# Correction: Soil organic carbon content: decreases partly attributed to dilution by increased depth of cultivation in southern Ontario

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SHORT COMMUNICATION

# Soil organic carbon content: decreases partly attributed to dilution by increased depth of cultivation in southern Ontario

C.J. Warren, D.D. Saurette, and A.W. Gillespie

**Abstract:** Soil organic carbon contents and depths of Ap horizons (i.e., cultivated topsoil) from Ontario soil survey reports were reviewed, analyzed, and compared from 1950 to 2019. Organic carbon concentrations have declined from 2.85% to 2.34% in Ap horizons, whereas depths have increased by 40%. Considering the entire Ap horizon depth, we show that soil carbon stocks (kg C·ha$^{-1}$) may be constant or increasing. Losses of organic carbon due to cultivation should not be discounted; however, dilution of organic carbon within a deeper plow layer may contribute significantly to observed decreases in organic carbon concentrations in topsoil.

*Key words:* soil organic carbon, topsoil depth, carbon stock, carbon concentration, cultivation, plow layer.

**Résumé :** Les auteurs ont examiné les relevés pédologiques de l'Ontario de 1950 à 2019 pour établir et comparer la concentration de carbone organique et l'épaisseur de l'horizon Ap (à savoir le sol de surface cultivé). La concentration de carbone organique dans l'horizon Ap est passée de 2,85 % à 2,34 %, alors que l'épaisseur de ce dernier a augmenté de 40 %. Prenant en compte l'horizon dans son entièreté, les auteurs montrent que les réserves de carbone dans le sol (kg de C par hectare) pourraient bien être constantes, voire augmenter. Certes, il ne faudrait pas négliger les pertes de carbone organique attribuables au travail du sol, mais la dilution de cet élément dans une semelle de labour plus épaisse pourrait expliquer dans une large mesure la baisse de la concentration de carbone organique dans la couche de sol superficielle. [Traduit par la Rédaction]

*Mots-clés :* carbone organique du sol, épaisseur de la couche de surface, réserves de carbone, concentration du carbone, travail du sol, semelle de labour.

## Introduction

Soil organic carbon (SOC) is the largest terrestrial reservoir of carbon containing more than terrestrial vegetation and the atmosphere combined. In agricultural soils, organic carbon stocks are fundamental for sustained food production and maintaining soil health by improving water dynamics, nutrient availability, and plant root growth. In addition, soil management practices such as tillage, types of crops grown, crop rotation, inclusion of cover crops, and application of animal and green manures all influence the level of SOC in agricultural soils. The link between SOC and soil health has brought increased interest in monitoring SOC levels in agricultural soils. Soil organic carbon levels have become an important baseline metric, and tracking soil organic C through time can be a powerful gauge of soil health changes, made possible because SOC has long been a part of standard soil analytical test suites and is available in many legacy soil datasets.

Field observations for the depth of soil Ap horizons in the Province along with reported decreases in soil carbon concentrations prompted a review of legacy Ontario soil survey reports. There is evidence indicating that concentrations of SOC are declining in general in agricultural soils (e.g., Smith 2008). Review of data from legacy soil survey reports from southern Ontario indicated that concentrations of SOC in topsoil have indeed decreased (AAFC 2012); however, it was also observed that the average depth of cultivation has gradually increased since 1950 to the point where thicknesses of

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**Table 1.** Average concentration of soil organic carbon (SOC), thickness of Ap horizon, and calculated carbon stock for three time periods based on a total of 4183 data points.

| Time period | No. of samples | SOC (%) | | Ap depth (cm) | | Carbon stock ($t{\cdot}ha^{-1}$) | |
|---|---|---|---|---|---|---|---|
| | | Mean | SD | Mean | SD | Mean | SD |
| 1950–1980 | 323 | 2.85a | 1.47 | 17.8a | 6.1 | 659a | 389 |
| 1980–2000 | 1490 | 2.42b | 1.30 | 23.9b | 8.2 | 783b | 516 |
| 2000–2019 | 2370 | 2.34b | 1.16 | 25.1c | 6.8 | 790b | 451 |

**Note:** Different lowercase letters indicate significant differences at the 99.9% level of significance. SD, standard deviation.

cultivated topsoil (i.e., Ap horizons), in some cases, have increased by about 40% during this time period. The increase in Ap horizon depth has the potential to show apparent decreases in soil C concentrations through dilution; however, increases in plow layer depth may not have been given full consideration as an influence over total soil C storage in the landscape. The objective of this study, therefore, was to collate legacy soil data to compare the changes of surface horizon thicknesses of Ap horizons in agricultural soils with changes in the concentration of SOC during the same time period.

## Materials and Methods

Data for the depth of soil Ap horizons and soil organic matter content were summarized from data available in more than 40 legacy reports from 1950 to 1992. Legacy carbon data reported as total soil organic matter (SOM) contents (obtained through wet or dry oxidation methods) were converted to SOC by dividing by a factor of 1.724. Data for SOC were also obtained from recent pedological investigations (2015–2019, unpublished) conducted by OMAFRA in the County of Peterborough (518 sites); Regional Municipality of Ottawa (1682 sites), and 664 sites from other areas of the province concentrated primarily in southwestern Ontario. The data were tabulated and summarized as described below. Values for carbon stock were calculated by multiplying the concentration of SOC by the thickness of Ap horizon as reported in the legacy reports. Where bulk density data were not available, a constant of 1350 $kg{\cdot}m^{-3}$ was assumed for the purposes of the calculation.

## Results

Concentrations of organic C in the Ap horizons of Ontario soils showed a significant ($P < 0.01$) decrease since 1950, from a mean of 2.85% during the span of 1950–1980, to 2.42% during the span of 1980–2000, and to 2.34% during the span of 2000–2019 (Fig. 1; Table 1). This represents an average SOC decrease of approximately 0.008% annually (Fig. 1). The regression output from this analysis showed a low $R^2$ value; however, the negative slope was statistically significant. Based on analysis of the Ottawa and Peterborough data, the mean SOC content of the horizons directly below the Ap horizons was 0.64% and 0.86%, respectively.

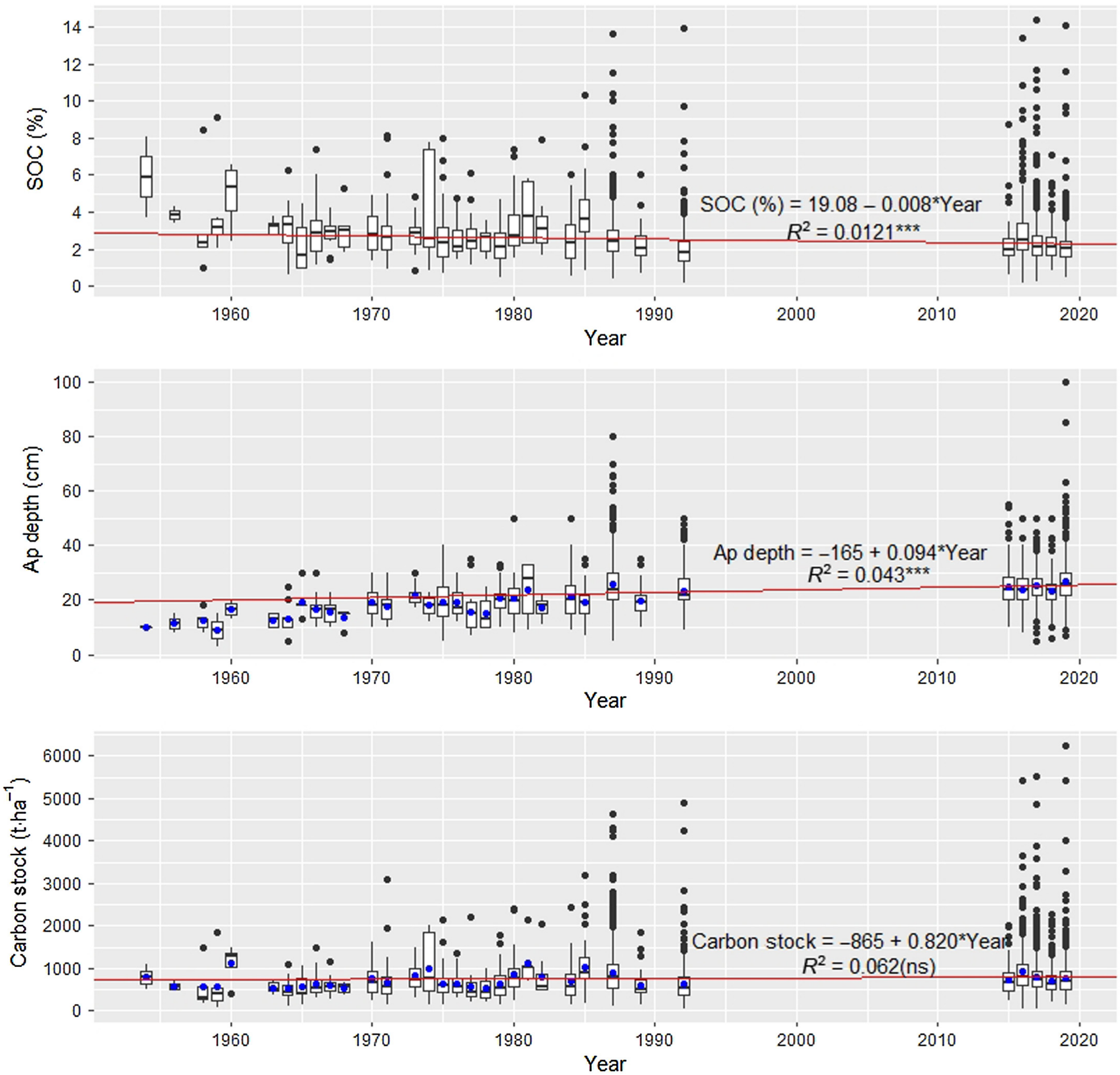
Topsoil thicknesses showed a significant increase since 1950, from an average of about 17.8 cm during the 1950–1980 time period, to an average of about 23.9 cm by 1980–2000; and to 25.1 cm by 2000–2019 (Table 1; Fig. 1). This represents an average constant increase of approximately 0.1 $cm{\cdot}yr^{-1}$ for the 70 yr period assuming a simple linear relationship (Fig. 1). When considering changes in the entire Ap horizon depth, calculated values for C stock in Ontario agricultural soils appear to have increased slightly pre-1980 to post-1980 but has not changed significantly since (Table 1; Fig. 1).

## Discussion

Standard sampling protocols for the purposes of soil fertility testing in Ontario recommend that surface samples be collected from the 0–15 cm depth increment (Munroe 2018). Although this sampling practice is considered appropriate for estimating soil fertility levels, it may perhaps contribute to overestimation of carbon losses from soil when estimating carbon stock in soil for environmental purposes. International guidelines for SOC stock calculations recommend a target depth of 30 cm (FAO and ITPS 2018; FAO 2019).

Tillage of the soil has been synonymous with agriculture for millennia evolving from human labor with hand tools to draft animals followed by steam and gas-powered machinery. Ease of cultivation has increased tremendously in the last 60 yr with increases in the mass of modern farm equipment (Schjonning et al. 2015). Tractor mass has increased by an average of about 0.4 $t{\cdot}yr^{-1}$ since the introduction of diesel-powered tractors in about 1960 (Shearer 2017). The increase in tractor mass appears to be directly related to a concomitant increase in the depth of cultivation and, therefore, the thickness of Ap horizons in agricultural soils (Fig. 1). Based on the measured carbon concentrations of Ap horizons for 0–15 cm samples, the content of organic carbon appears to decrease on a percentage basis (Fig. 1), with the loss of carbon attributed mainly to increased oxygenation of the soil mass, which contributes to organic carbon oxidation and loss as $CO_2$. It should be

**Fig. 1.** Boxplots for concentration of organic carbon (SOC %); depth (cm) of Ap horizons and calculated stock of organic carbon compiled from Legacy Ontario Soil Survey Reports and recently collected pedological data from southern Ontario. Dots inside of boxes indicate means; Dots outside of boxes indicate outliers. Value for $R^2$ is significant at the 99.99% confidence level***. Values of ns for $R^2$ are not significant. [Colour online.]




recognized that soil carbon initially confined to roughly the upper 15 cm of a soil profile prior to cultivation has become progressively diluted and mixed deeper into the profile (i.e., in many cases, up to approximately double the depth). Consequently, a soil initially containing, for example, 4% organic carbon in a 0–15 cm thick topsoil in the 1950s could in the present day potentially contain a measured carbon concentration of 2% with net loss of zero carbon with the apparent decrease owing simply to dilution with the increased depth of cultivated topsoil (Ap horizon). This observation demonstrates that direct comparison of organic carbon levels on a percentage basis with time is not an accurate means of comparison.

The mass of organic carbon stored in agricultural soils of Ontario was calculated from average soil organic matter values derived from legacy Ontario soil survey reports combined with reported topsoil thicknesses for years spanning from 1954 to 1992; while, more recent values were obtained directly (Fig. 1). Based on this calculation, the average mass of organic carbon stored in agricultural soils in Ontario was 659 t·ha$^{-1}$ before

1970 and 790 t·ha$^{-1}$ after the year 2000 (Table 1). Although this is an apparent increase in the average organic carbon stock in Ontario agricultural soils, the apparent increase is not statistically significant (Fig. 1). Although beyond the scope of this study, erosion and depositional processes are also strong drivers of organic carbon redistribution and dilution across landscapes (Gregorich et al. 1998), which may exacerbate observed carbon dilution in topsoil. It is important to recognize that losses of organic carbon from soil due to oxidative processes attributed to cultivation activities should not be discounted but rather, dilution due to increased topsoil depth should also be recognized and given due consideration.

There are potential implications for recent national and global predictions of SOC (FAO and ITPS 2018). Projects such as SoilGrids250 and Global Soil Map provide predicted maps of SOC concentrations at standard depths (0, 5, 15, 30, 60, 100, and 200 cm). The training data used for these predictions are sparse; therefore, legacy data collected over many years are combined without consideration for the temporal aspects which is a recognized limitation of the predictions. Based on our findings, overestimation of carbon concentrations in the upper prediction depths (0, 5, and 15 cm) is likely for regions when older data dominates. Despite the redistribution of SOC with depth, the stock estimates based on our recent data likely do not suffer the same issue, given that stock estimates have been made only for the 0–30 cm interval, which coincides roughly with the average current thickness of plow layers in Ontario.

Changes in the concentration of carbon and in the thickness of topsoil due to tillage also have profound implications on sustainable farming and soil fertility. Although we demonstrate here that C stocks may be unchanged with time, dilution of SOC still has the consequence of reducing the agronomic benefits. Soil fertility is impacted because any increase in the depth of Ap horizons comes through incorporation and at the expense of subsoil material. In southern Ontario, subsoil is generally less fertile than topsoil (Munroe 2018) and contains far less organic carbon (roughly 3.3 times less based on the current data). Subsoil composed of leached material (Ae horizons) can reduce the cation-exchange capacity and water-holding capacity. Materials incorporated from even deeper in the profile (B horizon materials) may contribute to nutrient losses due to chemical fixation (e.g., phosphate or potassium).

## Conclusion

Based on our review of legacy Ontario soil survey reports combined with recently collected pedological data, the average concentrations of organic carbon measured in cultivated Ontario topsoil (Ap) horizons have decreased at a rate of about 0.008% SOC per year during the past 70 yr. At the same time, the average thickness of Ap horizons has increased by approximately 0.1 cm·yr$^{-1}$. The observed reduction in the content of SOC in the 0–15 cm depth in agricultural soils in southern Ontario expressed as a percentage by mass is partially due to increased depth of cultivation and incorporation of SOC into a larger volume of soil. Although the average concentration of organic carbon in agricultural topsoil of Ontario may have decreased, a significant amount of the apparent loss may be attributed strictly to dilution of the carbon into a larger volume of soil due to increased tillage depth. Comparisons should include a depth component for the surface horizon and should be expressed on a carbon storage basis (e.g., t·ha$^{-1}$). Further research is needed to examine the full influence of Ap thickness on SOC content.

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We thank Laura McFarlane (currently University of Saskatchewan) for support with data assembly and Alex Barrie (OMAFRA) for providing reference materials for masses of farm equipment.

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Canadian Journal of Soil Science

Correction

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We discovered an error by a factor of 10 in our calculations for carbon stock in this published paper. This error does not affect any findings or conclusions.

In the abstract, the unit was kg C·ha$^{-1}$, but should instead be t C·ha$^{-1}$:

> Considering the entire Ap horizon depth, we show that soil carbon stocks (t C·ha$^{-1}$) may be constant or increasing.

In the French translation:

> Prenant en compte l'horizon dans son entièreté, les auteurs montrent que les réserves de carbone dans le sol (t de C par hectare) pourraient bien être constantes, voire augmenter.

On pages 337–338, the sentence should read as follows:

> Based on this calculation, the average mass of organic carbon stored in agricultural soils in ON was 65.9 t·ha$^{-1}$ before 1970 and 79 t·ha$^{-1}$ after the year 2000 (Table 1).

Please see the amended Table 1 and Fig. 1 on the following pages.

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| 1980–2000 | 1490 | 2.42b | 1.30 | 23.9b | 8.2 | 78.3b | 51.6 |
| 2000–2019 | 2370 | 2.34b | 1.16 | 25.1c | 6.8 | 79.0b | 45.1 |

**Note:** Different lowercase letters indicate significant differences at the 99.9% level of significance. SD, standard deviation.

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