Slow and unsteady? Soil carbon accumulation rates in Mediterranean and semi-arid post-agricultural landscapes

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November 22, 2022

Abstract

Increases in soil organic carbon (SOC) during secondary succession in Mediterranean and semi-arid climates, global hot-spots for agricultural land abandonment, have been notoriously difficult to predict and are subject to multiple environmental and land management factors. Field studies have reported positive, negative and no change varying over extended periods of time. To better evaluate the potential carbon sink capacity of regenerating semi-natural landscapes in these climates requires an improved understanding of the rates of SOC gains and losses. We compiled Mediterranean and semi-arid chronosequences and paired plots to investigate the effects of past land use, restoration intensity, and various environmental factors on SOC stocks during post-agricultural succession. Based on a preliminary synthesis of the western Mediterranean basin, we expect significant long-term accumulation rates globally although with high variability and the potential for net losses (compared to cropland control sites) even after several decades. Losses or minimal change are likely due to high initial SOC stock at the time of abandonment (e.g. from anthropogenic organic matter inputs) and too high or too low mean annual precipitation (e.g. < 450 or > 1000 mm), among other factors. A consolidated SOC accumulation rate for both Mediterranean and semi-arid soils undergoing post-agricultural succession is provided to better inform decision-makers on the benefits and challenges of agricultural land abandonment.

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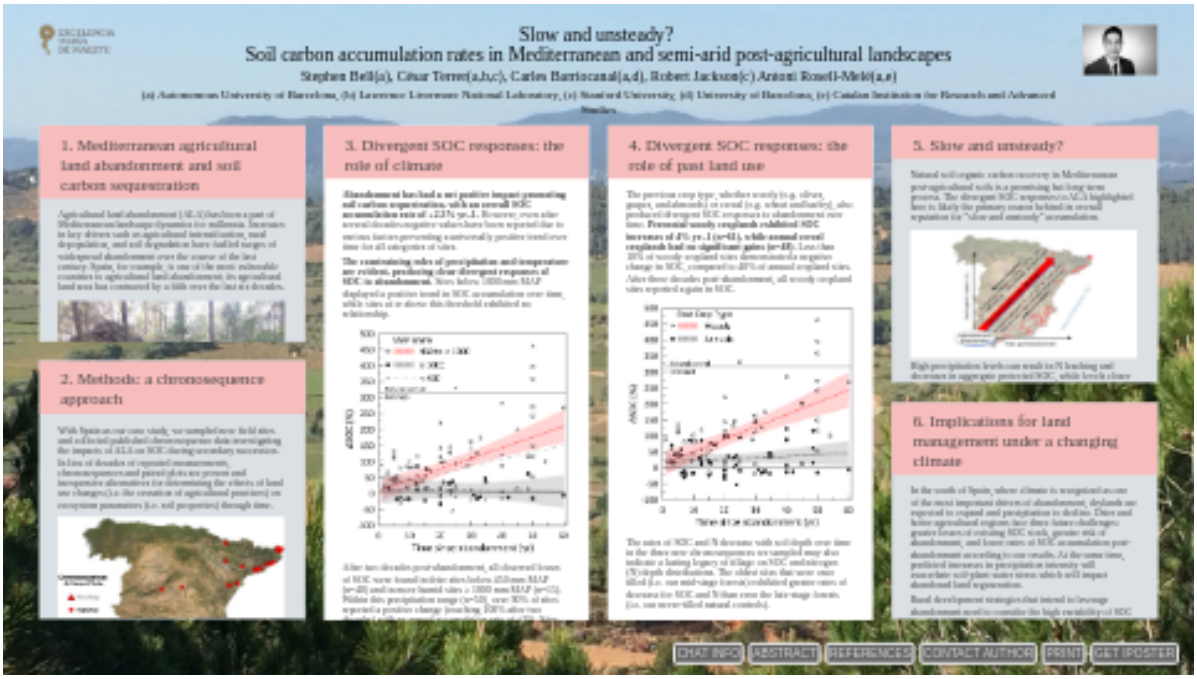

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PRESENTED AT:

AGU FALL MEETING
Online Everywhere | 1–17 December 2020

1. MEDITERRANEAN AGRICULTURAL LAND ABANDONMENT AND SOIL CARBON SEQUESTRATION

Agricultural land abandonment (ALA) in the Mediterranean region has accelerated due to various factors. Spain is one of the most vulnerable countries; its agricultural land area has contracted by a fifth over the last six decades.

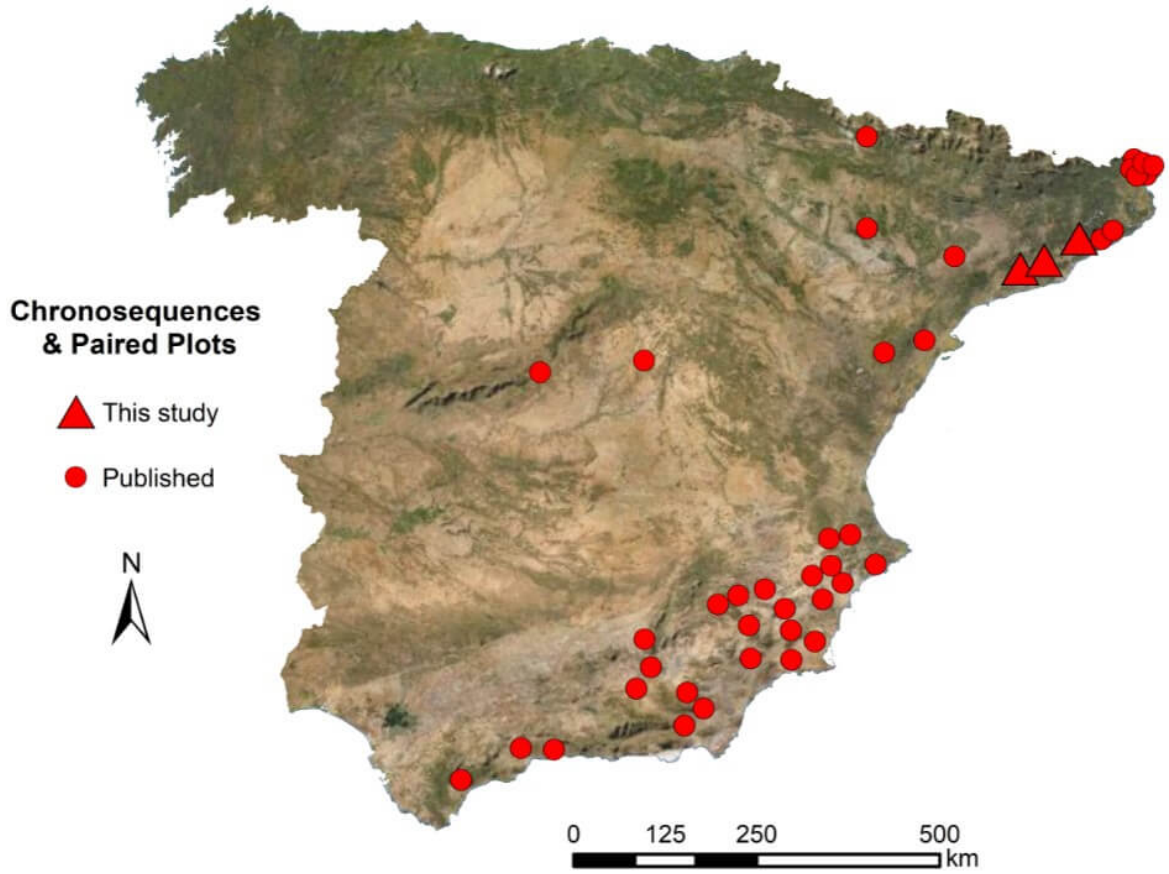
Intensive agriculture in Mediterranean and semi-arid landscapes can often degrade soils that then require long periods of natural or assisted restoration to overcome stalled vegetation recovery and enable soil carbon sequestration (SCS).

There have been numerous reports across Spain of fast, slow, and negligible increases in soil organic carbon (SOC) post-abandonment. This variability in SOC responses presents challenges for decision-makers involved in the management of regions undergoing ALA.

Here, we investigate some of the sources of this variability to understand why SOC accumulation in Mediterranean post-agricultural landscapes is often considered "slow and unsteady".

2. METHODS: A CHRONOSEQUENCE APPROACH

With Spain as our case study, we sampled new field sites and collected published chronosequence data investigating the impacts of ALA on SOC during secondary succession.



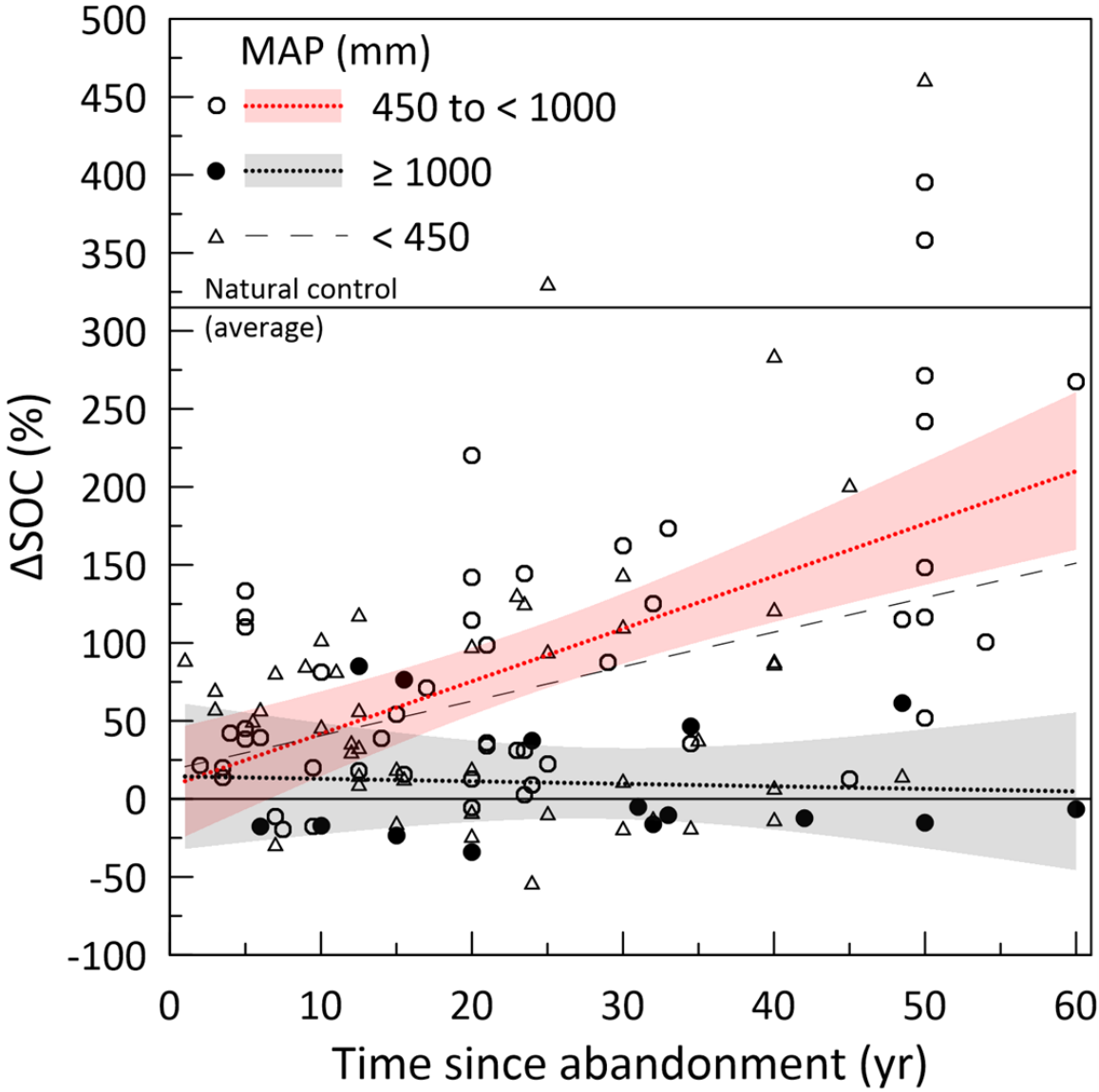
We identified three new chronosequences in Catalonia comprising fields abandoned at varying times in the past, and took soil samples at different depths for each stage of forest succession to measure SOC and nitrogen (N).

We also collected published chronosequences if they reported time since abandonment and the SOC concentration in the topsoils of each stage. We found 24 studies undertaken in Spain matching these criteria. With our field sites included (n=12), the final dataset featured 113 examples of ALA and 64 agricultural and natural (uncultivated) controls.

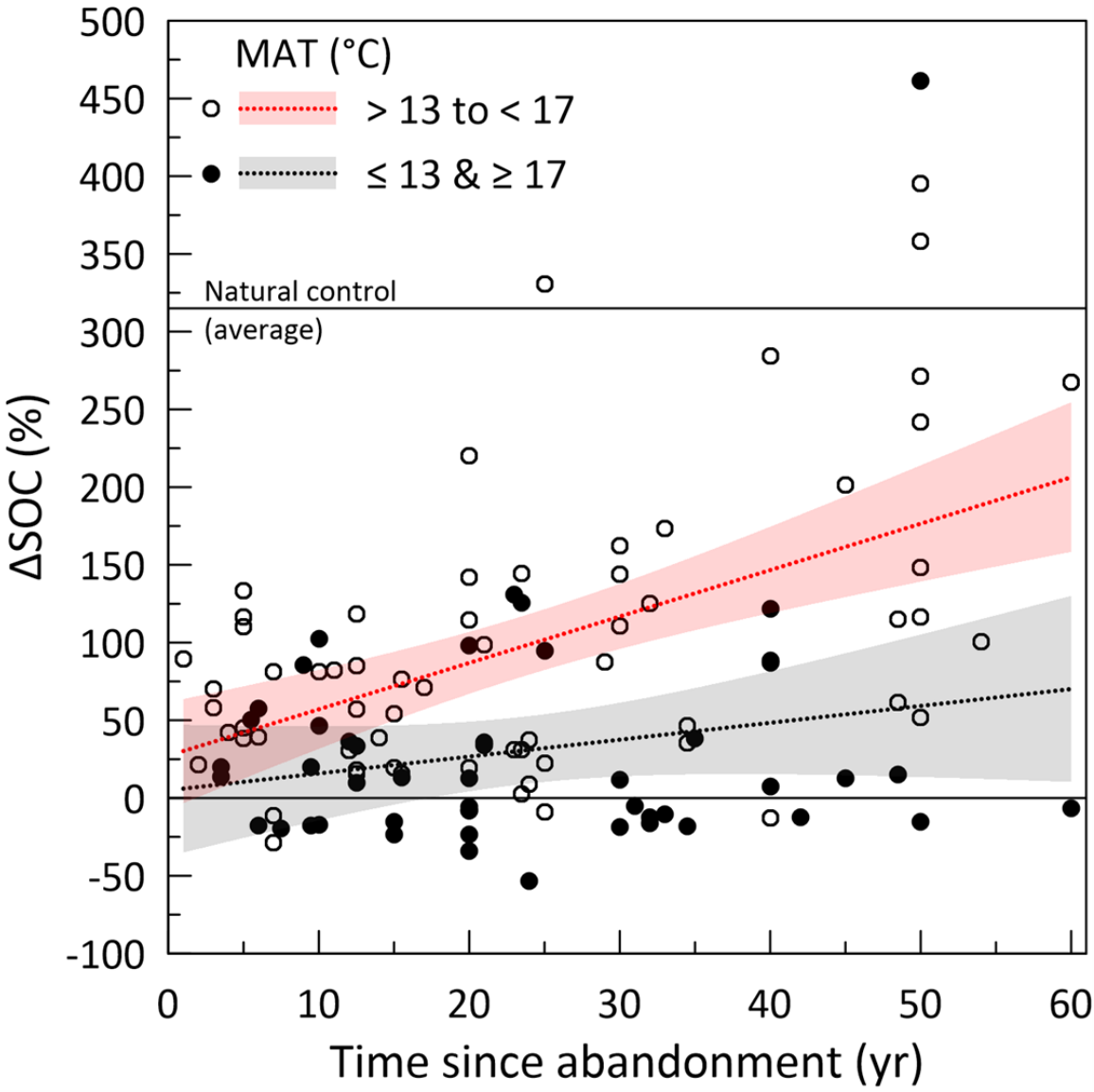
3. DIVERGENT SOC RESPONSES: THE ROLE OF CLIMATE

Abandonment has had a net positive impact promoting soil carbon sequestration, with an overall SOC accumulation rate of **+2.3% yr–1.** However, even after several decades negative values have been reported.

The constraining roles of precipitation and temperature are evident, producing divergent responses of SOC to abandonment.

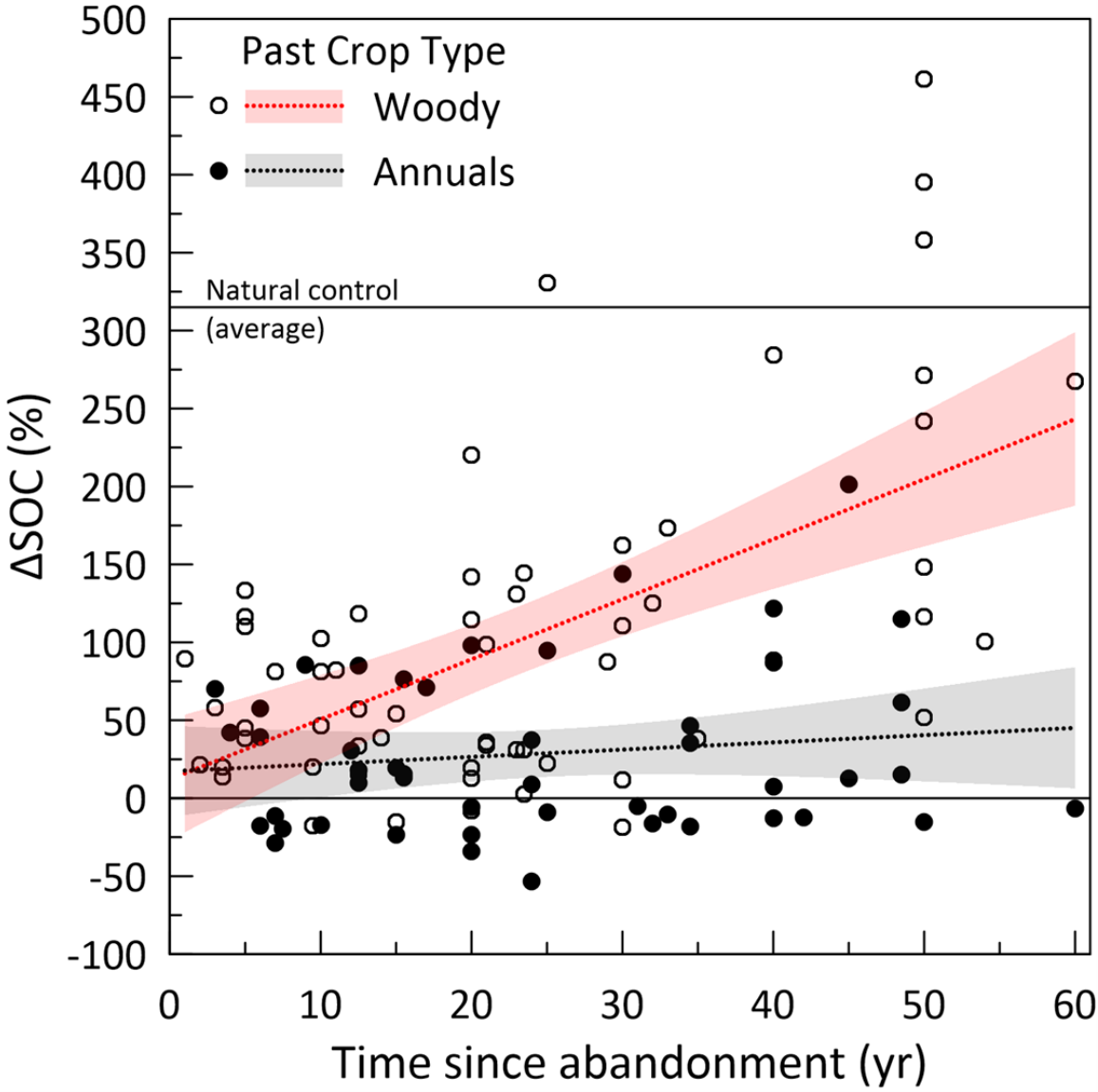


After two decades post-abandonment, all observed losses of SOC were found in drier sites below 450 mm MAP (n=48) and in more humid sites ≥ 1000 mm MAP (n=15). Sites within this precipitation range (n=50) accumulated SOC at +3% yr–1. Sites between 13 and 17 °C (n=64) also demonstrated a greater SOC accumulation rate of +3% yr–1 compared to sites above or below this range (not significant, n=49).

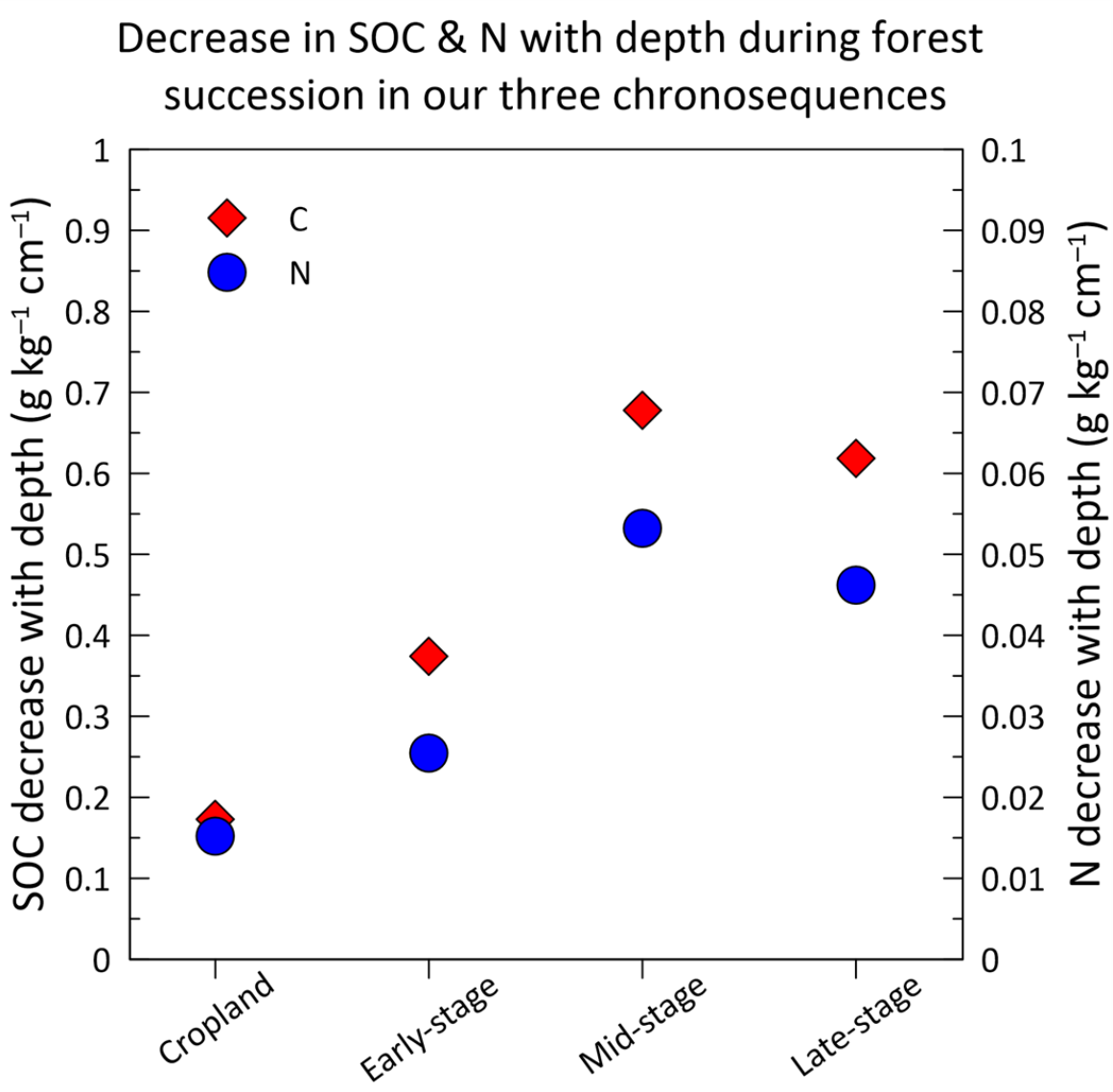

MAT (°C)
> 13 to < 17
≤ 13 & ≥ 17
Natural control
(average)
ΔSOC (%)
Time since abandonment (yr)
500
450
400
350
300
250
200
150
100
50
0
-50
-100
0
10
20
30
40
50
60

4. DIVERGENT SOC RESPONSES: THE ROLE OF PAST LAND USE

The previous crop type, whether woody (e.g. olives, grapes, and almonds) or cereal (e.g. wheat and barley), also produced divergent SOC responses to abandonment over time. Perennial woody croplands exhibited SOC increases of +4% yr–1 (n=61), while annual cereal croplands had no significant gains (n=48).

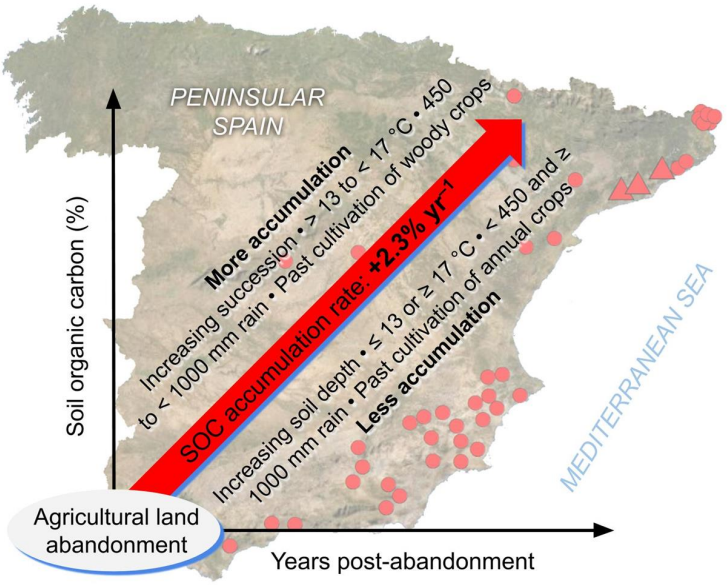


The rates of SOC and N decrease with soil depth over time in the three new chronosequences we sampled may also indicate a lasting legacy of tillage on SOC and N depth distributions. The oldest sites that were once tilled (mid-stage forests) exhibited greater rates of decrease for SOC and N than even the late-stage forests (never-tilled natural controls).


Decrease in SOC & N with depth during forest succession in our three chronosequences
SOC decrease with depth (g kg^{-1} cm^{-1})
N decrease with depth (g kg^{-1} cm^{-1})
C
N
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
Cropland
Early-stage
Mid-stage
Late-stage

5. SLOW AND UNSTEADY?

The divergent SOC responses to ALA highlighted here is likely the primary reason behind its reputation for “slow and unsteady” accumulation.



Our results indicate that the greatest SCS can be expected on abandoned woody croplands within a Goldilocks climate window of ~450–900 mm MAP and ~13–17 °C MAT. High precipitation brings N leaching and decreased SOC aggregate protection, while low precipitation limits net primary productivity.

Different initial SOC stocks of woody and cereal croplands at the time of abandonment also impacts SCS potential.

Lower initial SOC stocks found in vineyards/orchards due to:

- reduced SOM inputs (e.g. pruned branch removal)

- allocation on marginal, lower quality soils (i.e. sloping, shallow, and stony).

Higher initial SOC stocks found in cereal croplands due to:

- SOM friendly management (e.g. regular manure, stubble grazing, and seed fallowing), thereby promoting SOC losses immediately following cessation

6. IMPLICATIONS FOR LAND MANAGEMENT UNDER A CHANGING CLIMATE

Climate change is recognized as one of the most important drivers of ALA. Drylands are expected to expand and precipitation to decline in the semi-arid south of Spain, raising three future challenges:

- greater losses of existing SOC stock
- greater risk of abandonment
- lower rates of SOC accumulation post-abandonment, according to our results

Rural development strategies that intend to leverage ALA need to consider the high variability of SOC responses and any potential risks that can offset intended benefits. Widespread unmanaged forest regeneration can increase risk of wildfires.

By altering the SOC accumulation rates of existing secondary forests and influencing the locations and crop types of future ALA, climate change in the Mediterranean region will determine the SCS potential and ecological value of abandoned agricultural lands.

Regional climate change mitigation policies can consider abandonment as a low-cost but long-term option best incorporated in tandem with other multipurpose sustainable land management strategies.

For more information, please see: https://doi.org/10.1016/j.scitotenv.2020.143535 (https://doi.org/10.1016/j.scitotenv.2020.143535)

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REFERENCES

Bell, S. M., Terrer, C., Barriocanal, C., Jackson, R. B., & Rosell-Melé, A. (2020). Soil organic carbon accumulation rates on Mediterranean abandoned agricultural lands. Science of The Total Environment, 143535. https://doi.org/10.1016/j.scitotenv.2020.143535