



UNIVERSITÀ  
DEGLI STUDI  
DI MILANO

# Le migliori pratiche per favorire lo stoccaggio del carbonio nel suolo

Alessia Perego – Università di Milano | DISAA



**AGRI  
ENER**

**CARBON**

Soc. Agr. Palazzetto, Zanengo (CR) - 29 Maggio 2024



**PSR**  
2014 2020

**LOMBARDIA**  
L'INNOVAZIONE  
METTERADICI



**Regione  
Lombardia**

Fondo Europeo Agricolo per lo Sviluppo Rurale: l'Europa investe nelle zone rurali





# Il carbonio organico nel suolo agrario

Quali sono i fattori che incidono sul suo accumulo?

- Lavorazioni del suolo ridotte
- Residui colturali
- Fertilizzazione organica
- Cover crop



Management  
category

Management practices to  
increase soil carbon

*Crop management*

Soil fertility enhancement  
Better rotation  
Erosion control  
Irrigation

*Conservation tillage*

Stubble retention  
Reduced tillage  
No-tillage

*Organic  
amendments*

Animal manure  
Green manure  
Recycled organics

Chan, Y. (2008). Increasing soil  
organic carbon of agricultural  
land. Primefact, 735, 1-5.





# Il carbonio organico nel suolo agrario

## Quali sono i fattori che incidono sul suo accumulo?

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### Soil carbon 4 per mille

Budiman Minasny<sup>a,\*</sup>, Brendan P. Malone<sup>a</sup>, Alex B. McBratney<sup>a</sup>, Denis A. Anger<sup>d</sup>, Adam Chambers<sup>d</sup>, Vincent Chaplot<sup>e</sup>, Zueng-Sang Chen<sup>f</sup>, Kun Cheng<sup>g</sup>, Bhabani Alessandro Gimona<sup>i</sup>, Carolyn B. Hedley<sup>j</sup>, Suk Young Hong<sup>k</sup>, Biswapati Mandal<sup>c</sup>, Manuel Martin<sup>c</sup>, Brian G. McConkey<sup>b</sup>, Vera Leatitia Mulder<sup>n</sup>, Sharon O'Rourke<sup>a</sup>, Inakwu Odeh<sup>a</sup>, José Padarian<sup>a</sup>, Keith Paustian<sup>p</sup>, Genxing Pan<sup>g</sup>, Laura Poggio<sup>i</sup>, Ig Uta Stockmann<sup>a</sup>, Yiyi Sulaeman<sup>s</sup>, Chun-Chih Tsui<sup>f</sup>, Tor-Gunnar Vågen<sup>t</sup>, Bas van Wesemael<sup>u</sup>, Leigh Winowiecki<sup>t</sup>

**Table 1**  
Management practices that are reported to sequester soil carbon.

| Management practices                                                      | Country   | Depth observed                                                    | Carbon sequestration rates <sup>b</sup><br>t C ha <sup>-1</sup> yr <sup>-1</sup> | Average C stock <sup>a</sup><br>t C ha <sup>-1</sup> | Period of observation                 | References                                               |
|---------------------------------------------------------------------------|-----------|-------------------------------------------------------------------|----------------------------------------------------------------------------------|------------------------------------------------------|---------------------------------------|----------------------------------------------------------|
| <b>Arable land</b>                                                        |           |                                                                   |                                                                                  |                                                      |                                       |                                                          |
| Organic amendment                                                         | China     | Plough layer, 0–20 cm for dry cropland and 0–15 cm for paddy soil | 0.62                                                                             | 24.4                                                 | *6 to 25 years, 14.4 years on average | Wang et al. (2010)                                       |
| Organic amendment<br>Organic amendment combined with inorganic fertilizer | China     | Plough layer                                                      | 0.54                                                                             | 24.4                                                 | *3 to 25 years                        | Jin et al. (2008)                                        |
|                                                                           | China     | Plough layer, 0–20 cm for dry cropland and 0–15 cm for paddy soil | 0.62                                                                             | 24.4                                                 | *3 to 25 years                        | Jin et al. (2008); Zhu et al. (2015); Wang et al. (2010) |
|                                                                           | S. Korea  | 0–30 cm paddy soils                                               | 0.89                                                                             | 40.5                                                 | 42 years                              | Lee et al. (2013)                                        |
|                                                                           | S. Korea  | 0–30 cm, paddy soils                                              | 0.24                                                                             | 40.5                                                 | 42 years                              | Lee et al. (2013)                                        |
| Compost addition                                                          | Taiwan    | 0–15 cm                                                           | 0.39                                                                             | 36                                                   | *13–20 years                          | Wei et al. (2015a); Wei et al. (2015b)                   |
| Compost addition with inorganic fertilizer                                | Taiwan    | 0–15 cm                                                           | 0.46–1.00                                                                        | 37.4                                                 | *20 years                             | Wei et al. (2015a); Wei et al. (2015b)                   |
| Compost with inorganic fertilizer                                         | Taiwan    | 0–15 cm                                                           | 0.40–0.80                                                                        | 37.4                                                 | *20 years                             | Wei et al. (2015a); Wei et al. (2015b)                   |
| Farm yard manure                                                          | Belgium   | 0–25 cm                                                           | 0.45 ± 0.14                                                                      | 50                                                   | *20 years                             | Buyse et al. (2013)                                      |
| Farm yard manure/crop residue                                             | Nigeria   | Topsoil                                                           | 0.10–0.30                                                                        | 33.4                                                 | *50 years                             | FAO (2004)                                               |
| Inorganic fertilizer with straw return                                    | Indonesia | 0–15 cm, paddy soils                                              | 0.52 ± 0.16                                                                      | 17.9                                                 | 40 years                              | Minasny et al. (2012)                                    |
| Straw return with Inorganic fertilizer                                    | Indonesia | 0–15 cm, paddy soils                                              | 0.47                                                                             | 17.9                                                 | *3 years                              | Sugiyanta (2015)                                         |
| Inorganic fertilizer                                                      | S. Korea  | 0–15 cm, paddy soils                                              | 0.32 ± 0.29                                                                      | 27.3                                                 | 8 years                               | Minasny et al. (2012)                                    |
| Straw return                                                              | China     | Plough layer                                                      | 0.57–0.60                                                                        | 27.6                                                 | *3 to 25 years                        | Jin et al. (2008); Lu et al. (2009)                      |





# Il carbonio organico nel suolo agrario

## Quali sono i fattori che incidono sul suo accumulo?

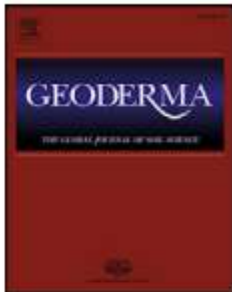
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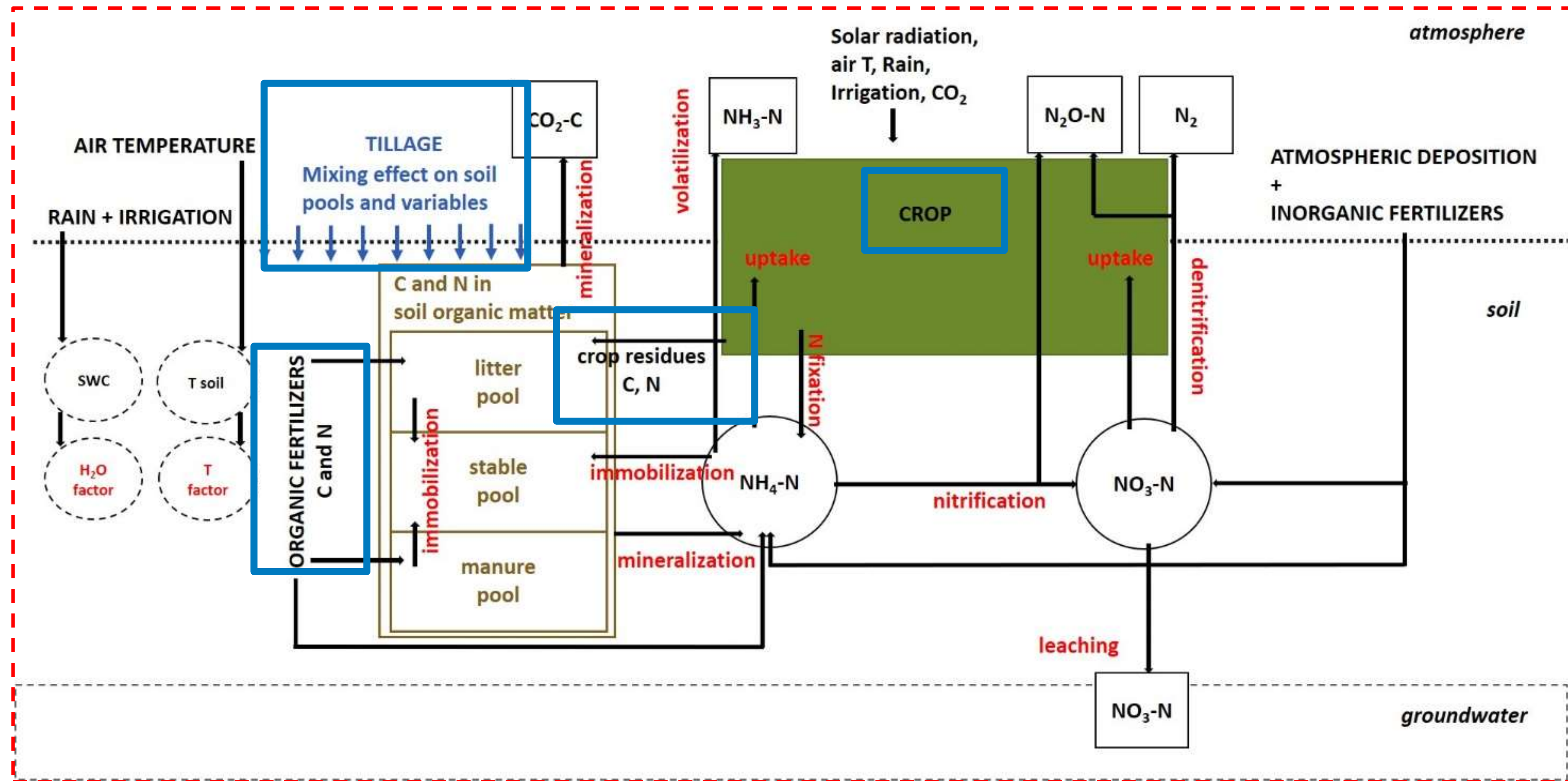
|                                                      |                 |                              |                         |            |                         |                                                               |
|------------------------------------------------------|-----------------|------------------------------|-------------------------|------------|-------------------------|---------------------------------------------------------------|
| Inorganic fertilizer                                 | India           | 0–15 cm                      | 0.16                    | 13.3       | 6–32 years              | Pathak et al. (2011)                                          |
| Inorganic fertilizer + FYM                           | India           | 0–15 cm                      | 0.33                    | 13.3       | 6–32 years              | Pathak et al. (2011)                                          |
| Residue incorporation                                | Nigeria         | 0–15 cm                      | 0.24                    | 20         | *18 years               | Raji and Ogunwole (2006)                                      |
| Stubble retention                                    | Australia       | 0–15 cm                      | 0.19 ± 0.08             | 21.2       | *                       | Sanderman et al. (2010)                                       |
| Stubble retention                                    | Australia       | 0–10 cm                      | 0.147 ± 0.059           | 18.3       | *4 to 40 y              | Lam et al. (2013)                                             |
| No till                                              | China           | Plough layer                 | 0.16–0.51               |            | 3 to 25 years           | Jin et al. (2008);<br>Lu et al. (2009);<br>Wang et al. (2009) |
| No till                                              | France          | 0–30 cm, Wheat-corn rotation | 0.2 ± 0.13              | 51.6       | 20 years                | Arrouays et al. (2002b)                                       |
| No till                                              | UK              | Topsoil                      | 0.31 ± 0.2              | 80         | 5–23 years              | Powlson et al. (2012)                                         |
| No till                                              | USA             | 0–20 or 0–30 cm              | 0.4 ± 0.61 <sup>c</sup> | 53 ± 25.2  | 12–34 years             | Johnson et al. (2005)                                         |
| No till plus cover crops                             | USA (southeast) | 0–20 cm                      | 0.45 ± 0.04             | 25.5 ± 0.9 | 11 ± 1 years            | Franzluebbers (2010)                                          |
| Conventional till to no-till                         | Canada          | 0–30 cm                      | 0.05–0.16               | 75         | 20 years                | VandenBygaart et al. (2008)                                   |
| Reduced use of summer fallow                         | Canada          | 0–30 cm                      | 0.30                    | 75         | 20 years                | VandenBygaart et al. (2008)                                   |
| Reduced tillage                                      | Australia       | 0–15 cm                      | 0.34 ± 0.06             | 21.2       | *Various, 4 to 42 years | Sanderman et al. (2010)                                       |
| Reduced tillage                                      | Belgium         | 0–60 cm                      | 0                       |            | 20 years                | D'Haene et al. (2009)                                         |
| Conservation tillage                                 | Australia       | 0–10 cm                      | 0.15 ± 0.028            | 18.3       | 4 to 40 years           | Lam et al. (2013)                                             |
| Conservation tillage                                 | France          | 0–25 cm                      | 0.10                    | 51.6       | 28 years                | Metay et al. (2009)                                           |
| Crop rotation                                        | Australia       | 0–15 cm                      | 0.20 ± 0.04             | 21.2       | Various, 4 to 42 years  | Sanderman et al. (2010)                                       |
| Crop rotation                                        | France          | 0–30 cm                      | 0.16 ± 0.08             | 51.6       | 20 years                | Arrouays et al. (2002a,b)                                     |
| Crop rotation with perennial grasses                 | Russia          | Plough layer                 | 0.03–0.08               | 32.3       | *5 years                | Savin et al. (2002)                                           |
| Conversion to ley farming                            | England         | 0–23 cm                      | 0.20                    | 80         | 30 years                | Powlson and Johnston (2015)                                   |
| Conversion of annual cropping to crop + ley rotation | USA             | 0–30 cm                      | 0.5                     | 78         | 30 years                | Dick et al. (1998)                                            |





# Accumulo del carbonio organico nel suolo agrario

## Fattori e processi coinvolti



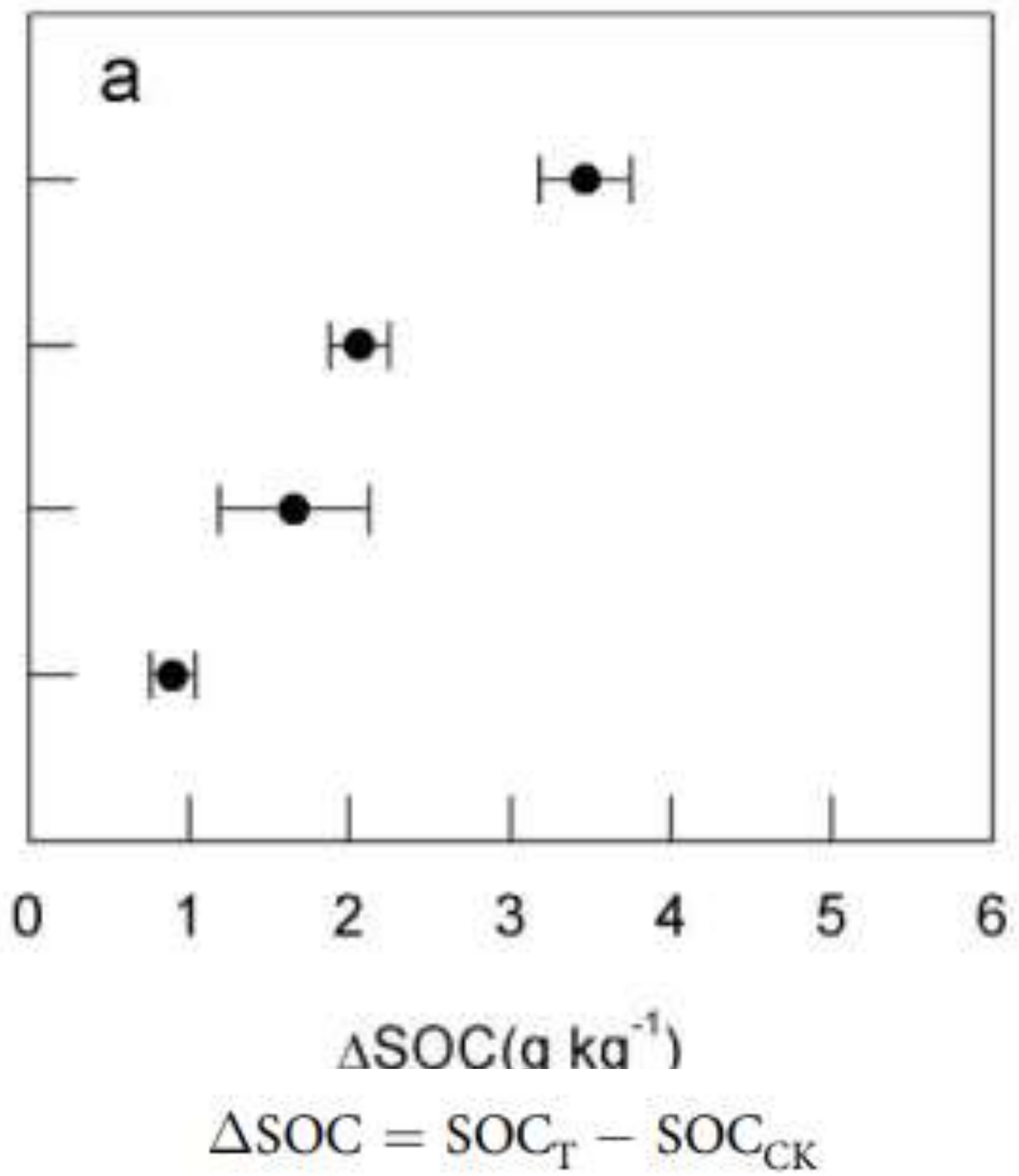


# Fertilizzanti di origine organica

## Effetto sull'accumulo carbonio organico (SOC)

Han, P., Zhang, W., Wang, G., Sun, W., & Huang, Y. (2016). Changes in soil organic carbon in croplands subjected to fertilizer management: a global meta-analysis. Scientific reports, 6(1), 27199.

- CONCIMI MIN. + ORG. CFM
- CONCIMI MIN. + RESIDUI CFS
- CONCIMI MIN. (DOSI OTTIMALI) CF
- CONCIMI MIN. (DOSI SUBOTTIMALI) UCF





# Fertilizzanti di origine organica

Effetto sull'accumulo carbonio organico (SOC)

CONCIMI MIN. + ORG. = CFM

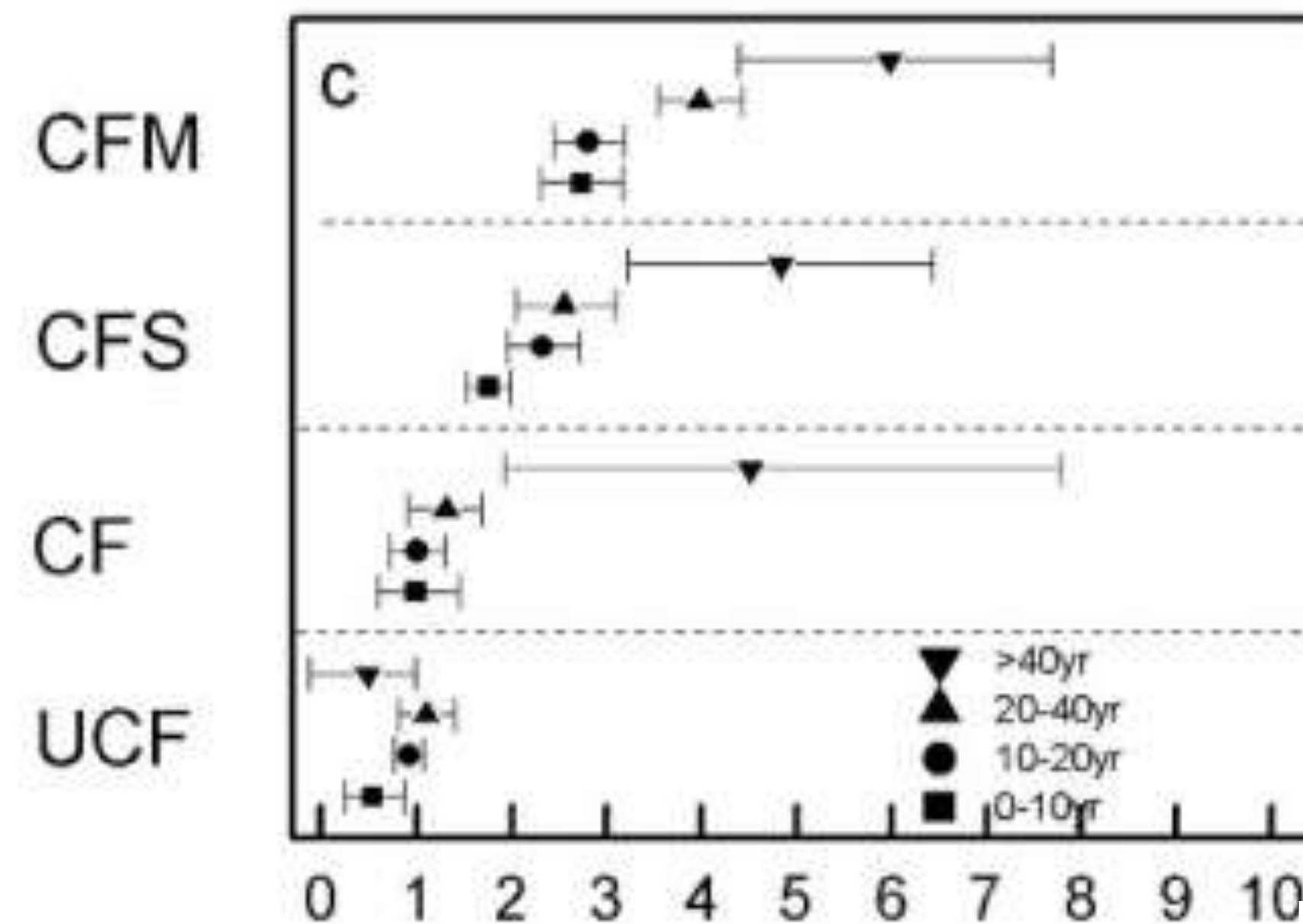
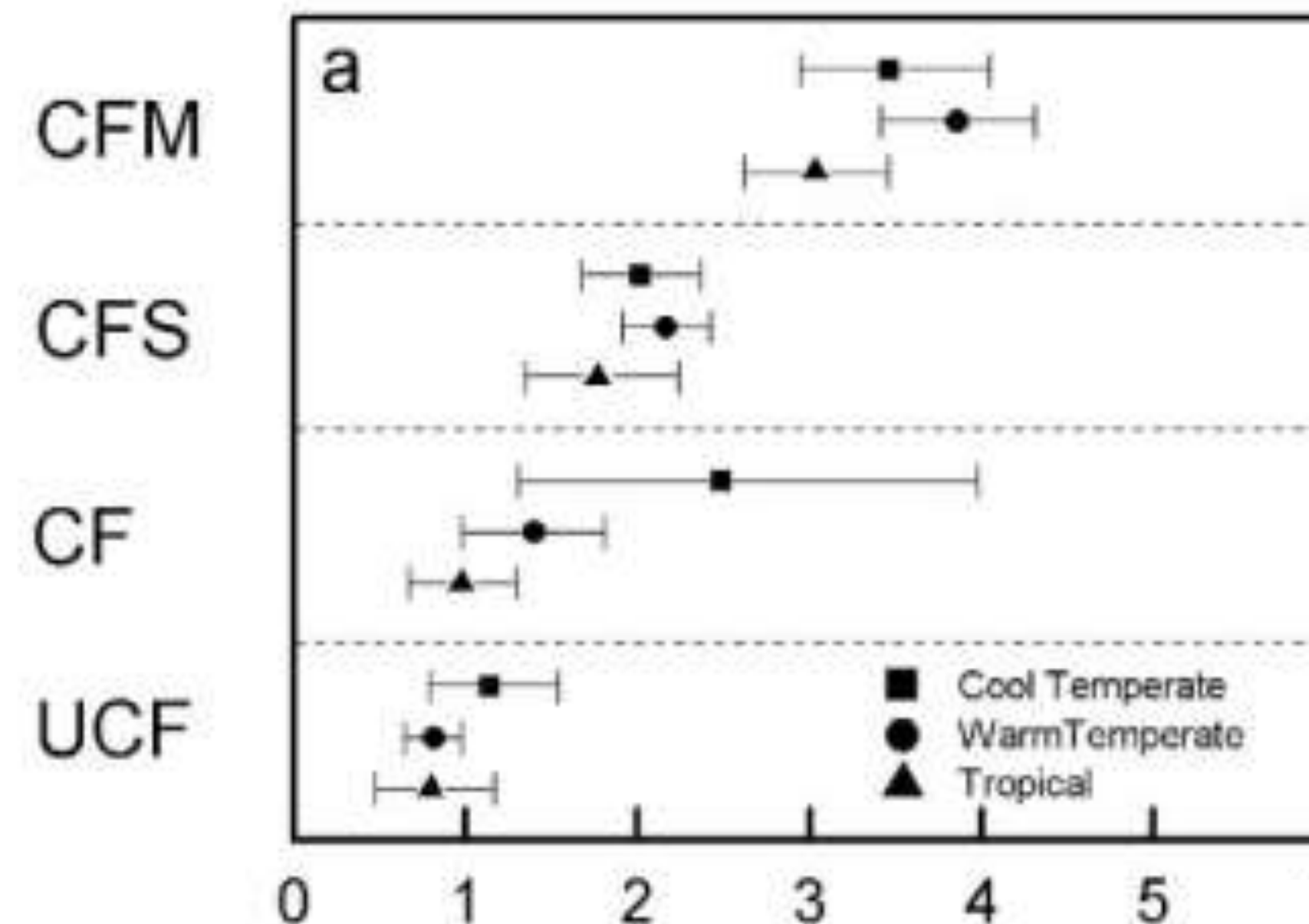
CONCIMI MIN. + RESIDUI = CFS

CONCIMI MIN. (DOSI OTTIMALI) = CF

CONCIMI MIN. (DOSI SUBOTTIMALI) = UCF

Han, P., Zhang, W., Wang, G., Sun, W., & Huang, Y. (2016). Changes in soil organic carbon in croplands subjected to fertilizer management: a global meta-analysis. Scientific reports, 6(1), 27199.

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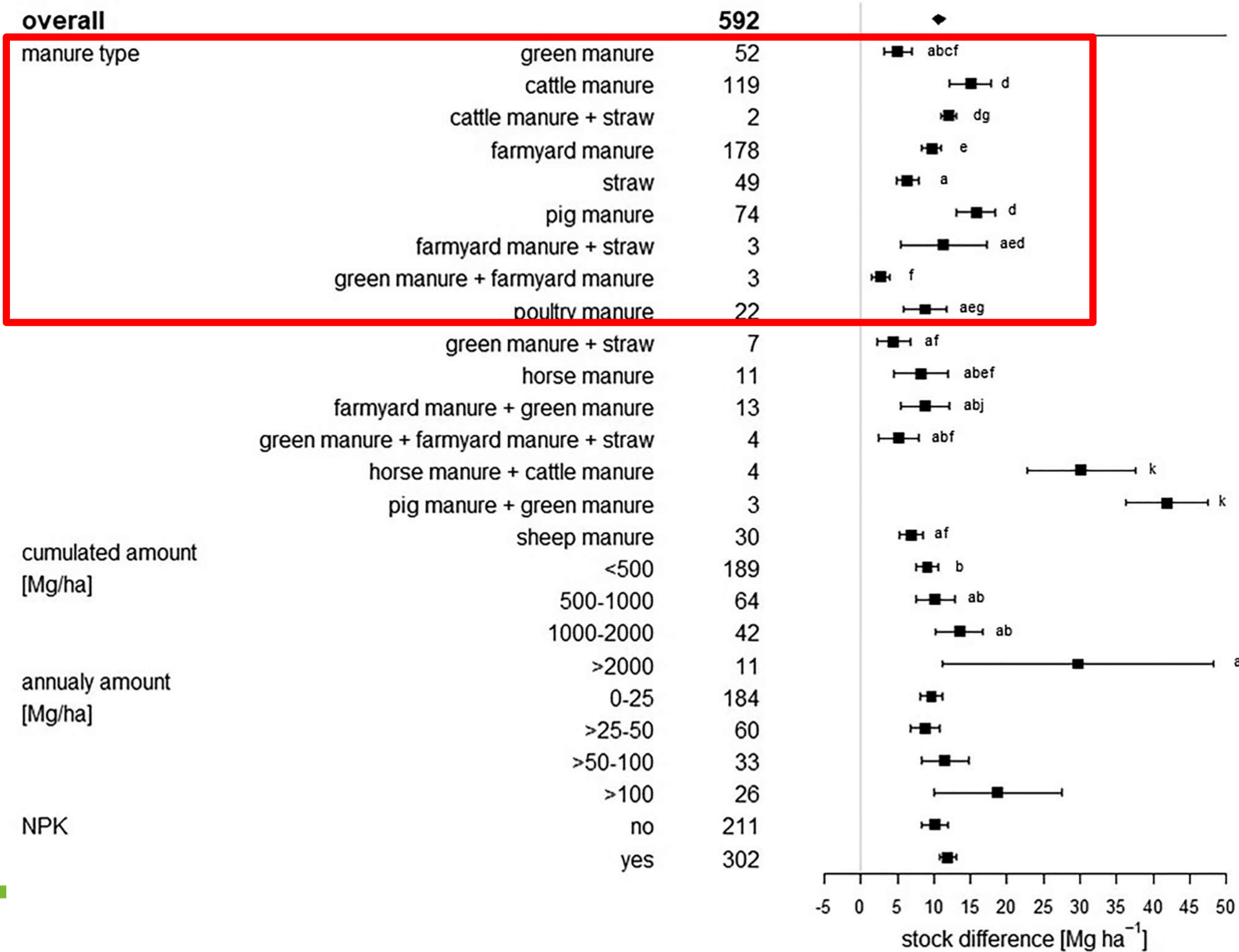






# Fertilizzanti di origine organica

## Effetto sull'accumulo carbonio organico (SOC)



Gross, A., & Glaser, B. (2021). Meta-analysis on how manure application changes soil organic carbon storage. Scientific reports, 11(1), 5516.





# Applicazione di digestato

## Effetto su SOC e GHG. Caso studio Lodi

|      |                     | Yield               | TOC                 |
|------|---------------------|---------------------|---------------------|
|      |                     | Gg ha <sup>-1</sup> | Gg ha <sup>-1</sup> |
| 2020 | Digestate           | 16.4 (1) a,b,c      | 44 (0.4) d,e,f      |
|      | Digestate + biochar | 16.9 (1) a,b,c      | 49 (2) c,g          |
|      | Slurry              | 14.9 (0.2) a,b,c    | 39 (0.8) f          |
|      | Slurry + biochar    | 14.9 (1) a,b,c      | 49 (0.6) c,d,g      |
|      | Mineral             | 13.6 (1) c          | 39 (1) f            |
| 2021 | Mineral + biochar   | 14.2 (0.8) b,c      | 56 (3) a,b          |
|      | Digestate           | 16.6 (0.5) a,b,c    | 46 (3) d,e,g        |
|      | Digestate + biochar | 18.6 (3) a,b        | 50 (2) c,g          |
|      | Slurry              | 16.9 (0.2) a,b,c    | 46 (0.8) d,e,g      |
|      | Slurry + biochar    | 15.6 (3) a,b,c      | 59 (3) a            |
|      | Mineral             | 19.2 (1) a          | 42 (1) e,f          |
|      | Mineral + biochar   | 14.0 (1) c          | 54 (1) b,c          |

|                                                 | Digestate |      | Slurry |      |
|-------------------------------------------------|-----------|------|--------|------|
|                                                 | 2020      | 2021 | 2020   | 2021 |
| Moisture content (%)                            | 92.1      | 93.1 | 94.6   | 94.7 |
| Norg content (g kg <sup>-1</sup> )              | 2.43      | 1.61 | 4.32   | 1.64 |
| N-NH <sub>4</sub> content (g kg <sup>-1</sup> ) | 2.57      | 1.48 | 0.98   | 0.46 |
| Effective N (%)                                 | 0.38      | 0.23 | 0.31   | 0.13 |
| Added dose (Mg ha <sup>-1</sup> )               | 54        | 74   | 45     | 133  |
| N added (Kg ha <sup>-1</sup> )                  | 270       | 229  | 239    | 279  |
| Effective N added (Kg ha <sup>-1</sup> )        | 205       | 170  | 140    | 173  |

|           | 2020                               |                 |                  |                    |                 |                  | 2021                               |                 |                  |                    |                 |                  |
|-----------|------------------------------------|-----------------|------------------|--------------------|-----------------|------------------|------------------------------------|-----------------|------------------|--------------------|-----------------|------------------|
|           | Organic vs. Mineral Fertilizer (%) |                 |                  | Biochar Effect (%) |                 |                  | Organic vs. Mineral Fertilizer (%) |                 |                  | Biochar Effect (%) |                 |                  |
|           | CO <sub>2</sub>                    | CH <sub>4</sub> | N <sub>2</sub> O | CO <sub>2</sub>    | CH <sub>4</sub> | N <sub>2</sub> O | CO <sub>2</sub>                    | CH <sub>4</sub> | N <sub>2</sub> O | CO <sub>2</sub>    | CH <sub>4</sub> | N <sub>2</sub> O |
| Digestate | 17 #                               | +31 *           | +202 #           | 0                  | +8              | +24              | +42 ***                            | -8              | +63 #            | -21 ***            | +58 *           | -59 *            |
| Slurry    | 25 *                               | +11             | -18              | 0                  | +24 **          | -6               | +18 *                              | +16 #           | +11              | +6 **              | -15             | +49              |
| Mineral   | -                                  | -               | -                | -8 *               | +7              | -57 **           | -                                  | -               | -                | -8 #               | +10             | -50 #            |

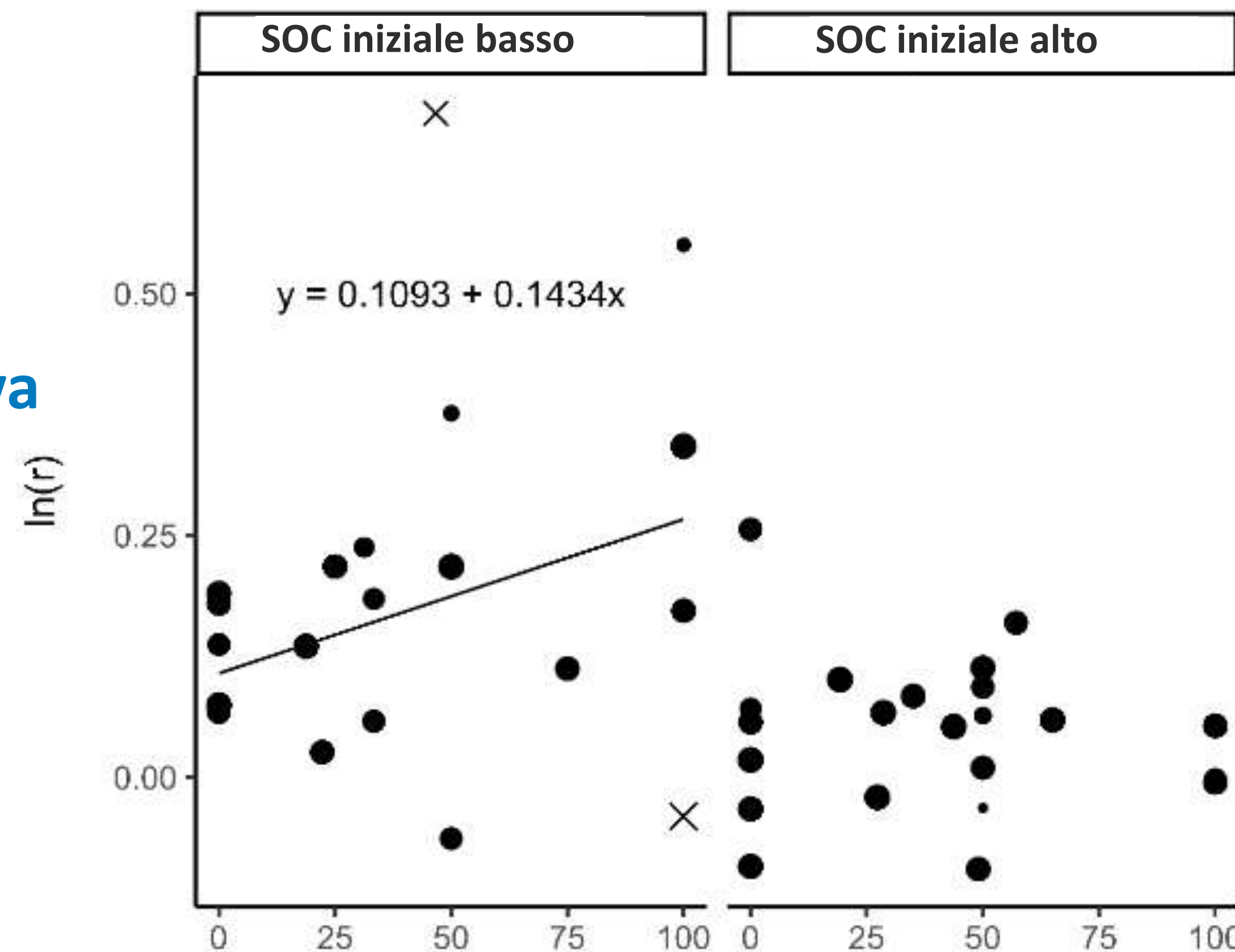




# Coservativa vs Convenzionale: Effetto sul SOC

Interazione significativa tra Valore iniziale di SOC x Quantità di Residui

Effetto positivo  
della Conservativa  
rispetto al  
Convenzionale



Tadiello, T., Acutis, M., Perego, A., Schillaci, C., & Valkama, E. (2023). Soil organic carbon under conservation agriculture in Mediterranean and humid subtropical climates: Global meta-analysis. *European Journal of Soil Science*, 74(1), e13338.





# Rotazione colturale e gestione agronomica

## Effetto sull'evoluzione di SOC

|                   |              |  |  |  |  |
|-------------------|--------------|--|--|--|--|
| tessitura         | Medio-fine   |  |  |  |  |
| Sostanza Organica | Alta (>2.7%) |  |  |  |  |

| RISULTATI ESPRESSI In t CO <sub>2</sub> eq. ha <sup>-1</sup> yr <sup>-1</sup><br>(+ emissions    - <u>sequestro</u> ) |                              |                          |                               |            |            |
|-----------------------------------------------------------------------------------------------------------------------|------------------------------|--------------------------|-------------------------------|------------|------------|
|                                                                                                                       | BASELINE                     | SCENARIO 1               | SCENARIO 2                    | SCENARIO 3 | SCENARIO 4 |
| Coltura                                                                                                               | SOIA<br>GIRASOLE<br>FRUMENTO | FRUMENTO<br>SOIA<br>MAIS | FRUMENTO<br>SOIA (II)<br>MAIS | VITE       | MIX FIORI  |
| Suolo                                                                                                                 | + 2.52                       | + 1.79                   | + 1.13                        | + 0.48     | - 0.37     |
| Carburante                                                                                                            | + 0.50                       | + 0.80                   | + 0.66                        | + 1.55     | + 0.00     |
| GHG                                                                                                                   | + 0.69                       | + 0.87                   | + 0.82                        | + 0.16     | + 0.47     |
| TOTALE                                                                                                                | + 3.71                       | + 3.45                   | + 2.61                        | + 2.19     | + 0.10     |
| SEQUESTRO<br>(EFFETTO DI<br>MITIGAZIONE)                                                                              | 0                            | -0.26                    | -1.11                         | -1.53      | -3.62      |





# Effetto delle pratiche agronomiche

## Bilancio del C

|                                                                                                                 |                                                               |                                                       |                                                               |                                                                 |                                                                               |                                                                      |            |
|-----------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------|-------------------------------------------------------|---------------------------------------------------------------|-----------------------------------------------------------------|-------------------------------------------------------------------------------|----------------------------------------------------------------------|------------|
| tessitura                                                                                                       | Medio-fine                                                    |                                                       |                                                               |                                                                 |                                                                               |                                                                      |            |
| Sostanza Organica                                                                                               | Alta (>2.7%)                                                  |                                                       |                                                               |                                                                 |                                                                               |                                                                      |            |
| RISULTATI ESPRESSI In t CO <sub>2</sub> eq. ha <sup>-1</sup> yr <sup>-1</sup><br>(+ emissions      - sequestro) |                                                               |                                                       |                                                               |                                                                 |                                                                               |                                                                      |            |
|                                                                                                                 |                                                               | BASELINE                                              | SCENARIO 1                                                    | SCENARIO 2                                                      | SCENARIO 3                                                                    | SCENARIO 4                                                           | SCENARIO 5 |
| COLTURA                                                                                                         | SOIA<br>GIRASOLE<br>FRUMENTO                                  |                                                       |                                                               |                                                                 | SOIA<br>GIRASOLE<br>FRUMENTO<br>COVER CROP                                    |                                                                      |            |
| Gestione Agronomica                                                                                             | Aratura +<br>Conc. Min. +<br>Residui<br>Frumento<br>Asportati | NT + Conc.<br>Min. + Residui<br>Frumento<br>Asportati | Aratura +<br>Conc. Org. +<br>Residui<br>Frumento<br>Asportati | Aratura +<br>Conc. Min. +<br>Residui<br>Frumento<br>incorporati | Aratura +<br>Conc. Min. +<br>Residui<br>Frumento<br>Asportati +<br>Cover Crop | NT + Conc.<br>Org. + Residui<br>Frumento<br>superficie<br>Cover Crop |            |
| Suolo                                                                                                           | + 2.52                                                        | + 2.37                                                | + 1.93                                                        | + 1.02                                                          | + 0.42                                                                        | -1.05                                                                |            |
| Carburante                                                                                                      | + 0.50                                                        | + 0.22                                                | + 0.60                                                        | + 0.49                                                          | + 0.57                                                                        | + 0.27                                                               |            |
| GHG                                                                                                             | + 0.69                                                        | + 0.86                                                | + 0.47                                                        | + 0.59                                                          | + 0.49                                                                        | + 0.48                                                               |            |
| TOTALE                                                                                                          | + 3.71                                                        | + 3.45                                                | + 3.00                                                        | + 2.10                                                          | + 1.47                                                                        | - 0.30                                                               |            |
| SEQUESTRO<br>(EFFETTO DI<br>MITIGAZIONE)                                                                        | 0                                                             | -0.26                                                 | -0.71                                                         | -1.61                                                           | -2.24                                                                         | -4.02                                                                |            |



# Conclusioni

- Lavorazioni del suolo ridotte + solo con input SO, altrimenti =
- Residui colturali +
- Fertilizzazione organica + +
- Cover crop + + in alternativa, doppia coltura nell'anno





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# Grazie per l'attenzione

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