A meta-analysis of meta-analyses? Evidence review indicates a re-think on the impact of organic inputs and soil organic matter on crop yield

Renske Hijbeek, Martin van Ittersum, Hein ten Berge, Andy Whitmore

Conference proceeding available at https://fertiliser-society.org/

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100years 1918 — 2018

ROTHAMSTED RESEARCH

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Background

- Soil organic matter might have multiple benefits (such as for soil fertility, soil biodiversity, soil carbon sequestration)
- A number of agricultural and environmental policies aim to increase soil organic matter and/or stimulate use of organic inputs (CAP, UNFCCC)

Soil fertility

What is soil fertility?

- Physical soil fertility (soil structure, aeration, water retention)
- Biological soil fertility (biodiversity, (de) composition, disease suppression)
- Chemical soil fertility (nutrients)

→Main indicator for soil fertility is the percentage of soil organic matter

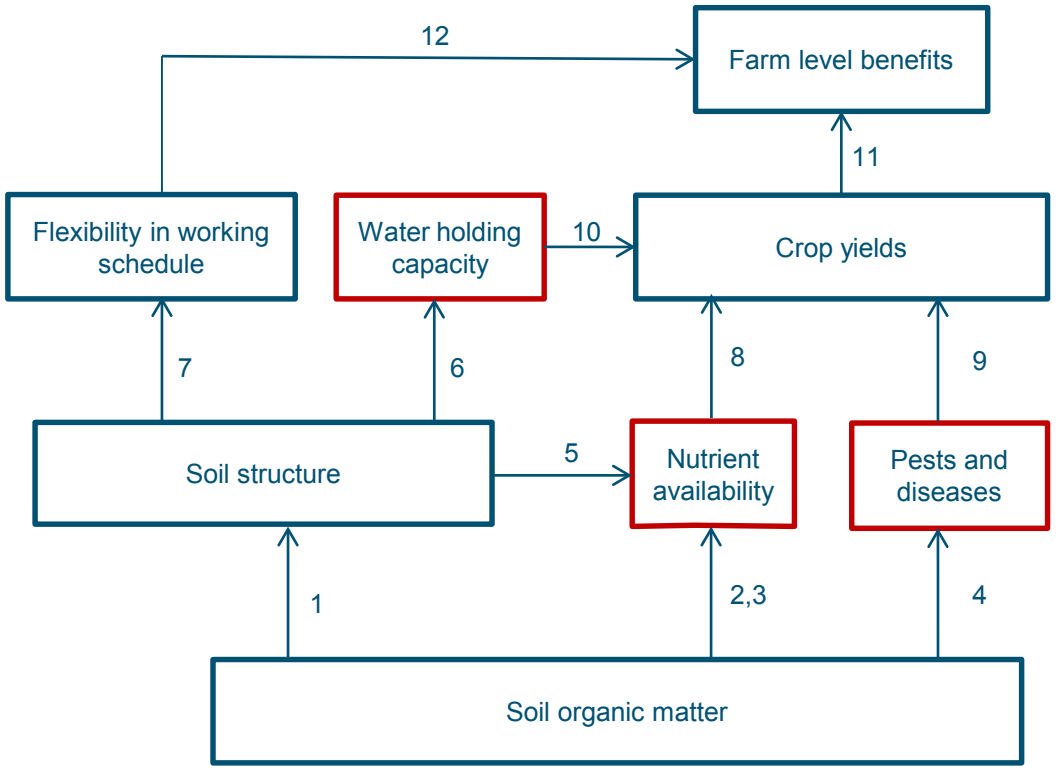
Relation between soil organic matter and crop yields/ farm benefits

Direct effects on soil fertility:

1. Aggregate stability
2. Increase of cation and anion exchange capacity
3. Year-round release of N,P,S and some trace elements
4. Increase or change in soil microbial biomass

Indirect effects on soil fertility:

5. Ease of root penetration
6. Increase of adhesive forces due to aggregation of mineral particles
7. Stabilization of soil structure



Effects on yield limiting factors:

8. Reducing nutrients as a yield limiting factor
9. Reducing pests and diseases as yield reducing factors
10. Reducing water as a yield limiting factor

Effects at farm Level:

11. Increase in crop production
12. Reduction in labour or machinery costs

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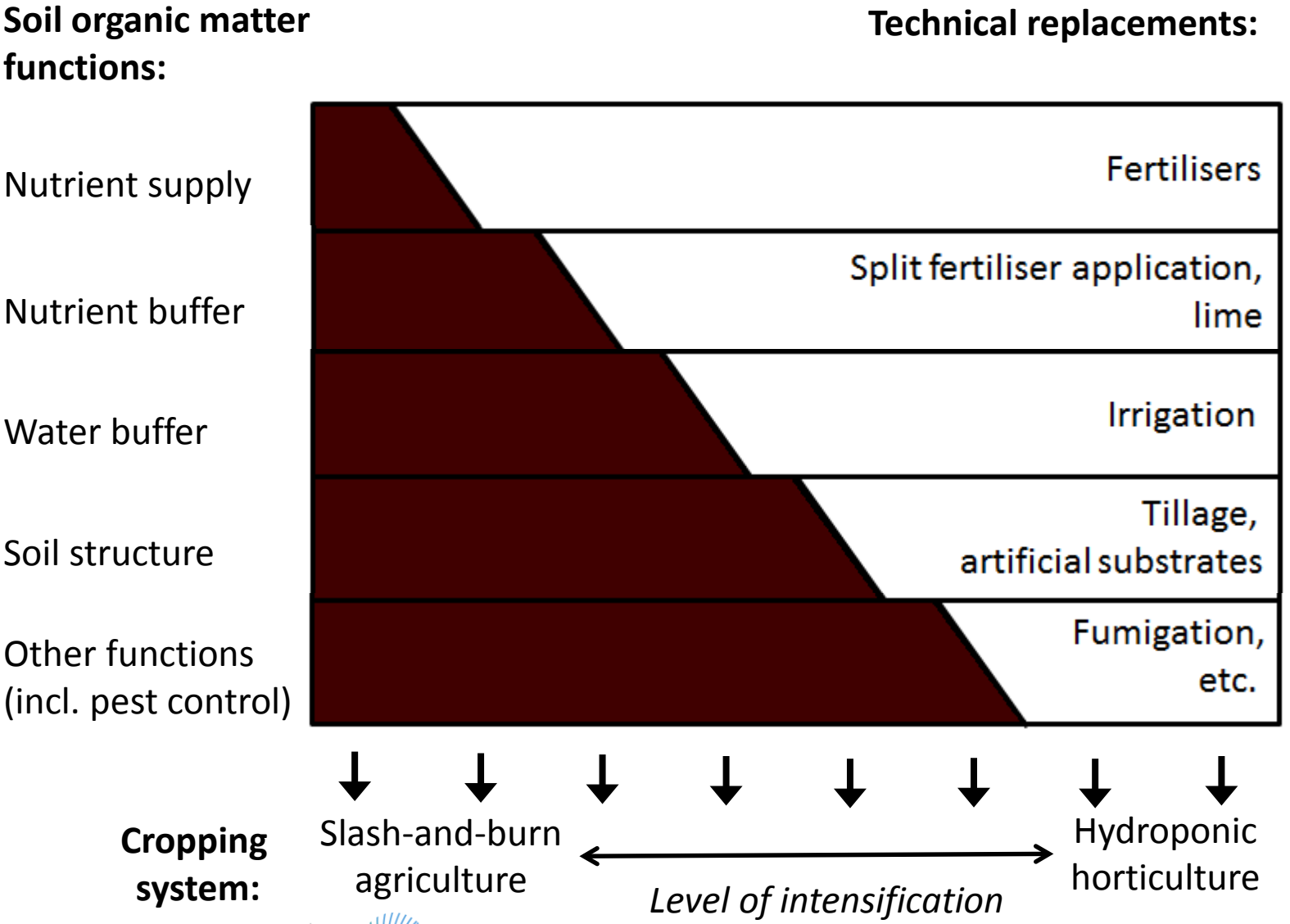
Hijbeek (2017) On the role of soil organic matter for crop production in European arable farming. PhD thesis, Wageningen University, Wageningen

Influence of degree of agricultural intensification



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Van Noordwijk et al. 1997; Hijbeek 2017

Some observed (cor)relations between soil organic matter and crop yields

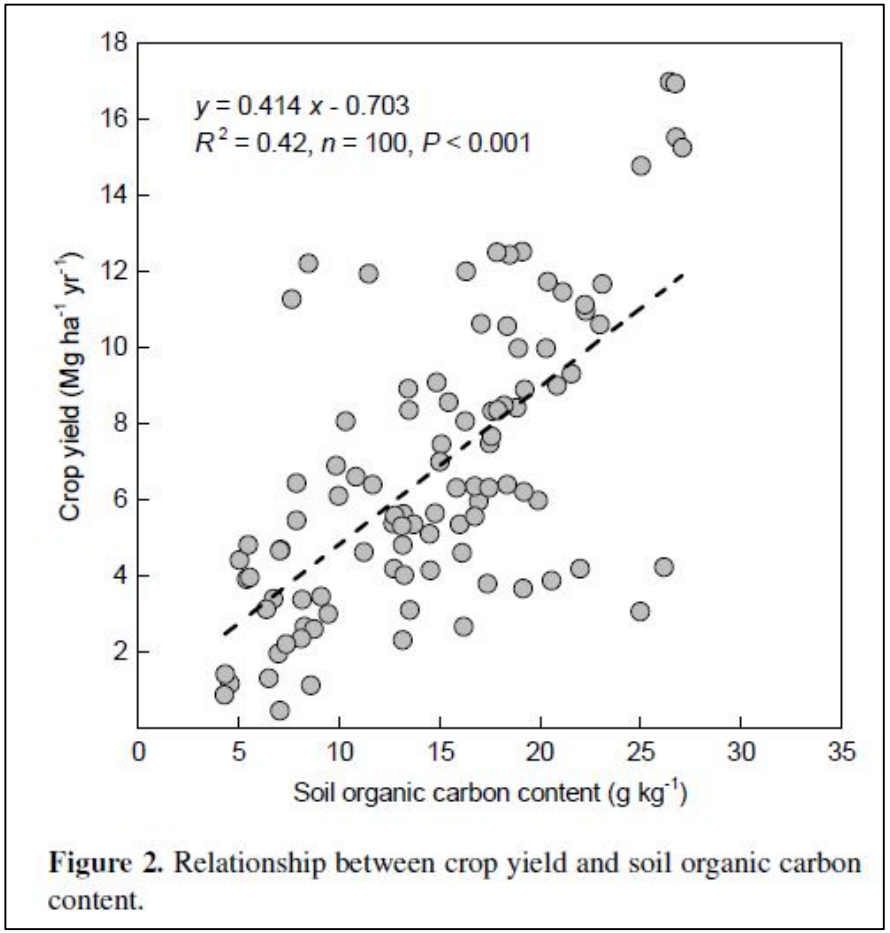


Figure 2. Relationship between crop yield and soil organic carbon content.

Based on 70 experiments in China (rice, maize, wheat)

"Overall, an increase of 1 g/ kg SOC content could improve crop yield by 267–414 kg ha/ yr"

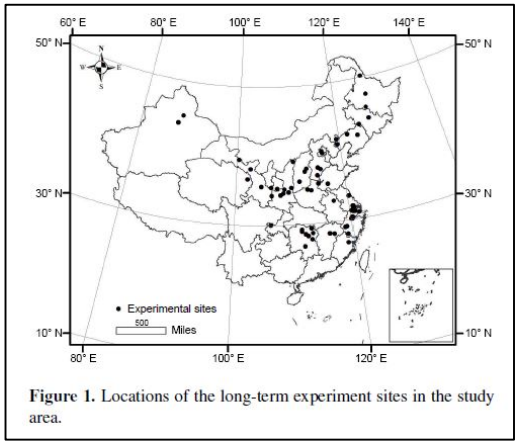
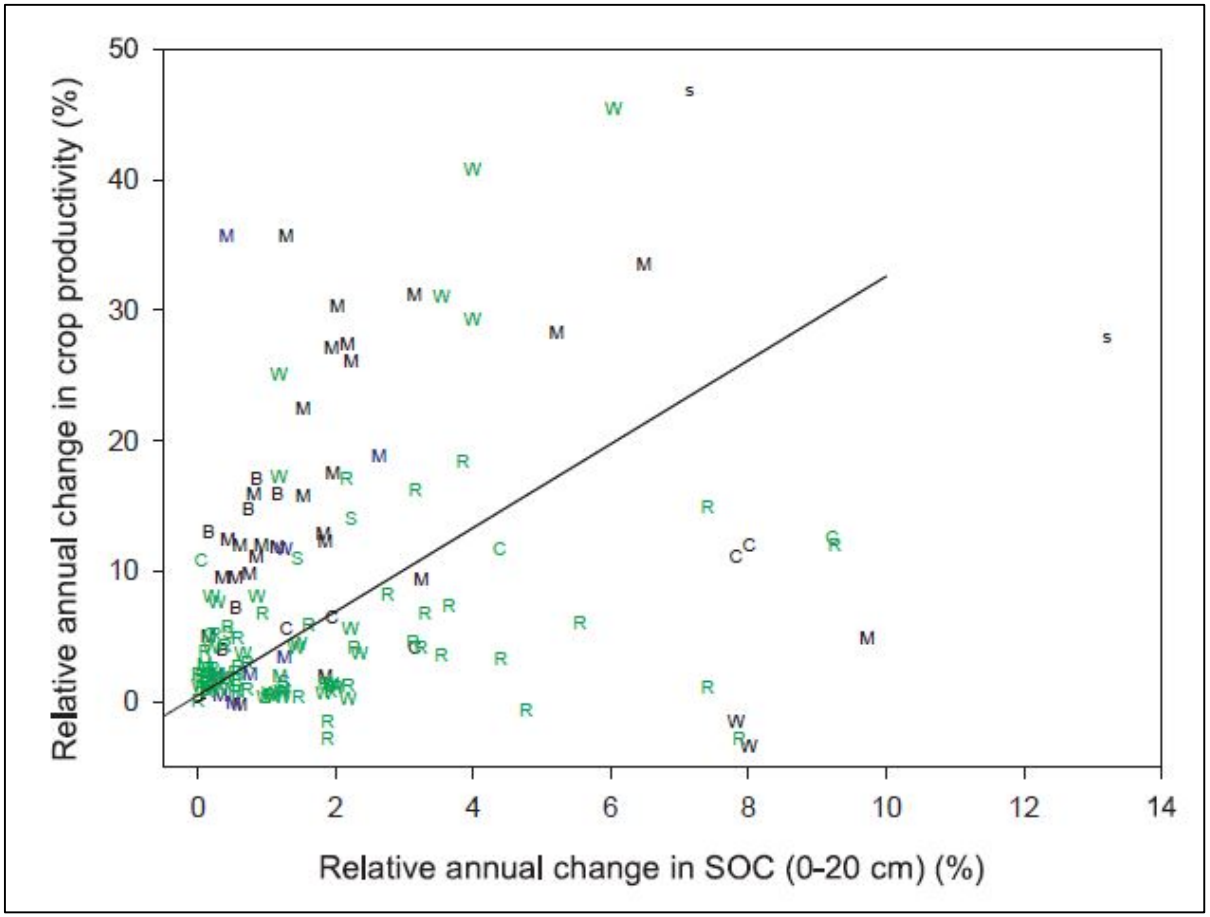


Figure 1. Locations of the long-term experiment sites in the study area.

Han, X., Xu, C., Dungait, J.A., Bol, R., Wang, X., Wu, W. and Meng, F. (2018). Straw incorporation increases crop yield and soil organic carbon sequestration but varies under different natural conditions and farming practices in China: a system analysis. *Biogeosciences* **15**, 1933-1946.

Some observed (cor)relations between soil organic matter and crop yields

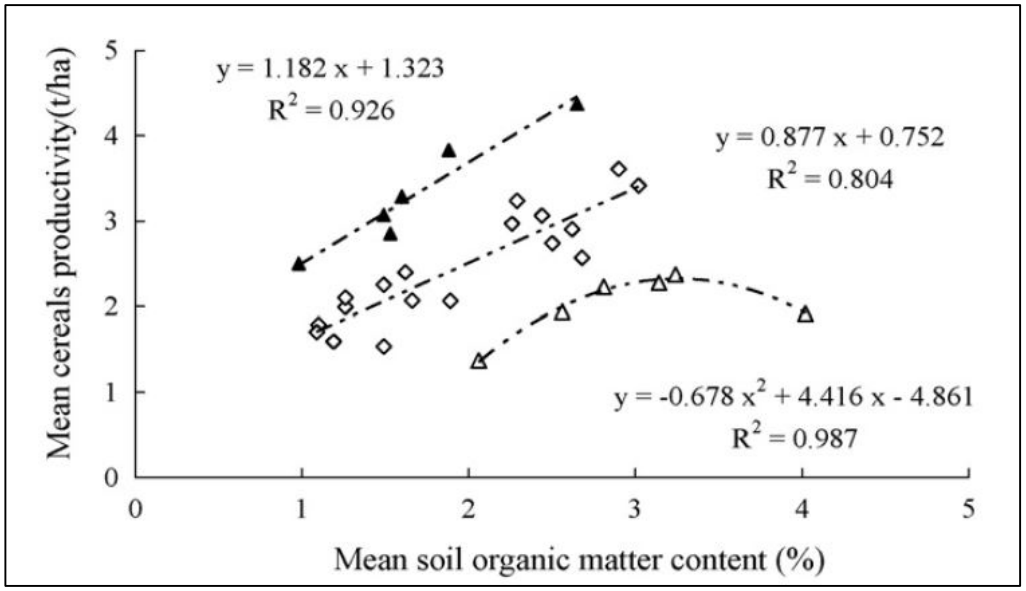


32 experiments in Africa, Asia and Latin America

"0.4% top soil C increase can lead to yearly grain yield increases (average: 1.3%)."

Soussana, J.-F., Lutfalla, S., Ehrhardt, F., Rosenstock, T., Lamanna, C., Havlík, P., Richards, M., Chotte, J.-L., Torquebiau, E. and Ciais, P. (2017). Matching policy and science: Rationale for the '4 per 1000-soils for food security and climate'initiative. Soil and Tillage Research.

Some observed (cor)relations between soil organic matter and crop yields



Based on national agricultural statistics (China)

"1% increase in SOM on average would lead to an increase in total cereal productivity of 0.43 t /ha

Pan, G., Smith, P. and Pan, W. (2009). The role of soil organic matter in maintaining the productivity and yield stability of cereals in China. Agriculture, Ecosystems and Environment 129, 344-348.

Some weaknesses in observed (cor)relations

- Causality difficult to prove
- Underlying mechanisms unclear
- Confounding factors (climate, soil) might be present

Research questions 1 & 2

- Which methods can be used to assess the relation between soil organic matter and crop yields?

- Which methods can distinguish between yield effects due to N,P,K supply and other 'additional' yield effects? (*i.e.* due to imrpoved soil structure or soil life)

Methods used to assess relation between soil organic matter and crop yields

1. Assessing a change in agronomic nitrogen use efficiency

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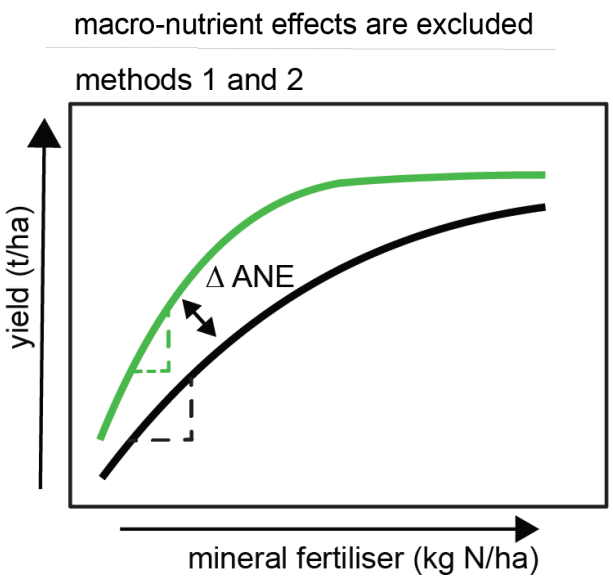
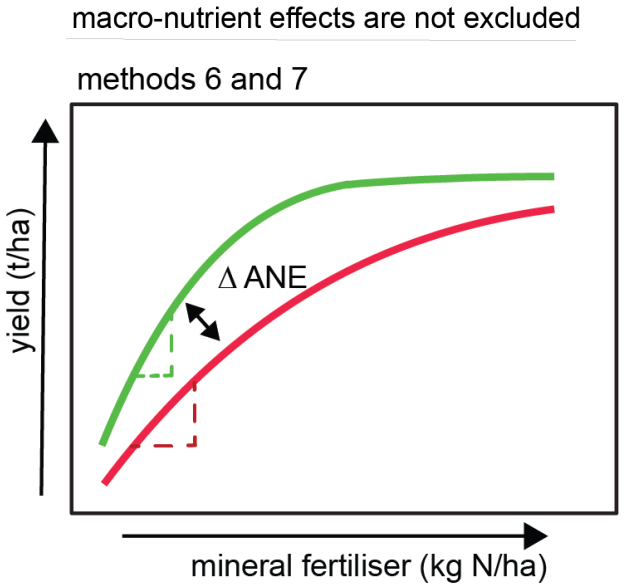
Agronomic nitrogen use efficiency = kg additional yield/ kg additional mineral fertiliser N





crop yields with organic inputs or more SOM (sufficient P &K)

crop yields with only mineral fertiliser (sufficient P & K)

crop yields with only mineral fertiliser & possibly insufficient P & K supply

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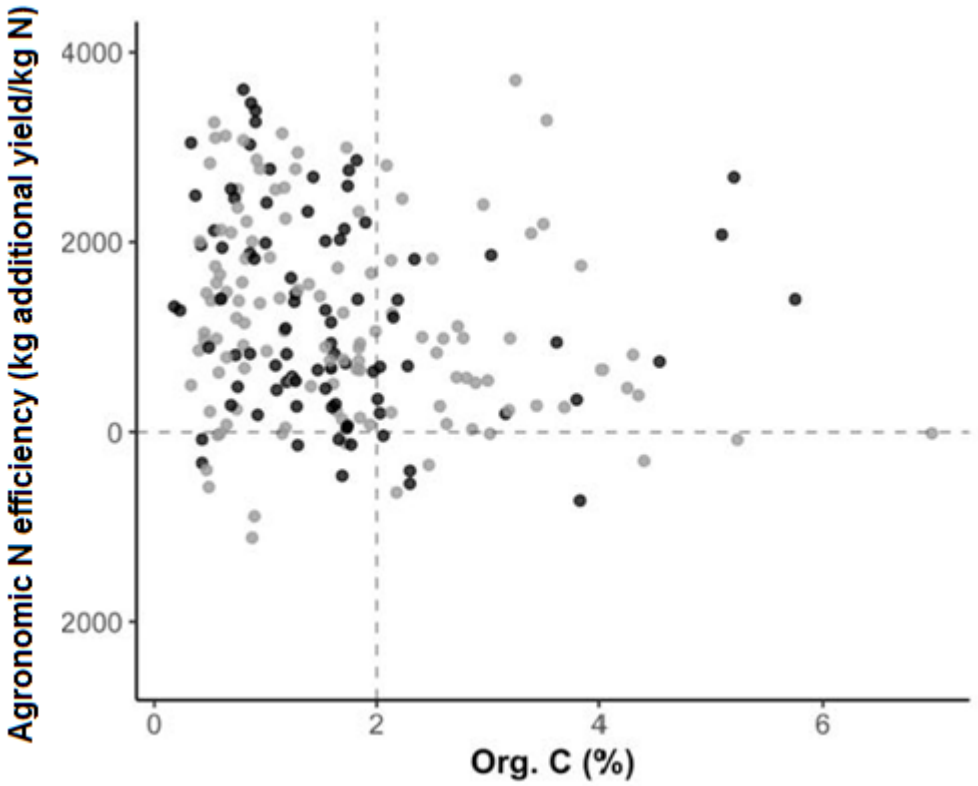
1. Assessing a change in agronomic nitrogen use efficiency – example TAMASA project

Agronomic nitrogen use efficiency = kg additional yield/ kg additional mineral fertiliser N



219 experiment locations in Tanzania

DeLaune, R.D. (2018). Characterizing the variability of maize yield response to mineral fertilizer in Tanzanian smallholder systems, MSc thesis Plant Sciences. Wageningen University, Wageningen, p. 74.

Which methods are currently used?

1. Assessing a change in agronomic nitrogen use efficiency
2. Comparing crop yields with organic inputs vs. mineral fertilisers

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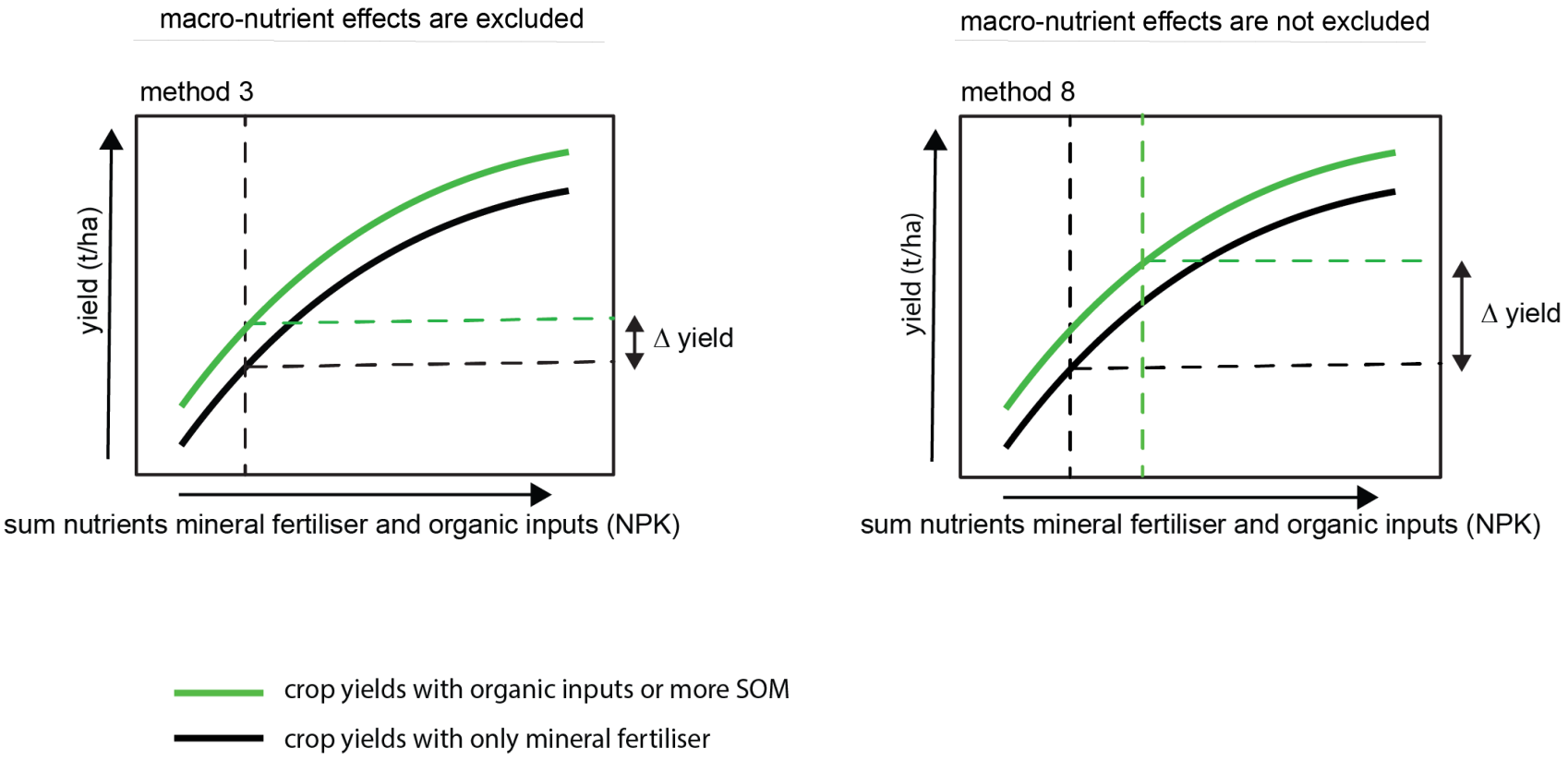
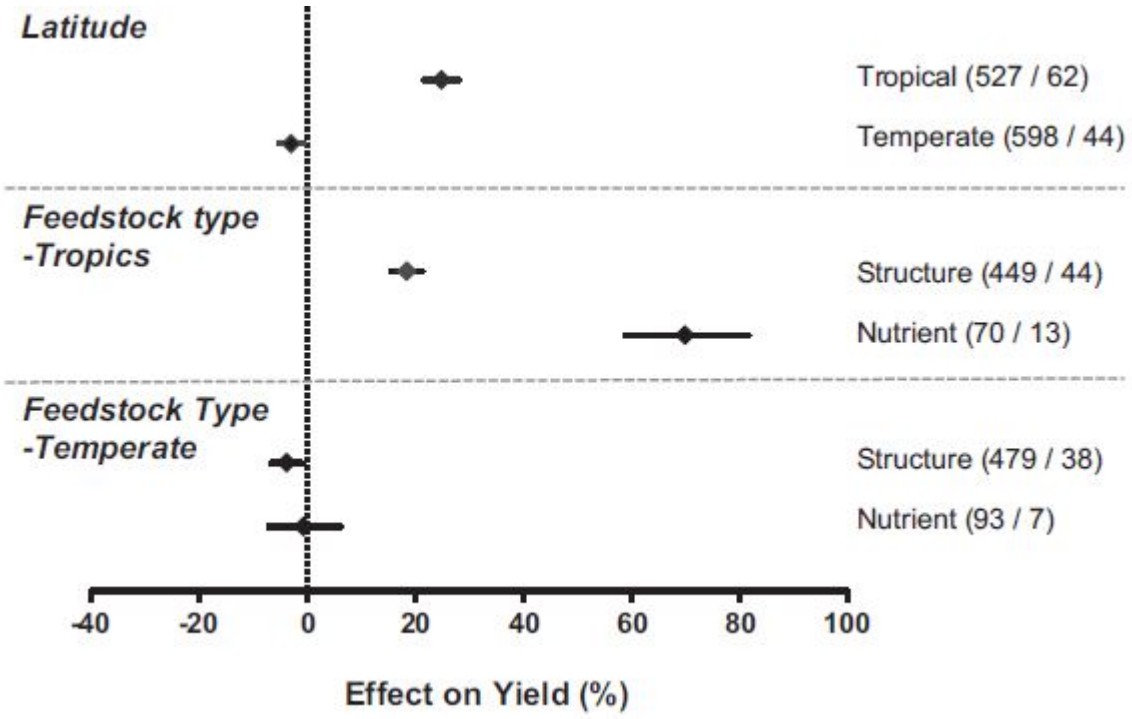


2. Comparing crop yields with organic inputs vs. mineral fertilisers – example with biochar



Jeffery, S., Abalos, D., Prodana, M., Bastos, A.C., Van Groenigen, J.W., Hungate, B.A. and Verheijen, F. (2017). Biochar boosts tropical but not temperate crop yields. Environmental Research Letters 12, 053001.

Which methods are currently used?

1. Assessing a change in agronomic nitrogen use efficiency
2. Comparing crop yields with organic inputs vs. mineral fertilisers
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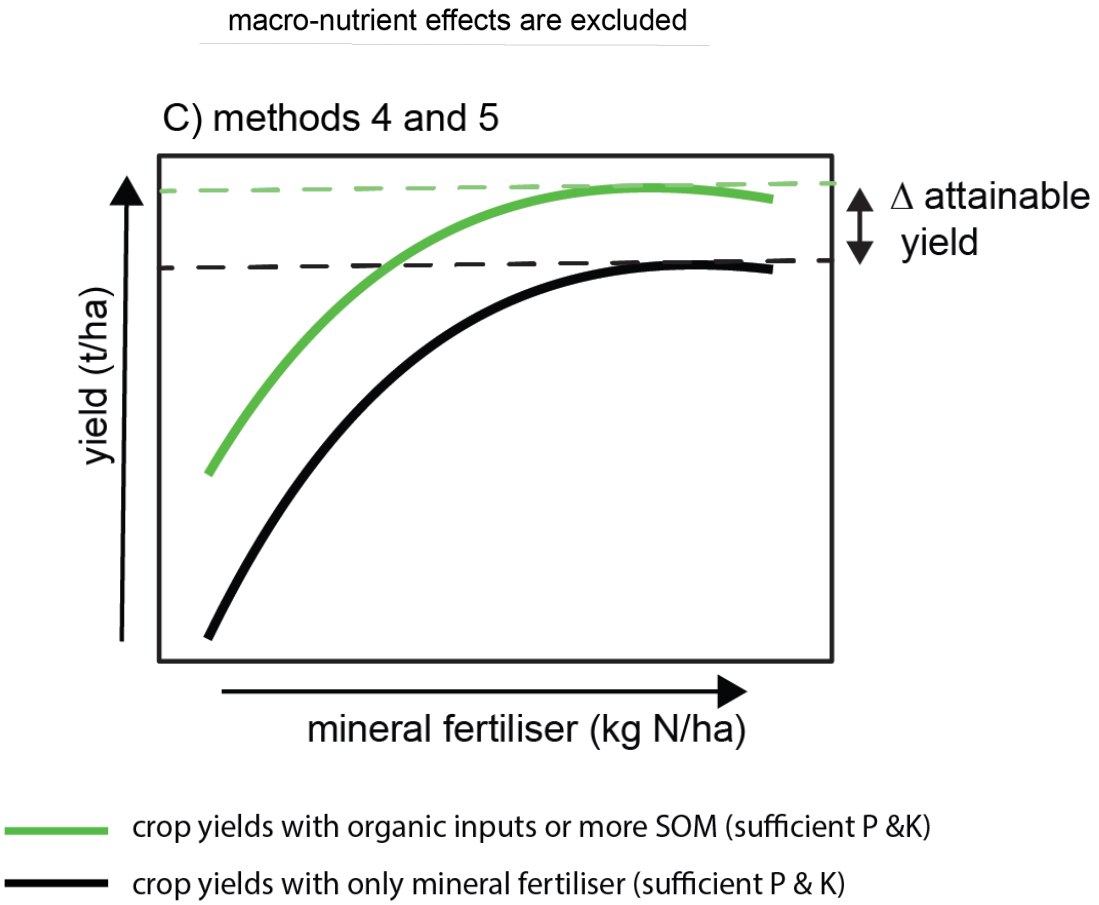
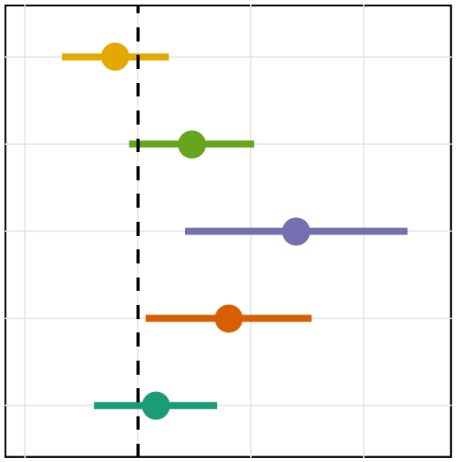


3. Assessing a change in attainable yield – example from Europe



wheat (31)

sugar beet (21)

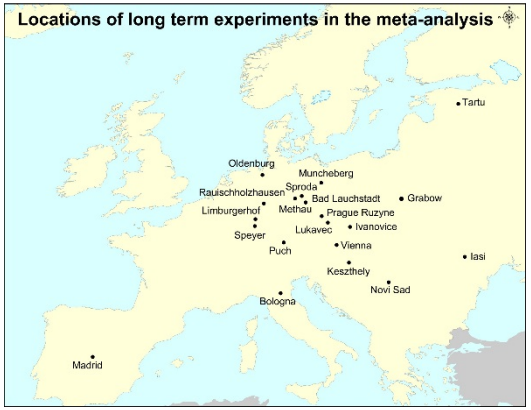
potatoes (11)

maize (15)

barley (27)

−5% 0% 5% 10%

additional yield effect of organic matter input



Hijbeek, R., van Ittersum, M.K., ten Berge, H.F.M., Gort, G., Spiegel, H., Whitmore, A.P., 2017. Do organic inputs matter – a meta-analysis of additional yield effects for arable crops in Europe. Plant and Soil 411, 293-303.

Which methods are currently used?

1. Assessing a change in agronomic nitrogen use efficiency
2. Comparing crop yields with organic inputs vs. mineral fertilisers
3. Assessing a change in attainable yield
4. Assessing the correlation between soil organic matter and crop yields

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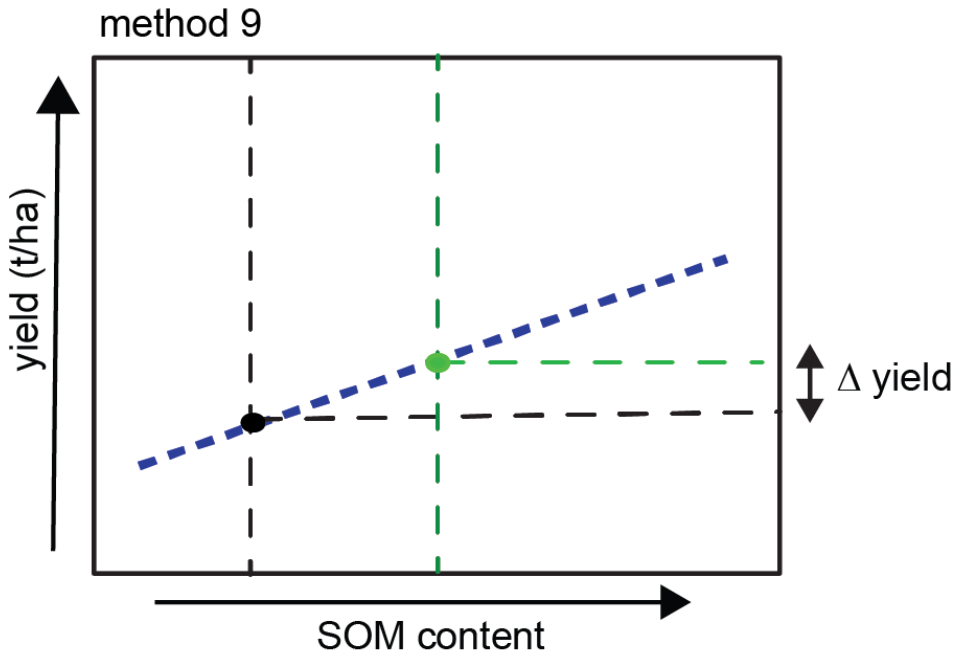
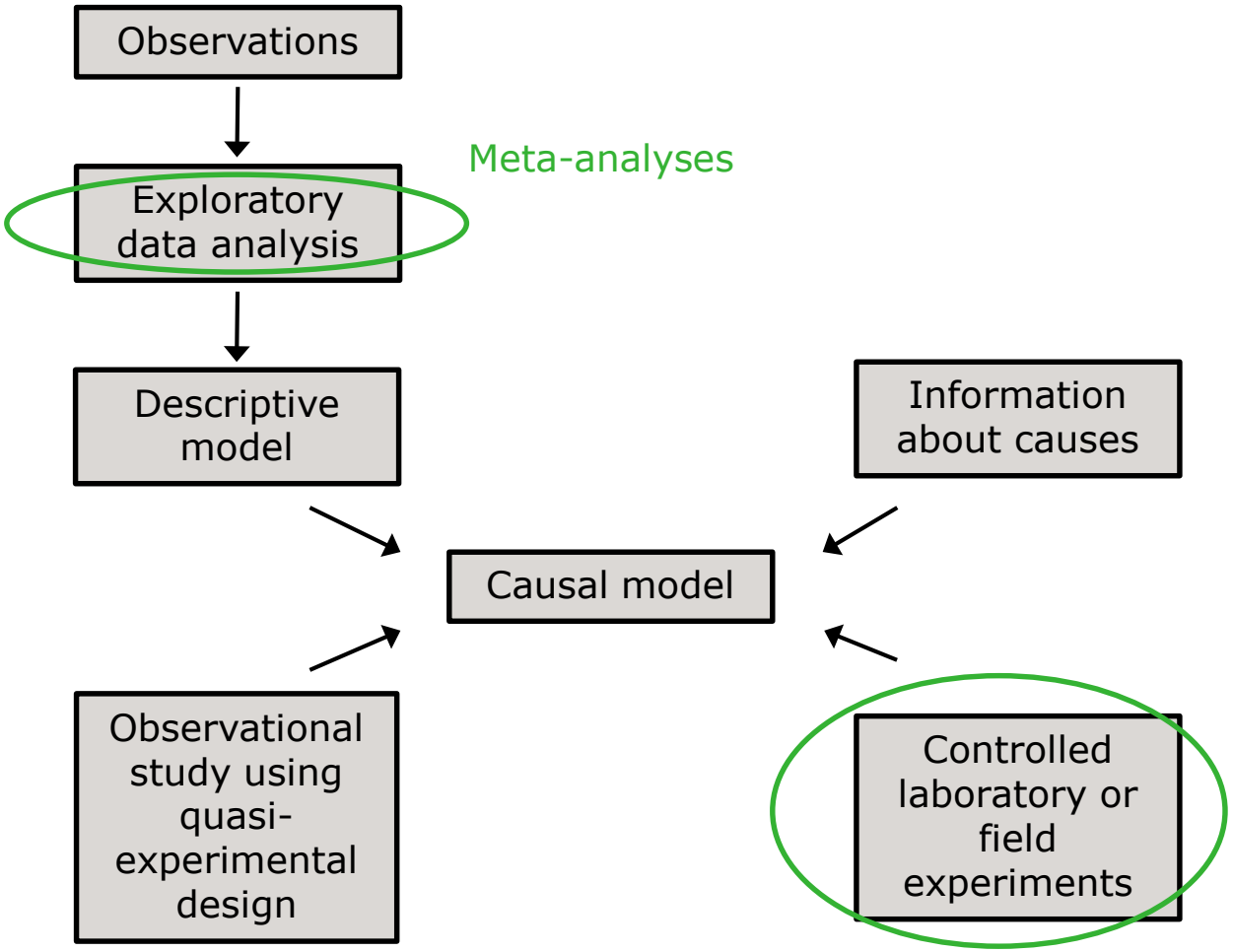
macro-nutrient effects are not excluded



Meta-analyses

- Aggregating data from multiple experiments
- Experiments should have a similar experimental design
- One common response variable in each experiment (*e.g.* yield in t/ha)
- Assessment of mean size of response variable and confidence interval
- If possible, statistical correlations with co-variables (such as climate, soil type)

Meta-analyses and their role in the research cycle



James, F.C. and McCulloch, C.E. (1990). Multivariate analysis in ecology and systematics: panacea or Pandora's box? Annual Review of Ecology and Systematics, 129-166.

Problem definition

- Outcomes of studies on the yield effect of soil organic matter or using organic inputs differ
- Yet.. methods used differ, regions differ, crop types differ..

→ a meta-analysis of meta-analyses?

Research questions 3 & 4

- What is the contribution of soil organic matter (or organic inputs) on crop yields when accounting for method used?

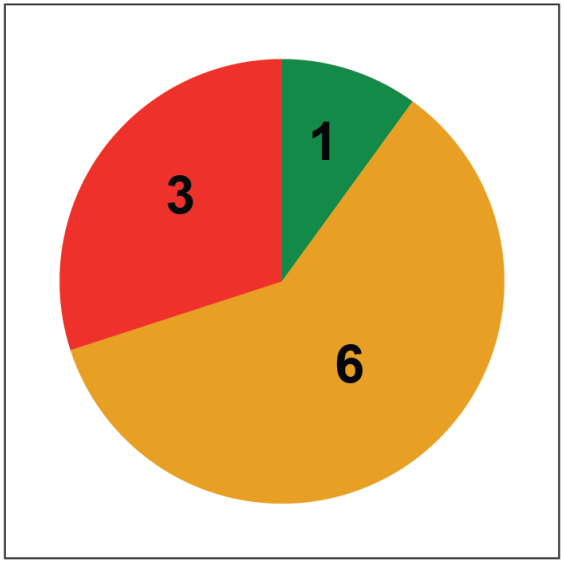
- What is the influence of crop types, input types and, climates?

14 meta-analyses of long-term experiments (>1000 experiments)

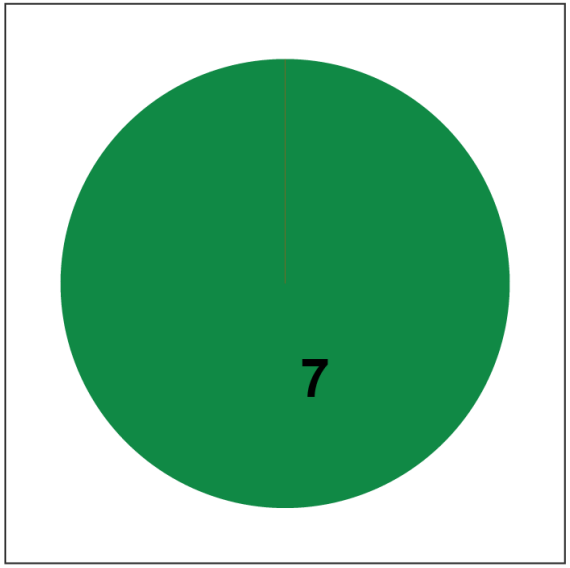
Study	Method used to quantify additional yield effect	Region	Crops	Effects of macro-nutrients excluded	# data points[1] included (# studies)
Delaune (2018)	(1) effect of SOM on ANE	Tanzania	Maize	Yes	219
Oelofse *et al.* (2015)	(1) effect of SOM on ANE & (4) effect of SOM on attainable yield	Denmark	Winter wheat, spring barley	Yes	869
Schjønning *et al.* (2018)	(1) effect of SOM on ANE & (4) effect of SOM on attainable yield	Denmark	Winter wheat	Yes	975
Dawe *et al.* (2003)	(3) effect of organic inputs on yield (equal nutrient content)	Asia	Rice, wheat	Yes	75 (25)
Wei *et al.* (2016)	(3) effect of organic inputs on yield (equal nutrient content)	China	Wheat, maize, rice	Yes	38 (32)
Zavattaro *et al.* (2017)[2]	(3) effect of organic inputs on yield (equal nutrient content)	Europe	Winter wheat, winter barley, rapeseed, spring wheat, spring barley, maize, potato, sunflower, sugar beet, fodder beet, grass, lucerne and others	Yes	310 on yield ratios (80)
Chen *et al.* (2018)	(3) effect of organic inputs on yield (equal nutrient content)	Global	Wheat, barley, maize, rice	Yes	329 (132)
Hijbeek *et al.* (2017b)	(5) effect of organic inputs on attainable yield	Europe	Winter wheat, maize, potatoes, sugar beet, spring barley, winter barley, winter rye	Yes	107 (20)
Vanlauwe *et al.* (2011)	(7) effect of organic inputs on ANE ((macro-nutrient effects possibly not excluded)	Sub-Saharan Africa	Maize	No	721 (90)
Jeffery *et al.* (2017)	(8) effect of organic inputs on yield	Global	Maize, wheat, rice, rye grass, lettuce, radish, barley, beans, rape, peanut, pepper, sweet potato and others	No	1125 (109)
Luo *et al.* (2018)	(8) effect of organic inputs on yield	Global	Wheat, rice, millet, maize, barley	No	226 (106)
Han *et al.* (2018)	(8) effect of organic inputs on yield & (9) correlation between SOM and yield	China	Rice, maize, wheat	No	75 (70)
Pan *et al.* (2009)	(9) correlation between SOM and yield	China	All cereals aggregated	No	National data
Soussana *et al.* (2017)	(9) correlation between SOM and yield	Africa, Asia and Latin America	Beans; cassava; maize; sweet potatoes; rice; soybean; sorghum; wheat	No	151 (32)

Comparing mean yield effects

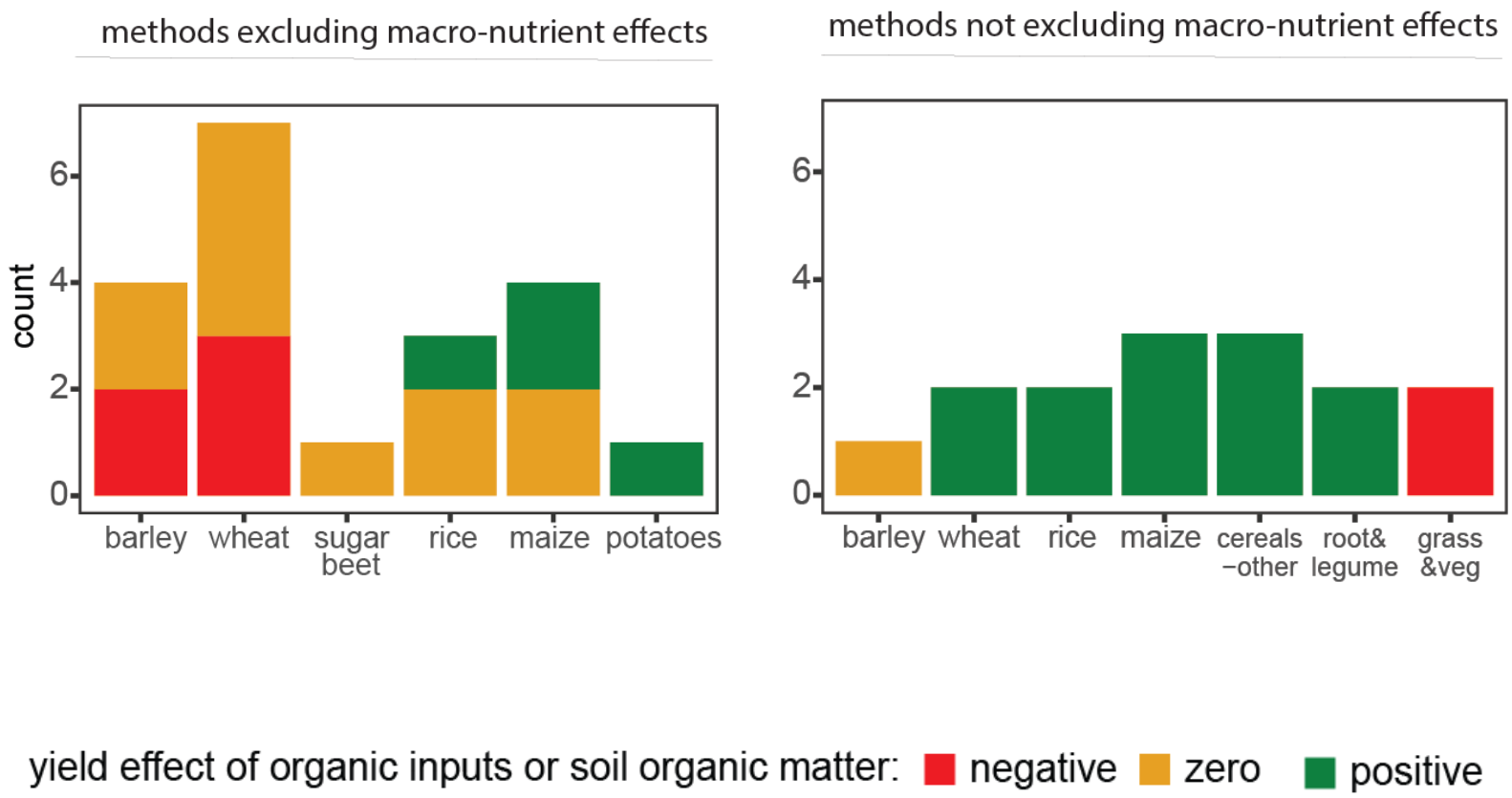
A. Mean yield effect of increasing SOM - N, P, K effects excluded



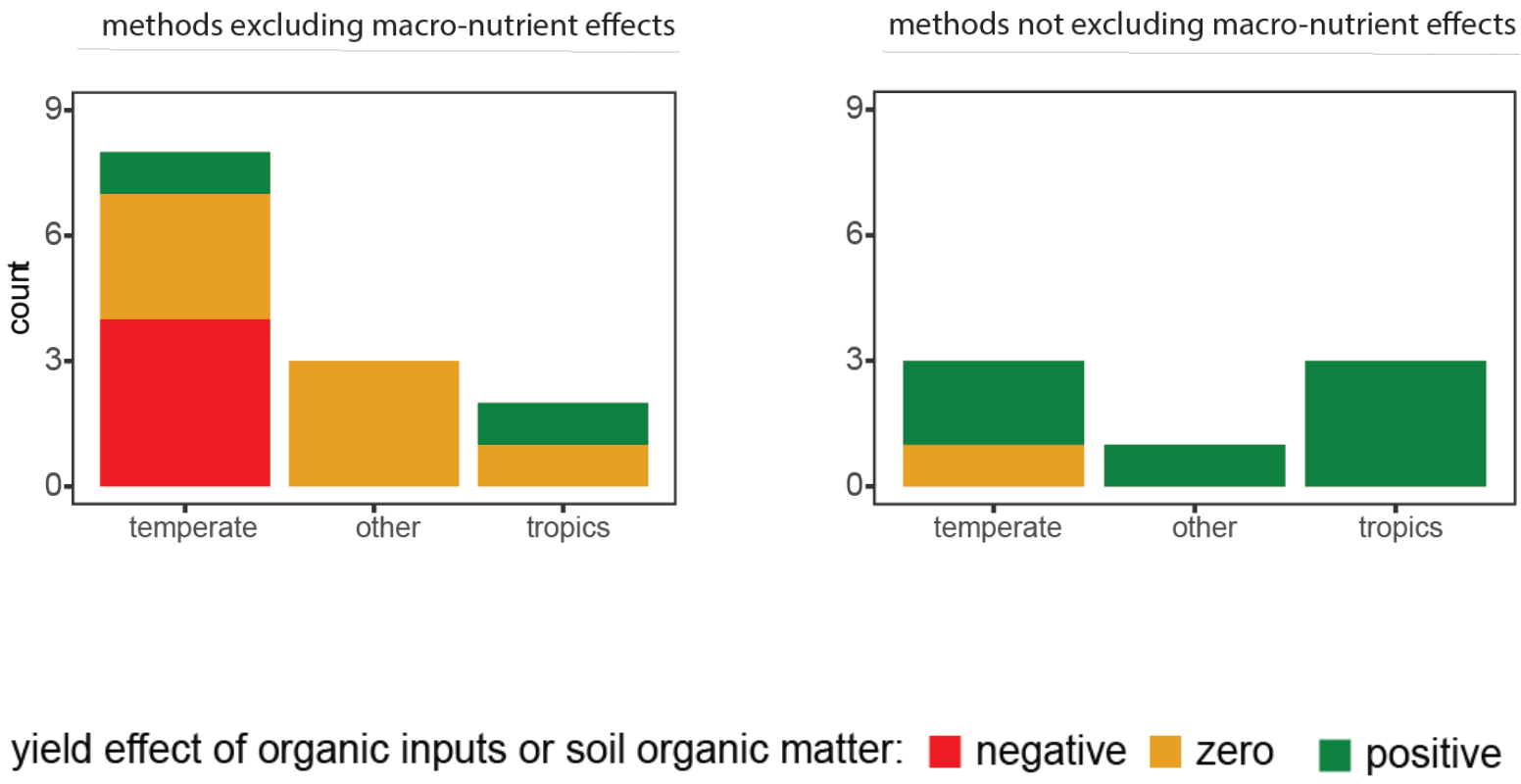
B. Mean yield effect of increasing SOM - N, P, K effects cannot be ruled out



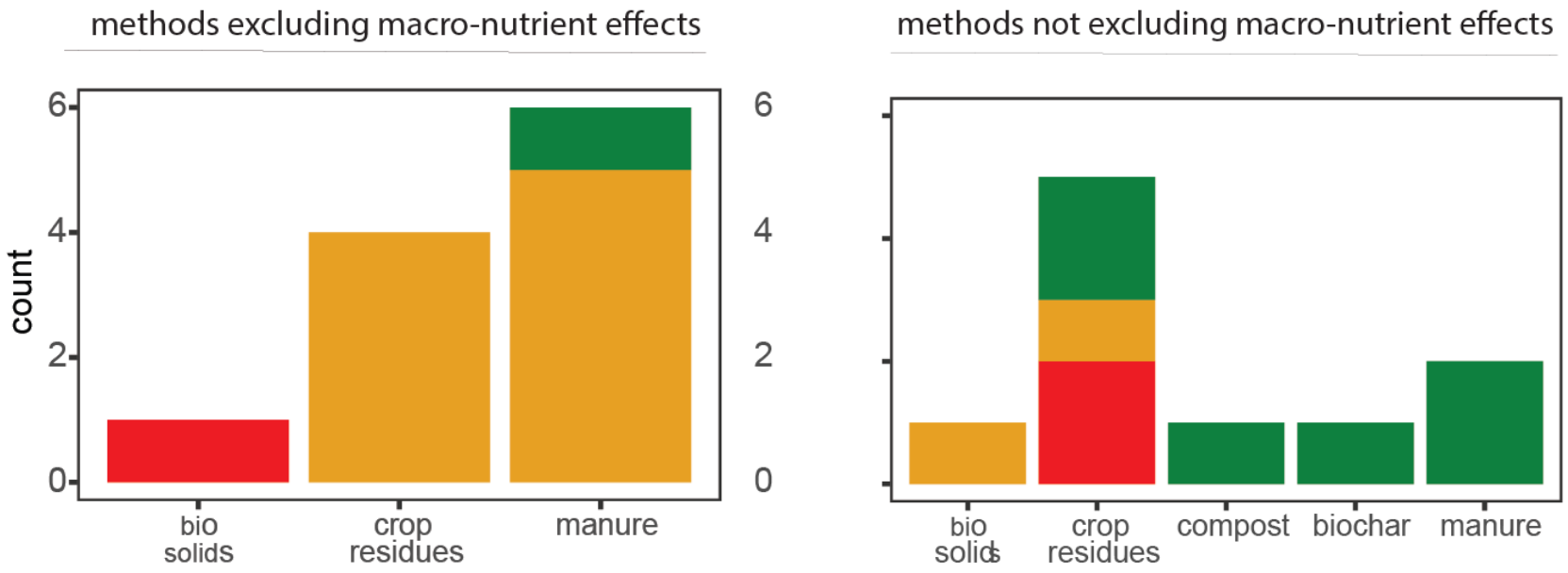
Yield effects across crop types



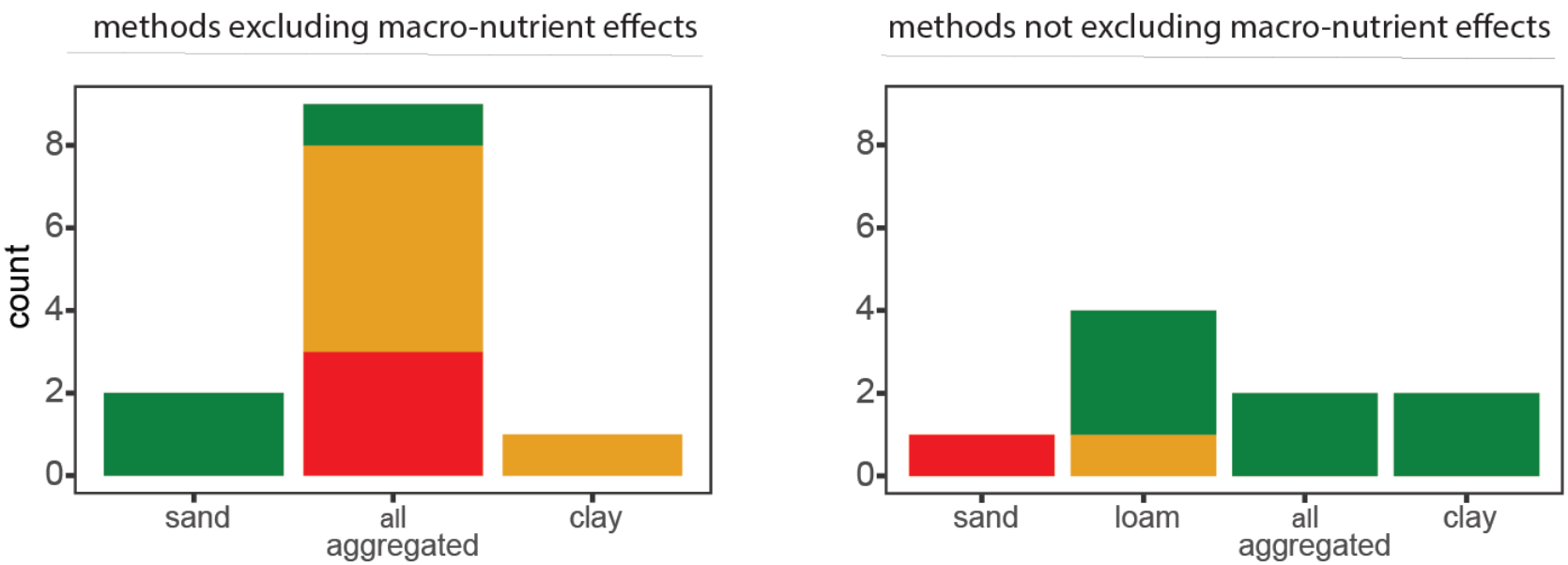
Yield effects across climates



Yield effects across input types



Yield effects across soil textures



On the merits of each method

- Including N,P,K effects: relevant for regions where nutrients are scarce or difficult accessible
- Excluding N,P,K effects: gives more insight into underlying mechanisms and more relevant for farming systems using mineral fertilisers

On the merits of each method

- Comparing yields at equal N,P, K supply: relevant for all farming systems (comparing mineral and organic fertilisers) but: difficult to establish 'equal' nutrient supply
- Assessing change in attainable yield: strong theoretical approach to exclude N,P,K effects, less immediate translation to farmers' current practice
- Correlations between soil organic matter and crop yields: most desirable quantification, but no causal effects & not possible to exclude N,P,K effects
- Assessing change in agronomic nutrient use efficiency: most promising with practical and scientific relevance, yet less consistent use of terminology/ definition of ANE in literature, giving a risk for confounding factors

Limitations of this review

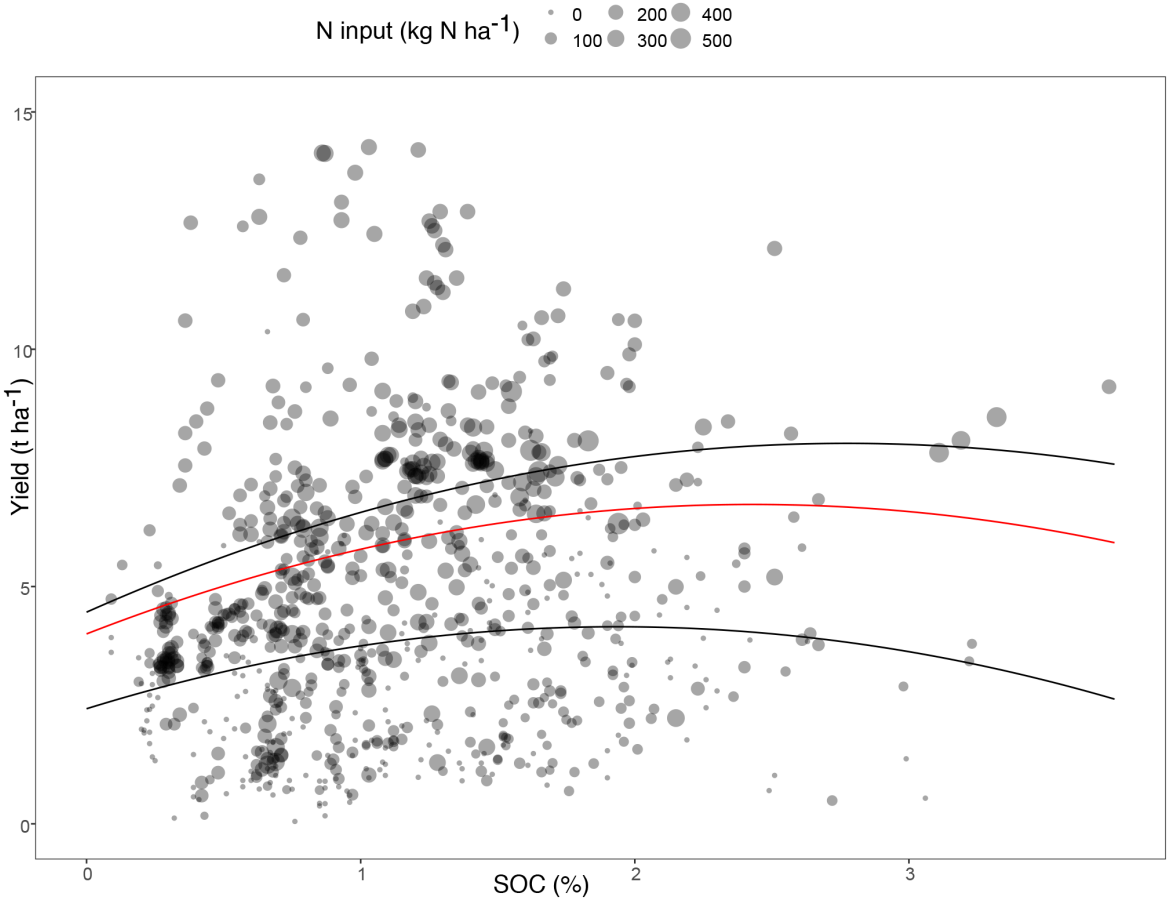
- Underlying data was not aggregated
- Different response variables could not be combined

Reflection on outcomes

- Measured yield effect of soil organic matter depends on method used
- Most studies indicating a positive yield effect of soil organic matter include N,P,K effects
- When N,P,K effects are excluded, mean yield effect of soil organic matter is often not significant
- In specific cases, soil organic matter does increase yield beyond the nutrients supplied
- More rigorous research and experimental set-ups are needed to disentangle yield effects of soil organic matter

Any questions?

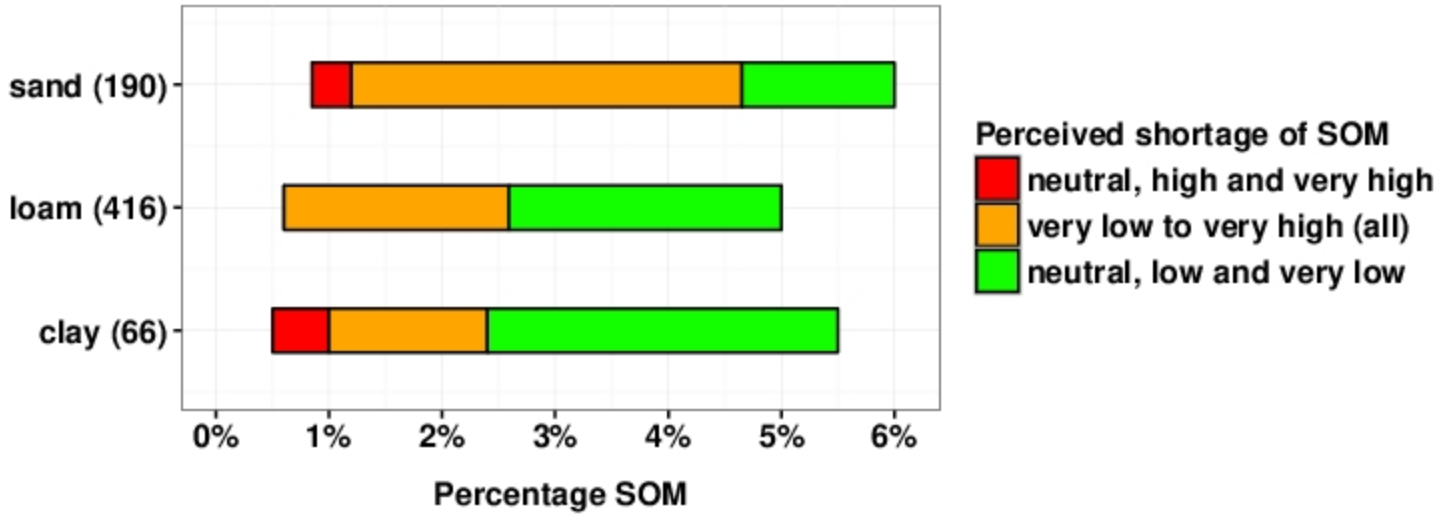
And it keeps on going..



"We find that greater concentrations of SOC are associated with greater yields up to an SOC concentration of 2 %"

Oldfield, E.E., Bradford, M.A., Wood, S.A., 2019. Global meta-analysis of the relationship between soil organic matter and crop yields. SOIL 5, 15-32.

2% SOC as a threshold?



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Functions of soil organic matter and technical replacements

Soil organic matter

Technical replacements

- Supply of nutrients
- Supply of water
- Soil structure
- Pest and disease control

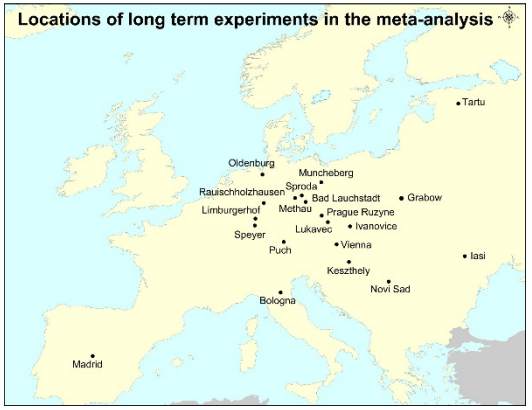
Ippmedia 2017; Wageningen UR 2017; Reekie 2017; Van Noordwijk et al 1997

How to increase soil organic matter?

- Soil organic matter can be increased by reducing outputs (*e.g.* reducing drainage or tillage) or increasing organic inputs such as:
  - Returning crop residues
  - Cultivation of green manures
  - Application of compost
  - Application of animal manure

3. Assessing a change in attainable yield – example from Europe

- Analysis of attainable crop yield
- With or without organic inputs
- The difference in attainable yield is taken as the response variable
- 20 experiments



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