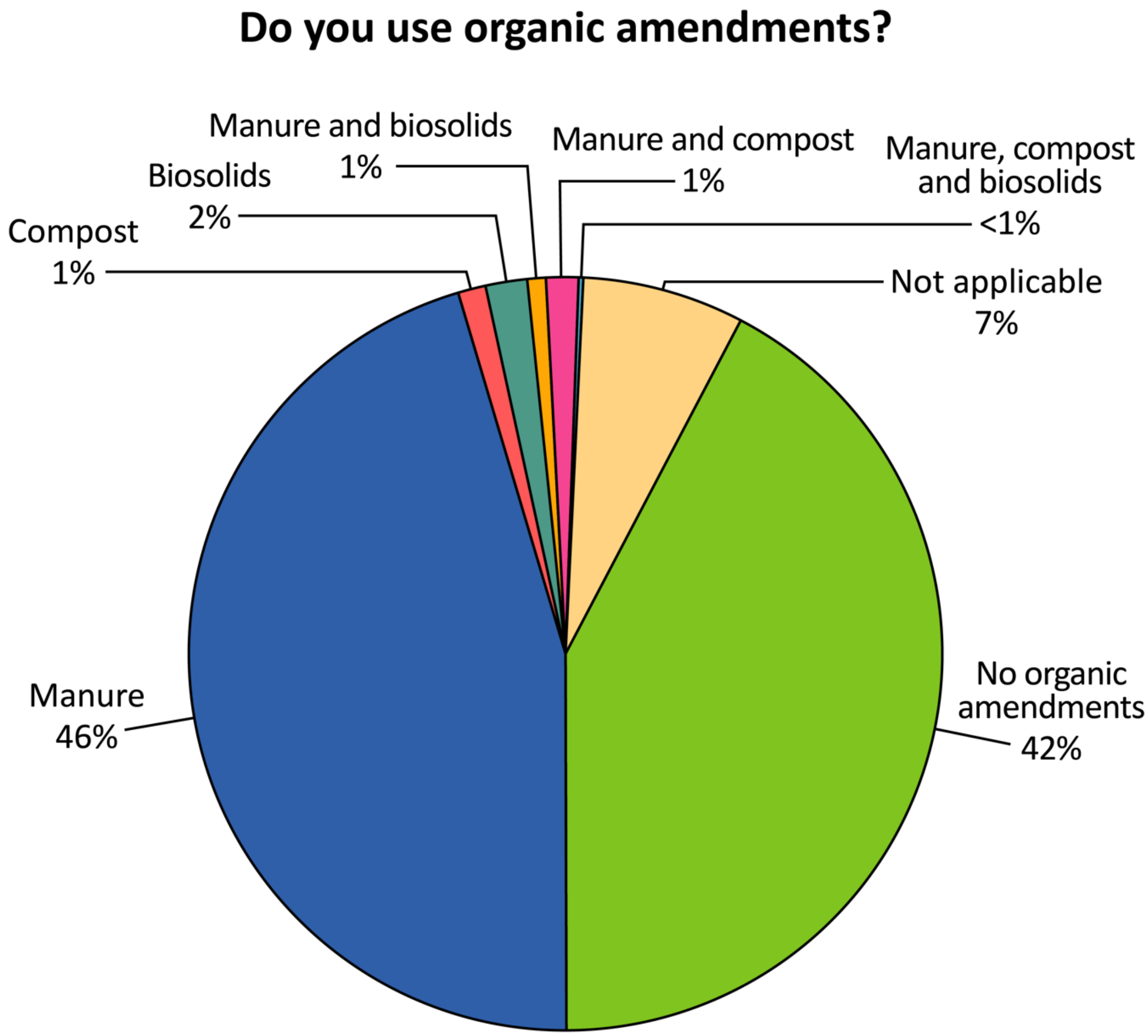

Figure 12. *Use and types of organic amendments across all cropping systems.*

For more information, refer to *Best Management Practices – Adding Organic Amendments* or *Best Management Practices – Cover Crops and Manure Application*.

4.1.5 Tillage

Low disturbance tillage practices (i.e., no till or strip/zone till) were used by 13% of participants, 29% indicated they used moderate disturbance tillage practices on their farm (two or less passes per year with disks/chisel plough) and 40% indicated they used high disturbance tillage practices on their farm (i.e., greater than two passes per year with disks/chisel plough or moldboard plough). No disturbance was classified as land not disturbed at all (e.g., pasture) and accounted for 13% of all responses (Figure 13).

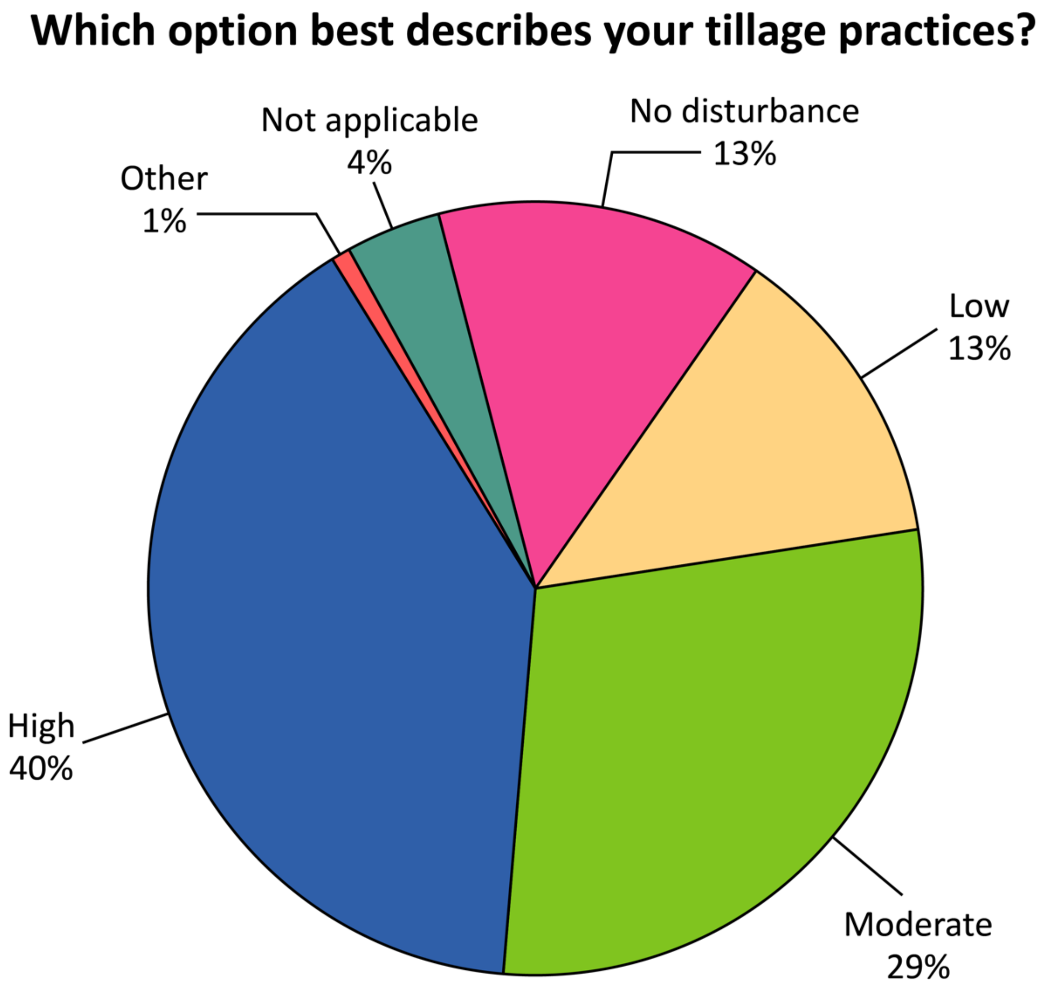

Figure 13. *Tillage intensity responses.*

4.2 Soil Properties and Soil Health Indicators

4.2.1 Topsoil Thickness

The lower slope position generally had the thickest topsoil (A) horizon with an average thickness of 25.8 cm (Figure 14). The mid and level slope positions had intermediate thickness, 24.4 cm and 24.5 cm, respectively. As expected, the upper slope position had the thinnest A horizons with an average of 22.8 cm. The difference in topsoil thickness may seem trivial, but calculations highlight the significance. For example, 1 cm of soil over an area of 1 hectare is equivalent to 136 metric tonnes of soil (assuming an average bulk density of 1.36 g/cm^3) and 4.8 tonnes of SOM (assume an average SOM concentration of 3.6%). Based on the 2016 Census of Agriculture, the average farm size in Ontario was 100 ha (249 acre). Therefore, for the average farm, a loss of 1 cm of topsoil would be equivalent to a loss of 13,600 tonnes of soil and 480 tonnes of SOM.

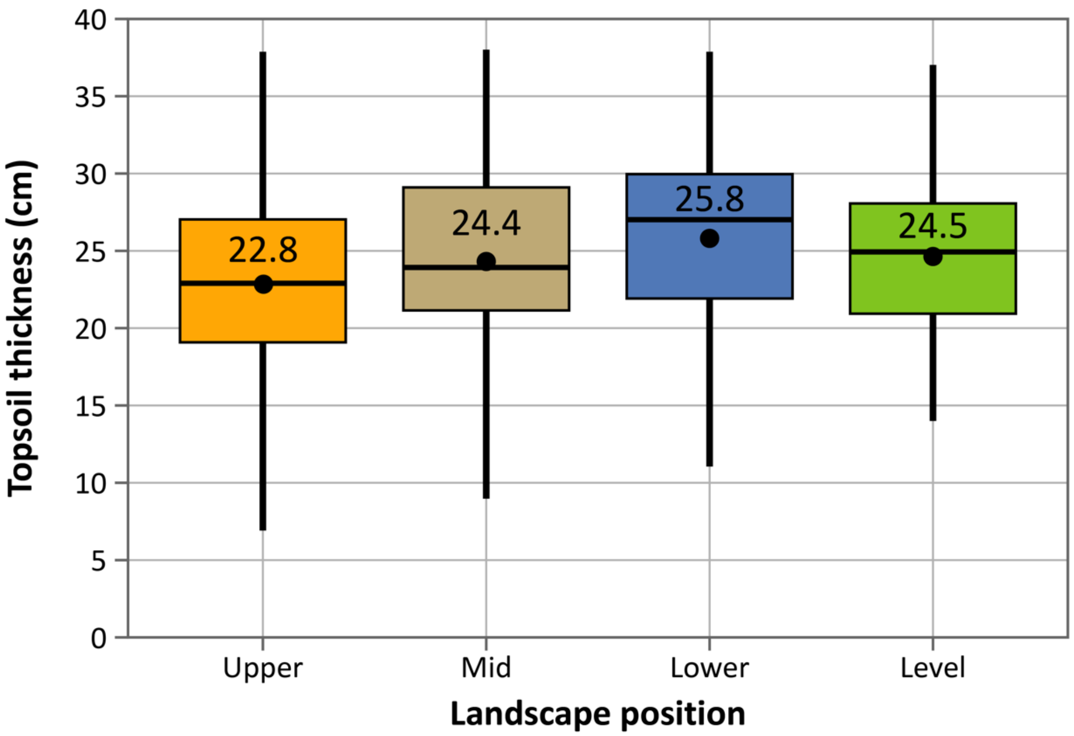

Figure 14. *Topsoil thickness compared across slope positions. Mean (average) values are indicated by the points and numbers shown inside each boxplot.*

For more information, refer to *Best Management Practices – Tillage Erosion* or *Best Management Practices – No Till for Soil Health*.

4.2.2 Influence of Soil Texture on Soil Health Indicators

As previously stated, soil texture has an important effect on other soil properties, including soil health indicators. Overall, most soil health indicator values increased from coarse to fine-textured soils (Figure 15). Aggregate stability is the exception with no trend across texture groups. This highlights the importance of considering soil texture when interpreting soil health in the field. Fine-textured soils have naturally higher values of soil health indicators.

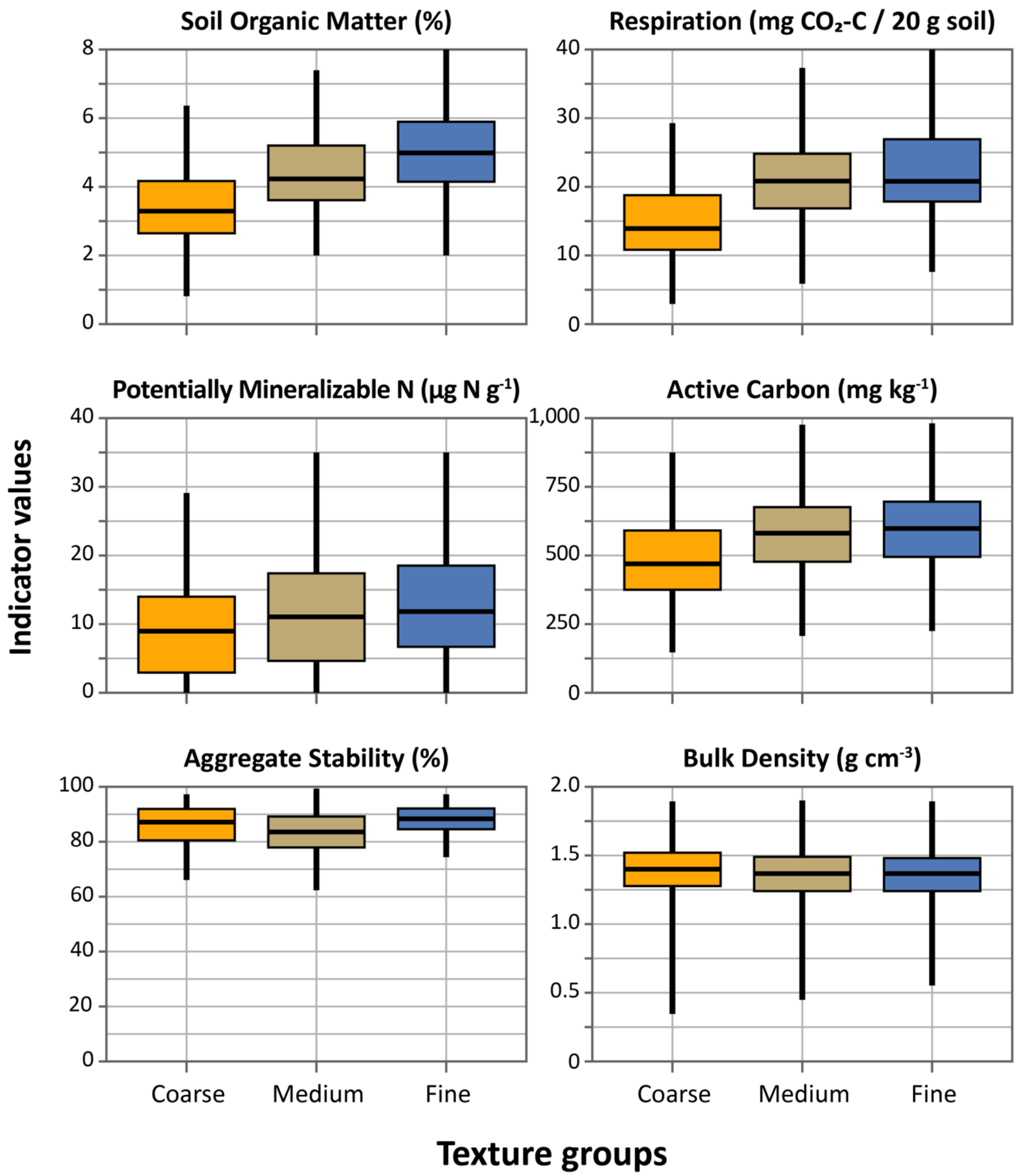

Figure 15. *Soil health indicators and bulk density trends as a function of texture groups.*

Bulk density affects chemical, physical and biological functions in the soil. It impedes proper root penetration and development. Ideal bulk density for plant growth is <1.1 g/cm^3 for fine-textured soils, <1.4 g/cm^3 for medium-textured soils and <1.6 g/cm^3 for coarse-textured soils (USDA-NRCS 2008). Root growth is restricted at a bulk density of 1.47 g/cm^3, 1.65 g/cm^3 and 1.80 g/cm^3 in fine, medium and coarse-textured soils, respectively (USDA-NRCS 2008). From the current work, the average bulk density of coarse-textured soils was found to be 1.40 g/cm^3 and is within the ideal range, whereas the average bulk density for medium-textured soils (1.36 g/cm^3) was at the upper end of the ideal range. The average bulk density for the fine-textured soils was found to be 1.35 g/cm^3 and is higher than the ideal range. These findings indicate compaction in approximately 12% of coarse-textured soils, 41% of medium-textured soils and 92% of fine-textured soils, all of which are above the ideal range in bulk density. This suggests that soil compaction is a widespread issue in Ontario and affects medium- and fine-textured soils disproportionately.

When soil bulk density is between the upper limit of the ideal range and the root restrictive number, root growth is affected, leading to reduction in productivity and yields. Unlike nutrient deficiencies which are identified by looking at a crop, the effects of soil compaction are not always as visible. For example, symptoms of compaction can include uneven crop growth (e.g., headlands) and inconsistent water infiltration after rain events (e.g., surface ponding). The surface compaction data reported here is in addition to subsurface compaction, a critical soil parameter not measured in this study.

For more information, refer to *Best Management Practices – Subsurface Compaction*.

4.2.3 Influence of Landscape Position on Soil Health Indicators

In sloping landscapes, soil health indicators tend to improve from the upper landscape positions to the lower landscape positions (Figure 16). This indicates that soils in upper slope positions within fields are the most degraded, commonly expressed as areas of below-average productivity. Multiple factors lead to the upper slope position being ranked the lowest based on soil health indicators, including water and tillage erosion, which result in net downhill movement of soils materials. Understanding the relationship between soil health and landscape position has implications when sampling a field to assess soil health. If upper slopes generally exhibit reduced soil health, it is advantageous to target these areas for sampling to quantify soil health and for selecting BMPs to address specific soil health concerns. It is also important to sample similar landscape positions if re-sampling a field in the future when tracking soil health, as sampling different slope positions could provide misleading information.

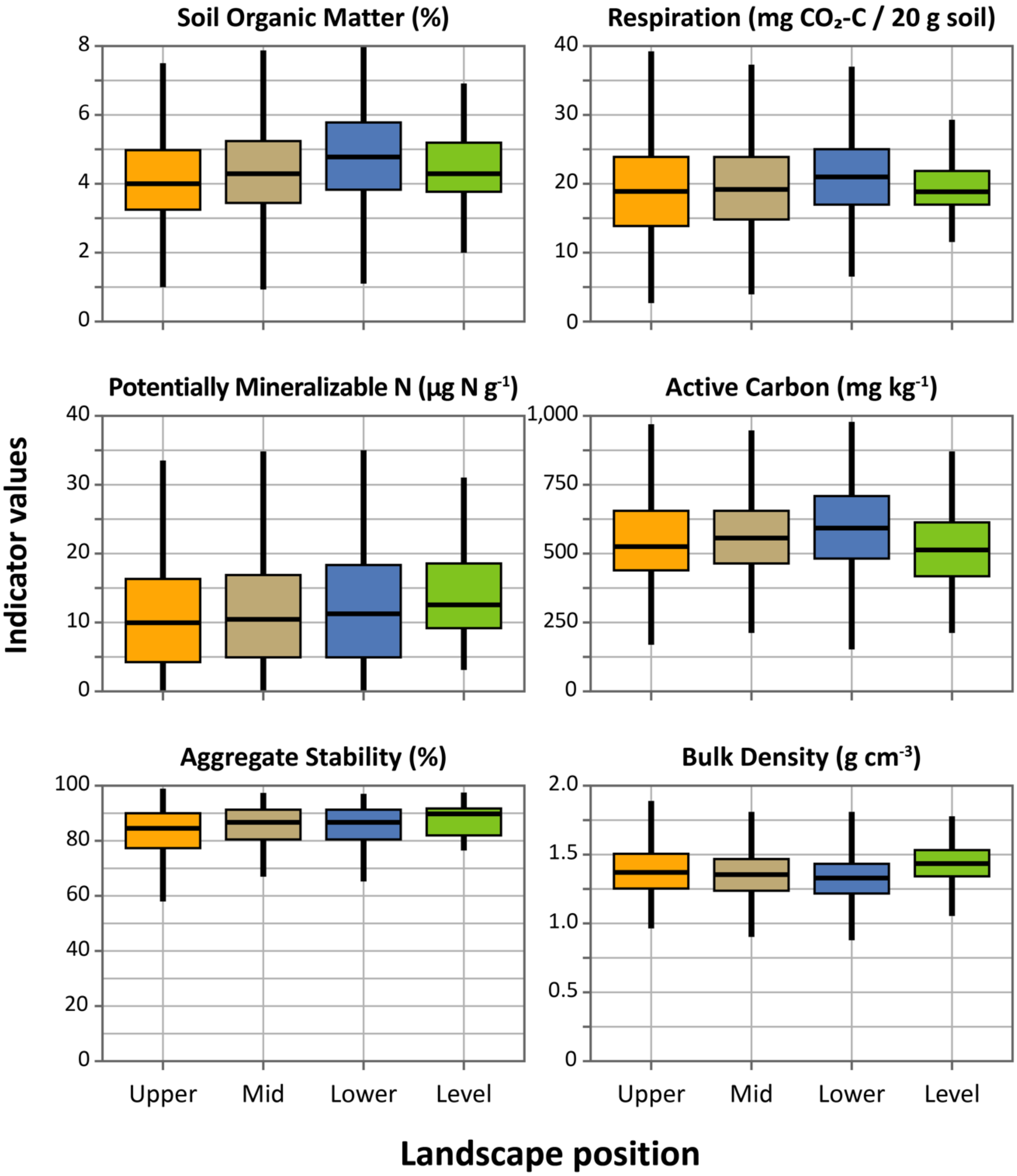

Figure 16. *Soil health indicators and bulk density trends as a function of landscape position.*

For more information, refer to *Best Management Practices – Soil Remediation.*

4.2.4 Influence of Cropping System on Soil Health Indicators

Using the crop rotation information provided by the project participants, sites were grouped into broader classes called “cropping systems”. Four cropping systems were created for this analysis, including Horticulture (32 observations), Annual (292 observations), Annual with Forage (107 observations) and Perennial (69 observations). Four respondents did not provide any cropping information. The Horticulture category was mostly annual cropping systems which had a vegetable in rotation (e.g., tomatoes), plus a few other specialty crops like vineyards and orchards. The Annual category was mainly cash-crops, different rotations which included corn, soybean and wheat. The Annual with Forage category was also mainly cash-crops, but included a forage in the rotation (e.g., hay). The Perennial category included hay and pasture fields.

Soil health indicators had higher values as the cropping systems became more perennialized (Figure 17). Perennial cropping systems had the highest soil health indicators and in contrast, intensively-managed annual horticultural crop systems had the lowest soil health indicator values. Note that by adding perennials into an annual cropping system, soil health indicators increased (i.e., annual vs annual with forage). It should also be noted that horticultural crops are often grown on coarser-textured soils, which have lower inherent soil health (Figure 15). A comprehensive understanding of soil health requires information about the production system and soil texture. While this project provides a baseline of information for interpreting soil health in Ontario, more sampling is required to better understand the interactions between soil texture and cropping systems. Across all annual cropping systems evaluated, soil health can be improved by adding diverse crop rotations, implementing proper residue management, using no-tillage or reduced tillage, applying organic amendments and incorporating legume-based cover crops or over-wintering cereals into the rotation.

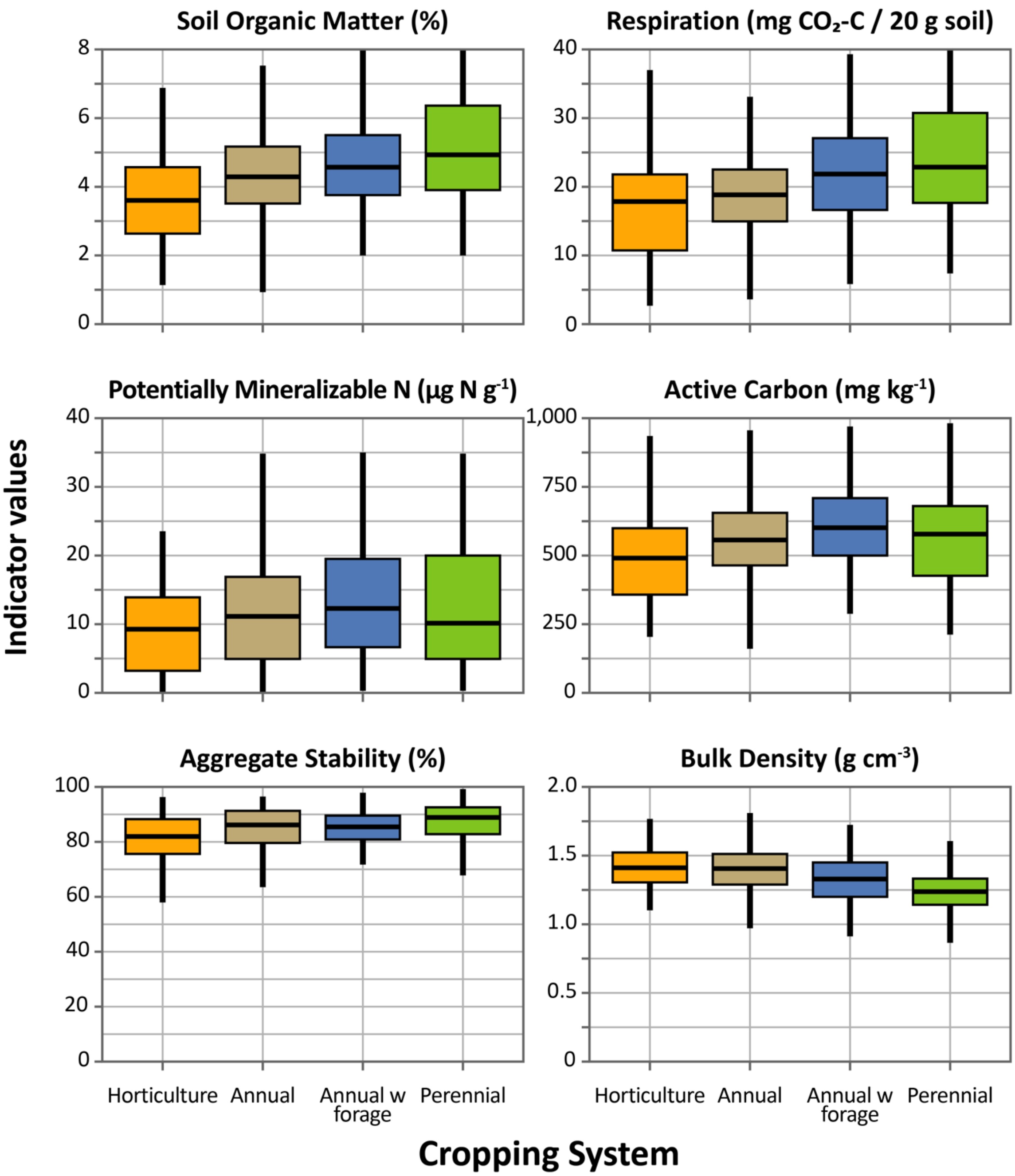

Figure 17. *Soil health indicators and bulk density trends as a function of cropping system.*

For more information, refer to *Best Management Practices – Horticultural Crops* and *Best Management Practices – Soil Health in Ontario*.

4.3 Interpretation of Soil Health Indicators

To interpret the soil health indicators, a "higher is better" approach was used to assign scores that ranged from 0 to 100, where high score values indicated greater soil health. The exception was for bulk density, where a "lower is better" approach was used to determine the scores. Soil health scores were categorized into ratings of very low (0–20), low (20–40), medium (40–60), high (60–80) and very high (80–100) classes. To help with interpretation, a five-colour scale consisting of red, orange, yellow, light green and dark green, was applied to each rating. The scores were determined using the range of values observed for the soil health indicators across Ontario and statistical analysis to convert those values to values ranging from 0 to 100.

Since soil texture has a significant controlling effect on some soil health indicators, where appropriate, independent scoring curves were developed for coarse-, medium- and fine-textured soils. The scoring curves reflect the full range of soil health values observed in the OTSP and are used to rate the relative soil health of soils in Ontario. This means the scoring, or interpretation, of the indicators is relative to Ontario-specific conditions.

As discussed earlier in the report, the cropping system is also integral to the interpretation of soil health. While this report provides a baseline to interpret soil health based on differences in texture, additional sampling is required to further evaluate the combined effects of soil texture and cropping system on soil health indicators. For this reason, scoring curves presented are based on differences in soil texture alone.

To use the scoring curve plots, an example is provided for a soil sample with SOM content of 5% (Figure 18). Drawing a vertical line (black arrow) from the bottom of the plot at 5% SOM, all three soil texture curves are intersected. Where the vertical line intersects the scoring curve, a horizontal line is drawn to the "Score" axis. In this example, a soil test of 5% SOM results in a soil health score of approximately 50 for fine-textured soils, 70 for medium-textured soils, and 90 for coarse-textured soils. This reflects the inherent ability of finer-textured (i.e., more clay-rich) soils to store more organic matter than coarser-textured (i.e., more sand-rich) soils.

Figures 18 to 23 show the scoring curves for soil organic matter, respiration, potentially mineralizable nitrogen, active carbon, aggregate stability and bulk density. Like the SOM example, results for these analyses can be plotted to determine the soil health score for that metric. Use the SHAP to enter lab results and get a corresponding soil health score for the soil health indicators.

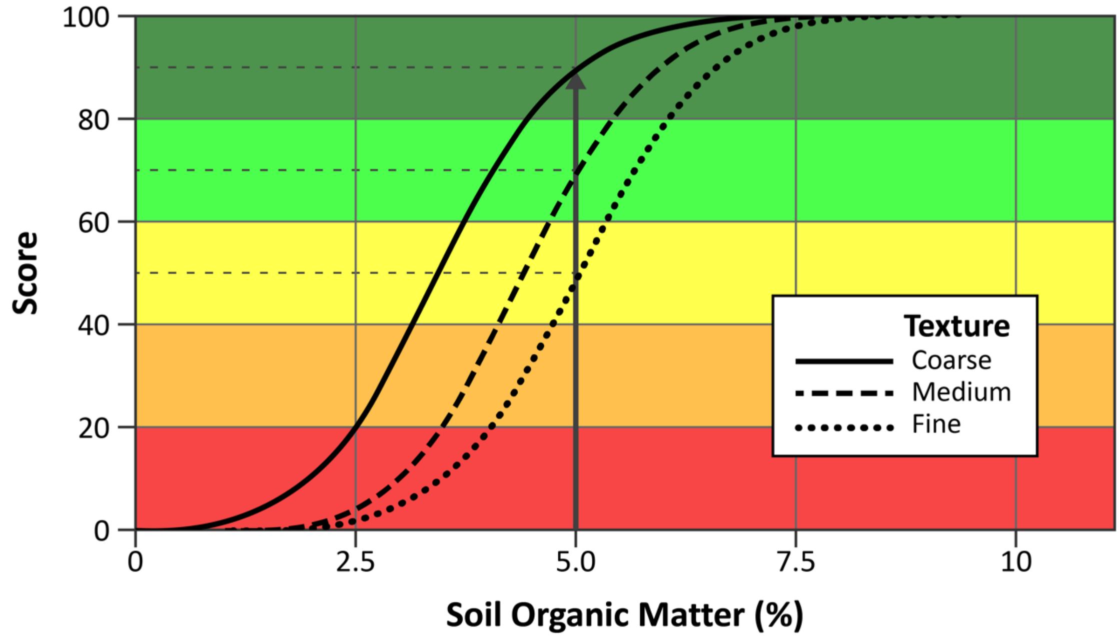

Figure 18. *Soil organic matter soil health interpretation curve.*

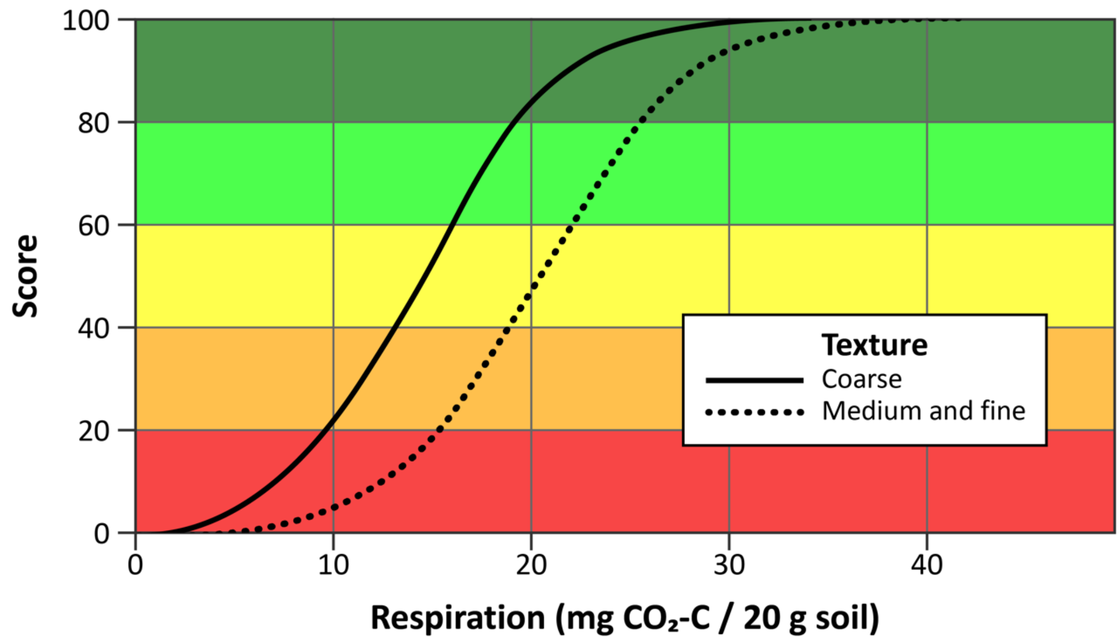

Figure 19. *Respiration soil health interpretation curve.*

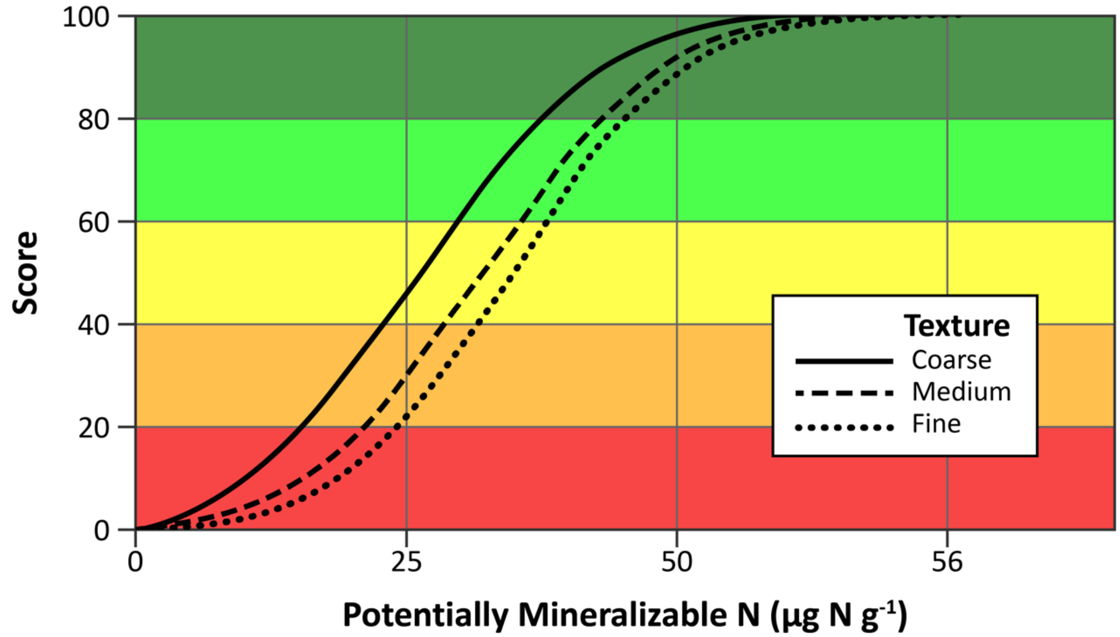

Figure 20. *Potentially mineralizable nitrogen soil health interpretation curve.*

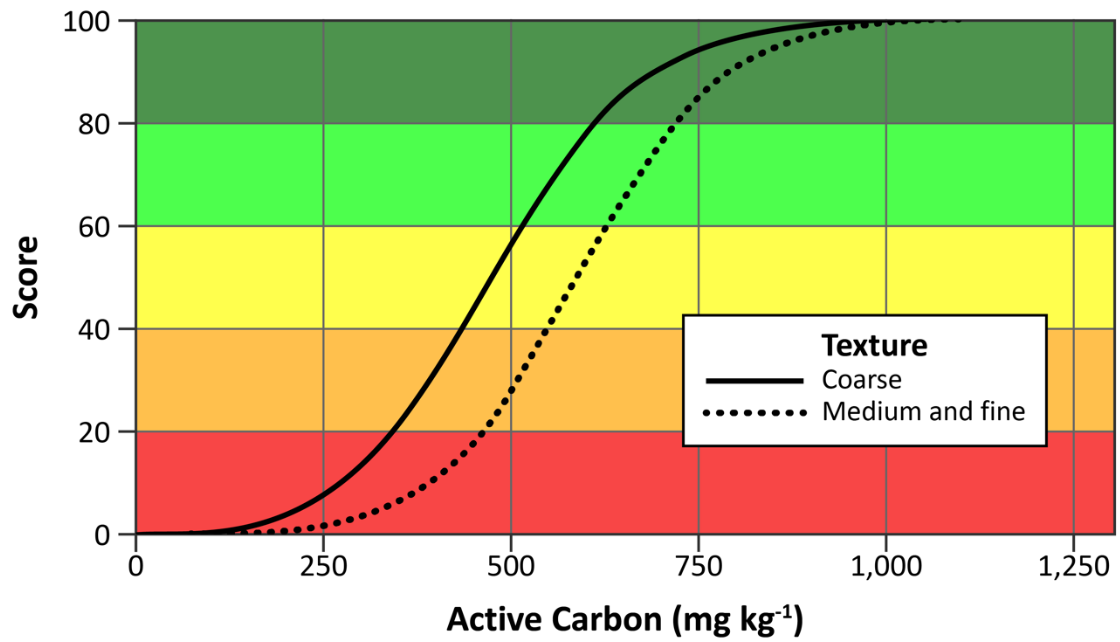

Figure 21. *Active carbon soil health interpretation curve.*

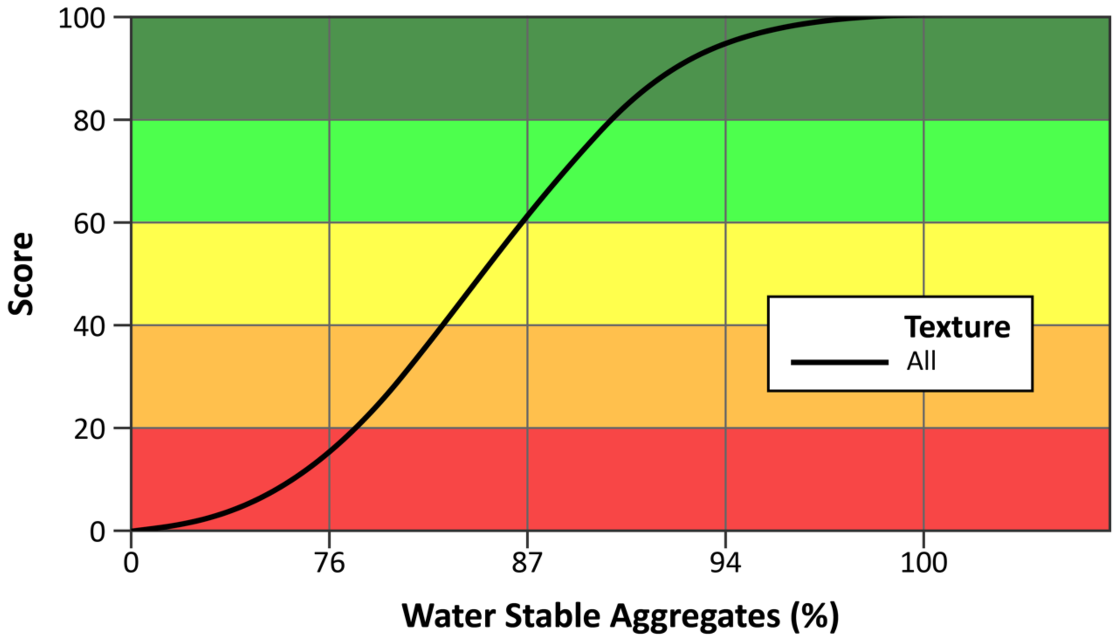

Figure 22. *Water stable aggregates soil health interpretation curve.*

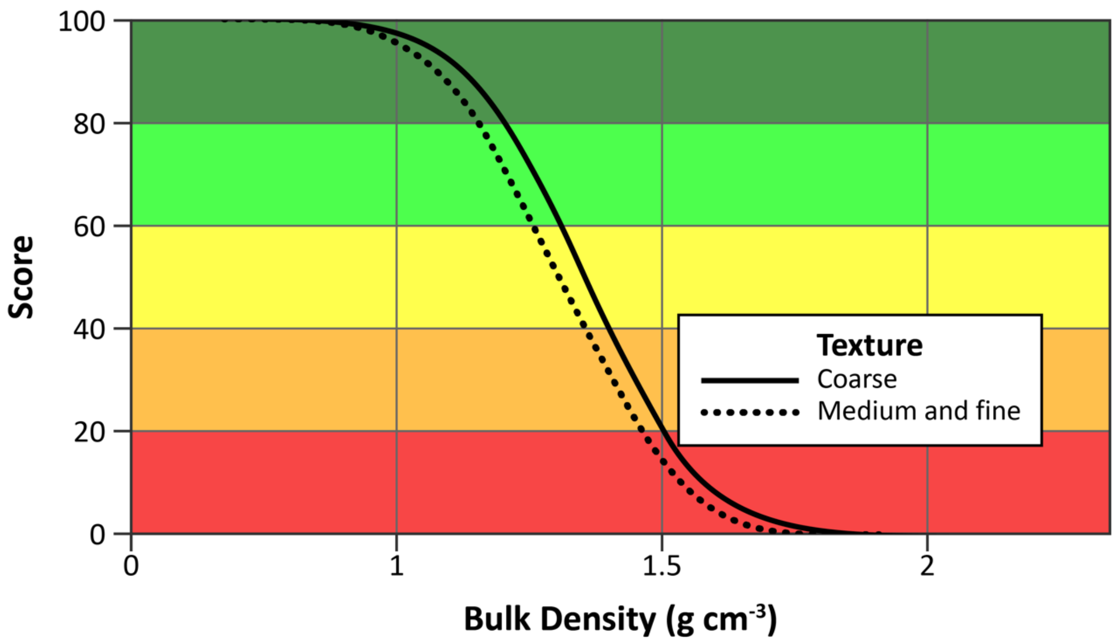

Figure 23. *Bulk density soil health interpretation curve.*

5. Summary and Conclusions

The purpose of the Ontario Topsoil Sampling Project was to establish baseline information for indictors of soil health in Ontario. In conclusion, soil texture, landscape position and cropping system are all important factors that influence soil health indictors. Scoring curves help in the interpretation of soil health indicators that are specific to Ontario conditions.

For detailed information on the SHAP developed for Ontario conditions, refer to the Soil Health Assessment and Plan Guidebook.

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SHAP