Considerations in soil (organic) carbon measurement and reproducibility: sampling design

...at the field scale

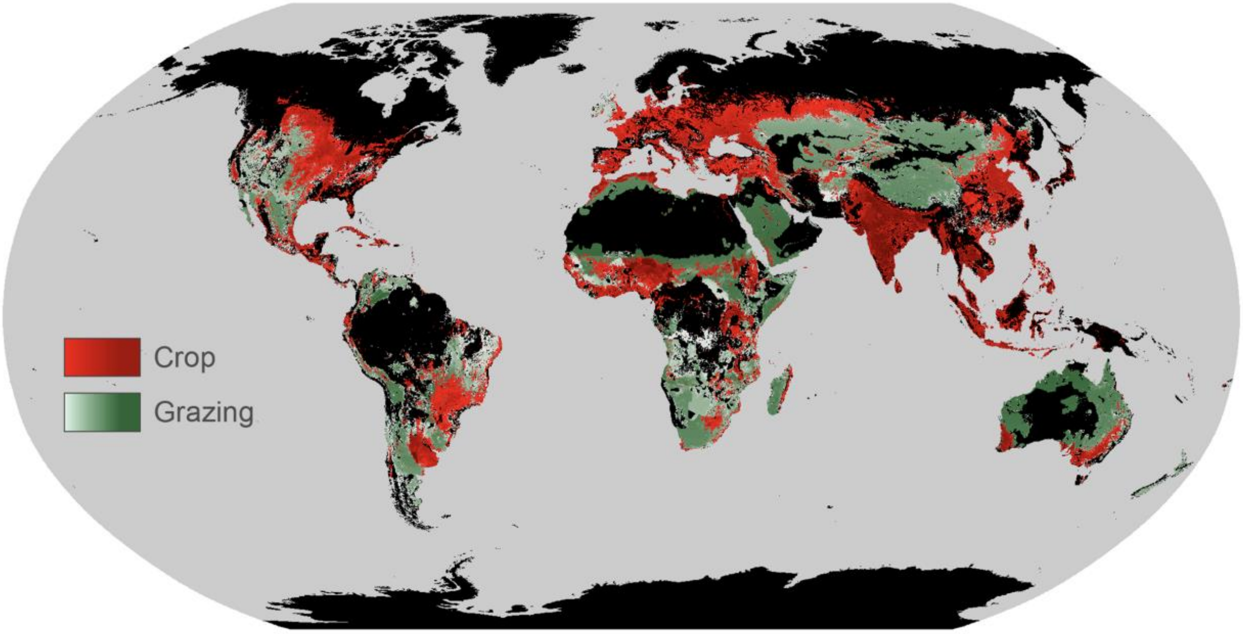
ALTA SUMMER WORKSHOP

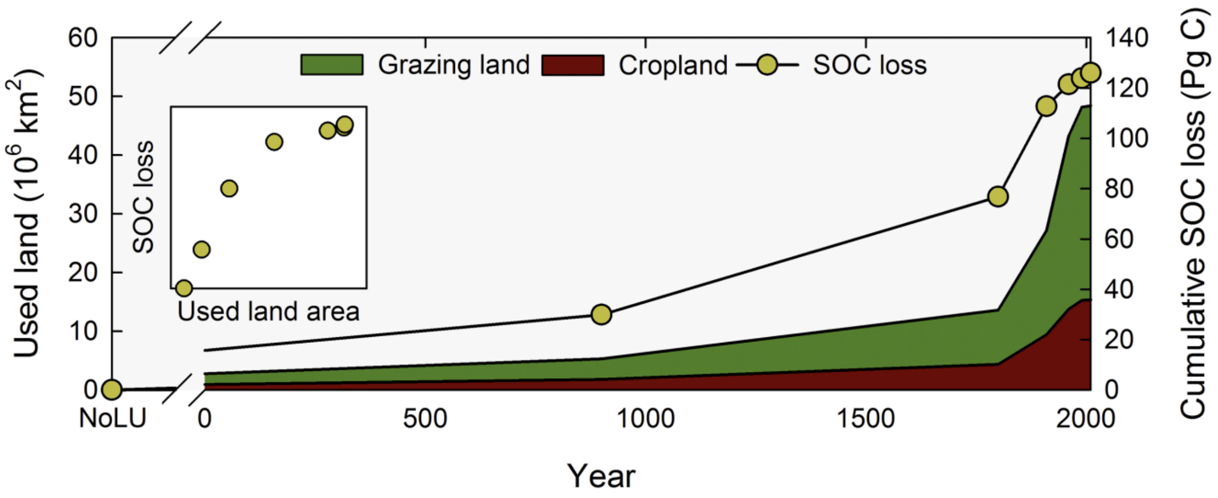
20 August 2024
Normal, IL

Andrew Margenot | Soil Scientist | Associate Professor

https://margenot.cropsciences.illinois.edu/

“Soil carbon debt of 12,000 years of human land use”





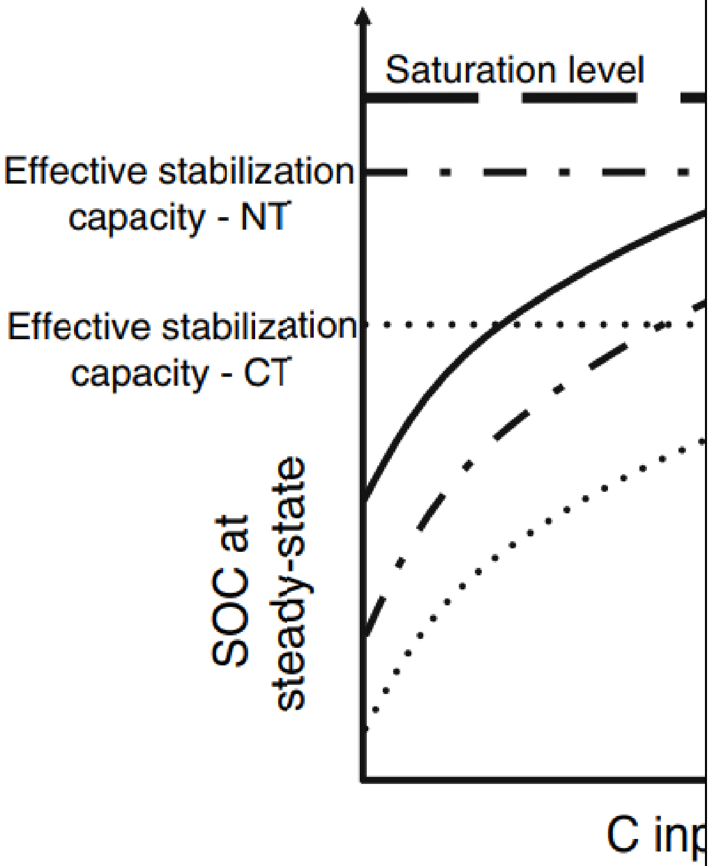
- Soils hold 3x more C than the atmosphere
- Terrestrial ecosystem C is ~ 3170 Pg
  - 80% (2500 Pg) is in soil

- Agricultural land use is *estimated* to have resulted in loss of 133 Pg C

Sanderman et al. 2017 *PNAS*

Skepticism

1. Soil carbon saturation



2. Not enough nitrogen

Environmental Science & Technology
Viewpoint
pubs.acs.org/est

Sequestering Soil Organic Carbon: A Nitrogen Dilemma

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To slow down rising levels of atmospheric CO_2, the "4 per 1000" (4p1000) initiative was launched at the COP21 conference in Paris (http://4p1000.org). This initiative aims at a yearly 4‰ (0.4%) increase in global agricultural soil organic carbon (SOC) stocks. If applied to all (also nonagricultural) soils, such a C sequestration rate could in theory fully compensate increases in atmospheric CO_2−C levels of 4300 Tg yr^{-1}. We question the feasibility of the 4p1000 goal, using basic stoichiometric arguments. Soil organic matter (SOM) contains nitrogen (N) as well as C, and it is unclear what will be the origin of this N.

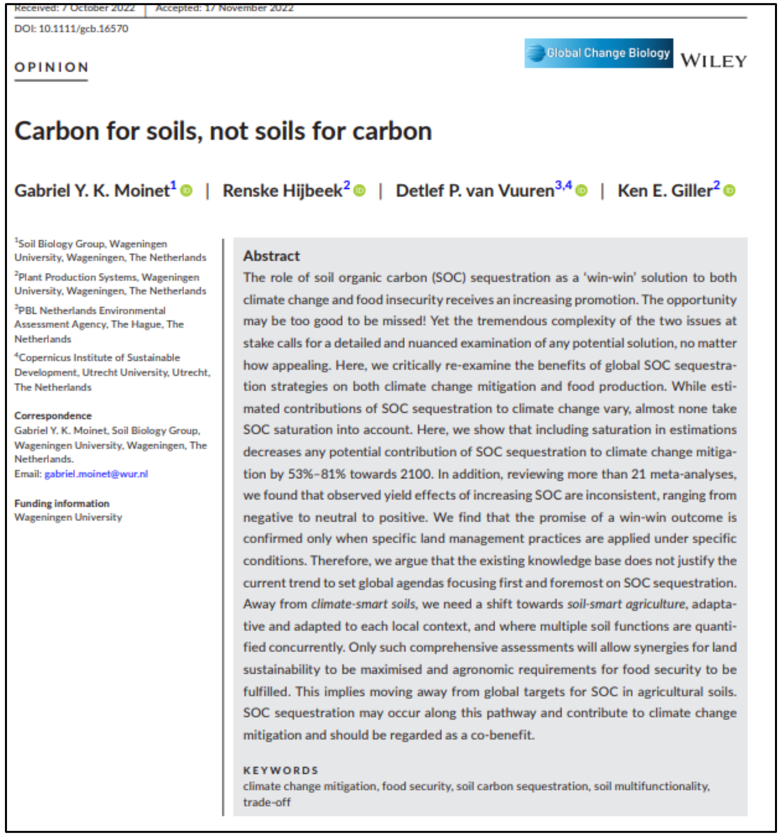
Implementing the 4p1000 initiative on all agricultural soils pollution impacts. However, these surpluses are not evenly distributed but highly concentrated in specific regions, notably China.[3] There are also substantial differences between land uses: surpluses are large in soils under intensive agricultural and horticultural management but small in low intensity grazed rangelands and small-holder arable cropping (for instance, in Africa). Even if the N surpluses were more evenly distributed, they would first have to be accumulated by crops in order to supply organic C to the soil. The rate of N accumulated in global cropland residue is estimated to be ~30 Tg N yr^{-1},[4] far less than the 100 Tg N yr^{-1} required. Furthermore, as a consequence of environmental regulations, intensive efforts to decrease N surpluses are anticipated over the coming decades.[3] Thus, the increase in plant N uptake that is needed to meet the 4p1000 goals is unrealistic.

As plant material has higher C-to-N ratios than SOM, a steady increase in the C-to-N ratio of SOM could facilitate soil C sequestration without extra N. However, it is difficult to see how the required increase in the C-to-N ratio of SOM (0.05 per year) could be achieved and sustained; with the exception of peat, soils globally tend to move toward a C-to-N ratio of 12[1] and we do not know of a mechanism to increase this without also reducing the capacity of soil to supply N.

As increasing soil C content is almost always desirable for improving soil quality and functioning, the 4p1000 initiative is laudable. Since the 4p1000 initiative was introduced, several studies assessed approaches to meet its goals (e.g., ref 5). However, these assessments overlooked limitations imposed by nutrient availability. We conclude that the stated 4p1000 goal of sequestering 1200 Tg C yr^{-1} in agricultural soils is unlikely to be met, due to stoichiometric constraints.

We argue for a more spatially diversified strategy for climate change mitigation from agricultural soils. In agricultural soils with low C sequestration potential, mitigation efforts should

3. Misguided focus



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Global Change Biology WILEY
OPINION

Carbon for soils, not soils for carbon

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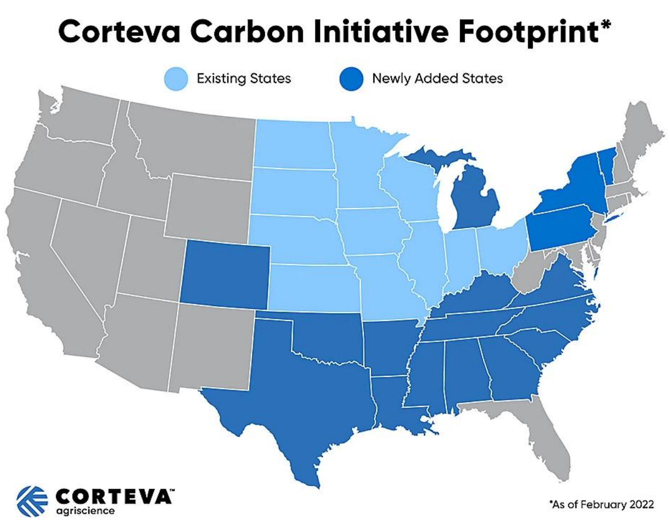
Abstract
The role of soil organic carbon (SOC) sequestration as a 'win-win' solution to both climate change and food insecurity receives an increasing promotion. The opportunity may be too good to be missed! Yet the tremendous complexity of the two issues at stake calls for a detailed and nuanced examination of any potential solution, no matter how appealing. Here, we critically re-examine the benefits of global SOC sequestration strategies on both climate change mitigation and food production. While estimated contributions of SOC sequestration to climate change vary, almost none take SOC saturation into account. Here, we show that including saturation in estimations decreases any potential contribution of SOC sequestration to climate change mitigation by 53%–81% towards 2100. In addition, reviewing more than 21 meta-analyses, we found that observed yield effects of increasing SOC are inconsistent, ranging from negative to neutral to positive. We find that the promise of a win-win outcome is confirmed only when specific land management practices are applied under specific conditions. Therefore, we argue that the existing knowledge base does not justify the current trend to set global agendas focusing first and foremost on SOC sequestration. Away from *climate-smart soils*, we need a shift towards *soil-smart agriculture*, adaptive and adapted to each local context, and where multiple soil functions are quantified concurrently. Only such comprehensive assessments will allow synergies for land sustainability to be maximised and agronomic requirements for food security to be fulfilled. This implies moving away from global targets for SOC in agricultural soils. SOC sequestration may occur along this pathway and contribute to climate change mitigation and should be regarded as a co-benefit.

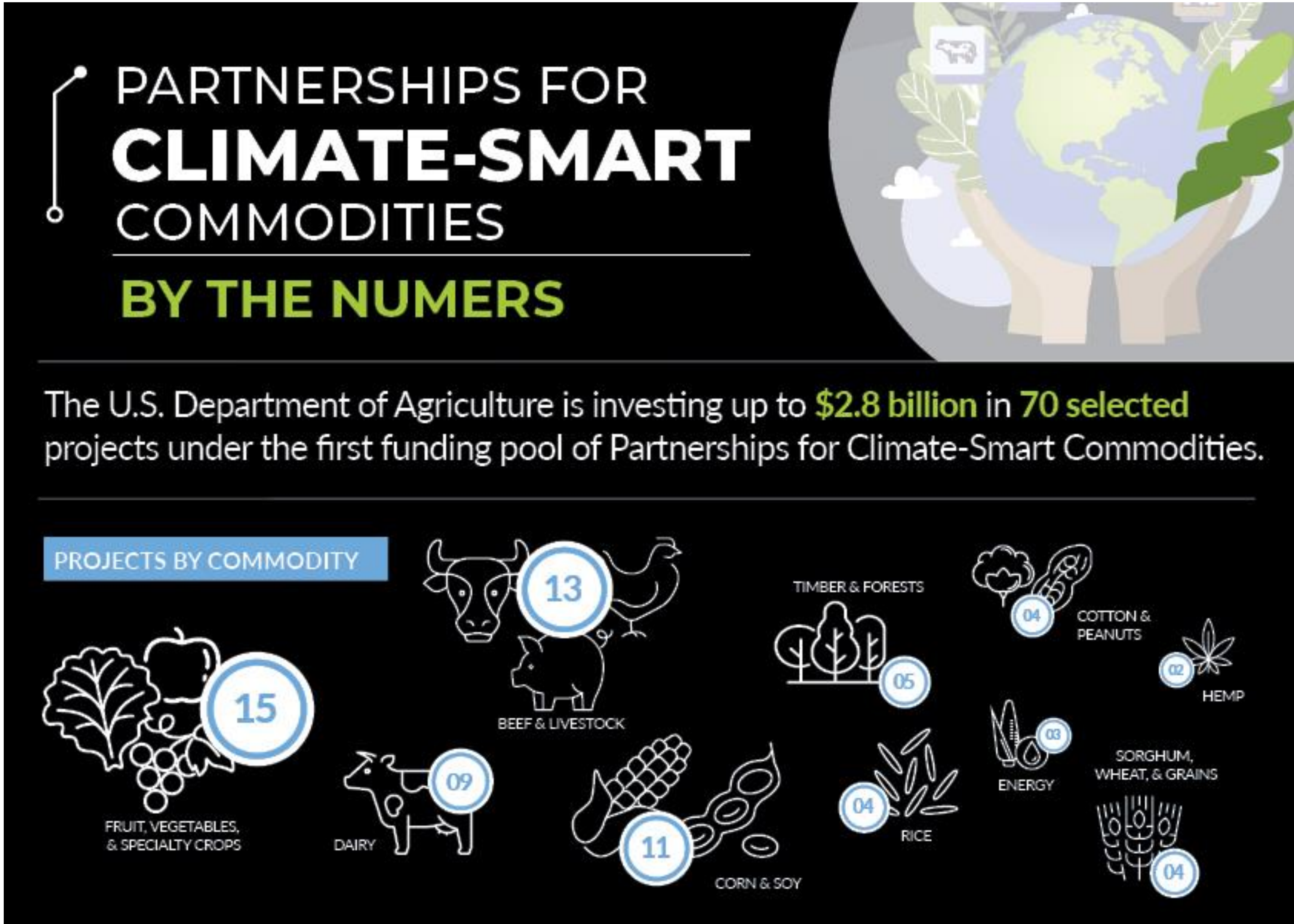
KEYWORDS
climate change mitigation, food security, soil carbon sequestration, soil multifunctionality, trade-off

The Wild West of carbon markets

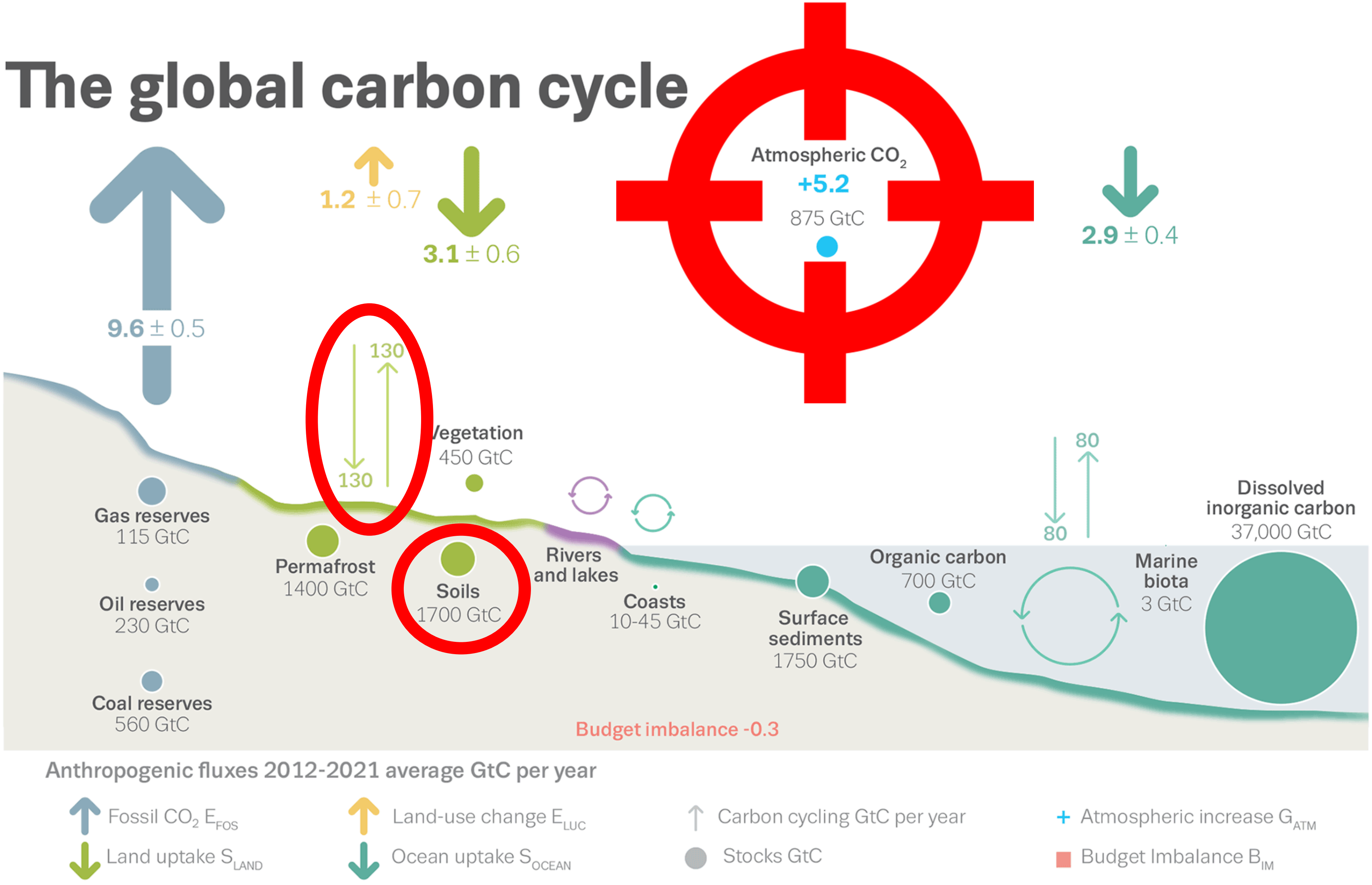
CARBON MARKET EXCHANGE

carbon™ by indigo

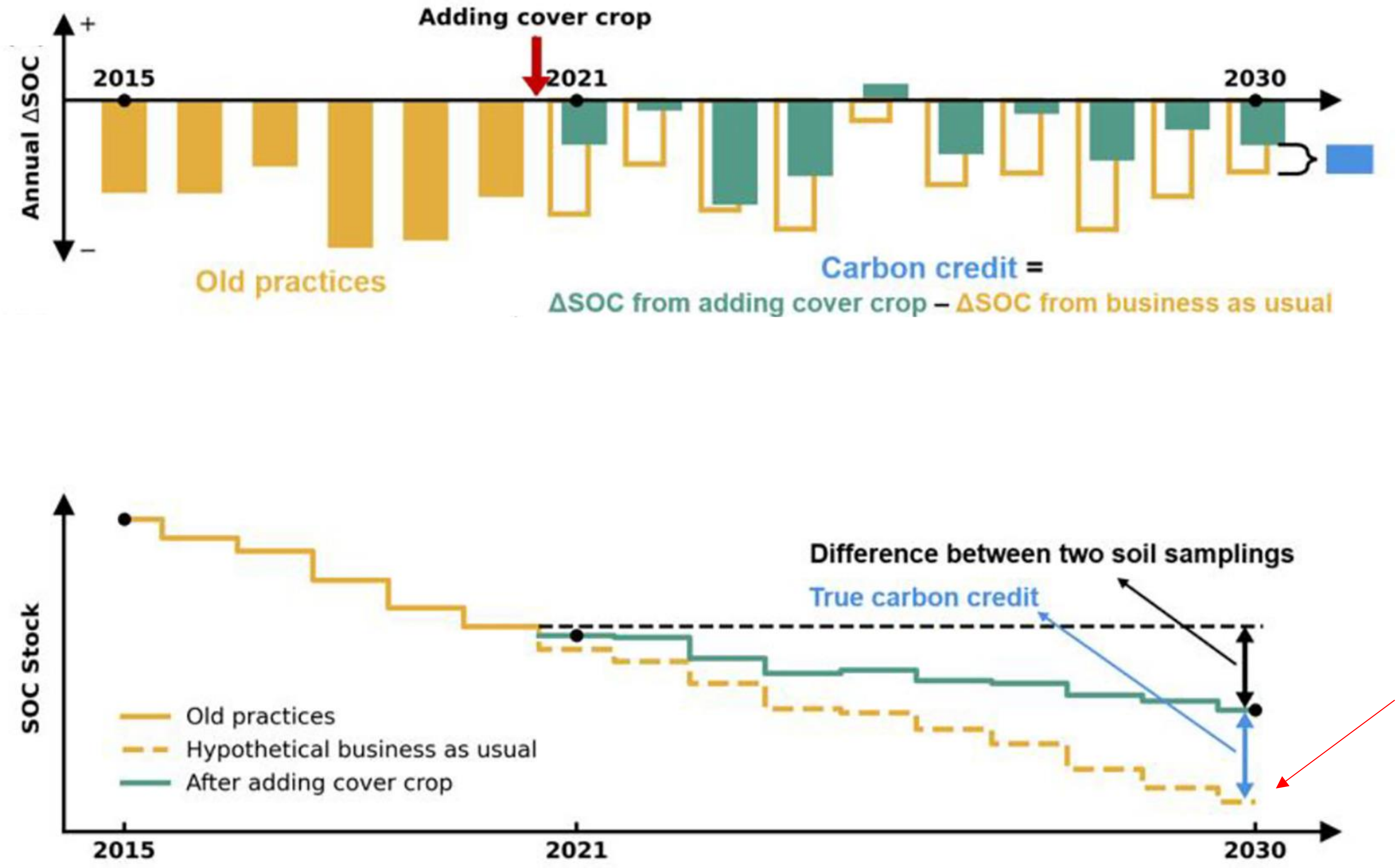




Premise of C credits: certain agricultural practices can lead to net decreases in atmospheric CO_2



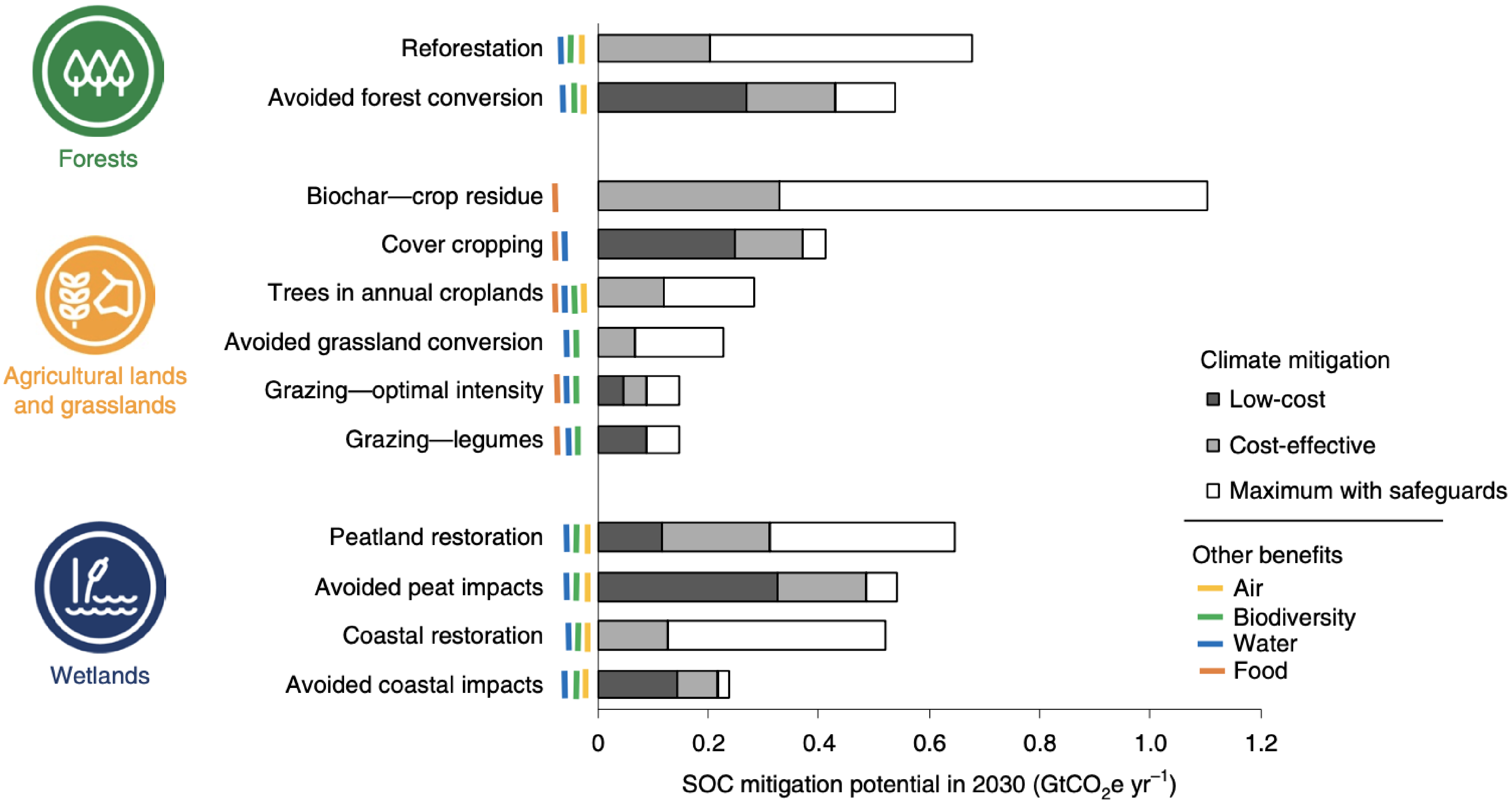
C credits as *averted* CO_2-C emissions: The counterfactual challenge



Business as usual is the counterfactual; usually missed in most C credit programs

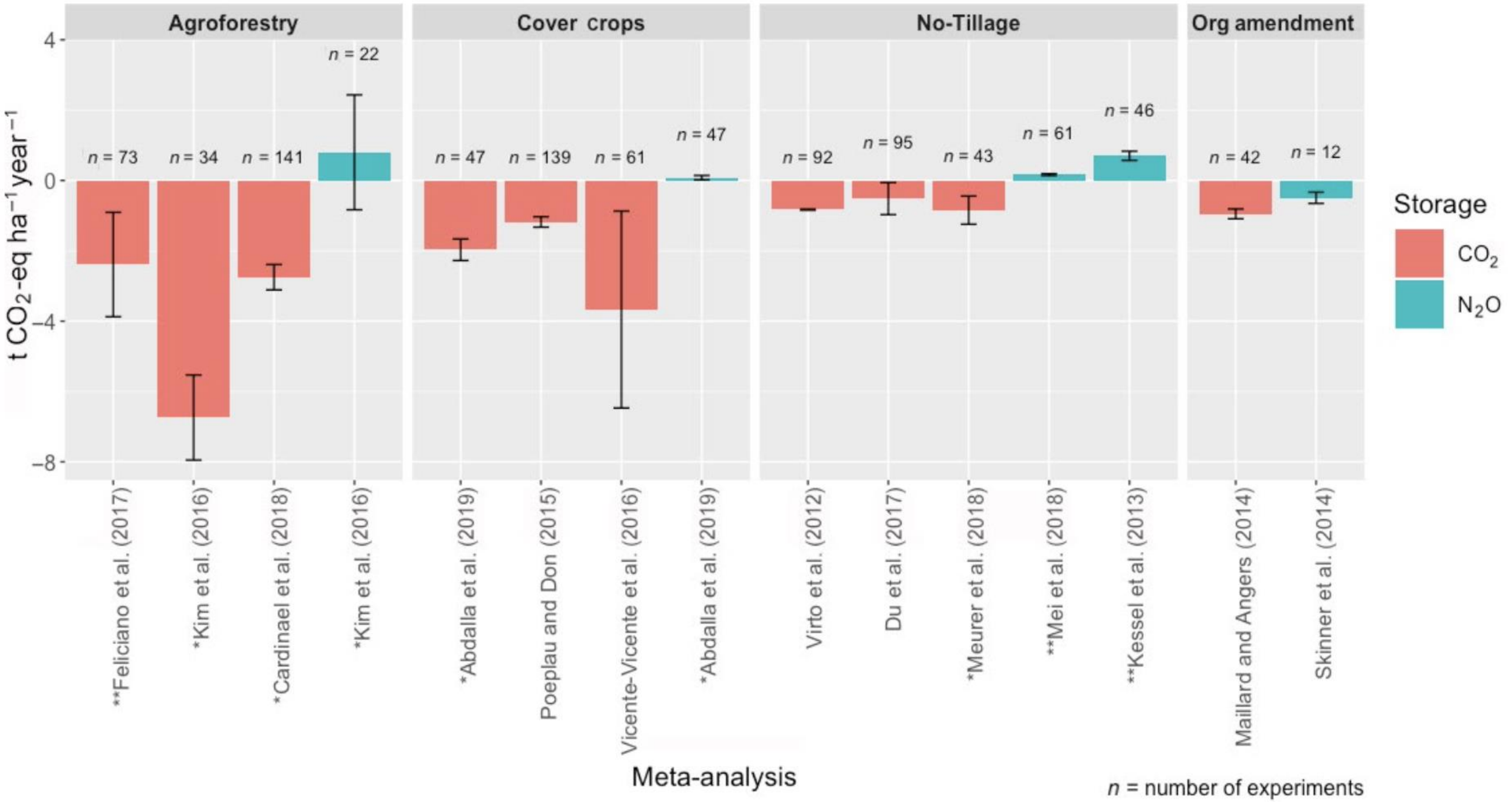
Guan et al. 2023 *Earth Science Reviews* 243: 104462

Proposed methods to decrease SOC



Bossio et al. 2020 *Nature Sustainability*

What (meta)data suggests might work



Guenet et al. 2020 *GCB*

How are "C credits" measured in-field?

Two components to a C credit:

1. Soil (organic) C stocks
2. Greenhouse gases (GHGs)

   Carbon dioxide / CO_2

   Methane / CH_4 (84x CO_2)

   Nitrous oxide / N_2O (298x CO_2)

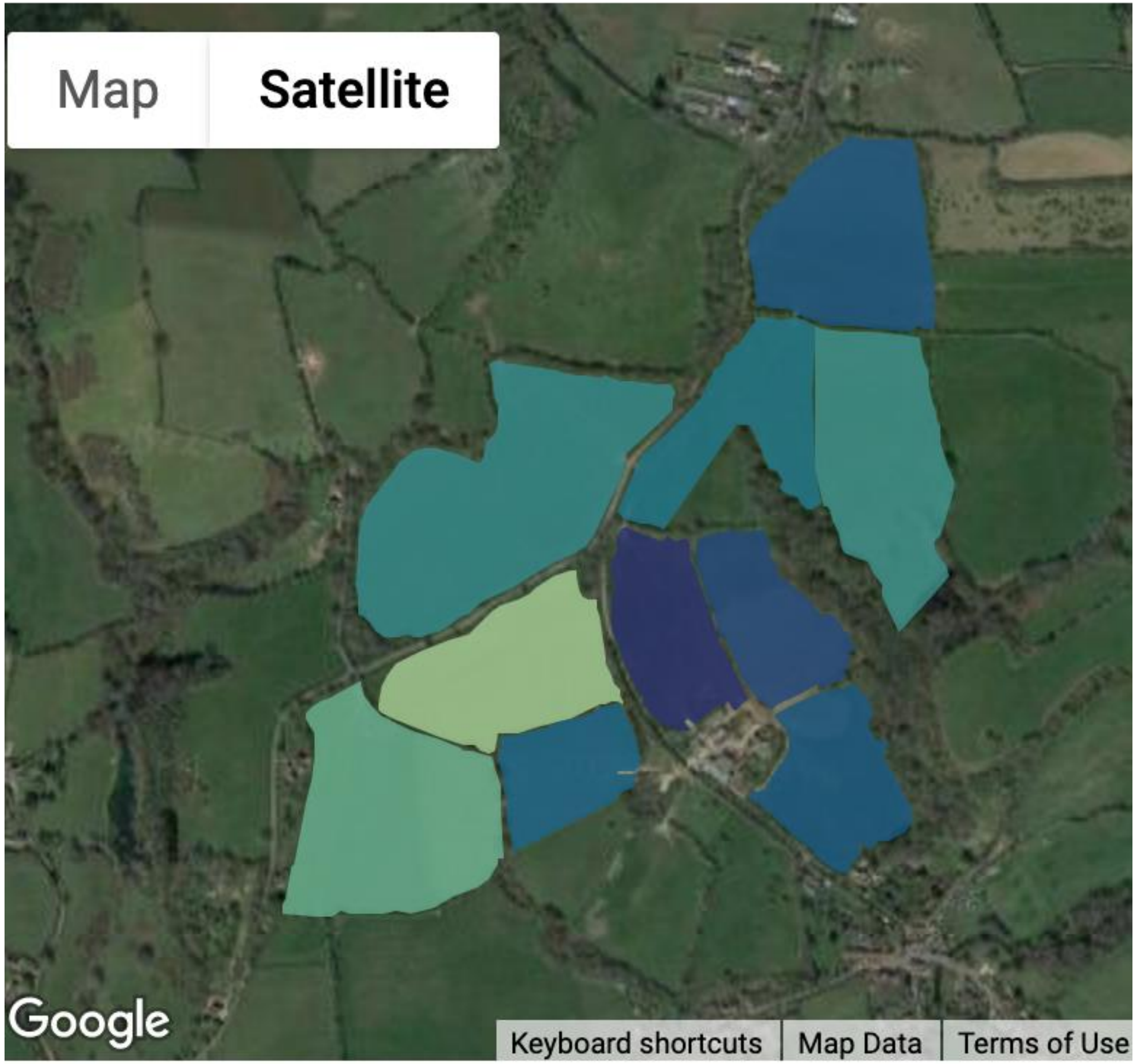
Measurement

- SOC stocks: multiyear scale
- GHG: weekly scale

Hydraulic probing in fall 2022 for 30-36" carbon stocks

GHG measurement weekly….rain, shine or snow

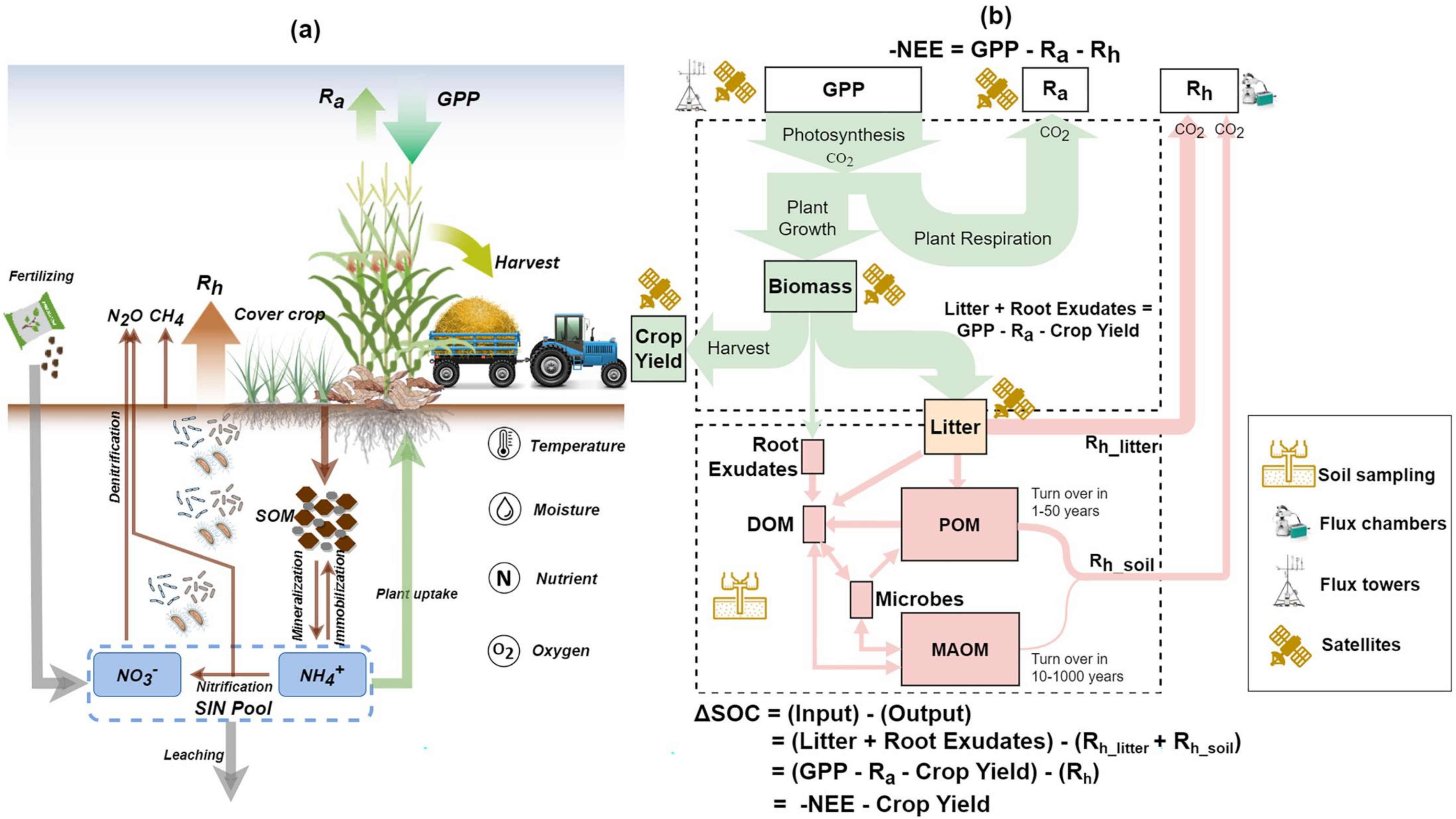
How to increase precision of field-scale SOC stocks?



Example of sign-up for C credits
Note emphasis on field-scale

Steps	What to do (for farmers)
1: SIGN UP	You map (or import) some or all of your field boundaries and enroll in Carbon by Indigo.
2: MAKE CHANGES	You add new practices that increase soil carbon and reduce emissions on your farm, with agronomic support from Indigo.
3: RECORD DATA	You record your historical and current season management data in our software platform, and Indigo takes soil samples on a subset of fields.
4: CALCULATE IMPACT	Indigo calculates the carbon credits generated on your farm, based on greenhouse gases sequestered and abated.
5: VERIFY RESULTS	Independent carbon credit issuers verify carbon credits.
6: GET PAID	After Indigo sells credits to corporate buyers and other organizations, you get paid for the carbon credits you earn.

Carbon (and N balance) and linkages with greenhouse gas (GHG) emissions: direct quantification vs mass balance

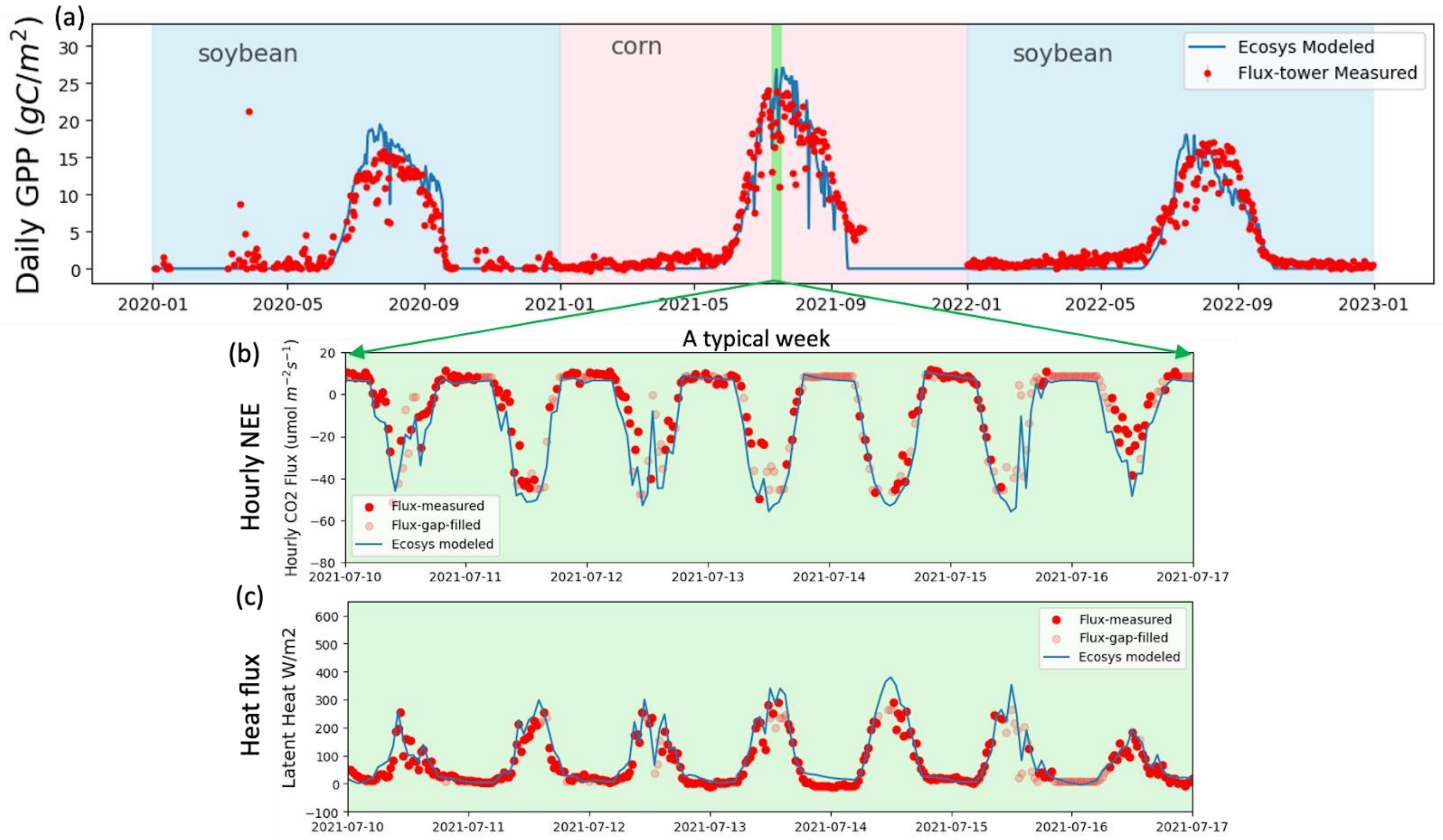


Guan et al. 2023 *Earth Science Reviews* 243: 104462

Example of C fluxes used in balance approach

(Guan et al. 2024)

$$\Delta SOC = (Input) - (Output)$$
$$= (Litter + Root\ Exudates) - (R_{h\_litter} + R_{h\_soil})$$
$$= (GPP - R_a - Crop\ Yield) - (R_h)$$
$$= -NEE - Crop\ Yield$$



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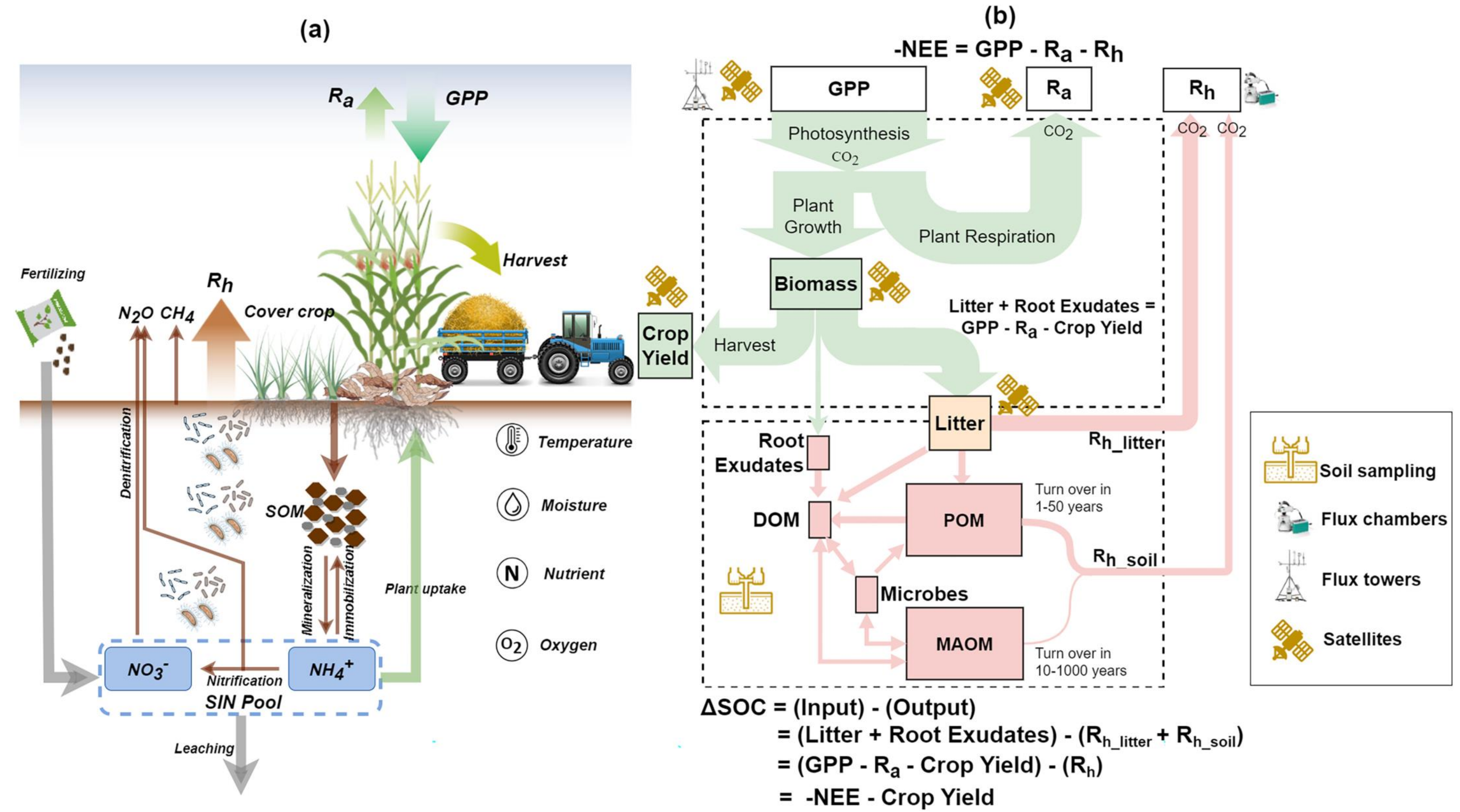

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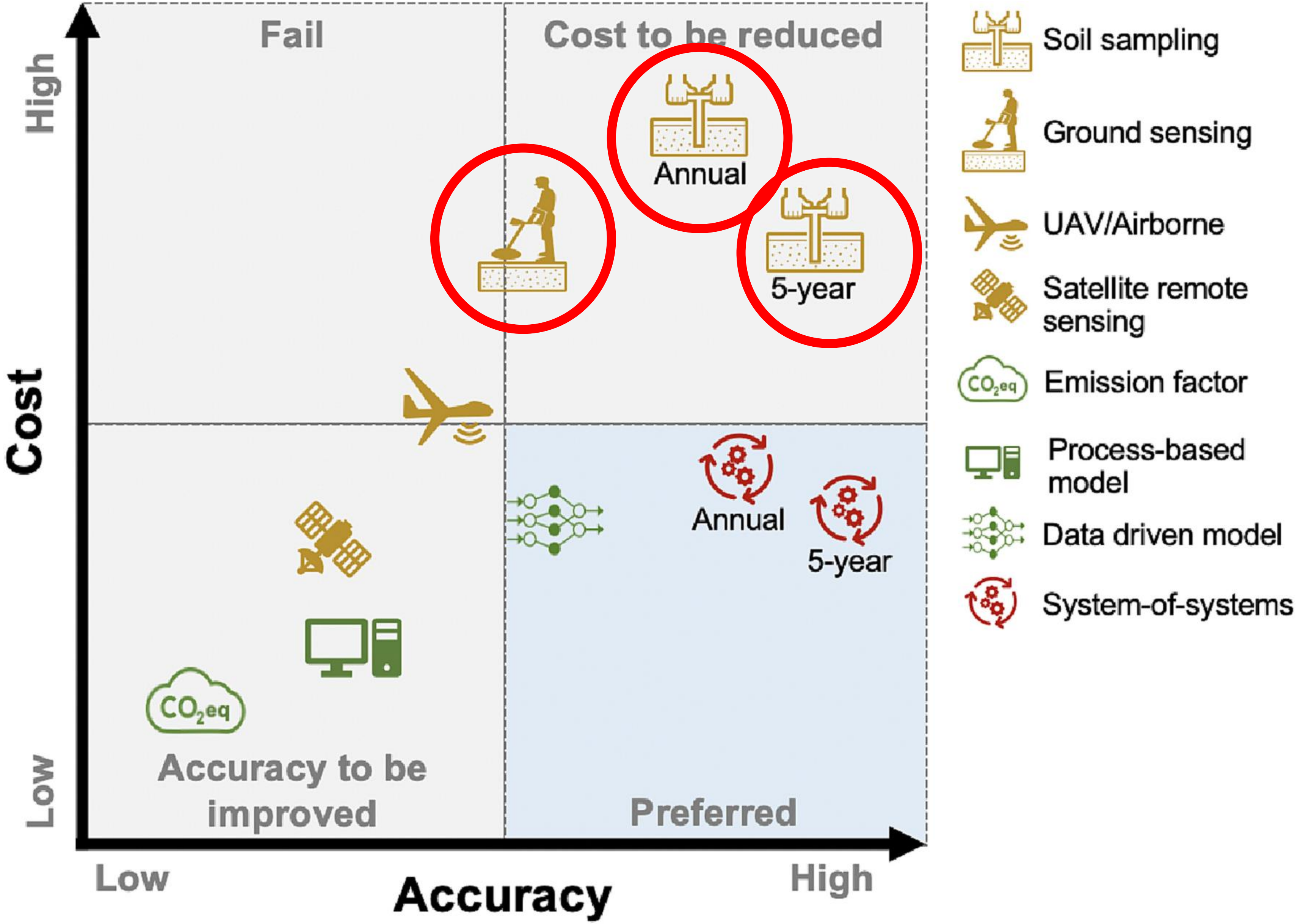
Upscaling will need to be done with models



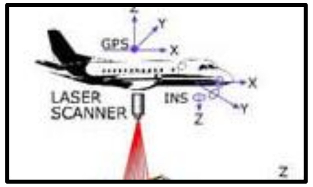
Guan et al. 2023 *Earth Science Reviews* 243: 104462

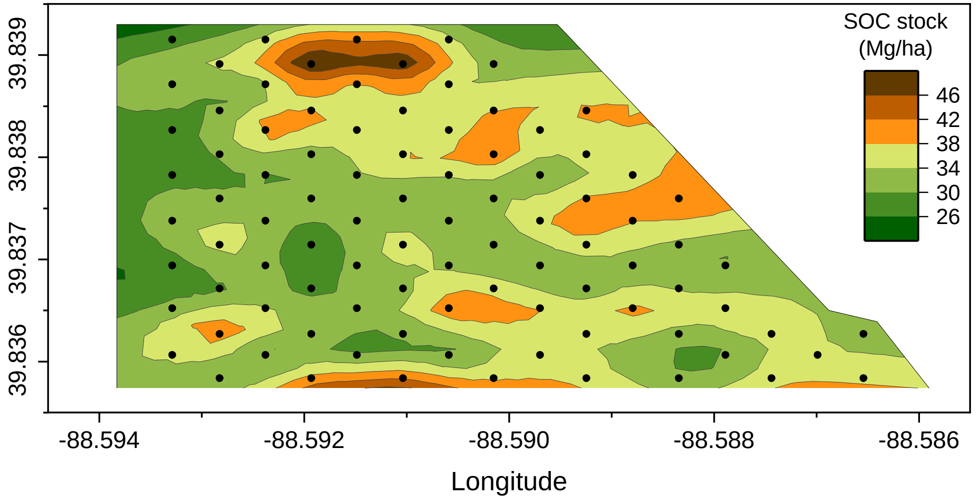
Challenge: variability!

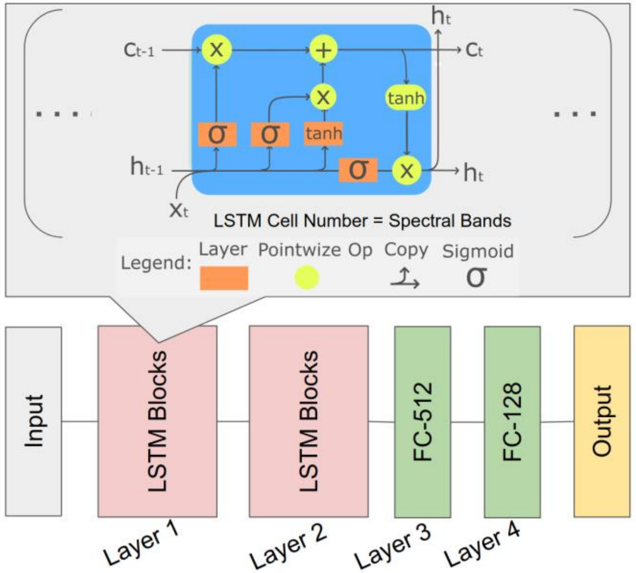

Interfield and intrafield variation

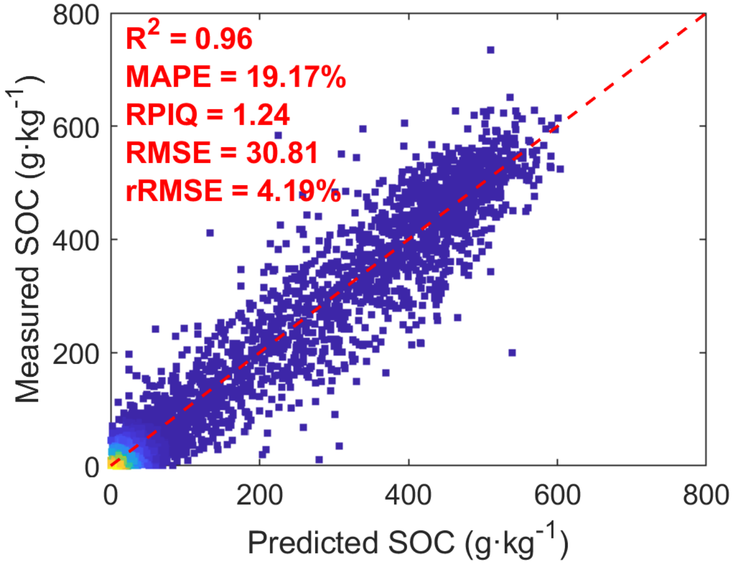
Scale-up option #1: combine empirical measurements and remote (or proximal) sensing with modeling

Proximal sensing + Remote sensing







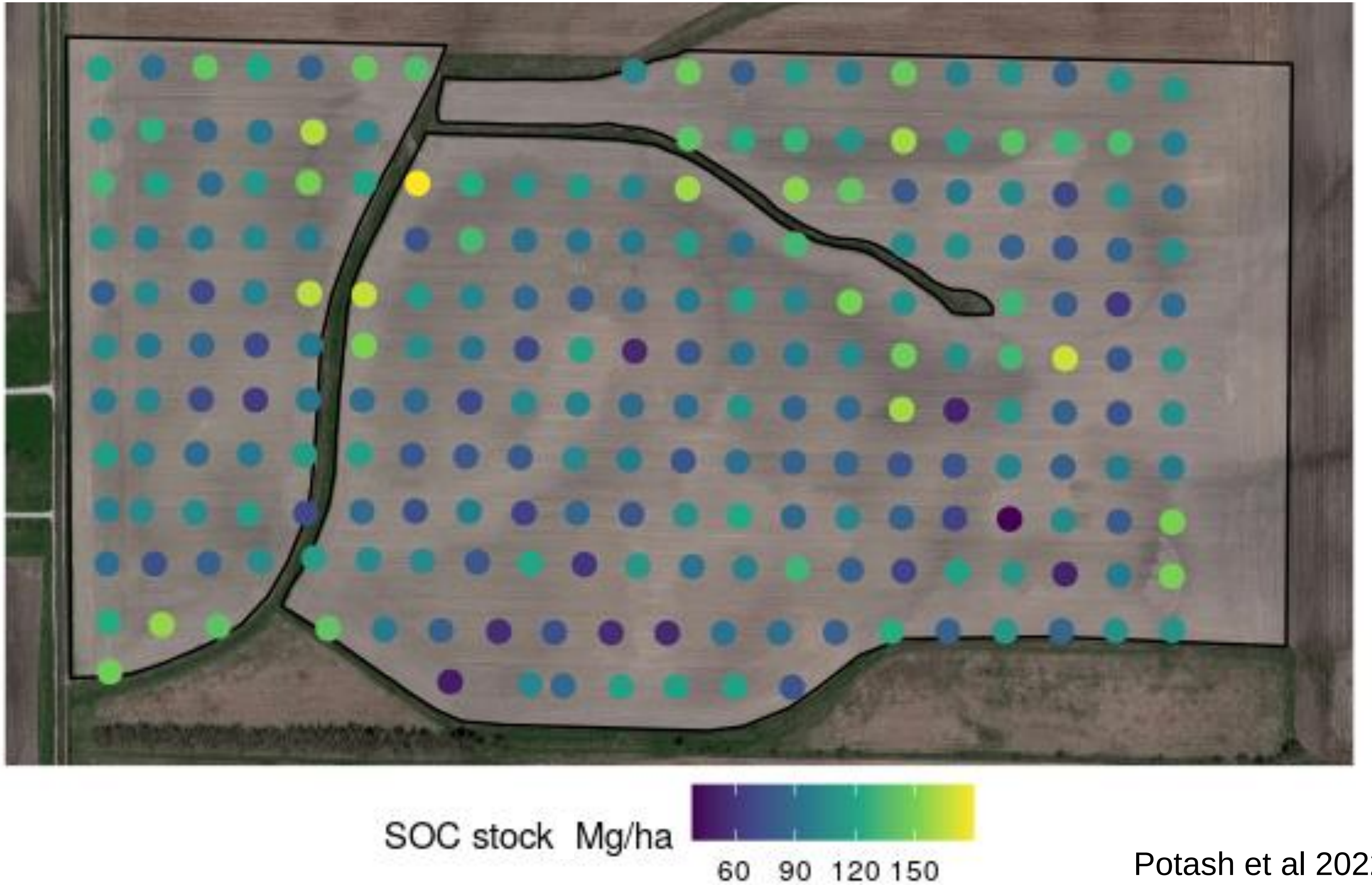


- 0.5 acre grid
- 120 cm depth
- 15 cm depth intervals

Scale-up option #2: reduce sampling density

Field-based estimates are averages of different points

≈ 0.00000075 acre (1.5” diameter hydraulic probe)



- 84 acre
- 0.5 acre sampling grid

Potash et al 2022 *Geoderma* 411:115693

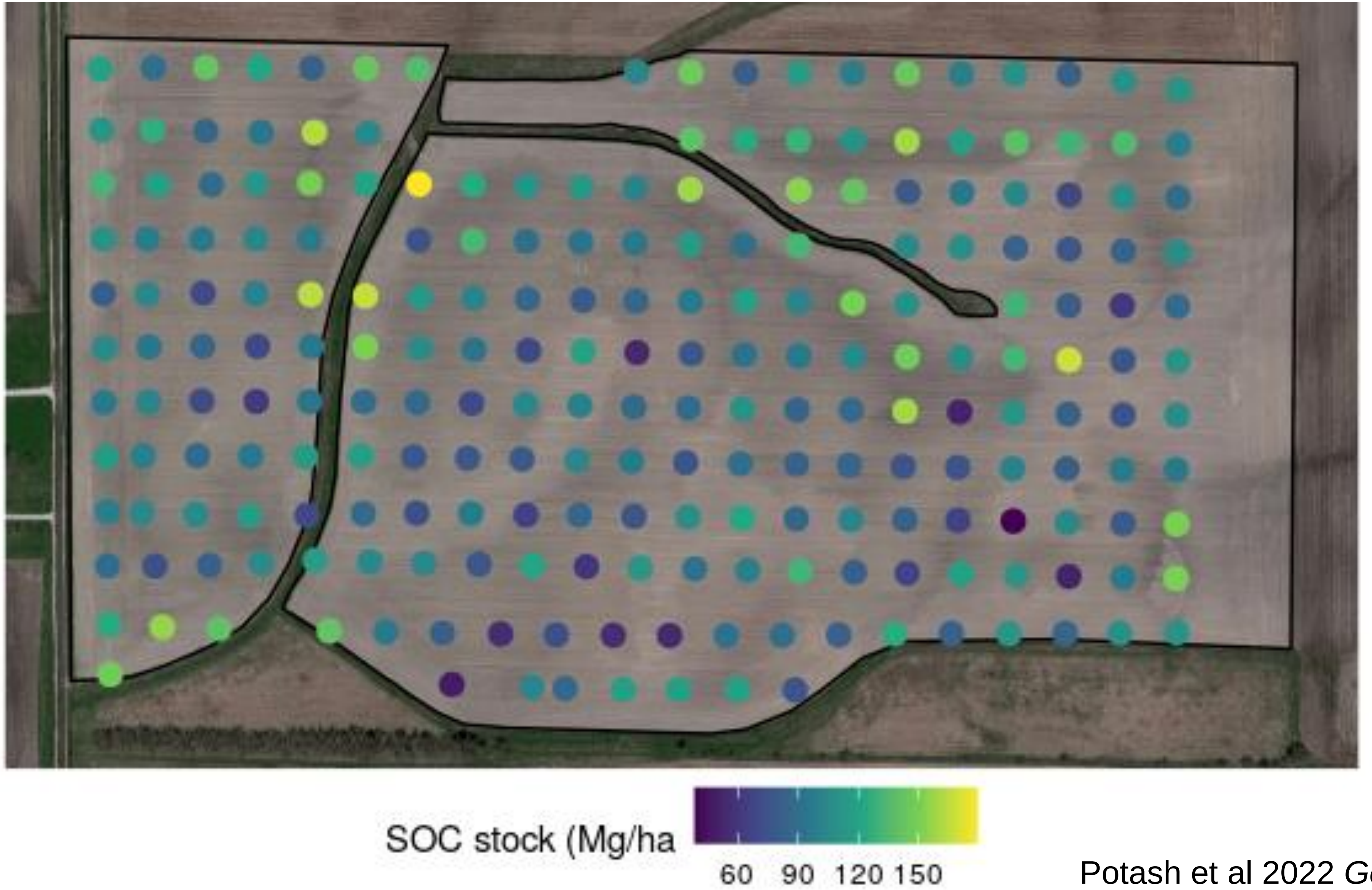
How to design sampling strategies for SOC stock?

- Estimating SOC stocks at the field scale by measurements requires entails two (statistical) steps:
  1. A sampling design selects locations at which to take measurements
  2. An estimator combines those sample measurements to estimate mean SOC stock across the field

- Typical: simple random sampling
- Alternative ways:
  1. Stratified sampling that incorporates auxiliary information (**covariates**) in the selection of sample locations
  2. Balanced sampling selects samples that are *spatially representative* (‘grid’ in a square-sized field)

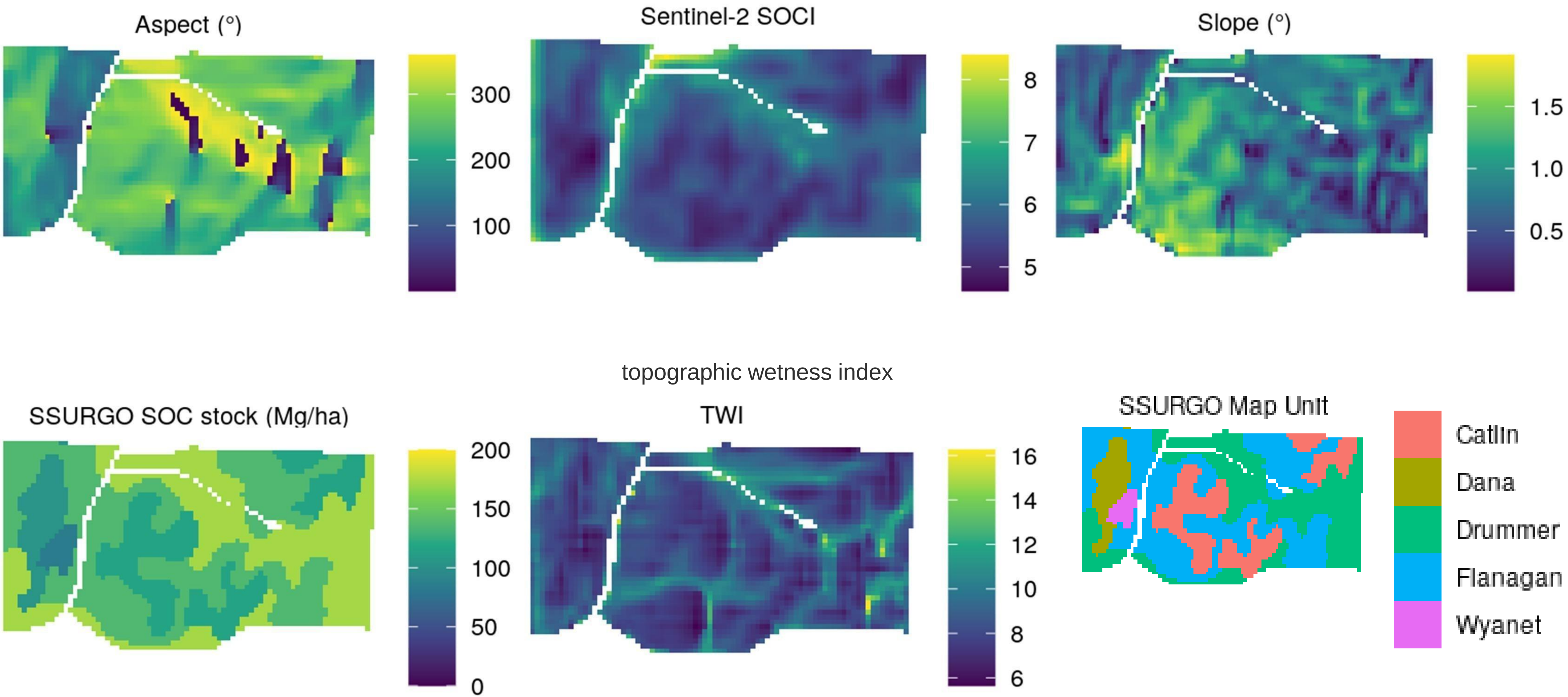
Several choices must be made to design a stratification

What are ways to design stratified sampling for SOC stock determination?

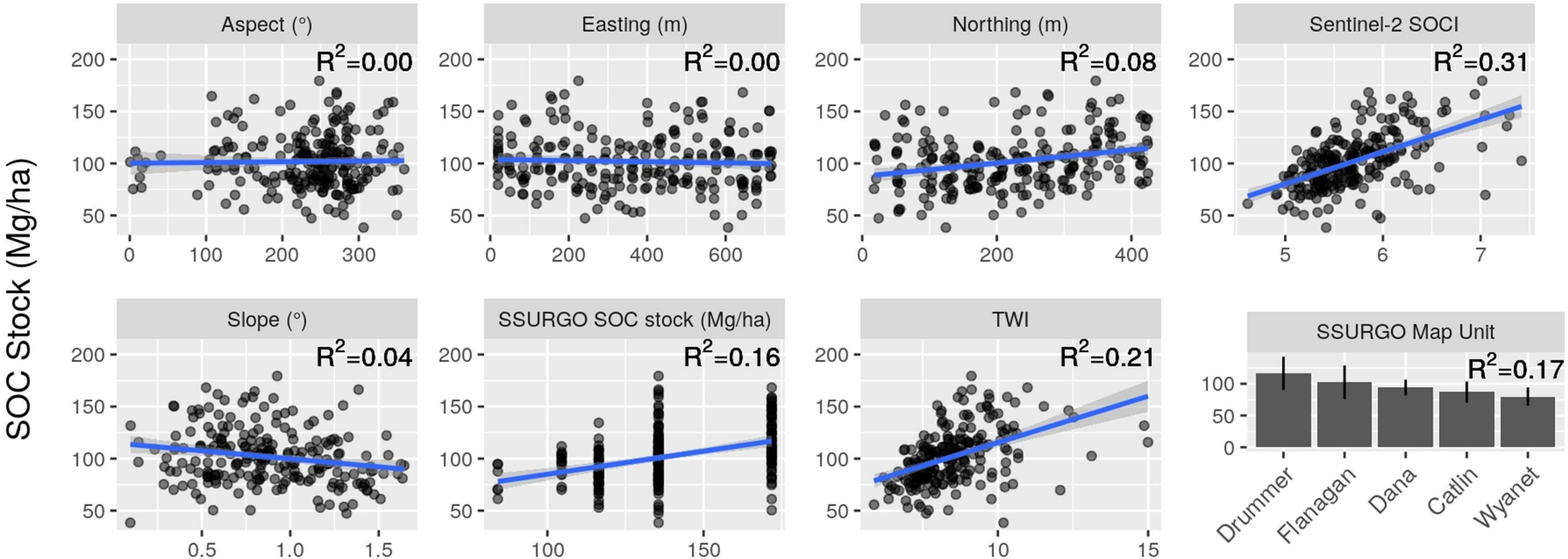


Potash et al 2022 *Geoderma* 411:115693

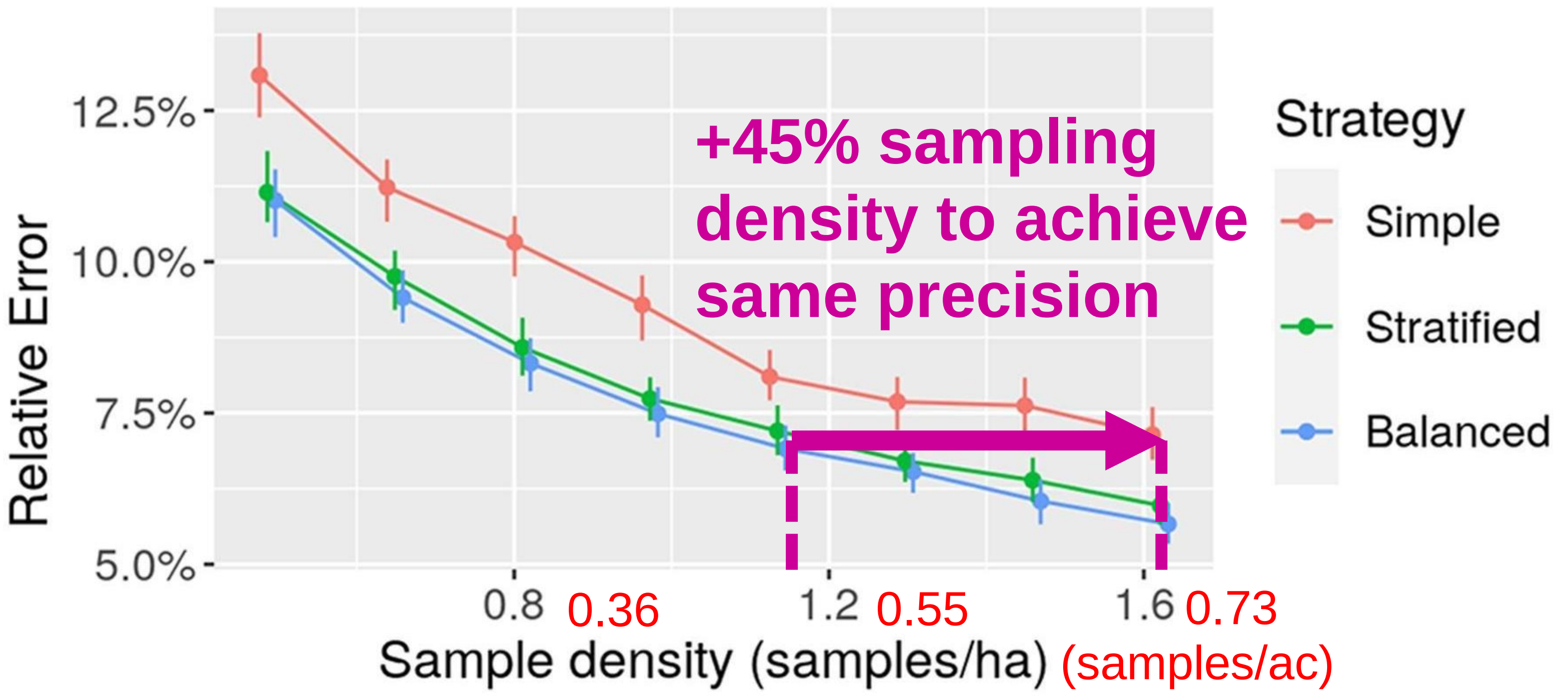
Auxiliary variables: accessible and related. Can we use them to design sampling strategies?



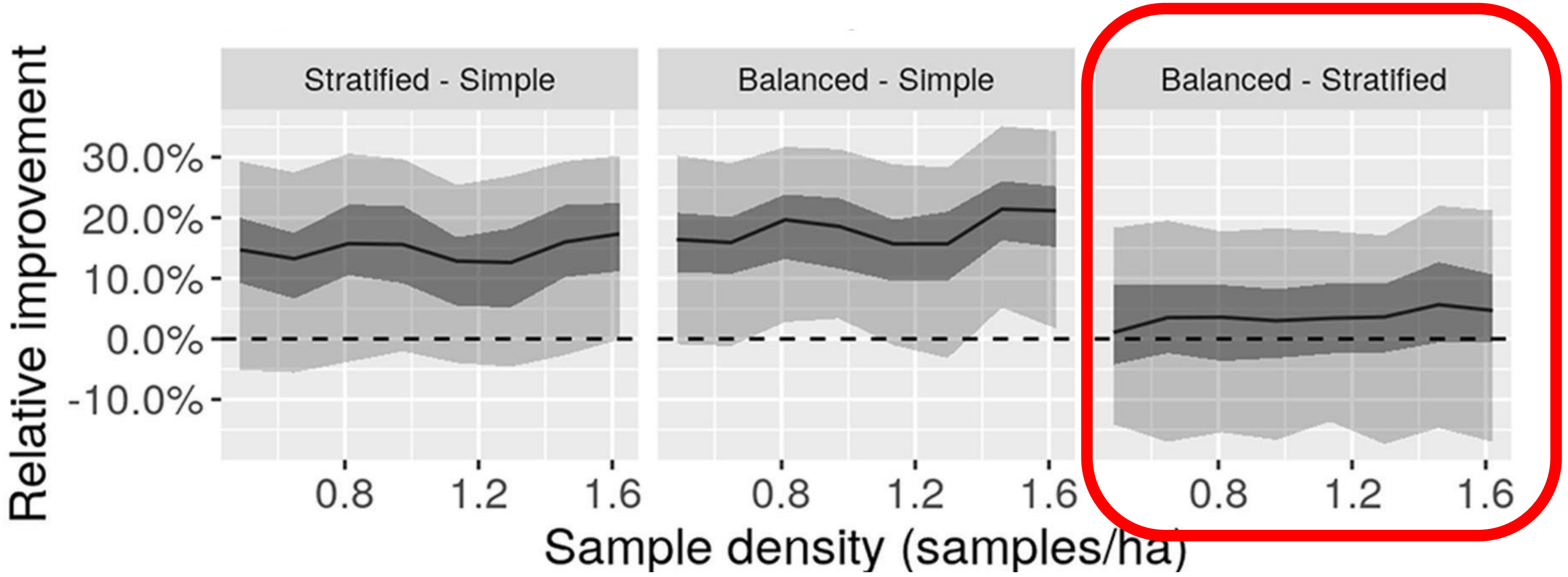
Auxiliary variables: accessible, and sometimes causally related to SOC stock



Lower sampling density needed to achieve same accuracy **stratified** or **balanced**, compared to simple



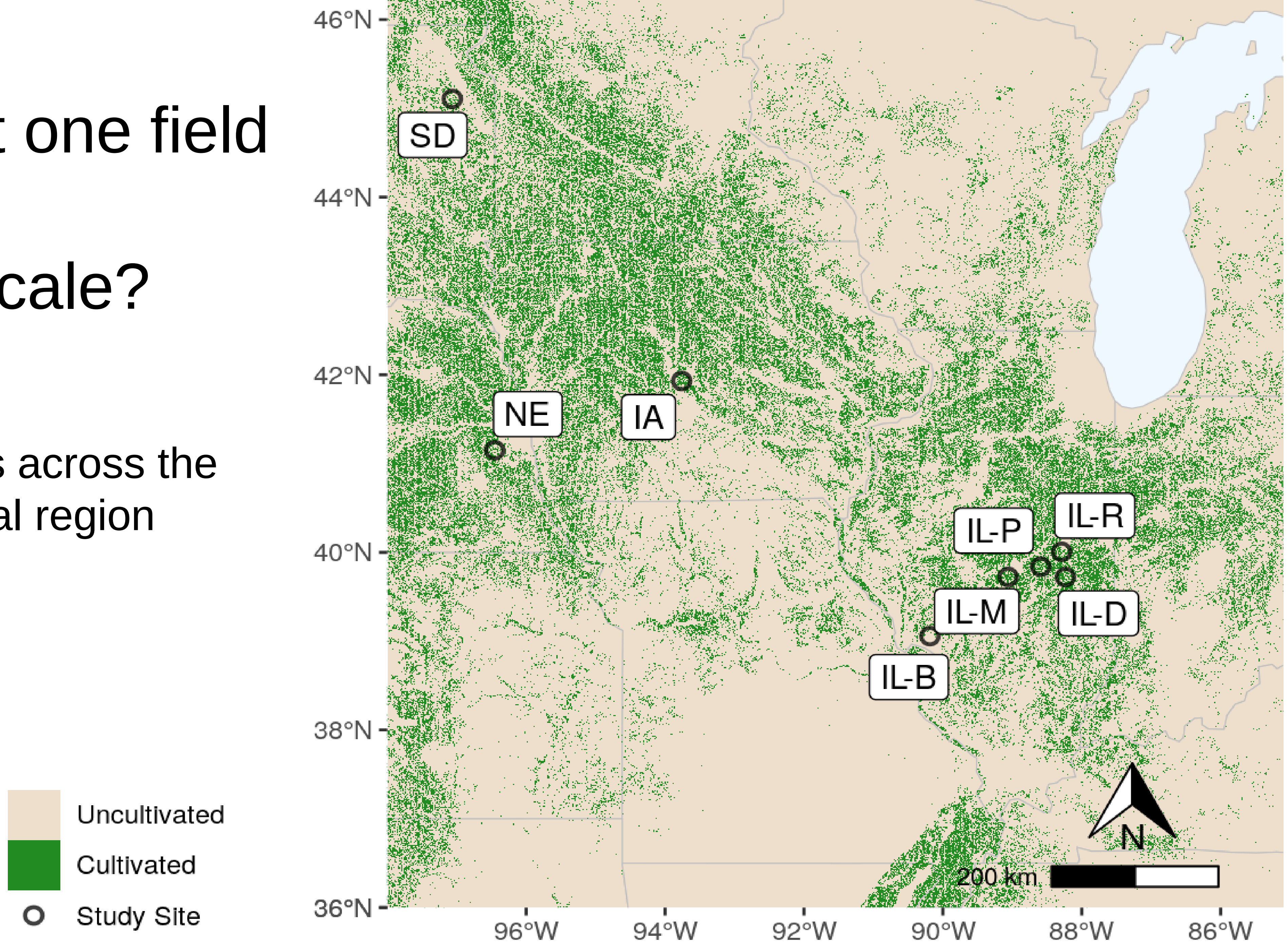
Across sampling densities, **stratified** and **balanced** maintain advantage (+15% precision) over random sampling



That was just one field

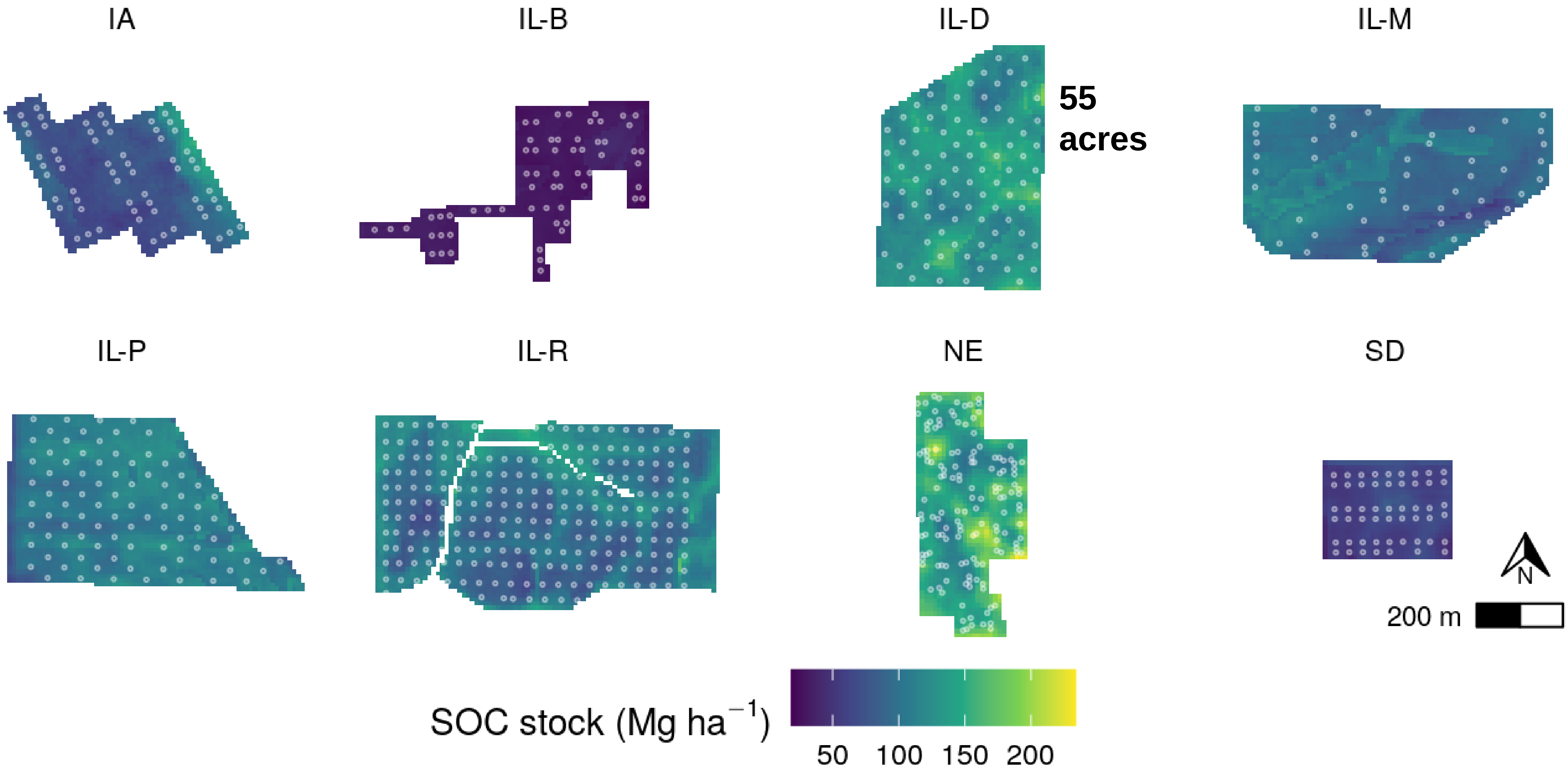
Does it scale?

Eight field sites across the North Central region

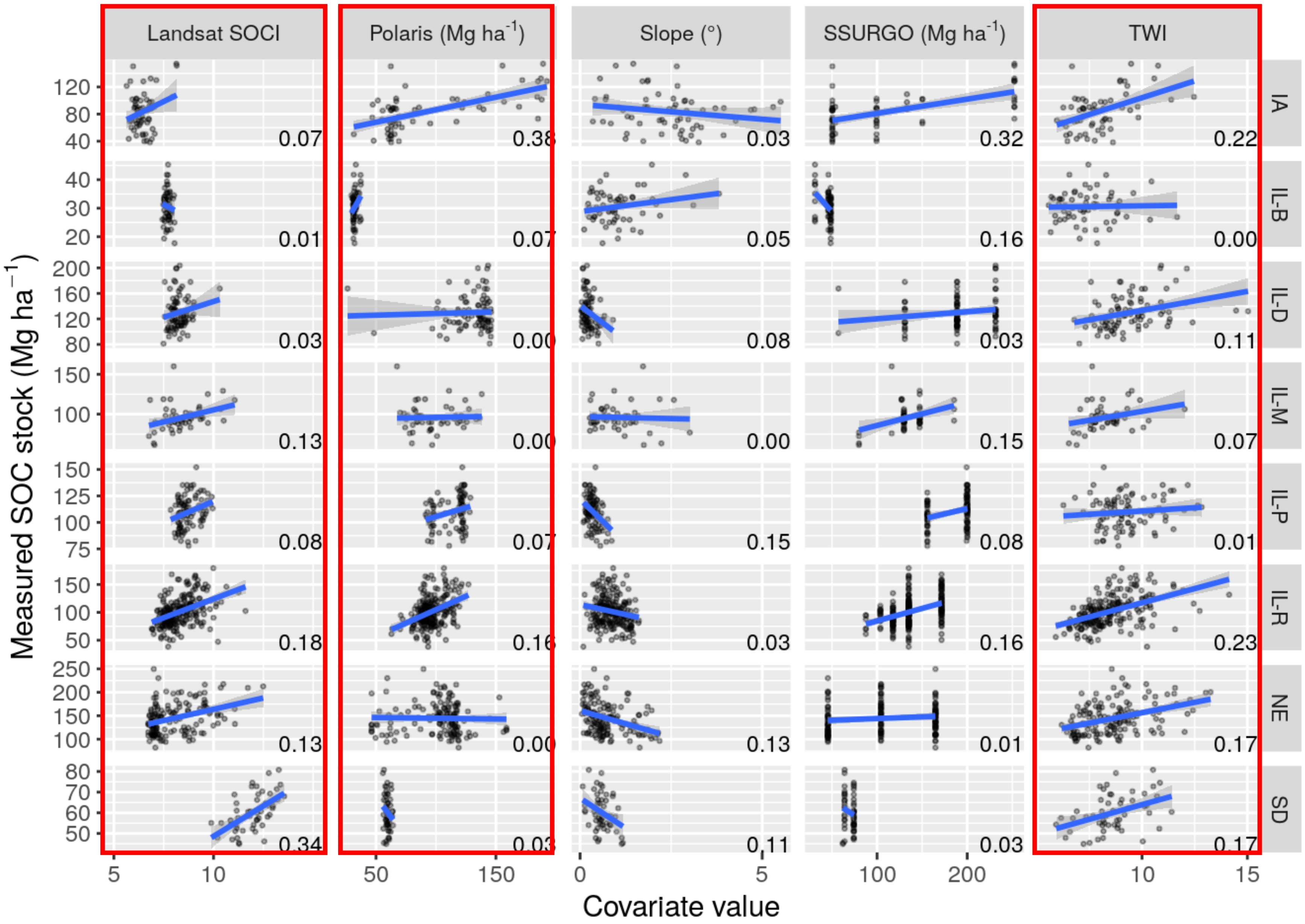


Potash et al. *Geoderma.* In revision.

SOC stocks (0-30” depth) varied within and among fields



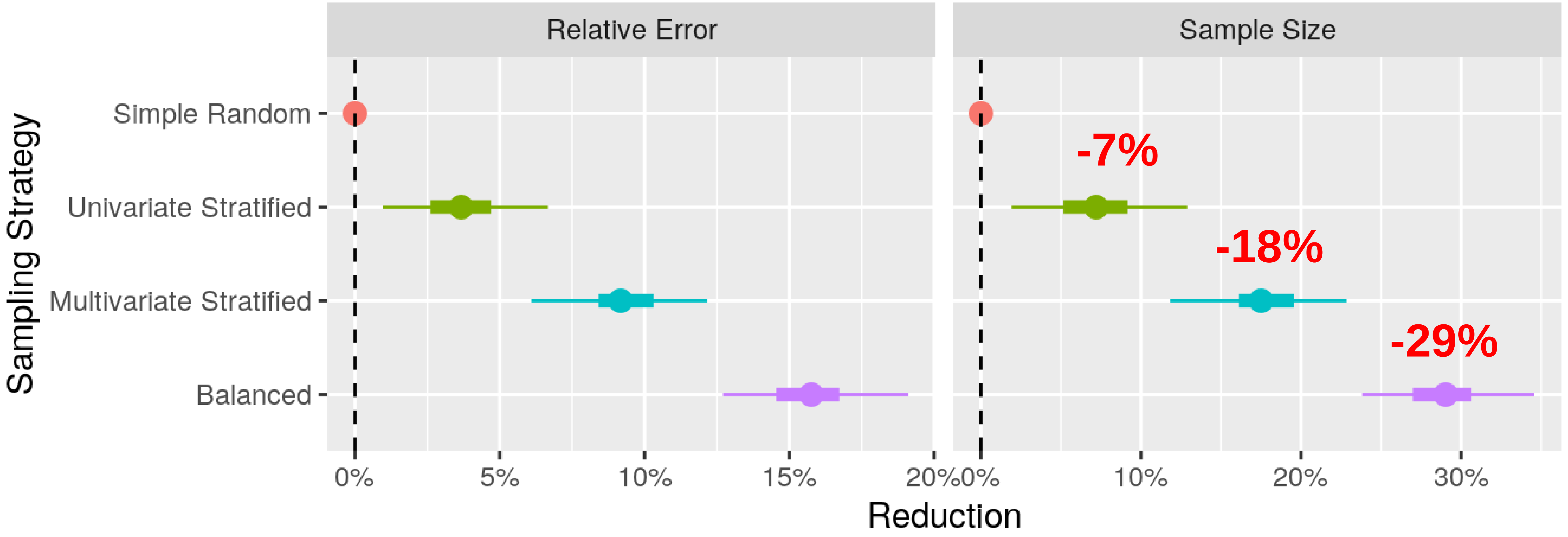
Which (easily accessible) covariates relate to SOC stock?



- Landsat SOCI, SSURGO SOC stock, and TWI covariates had the strongest and positive correlations with SOC stocks
- No single covariate was consistently predictive across all sites

Overall: *balanced* design appears best

Because precision error goes down,
sample size goes down (for a given precision target)



Summary

- C credits involve measure of change in SOC stocks and in GHG emissions
- Sampling strategies to determine SOC stock at the field-scale can be
    1. simple random
    2. stratified by co-variates
    3. balanced ('evenness' of coverage)
- SOC stock variability can be explained by co-variates already in existence
    - Which one(s) best associated with SOC often depends on the site
- Simple random sampling is the least effective
- On average, balanced sampling significantly outperformed other sampling strategies

Questions?

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What: Enrolling fields for 2025 on-farm P and K trials

Goal: update the Illinois Agronomy Handbook critical soil test value (CSTV)

margenot@illinois.edu

UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

ILLINOIS NREC

Phosphorus and Potassium Omission Trials to Validate CSTV

Enrollment Form
For Trials with 2025 Crop

Summary

Dr. Andrew Margenot's soil lab at the University of Illinois Urbana-Champaign, in collaboration with KSI Laboratories, is hosting an on-farm Illinois NREC-funded project which will provide much-needed updates to the critical soil test values (CSTV) on phosphorus (P) and potassium (K) in the Illinois Agronomy Handbook. The overall design is a pairwise P fertilized and P-unfertilized strip, and/or a pairwise K fertilized and K unfertilized strip, each pairwise comparison replicated 3-4x for each field. Comparing soil test P and K values in fertilized vs. unfertilized along with yields will let us determine the CSTV for P and K, by soil type.

Compensation

Participating farmers who complete all trial requirements will receive:

- $1000-$1500 per field per year
- A suite of data for each enrolled field which includes basic soil tests, soil enzyme activity, and other soil biological indicators at 0-7 inch and 7-14 inch depths
- CSTVs calibrated specifically for each enrolled field

Requirements

Please check boxes to affirm each requirement is fulfilled for the field/farm to be enrolled.

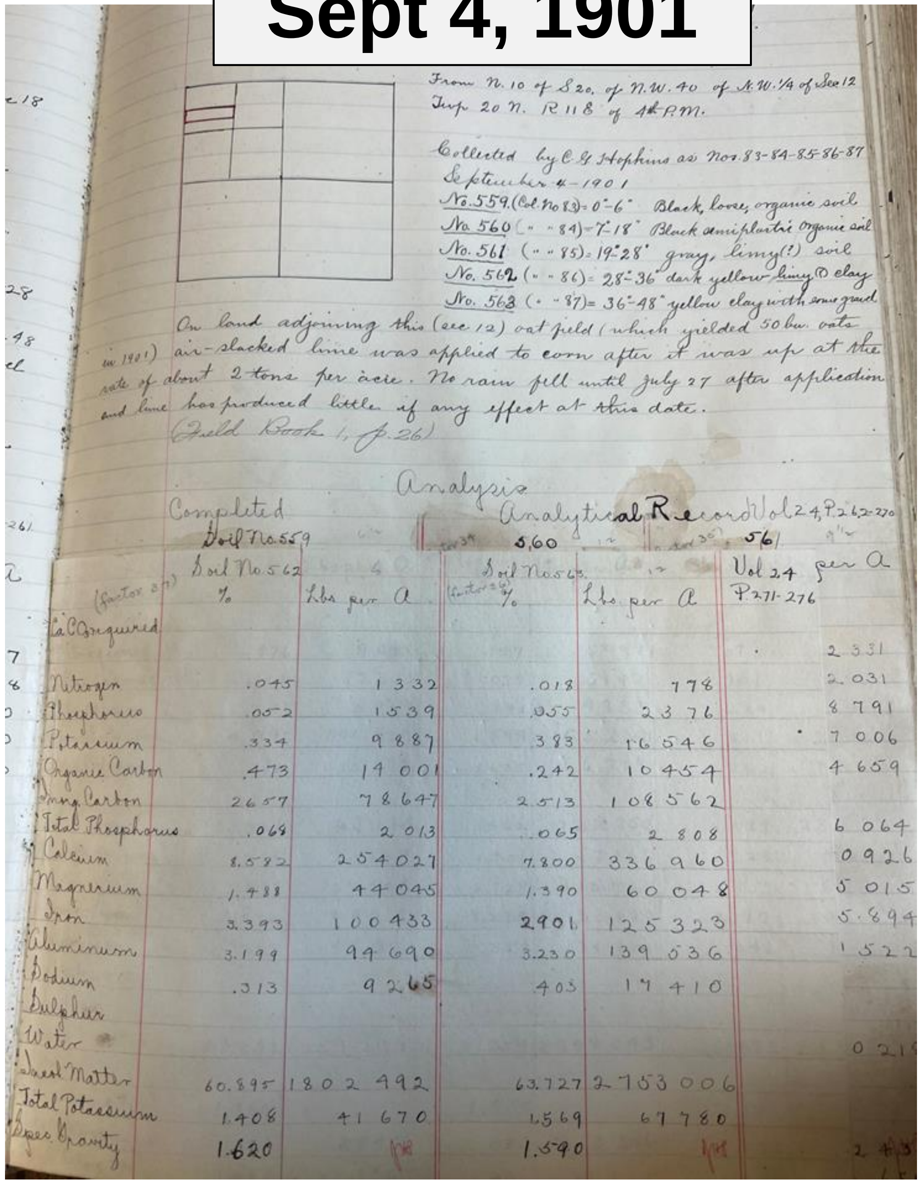
Ideal fields for these trials will:

- ☐ Have had **no** P or K applications in the past year (e.g. if the field is being enrolled for fall 2024 fertilizer application and 2025 crop, there must have been no P or K applied to the field since fall 2023),
- ☐ Be at least 9 acres,
- ☐ Have had **no** manure applied in 2+ years,
- ☐ Have soil test results available from the previous year or 2 years ago,
- ☐ Have areas of low P and/or K, and
- ☐ Have corn or soybean planted in 2025.

Soil archive resampling: How have soils in Illinois changed?

Sampled 1861

Sept 4, 1901



Pedon re-sampling effort

Status

- 453 locations total
- 80 of 453 (**18%**) **identified for landowner**
- 34 of 453 (**7.5%**) sampled as of Dec 2023

Need your help identifying owner contacts!