

**Drivers of soil C quality and stability: Insights from a topsoil dataset at landscape scale in Ontario, Canada**

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**Table S1** Within each soil textural class, interactive effect of cropping system and tillage intensity treatment on the soil C indicators in the Ontario Topsoil Sampling Project from 2019 to 2022.

| Soil textural class                                                   | Cropping system | n   | Conventional tillage <sup>z</sup> | Moderate disturbance | Light disturbance | No disturbance <sup>y</sup> | No-tillage    |
|-----------------------------------------------------------------------|-----------------|-----|-----------------------------------|----------------------|-------------------|-----------------------------|---------------|
|                                                                       |                 |     | SOC (mg g <sup>-1</sup> )         |                      |                   |                             |               |
| Coarse                                                                | Annual grain    | 163 | 17.7 (1.40) <sup>x</sup>          | 14.8 (1.20)          | 18.9 (1.00)       | 13.3 (3.10)                 | 16.7 (2.00)   |
|                                                                       | Forage          | 52  | 19.4 (5.60)                       | 19.4 (1.90)          | 20.4 (1.80)       | 17.3 (3.30)                 | 16.8 (3.60)   |
| Medium                                                                | Annual grain    | 307 | 20.6 (0.80)ab                     | 21.2 (0.70)ab        | 20.8 (0.60)ab     | 23.2 (1.80)a                | 21.0 (1.10)ab |
|                                                                       | Forage          | 129 | 20.9 (1.00)ab                     | 21.0 (0.90)ab        | 20.5 (1.20)ab     | 21.8 (2.20)ab               | 16.6 (2.10)b  |
| Fine                                                                  | Annual grain    | 282 | 24.4 (1.20)ab                     | 22.2 (0.90)ab        | 24.0 (0.80)ab     | 21.8 (2.30)ab               | 21.7 (1.10)b  |
|                                                                       | Forage          | 130 | 24.2 (1.40)ab                     | 26.5 (1.30)a         | 26.1 (1.20)a      | 22.1 (3.70)ab               | 24.8 (2.50)ab |
| C <sub>min</sub> -96h (mg CO <sub>2</sub> -C 20 g <sup>-1</sup> soil) |                 |     |                                   |                      |                   |                             |               |
| Coarse                                                                | Annual grain    | 107 | 12.8 (1.80)b                      | 12.7 (1.41)b         | 15.9 (1.14)ab     | 15.0 (3.94)ab               | 12.5 (3.21)b  |
|                                                                       | Forage          | 34  | 14.0 (7.88)ab                     | 21.6 (2.18)a         | 21.9 (2.37)a      | 18.2 (3.94)ab               | 14.5 (3.52)ab |
| Medium                                                                | Annual grain    | 225 | 19.7 (1.23)b                      | 19.1 (0.92)b         | 20.7 (0.84)ab     | 22.8 (2.10)ab               | 20.2 (1.48)b  |
|                                                                       | Forage          | 83  | 23.7 (1.61)ab                     | 22.9 (1.43)ab        | 21.4 (1.61)ab     | 25.5 (2.87)a                | 17.5 (3.79)b  |
| Fine                                                                  | Annual grain    | 170 | 20.0 (1.44)b                      | 19.9 (1.04)b         | 22.2 (1.02)ab     | 20.6 (3.17)ab               | 21.4 (1.67)ab |
|                                                                       | Forage          | 64  | 25.4 (2.45)a                      | 26.0 (1.65)a         | 24.6 (1.58)a      | 27.6 (3.47)a                | 22.3 (4.48)ab |
| POXC (µg g <sup>-1</sup> )                                            |                 |     |                                   |                      |                   |                             |               |
| Coarse                                                                | Annual grain    | 154 | 484 (30.4)ab                      | 447 (23.7)ab         | 484 (20.9)ab      | 410 (60.9)b                 | 478 (43.0)ab  |
|                                                                       | Forage          | 51  | 560 (113)ab                       | 564 (39.0)a          | 563 (35.1)a       | 511 (65.7)ab                | 426 (72.0)ab  |
| Medium                                                                | Annual grain    | 282 | 585 (20.3)a                       | 573 (16.7)a          | 590 (13.9)a       | 626 (40.3)a                 | 589 (24.9)a   |
|                                                                       | Forage          | 113 | 599 (24.9)a                       | 620 (24.2)a          | 603 (28.5)a       | 617 (51.3)a                 | 468 (48.4)b   |
| Fine                                                                  | Annual grain    | 272 | 620 (24.1)ab                      | 582 (18.1)ab         | 600 (16.9)ab      | 536 (43.9)b                 | 520 (21.7)b   |
|                                                                       | Forage          | 123 | 620 (27.5)ab                      | 685 (27.9)a          | 657 (24.1)a       | 498 (70.8)b                 | 579 (50.0)ab  |
| Solvita CO <sub>2</sub> -burst (mg kg <sup>-1</sup> )                 |                 |     |                                   |                      |                   |                             |               |
| Coarse                                                                | Annual grain    | 88  | 52.8 (6.75)b                      | 58.2 (5.23)b         | 59.9 (4.55)b      | 41.2 (13.0)b                | 51.4 (7.88)b  |
|                                                                       | Forage          | 21  | 76.4 (26.1)ab                     | 87.1 (8.71)a         | 70.8 (8.71)ab     | 67.7 (18.4)ab               | --            |
| Medium                                                                | Annual grain    | 142 | 59.3 (4.83)                       | 71.4 (5.08)          | 69.0 (3.33)       | 69.5 (19.0)                 | 81.5 (6.72)   |
|                                                                       | Forage          | 70  | 76.1 (5.61)                       | 80.5 (5.73)          | 81.9 (6.94)       | 76.9 (13.4)                 | 52.0 (10.9)   |
| Fine                                                                  | Annual grain    | 201 | 71.3 (4.67)c                      | 69.7 (3.74)c         | 79.4 (3.44)bc     | 77.4 (9.35)bc               | 83.8 (3.67)bc |
|                                                                       | Forage          | 80  | 88.7 (5.40)ab                     | 82.9 (6.23)abc       | 88.9 (5.19)ab     | 119 (18.7)a                 | 79.0 (8.36)ab |
| ACE (mg kg <sup>-1</sup> )                                            |                 |     |                                   |                      |                   |                             |               |
| Coarse                                                                | Annual grain    | 22  | 8.76 (1.19)                       | 5.76 (1.09)          | 6.08 (0.89)       | --                          | 8.09 (1.88)   |
|                                                                       | Forage          | 3   | 10.1 (2.67)                       | --                   | 9.92 (2.67)       | 5.40 (2.67)                 | --            |
| Medium                                                                | Annual grain    | 23  | 5.44 (1.17)ab                     | 4.63 (0.82)b         | 5.59 (0.47)ab     | 5.55 (1.65)ab               | 6.67 (0.82)ab |
|                                                                       | Forage          | 14  | 6.18 (0.82)ab                     | 8.16 (0.82)a         | 6.02 (0.82)ab     | 5.89 (1.65)ab               | 5.35 (1.65)ab |
| Fine                                                                  | Annual grain    | 49  | 5.70 (0.58)                       | 5.41 (0.55)          | 6.18 (0.49)       | 2.55 (1.84)                 | --            |
|                                                                       | Forage          | 10  | 6.00 (1.06)                       | 5.49 (1.84)          | 6.95 (0.82)       | --                          | 7.26 (1.84)   |

<sup>z</sup>Conventional tillage represents plow tillage in our study.

<sup>y</sup>No disturbance represented little to no soil movement and was associated mainly with pastures and perennial forages.

<sup>x</sup>represents standard error of treatment means.

<sup>a-c</sup>Within each soil textural class and for each parameter, treatment means followed by a different letter indicate statistical significance at  $P < 0.05$ .

SOC=soil organic carbon; C<sub>min</sub>-96h= 96-hr carbon mineralization; POXC=permanganate oxidizable carbon; Solvita CO<sub>2</sub>-burst= 24 h soil respiration test; and

ACE=autoclaved citrate extractable protein index; --=not applicable

**Table S2** Within coarse-textured soil (n=29), interactive effect of cropping system and tillage intensity treatment on the programmed pyrolysis parameters analyzed in the Ontario Topsoil Sampling Project in 2019.

|                 | Conventional tillage <sup>z</sup>                           | Moderate disturbance | Light disturbance | No disturbance <sup>y</sup> | No-tillage  |
|-----------------|-------------------------------------------------------------|----------------------|-------------------|-----------------------------|-------------|
| Cropping system | Hydrogen Index (mg HC g <sup>-1</sup> OC)                   |                      |                   |                             |             |
| Annual grain    | 161 (13.5) <sup>x</sup>                                     | 138 (13.5)           | 151 (10.0)        | --                          | 164 (21.3)  |
| Forage          | 158 (30.2)                                                  | --                   | 182 (30.2)        | 151 (30.2)                  | --          |
| Vegetable       | --                                                          | 169 (30.2)           | 156 (30.2)        | --                          | --          |
| Orchard         | --                                                          | 130 (30.2)           | 134 (30.2)        | --                          | --          |
| Perennial       | --                                                          | --                   | --                | --                          | --          |
|                 | Oxygen Index (mg CO <sub>2</sub> g <sup>-1</sup> OC)        |                      |                   |                             |             |
| Annual grain    | 158 (7.60)                                                  | 161 (7.60)           | 180 (5.66)        | --                          | 162 (12.0)  |
| Forage          | 218 (17.0)                                                  | --                   | 209 (17.0)        | 195 (17.0)                  | --          |
| Vegetable       | --                                                          | 139 (17.0)           | 156 (17.0)        | --                          | --          |
| Orchard         | --                                                          | 232 (17.0)           | 175 (17.0)        | --                          | --          |
| Perennial       | --                                                          | --                   | --                | --                          | --          |
|                 | T50 (°C)                                                    |                      |                   |                             |             |
| Annual grain    | 414 (3.12)                                                  | 415 (3.12)           | 418 (2.32)        | --                          | 416 (4.94)  |
| Forage          | 420 (6.98)                                                  | --                   | 411 (6.98)        | 406 (6.98)                  | --          |
| Vegetable       | --                                                          | 405 (6.98)           | 425 (6.98)        | --                          | --          |
| Orchard         | --                                                          | 426 (6.98)           | 412 (6.98)        | --                          | --          |
| Perennial       | --                                                          | --                   | --                | --                          | --          |
|                 | S1 (mg HC g <sup>-1</sup> rock)                             |                      |                   |                             |             |
| Annual grain    | 0.47 (0.07)                                                 | 0.24 (0.07)          | 0.29 (0.05)       | --                          | 0.30 (0.12) |
| Forage          | 0.49 (0.17)                                                 | --                   | 0.79 (0.17)       | 0.37 (0.17)                 | --          |
| Vegetable       | --                                                          | 0.51 (0.17)          | 0.22 (0.17)       | --                          | --          |
| Orchard         | --                                                          | 0.08 (0.17)          | 0.24 (0.17)       | --                          | --          |
| Perennial       | --                                                          | --                   | --                | --                          | --          |
|                 | S2 (mg HC g <sup>-1</sup> rock)                             |                      |                   |                             |             |
| Annual grain    | 3.06 (0.49)                                                 | 1.73 (0.49)          | 2.30 (0.37)       | --                          | 2.30 (0.78) |
| Forage          | 3.45 (1.11)                                                 | --                   | 1.64 (1.11)       | 2.22 (1.11)                 | --          |
| Vegetable       | --                                                          | 3.34 (1.11)          | 2.09 (1.11)       | --                          | --          |
| Orchard         | --                                                          | 0.95 (1.11)          | 1.64 (1.11)       | --                          | --          |
| Perennial       | --                                                          | --                   | --                | --                          | --          |
|                 | S3CO <sub>2</sub> (mg CO <sub>2</sub> g <sup>-1</sup> rock) |                      |                   |                             |             |
| Annual grain    | 2.84 (0.40)                                                 | 1.92 (0.40)          | 2.64 (0.29)       | --                          | 2.26 (0.63) |
| Forage          | 4.76 (0.89)                                                 | --                   | 5.49 (0.89)       | 2.86 (0.89)                 | --          |
| Vegetable       | --                                                          | 2.75 (0.89)          | 2.09 (0.89)       | --                          | --          |
| Orchard         | --                                                          | 1.70 (0.89)          | 2.14 (0.89)       | --                          | --          |
| Perennial       | --                                                          | --                   | --                | --                          | --          |
|                 | Generative organic C (%)                                    |                      |                   |                             |             |
| Annual grain    | 0.40 (0.06)                                                 | 0.24 (0.06)          | 0.32 (0.04)       | --                          | 0.31 (0.09) |
| Forage          | 0.52 (0.13)                                                 | --                   | 0.67 (0.13)       | 0.33 (0.13)                 | --          |
| Vegetable       | --                                                          | 0.42 (0.13)          | 0.27 (0.13)       | --                          | --          |
| Orchard         | --                                                          | 0.16 (0.13)          | 0.27 (0.13)       | --                          | --          |
| Perennial       | --                                                          | --                   | --                | --                          | --          |
|                 | Non-generative organic C (%)                                |                      |                   |                             |             |
| Annual grain    | 1.40 (0.15)                                                 | 0.96 (0.15)          | 1.11 (0.11)       | --                          | 1.08 (0.23) |
| Forage          | 1.66 (0.33)                                                 | --                   | 1.95 (0.33)       | 1.13 (0.33)                 | --          |
| Vegetable       | --                                                          | 1.55 (0.33)          | 1.07 (0.33)       | --                          | --          |
| Orchard         | --                                                          | 0.57 (0.33)          | 0.95 (0.33)       | --                          | --          |
| Perennial       | --                                                          | --                   | --                | --                          | --          |

<sup>z</sup>Conventional tillage represents plow tillage in our study.

<sup>y</sup>No disturbance represented little to no soil movement and was associated mainly with pastures and perennial forages.

<sup>x</sup>represents standard error of treatment means.

--=not applicable.

**Table S3** Within medium-textured soil (n=46), interactive effect of cropping system and tillage intensity treatment on the programmed pyrolysis parameters analyzed in the Ontario Topsoil Sampling Project in 2019.

|                 | Conventional tillage <sup>z</sup>                           | Moderate disturbance | Light disturbance | No disturbance <sup>y</sup> | No-tillage  |
|-----------------|-------------------------------------------------------------|----------------------|-------------------|-----------------------------|-------------|
| Cropping system | Hydrogen Index (mg HC g <sup>-1</sup> OC)                   |                      |                   |                             |             |
| Annual grain    | 109 (16.9) <sup>x</sup>                                     | 137 (14.6)           | 134 (8.46)        | 153 (29.3)                  | 132 (14.6)  |
| Forage          | 138 (14.6)                                                  | 180 (14.6)           | 173 (16.9)        | 144 (29.3)                  | 130 (29.3)  |
| Vegetable       | 132 (29.3)                                                  | 136 (29.3)           | --                | --                          | --          |
| Orchard         | 161 (29.3)                                                  | --                   | 208 (29.3)        | --                          | --          |
| Perennial       | --                                                          | --                   | --                | 200 (13.1)                  | --          |
|                 | Oxygen Index (mg CO <sub>2</sub> g <sup>-1</sup> OC)        |                      |                   |                             |             |
| Annual grain    | 182 (14.9)                                                  | 192 (12.9)           | 190 (7.48)        | 203 (25.9)                  | 225 (12.9)  |
| Forage          | 206 (12.9)                                                  | 189 (12.9)           | 186 (14.9)        | 199 (25.9)                  | 195 (25.9)  |
| Vegetable       | 156 (25.9)                                                  | 173 (25.9)           | --                | --                          | --          |
| Orchard         | 168 (25.9)                                                  | --                   | 192 (25.9)        | --                          | --          |
| Perennial       | --                                                          | --                   | --                | 188 (11.5)                  | --          |
|                 | T50 (°C)                                                    |                      |                   |                             |             |
| Annual grain    | 418 (4.90)                                                  | 421 (4.24)           | 421 (2.45)        | 420 (8.48)                  | 425 (4.24)  |
| Forage          | 417 (4.24)                                                  | 416 (4.24)           | 414 (4.90)        | 419 (8.48)                  | 430 (8.48)  |
| Vegetable       | 419 (8.48)                                                  | 410 (8.48)           | --                | --                          | --          |
| Orchard         | 427 (8.48)                                                  | --                   | 412 (8.48)        | --                          | --          |
| Perennial       | --                                                          | --                   | --                | --                          | 412 (3.79)  |
|                 | S1 (mg HC g <sup>-1</sup> rock)                             |                      |                   |                             |             |
| Annual grain    | 0.18 (0.12)                                                 | 0.30 (0.10)          | 0.27 (0.06)       | 0.29 (0.21)                 | 0.25 (0.10) |
| Forage          | 0.35 (0.10)                                                 | 0.64 (0.10)          | 0.42 (0.12)       | 0.28 (0.21)                 | 0.30 (0.21) |
| Vegetable       | 0.16 (0.21)                                                 | 0.28 (0.21)          | --                | --                          | --          |
| Orchard         | 0.24 (0.21)                                                 | --                   | 0.56 (0.21)       | --                          | --          |
| Perennial       | --                                                          | --                   | --                | 0.80 (0.09)                 | --          |
|                 | S2 (mg HC g <sup>-1</sup> rock)                             |                      |                   |                             |             |
| Annual grain    | 1.43 (0.75)                                                 | 2.42 (0.65)          | 2.28 (0.37)       | 2.44 (1.31)                 | 2.34 (0.65) |
| Forage          | 2.53 (0.65)                                                 | 4.58 (0.65)          | 3.03 (0.75)       | 2.50 (1.31)                 | 2.97 (1.31) |
| Vegetable       | 1.44 (1.31)                                                 | 2.04 (1.31)          | --                | --                          | --          |
| Orchard         | 2.21 (1.31)                                                 | --                   | 4.24 (1.31)       | --                          | --          |
| Perennial       | --                                                          | --                   | --                | 4.97 (0.58)                 | --          |
|                 | S3CO <sub>2</sub> (mg CO <sub>2</sub> g <sup>-1</sup> rock) |                      |                   |                             |             |
| Annual grain    | 2.30 (0.72)                                                 | 3.18 (0.62)          | 3.29 (0.36)       | 3.22 (1.25)                 | 4.24 (0.62) |
| Forage          | 3.76 (0.62)                                                 | 4.76 (0.62)          | 3.18 (0.72)       | 3.44 (1.25)                 | 4.43 (1.25) |
| Vegetable       | 1.70 (1.25)                                                 | 2.60 (1.25)          | --                | --                          | --          |
| Orchard         | 2.30 (1.25)                                                 | --                   | 3.91 (1.25)       | --                          | --          |
| Perennial       | --                                                          | --                   | --                | 4.43 (0.56)                 | --          |
|                 | Generative organic C (%)                                    |                      |                   |                             |             |
| Annual grain    | 0.23 (0.09)                                                 | 0.34 (0.07)          | 0.34 (0.04)       | 0.36 (0.07)                 | 0.36 (0.07) |
| Forage          | 0.37 (0.07)                                                 | 0.60 (0.07)          | 0.40 (0.09)       | 0.37 (0.15)                 | 0.43 (0.15) |
| Vegetable       | 0.21 (0.15)                                                 | 0.29 (0.15)          | --                | --                          | --          |
| Orchard         | 0.29 (0.15)                                                 | --                   | 0.54 (0.15)       | --                          | --          |
| Perennial       | --                                                          | --                   | --                | 0.64 (0.07)                 | --          |
|                 | Non-generative organic C (%)                                |                      |                   |                             |             |
| Annual grain    | 1.03 (0.21)                                                 | 1.32 (0.18)          | 1.34 (0.10)       | 1.22 (0.37)                 | 1.43 (0.18) |
| Forage          | 1.44 (0.18)                                                 | 1.90 (0.18)          | 1.29 (0.21)       | 1.35 (0.37)                 | 1.84 (0.37) |
| Vegetable       | 0.88 (0.37)                                                 | 1.20 (0.37)          | --                | --                          | --          |
| Orchard         | 1.07 (0.37)                                                 | --                   | 1.50 (0.37)       | --                          | --          |
| Perennial       | --                                                          | --                   | --                | 1.71 (0.16)                 | --          |

<sup>z</sup>Conventional tillage represents plow tillage in our study.

<sup>y</sup>No disturbance represented little to no soil movement and was associated mainly with pastures and perennial forages.

<sup>x</sup>represents standard error of treatment means.

--=not applicable.

**Table S4** Within fine-textured soil (n=76), interactive effect of cropping system and tillage intensity treatment on the programmed pyrolysis parameters analyzed in the Ontario Topsoil Sampling Project in 2019.

|                 | Conventional tillage <sup>z</sup>                           | Moderate disturbance | Light disturbance | No disturbance <sup>y</sup> | No-tillage  |
|-----------------|-------------------------------------------------------------|----------------------|-------------------|-----------------------------|-------------|
| Cropping system | Hydrogen Index (mg HC g <sup>-1</sup> OC)                   |                      |                   |                             |             |
| Annual grain    | 126 (9.47) <sup>x</sup>                                     | 125 (9.07)           | 137 (8.40)        | 115 (31.4)                  | 137 (8.40)  |
| Forage          | 133 (18.1)                                                  | 115 (31.4)           | 142 (12.8)        | --                          | 174 (31.4)  |
| Vegetable       | --                                                          | --                   | --                | --                          | --          |
| Orchard         | --                                                          | --                   | --                | 161 (31.4)                  | --          |
| Perennial       | 158 (22.2)                                                  | 171 (31.4)           | --                | 150 (12.8)                  | --          |
|                 | Oxygen Index (mg CO <sub>2</sub> g <sup>-1</sup> OC)        |                      |                   |                             |             |
| Annual grain    | 187 (6.97)                                                  | 186 (6.67)           | 187 (6.18)        | 197 (23.1)                  | 182 (6.18)  |
| Forage          | 209 (13.3)                                                  | 217 (23.1)           | 181 (9.44)        | --                          | 173 (23.1)  |
| Vegetable       | --                                                          | --                   | --                | --                          | --          |
| Orchard         | --                                                          | --                   | --                | 195 (23.1)                  | --          |
| Perennial       | 207 (16.3)                                                  | 167 (23.1)           | --                | 211 (9.44)                  | --          |
|                 | T50 (°C)                                                    |                      |                   |                             |             |
| Annual grain    | 429 (2.45)                                                  | 427 (2.35)           | 427 (2.17)        | 438 (8.14)                  | 428 (2.17)  |
| Forage          | 426 (4.70)                                                  | 417 (8.14)           | 429 (3.32)        | --                          | 434 (8.14)  |
| Vegetable       | --                                                          | --                   | --                | --                          | --          |
| Orchard         | --                                                          | --                   | --                | 426 (8.14)                  | --          |
| Perennial       | 424 (5.75)                                                  | 446 (8.14)           | --                | 424 (3.32)                  | --          |
|                 | S1 (mg HC g <sup>-1</sup> rock)                             |                      |                   |                             |             |
| Annual grain    | 0.28 (0.16)                                                 | 0.47 (0.16)          | 0.34 (0.14)       | 0.07 (0.55)                 | --          |
| Forage          | 0.25 (0.32)                                                 | 0.28 (0.55)          | 0.36 (0.22)       | --                          | 0.57 (0.55) |
| Vegetable       | --                                                          | --                   | --                | --                          | --          |
| Orchard         | --                                                          | --                   | --                | 0.39 (0.55)                 | --          |
| Perennial       | 0.62 (0.39)                                                 | 0.42 (0.55)          | --                | 0.68 (0.22)                 | --          |
|                 | S2 (mg HC g <sup>-1</sup> rock)                             |                      |                   |                             |             |
| Annual grain    | 3.19 (1.35)                                                 | 3.84 (1.29)          | 2.89 (1.20)       | 1.14 (4.49)                 | 4.46 (1.20) |
| Forage          | 2.54 (2.59)                                                 | 1.88 (4.49)          | 3.38 (1.83)       | --                          | 5.03 (4.49) |
| Vegetable       | --                                                          | --                   | --                | --                          | --          |
| Orchard         | --                                                          | --                   | --                | 4.11 (4.49)                 | --          |
| Perennial       | 4.82 (3.18)                                                 | 5.75 (4.49)          | --                | 4.98 (1.83)                 | --          |
|                 | S3CO <sub>2</sub> (mg CO <sub>2</sub> g <sup>-1</sup> rock) |                      |                   |                             |             |
| Annual grain    | 3.92 (0.92)                                                 | 4.94 (0.88)          | 3.95 (0.81)       | 1.95 (3.05)                 | 4.63 (0.81) |
| Forage          | 4.05 (1.76)                                                 | 3.55 (3.05)          | 4.37 (1.24)       | --                          | 5.01 (3.05) |
| Vegetable       | --                                                          | --                   | --                | --                          | --          |
| Orchard         | --                                                          | --                   | --                | 4.97 (3.05)                 | --          |
| Perennial       | 6.16 (2.15)                                                 | 5.63 (3.05)          | --                | 6.01 (1.24)                 | --          |
|                 | Generative organic C (%)                                    |                      |                   |                             |             |
| Annual grain    | 0.43 (0.15)                                                 | 0.53 (0.14)          | 0.41 (0.13)       | 0.18 (0.51)                 | 0.58 (0.13) |
| Forage          | 0.38 (0.29)                                                 | 0.30 (0.51)          | 0.47 (0.21)       | --                          | 0.65 (0.51) |
| Vegetable       | --                                                          | --                   | --                | --                          | --          |
| Orchard         | --                                                          | --                   | --                | 0.58 (0.51)                 | --          |
| Perennial       | 0.67 (0.36)                                                 | 0.73 (0.51)          | --                | 0.69 (0.21)                 | --          |
|                 | Non-generative organic C (%)                                |                      |                   |                             |             |
| Annual grain    | 1.73 (0.42)                                                 | 2.20 (0.40)          | 1.66 (0.37)       | 0.81 (1.39)                 | 2.02 (0.37) |
| Forage          | 1.53 (0.80)                                                 | 1.32 (1.39)          | 1.89 (0.57)       | --                          | 2.23 (1.39) |
| Vegetable       | --                                                          | --                   | --                | --                          | --          |
| Orchard         | --                                                          | --                   | --                | 1.97 (1.39)                 | --          |
| Perennial       | 2.33 (0.98)                                                 | 2.62 (1.39)          | --                | 2.33 (0.57)                 | --          |

<sup>z</sup>Conventional tillage represents plow tillage in our study.

<sup>y</sup>No disturbance represented little to no soil movement and was associated mainly with pastures and perennial forages.

<sup>x</sup>represents standard error of treatment means.

--=not applicable

**Table S5** Within each soil textural class, mean (SE) values of the soil C indicators (n=1490) and programmed pyrolysis parameters (n=151) by the tillage intensity in the Ontario Topsoil Sampling Project from 2019 to 2022.

|                                   | SOC                      | C <sub>min</sub> -96h                         | POXC               | Solvita CO <sub>2</sub> -burst | ACE                 | T50        | HI                       | OI                                    |
|-----------------------------------|--------------------------|-----------------------------------------------|--------------------|--------------------------------|---------------------|------------|--------------------------|---------------------------------------|
|                                   | mg g <sup>-1</sup>       | mg CO <sub>2</sub> -C 20 g <sup>-1</sup> soil | µg g <sup>-1</sup> | mg kg <sup>-1</sup>            | mg kg <sup>-1</sup> | °C         | mg HC g <sup>-1</sup> OC | mg CO <sub>2</sub> g <sup>-1</sup> OC |
| Tillage intensity                 | Coarse-textured          |                                               |                    |                                |                     |            |                          |                                       |
| Conventional tillage <sup>z</sup> | 17.2 (1.50) <sup>y</sup> | 14.9 (2.14)                                   | 469 (32.3)         | 64.2 (8.37)                    | 9.32 (1.12)         | 415 (2.53) | 161 (10.8)               | 167 (10.2)                            |
| Moderate disturbance              | 15.6 (1.00)              | 15.7 (1.63)                                   | 458 (22.1)         | 72.0 (6.06)                    | 5.92 (1.07)         | 415 (2.63) | 140 (11.3)               | 164 (10.6)                            |
| Light disturbance                 | 17.5 (1.00)              | 16.4 (1.57)                                   | 461 (21.3)         | 67.7 (5.77)                    | 6.98 (0.93)         | 416 (1.93) | 155 (8.29)               | 176 (7.82)                            |
| No disturbance <sup>x</sup>       | 15.0 (1.50)              | 17.6 (1.98)                                   | 440 (31.3)         | 57.9 (8.34)                    | 2.10 (2.64)         | 408 (6.50) | 145 (27.9)               | 190 (26.3)                            |
| No tillage                        | 17.5 (1.70)              | 14.0 (2.15)                                   | 484 (35.8)         | 57.8 (9.35)                    | 7.24 (1.78)         | 422 (4.76) | 150 (20.4)               | 172 (19.3)                            |
|                                   | Medium-textured          |                                               |                    |                                |                     |            |                          |                                       |
| Conventional tillage              | 20.6 (0.70)              | 21.1 (1.09)                                   | 549 (16.5)         | 67.4 (4.25)                    | 6.42 (0.69)         | 419 (2.78) | 130 (11.2)               | 187 (7.95)                            |
| Moderate disturbance              | 20.8 (0.76)              | 20.3 (0.89)                                   | 554 (14.9)         | 76.9 (4.60)                    | 7.37 (0.72)         | 418 (2.84) | 157 (11.5)               | 186 (8.13)                            |
| Light disturbance                 | 20.7 (0.60)              | 22.0 (0.92)                                   | 562 (14.8)         | 76.6 (4.15)                    | 6.78 (0.61)         | 419 (2.10) | 147(8.55)                | 191 (6.03)                            |
| No disturbance                    | 20.0 (0.80)              | 22.2 (1.10)                                   | 565 (18.3)         | 74.3 (5.86)                    | 6.41 (1.05)         | 414 (3.29) | 186 (13.3)               | 186 (9.41)                            |
| No tillage                        | 19.4 (0.50)              | 19.7 (0.95)                                   | 511 (16.4)         | 75.4 (5.97)                    | 7.46 (0.82)         | 426 (3.74) | 132 (15.1)               | 217 (10.7)                            |
|                                   | Fine-textured            |                                               |                    |                                |                     |            |                          |                                       |
| Conventional tillage              | 25.3(1.40)               | 25.6 (1.56)                                   | 644ab (26.7)       | 92.9 (5.18)                    | 7.25 (0.74)         | 428 (2.02) | 132 (7.77)               | 194 (5.73)                            |
| Moderate disturbance              | 25.0 (1.10)              | 26.0 (1.20)                                   | 647a (23.0)        | 89.8 (4.95)                    | 6.91 (0.80)         | 429 (2.25) | 131 (8.63)               | 189 (6.36)                            |
| Light disturbance                 | 25.6 (1.20)              | 26.9 (1.29)                                   | 644a (23.7)        | 96.8 (4.68)                    | 7.69 (0.77)         | 428 (1.85) | 139 (7.12)               | 185 (5.25)                            |
| No disturbance                    | 25.7 (1.40)              | 28.1 (1.61)                                   | 599ab (28.7)       | 95.8 (5.56)                    | 5.97 (0.78)         | 426 (3.01) | 145 (11.5)               | 206 (8.53)                            |
| No tillage                        | 23.9 (1.40)              | 27.1 (1.80)                                   | 576b (28.5)        | 100 (5.33)                     | 7.77 (0.82)         | 429 (2.12) | 141 (8.16)               | 183 (6.02)                            |

<sup>z</sup>Conventional tillage represents plow tillage in our study.

<sup>y</sup>represents standard error of treatment means.

<sup>x</sup>No disturbance represented little to no soil movement and was associated mainly with pastures and perennial forages.

SOC=soil organic C; C<sub>min</sub>-96h= 96-hr carbon mineralization; POXC=permanganate oxidizable carbon; Solvita CO<sub>2</sub>-burst= 24 h soil respiration test; ACE=autoclaved citrate extractable protein index; HI=hydrogen index; and OI=oxygen index.

**Table S6** Within each soil textural class, mean (SE) values of the soil C indicators (n=1490) and programmed pyrolysis parameters (n=151) by the cover crop usage in the Ontario Topsoil Sampling Project from 2019 to 2022.

|            | SOC                         | C <sub>min</sub> -96h                         | POXC               | Solvita CO <sub>2</sub> -burst | ACE                 | T50            | HI                       | OI                                    |
|------------|-----------------------------|-----------------------------------------------|--------------------|--------------------------------|---------------------|----------------|--------------------------|---------------------------------------|
|            | mg g <sup>-1</sup>          | mg CO <sub>2</sub> -C 20 g <sup>-1</sup> soil | µg g <sup>-1</sup> | mg kg <sup>-1</sup>            | mg kg <sup>-1</sup> | °C             | mg HC g <sup>-1</sup> OC | mg CO <sub>2</sub> g <sup>-1</sup> OC |
| Cover crop |                             |                                               |                    |                                |                     |                |                          |                                       |
|            | Coarse-textured             |                                               |                    |                                |                     |                |                          |                                       |
| Yes        | 16.2<br>(1.10) <sup>z</sup> | 16.5 (1.49)                                   | 471<br>(20.9)      | 61.6 (5.83)                    | 4.89b<br>(1.04)     | 419a<br>(2.58) | 140 (11.2)               | 177 (10.4)                            |
| No         | 16.9<br>(0.90)              | 14.9 (1.36)                                   | 454<br>(18.5)      | 66.3 (5.06)                    | 7.73a<br>(0.87)     | 412b<br>(1.85) | 160 (7.96)               | 171 (7.51)                            |
|            | Medium-textured             |                                               |                    |                                |                     |                |                          |                                       |
| Yes        | 20.3<br>(0.50)              | 20.9 (0.79)                                   | 539<br>(12.1)      | 73.1 (3.19)                    | 7.16<br>(0.54)      | 419<br>(2.11)  | 151 (8.58)               | 185b (6.05)                           |
| No         | 20.3<br>(0.50)              | 21.2 (0.73)                                   | 557<br>(11.2)      | 75.1 (3.11)                    | 6.61<br>(0.40)      | 420<br>(1.64)  | 149 (6.68)               | 202a (4.71)                           |
|            | Fine-textured               |                                               |                    |                                |                     |                |                          |                                       |
| Yes        | 25.7<br>(1.10)              | 26.3 (1.16)                                   | 636<br>(21.8)      | 92.3 (4.14)                    | 6.73<br>(0.59)      | 429<br>(1.77)  | 137 (6.82)               | 191 (5.02)                            |
| No         | 24.6<br>(1.00)              | 27.1 (1.10)                                   | 608<br>(20.8)      | 98.0 (4.04)                    | 7.50<br>(0.62)      | 427<br>(1.25)  | 138 (4.82)               | 192 (3.55)                            |

<sup>z</sup>represents standard error of treatment means.

SOC=soil organic C; C<sub>min</sub>-96h= 96-hr carbon mineralization; POXC=permanganate oxidizable carbon; Solvita CO<sub>2</sub>-burst= 24 h soil respiration test; ACE=autoclaved citrate extractable protein index; HI=hydrogen index; and OI=oxygen index.

**Table S7** Within each soil textural class, mean values of the soil C indicators (n=1490) and programmed pyrolysis parameters (n=151) by the use of organic amendments in the Ontario Topsoil Sampling Project from 2019 to 2022.

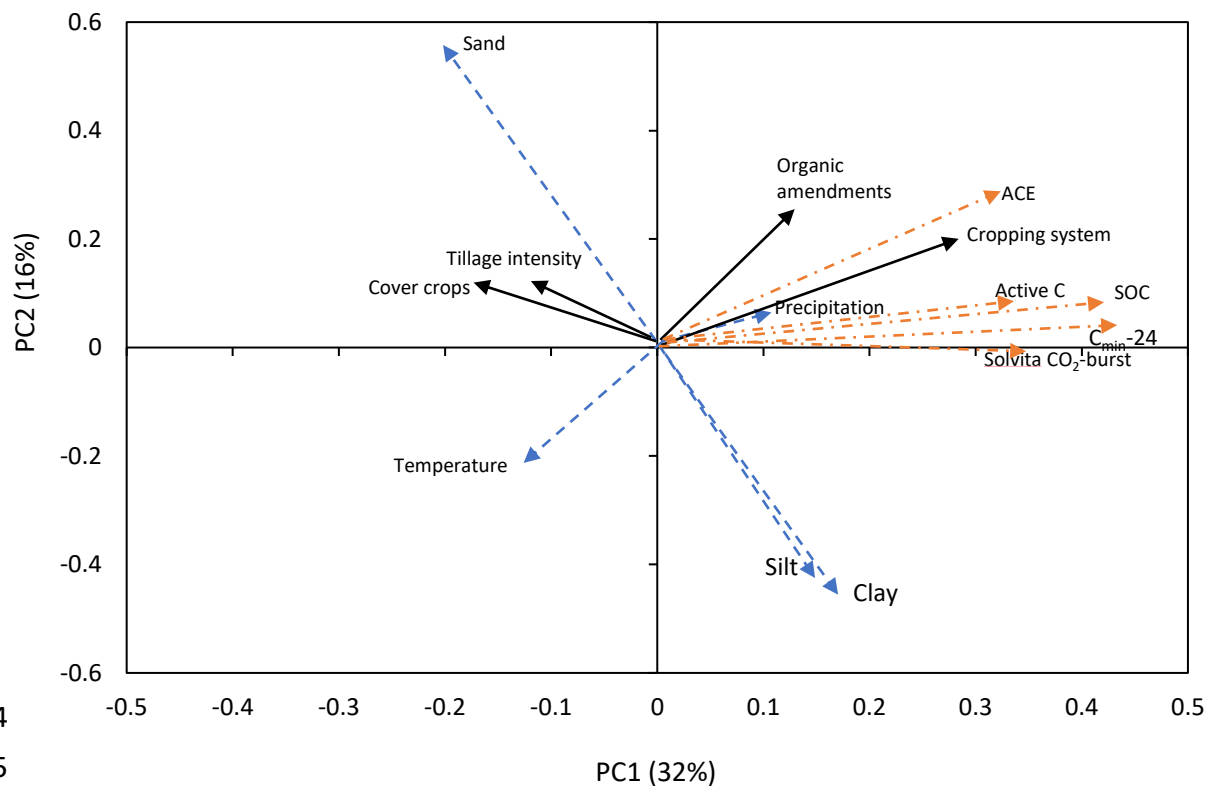
|                              | SOC                      | C <sub>min</sub> -96h                                | POXC               | Solvita<br>CO <sub>2</sub> -burst | ACE                 | T50           | HI                          | OI                                       |
|------------------------------|--------------------------|------------------------------------------------------|--------------------|-----------------------------------|---------------------|---------------|-----------------------------|------------------------------------------|
|                              | mg g <sup>-1</sup>       | mg CO <sub>2</sub> -<br>C 20 g <sup>-1</sup><br>soil | µg g <sup>-1</sup> | mg kg <sup>-1</sup>               | mg kg <sup>-1</sup> | °C            | mg HC g <sup>-1</sup><br>OC | mg CO <sub>2</sub><br>g <sup>-1</sup> OC |
| Use of organic<br>amendments |                          |                                                      |                    |                                   |                     |               |                             |                                          |
|                              |                          |                                                      |                    | Coarse-textured                   |                     |               |                             |                                          |
| Yes                          | 16.6 (0.90) <sup>z</sup> | 16.0<br>(1.47)                                       | 479<br>(19.6)      | 64.2 (5.37)                       | 6.05<br>(0.85)      | 417<br>(2.10) | 146<br>(9.03)               | 181<br>(8.52)                            |
| No                           | 16.5 (0.90)              | 15.4<br>(1.36)                                       | 446<br>(18.8)      | 63.2 (5.70)                       | 6.57<br>(1.12)      | 413<br>(2.57) | 154<br>(11.0)               | 167<br>(10.4)                            |
|                              |                          |                                                      |                    | Medium-textured                   |                     |               |                             |                                          |
| Yes                          | 20.5 (0.40)              | 21.1<br>(0.72)                                       | 561<br>(11.0)      | 78.4a<br>(2.96)                   | 6.82<br>(0.45)      | 419<br>(1.70) | 147<br>(6.91)               | 193<br>(4.88)                            |
| No                           | 20.0 (0.50)              | 21.0<br>(0.77)                                       | 535<br>(12.0)      | 69.9b<br>(3.42)                   | 6.95<br>(0.52)      | 419<br>(2.02) | 153<br>(8.19)               | 193<br>(5.78)                            |
|                              |                          |                                                      |                    | Fine-textured                     |                     |               |                             |                                          |
| Yes                          | 25.0 (1.00)              | 27.3<br>(1.10)                                       | 634<br>(20.8)      | 96.2 (4.13)                       | 7.59<br>(0.63)      | 430<br>(1.53) | 143<br>(5.89)               | 195<br>(4.34)                            |
| No                           | 25.2 (1.10)              | 26.1<br>(1.14)                                       | 610<br>(21.6)      | 94.1 (4.07)                       | 6.64<br>(0.60)      | 426<br>(1.48) | 131<br>(5.69)               | 187<br>(4.19)                            |

<sup>z</sup>represents standard error of treatment means.

SOC=soil organic C; C<sub>min</sub>-96h= 96-hr carbon mineralization; POXC=permanganate oxidizable carbon; Solvita CO<sub>2</sub>-burst= 24 h soil respiration test; ACE=autoclaved citrate extractable protein index; HI=hydrogen index; and OI=oxygen index.



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66 **Figure S1** Principal component analysis (PCA) demonstrating relationships between site characteristics (blue dash-  
 67 line vectors), management practices (black solid-line vectors), and soil C indicators (orange dash-line vectors,  
 68 n=1490), sampled in the Ontario Topsoil Sampling Project from 2019 to 2022. ACE=autoclaved citrate extractable  
 69 protein index;  $C_{min}$ -96h= 96-hr carbon mineralization; POXC=permanganate oxidizable carbon; SOC=soil organic  
 70 carbon; and Solvita CO<sub>2</sub>-burst= 24 h soil respiration test.

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