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CL:AIRE's INSPIRATION bulletins describe practical aspects of research which have direct application to the management of contaminated soil or groundwater in an agricultural context. This bulletin describes the development and use of a decision support framework (DSF) for assessing agricultural management impacts.

Integrated use of meta-analytical data to identify management trade-offs on crop growth, soil quality and environmental quality in agriculture

1. A Framework to Support Decision-Making

As agriculture further intensifies, there are increasing and evolving impacts on crop growth, soil quality and environmental quality. Integrated and optimal combinations of recommended farm measures are needed to intensify production sustainably. A framework to evaluate benefits and trade-offs among the various management strategies with respect to these above-mentioned impacts would be a valuable aid for decisions affecting farm productivity as well as the societal benefits of soil, air and water quality. Since the opportunities and trade-offs vary by agro-ecological conditions, a system quantifying these impacts could stimulate sustainable management in Europe.

Various tools have been developed for farming, often with a specific focus such as soil and water conservation (Sarangi *et al.*, 2004), soil organic carbon (SOC) impacts (Hansen, 2016), or nutrient planning (PLANET, 2019). Other tools have a broad perspective such as land evaluation (De la Rosa *et al.*, 2004), or are for a specific geographic context (Manos *et al.*, 2007). However, an integrated assessment of a range of agricultural management impacts on crop growth, soil quality and environmental quality is lacking. This study is developing such a decision support framework (DSF), focusing on crop yield, SOC, and environmental N losses (Fig. 1).

This DSF is based on a quantitative review of changes in impacts due to management practices (Fig. 1a, b, c), which are evaluated by examining trade-offs and synergies in an integrated assessment (Fig. 1d, e). The DSF is unique in (1) assessing recommended soil, crop and nutrient measures under specific crop, soil and climate types in Europe and (2) evaluating performance of measures based on targets and critical limits for indicators. Results are presented on the first steps of the DSF (Fig. 1a, b), while the last stages (Fig. 1c, d, e) are indicated for context.

2. Approach

Meta-analysis is the quantitative analysis of empirical research results, where an average effect size and its significance is summarised across multiple studies, in the case of this work impacts of management measures on agricultural indicators (Franke, 2015). There is a growing body of knowledge on the effect of management practices in the form of field studies as well as meta-analysis studies in literature (meta-studies) (Eagle *et al.*, 2017). Existing meta-analytical results are integrated, addressing the effects of crop, soil and fertiliser management measures.

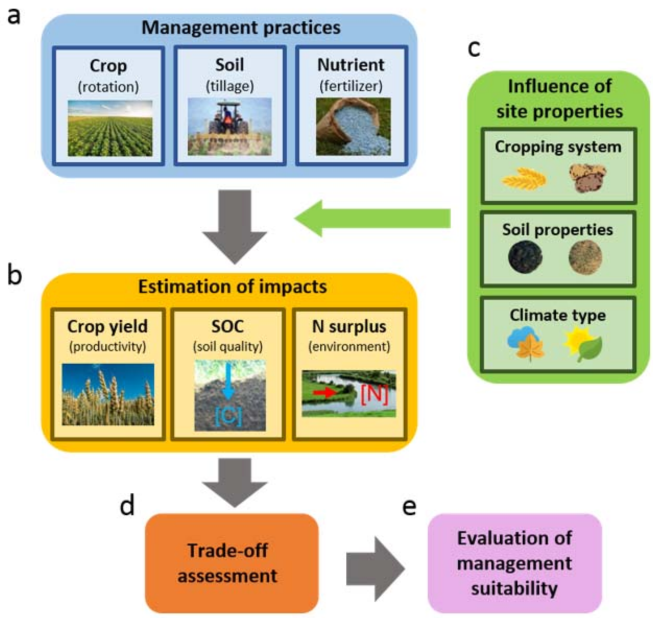

Figure 1: Overview of the DSF approach, consisting of (a) management practices assessed, (b) estimation of management impacts, (c) the influence of site properties on impacts, (d) trade-off assessment for the impacts of each management practice, and (e) integrated evaluation of management practices and their suitability.

Estimates of impacts were derived from effect sizes reported by meta -studies from continental to global geographic scale, neglecting impacts of variations in site properties. Where multiple meta-studies report on the same management-impact, an overall weighted mean effect size and standard error was derived (Eq. 1, 2). The individual effect sizes were weighted inversely proportional to the variance reported by each study. This can lead to greater insights than individual studies, since results may conflict in terms of positive or negative outcomes.

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$$\bar{x} = \frac{\sum(x_i/\sigma_i^2)}{\sum(1/\sigma_i^2)} \quad \text{(Eq. 1)} \qquad \sigma_{\bar{x}} = \frac{1}{\sqrt{\sum(1/\sigma_i^2)}} \quad \text{(Eq. 2)}$$

Where:

$\bar{x}$ = *weighted mean*

$\sigma_{\bar{x}}$ = *standard error of weighted mean*

x_i = *individual mean from reported effect size*

σ_i^2 = *individual variance from reported effect size*

Effect sizes for crop yield, soil organic carbon (SOC), and N surplus are presented, with preference to effect sizes reported in percentage change. For SOC, measures of both content and stock are included. Bulk density is the main difference between content and stock estimates, and it is assumed this is not affected by management measures. For studies reporting both content and stock, percentage change in stock is excluded in order to avoid data overlap. For the same reason, studies that use the same dataset are left out of the weighted mean.

3. Results and Discussion

Weighted annual mean changes in crop yield, SOC content/stock, and N surplus are shown in Figure 2 for crop, nutrient and soil management treatments.

Although the margin of error is wide, crop yield shows an overall 1% increase for diversified rotations (Fig. 2a: DR), matching the expectation that the overall increase in organic matter and soil structure improvement from more diverse rooting types indirectly leads to an increase in yields. An average decrease of 7% in crop yields is indicated for organic fertiliser as compared with mineral fertiliser, and an average increase of 0.6% in the case of applying combined mineral and organic fertilisers (Fig. 2a: OF, CF). This is plausible and could be related to the complementary benefits of mineral and organic fertilisers (Janssen, 2002). On one hand mineral sources provide macronutrients for plant uptake, while organic sources contain vital micronutrients for crop growth and soil quality. Reduced tillage practices show a 5% decrease in yield, although not significantly different from zero (Fig. 2a: RT). Literature findings show that reduced or no tillage may lead to less optimal crop rooting conditions in the short-term (Cooper *et al.*, 2016; Soane *et al.*, 2012).

There is an overall average increase of 0.1% in SOC for diverse rotations and 0.5% for reduced tillage, and a significant increase of 0.9% for organic fertiliser and 0.8% for combined practices (Fig. 2b: OF, DR, CF, RT). This is logical considering that organic amendments as well as residues from cover crops both increase the organic carbon input to the soil, and reduced tillage generally leads to less soil disturbance and less carbon losses (Pittelkow *et al.*, 2015).

An increase in N surplus of 15 kg ha^{-1} is indicated for organic fertiliser and 10 kg ha^{-1} for reduced tillage, (Fig. 2c: OF, RT), which may be related to the negative reported effects for yield (Fig. 2b: OF, RT). This would imply less overall N uptake by crops and thus more N surplus, which is generally lost to the environment. The decrease of 3 kg ha^{-1} in N surplus for diverse rotations (Fig. 2c: DR) could be expected for the same reason of increased yield and thus more N

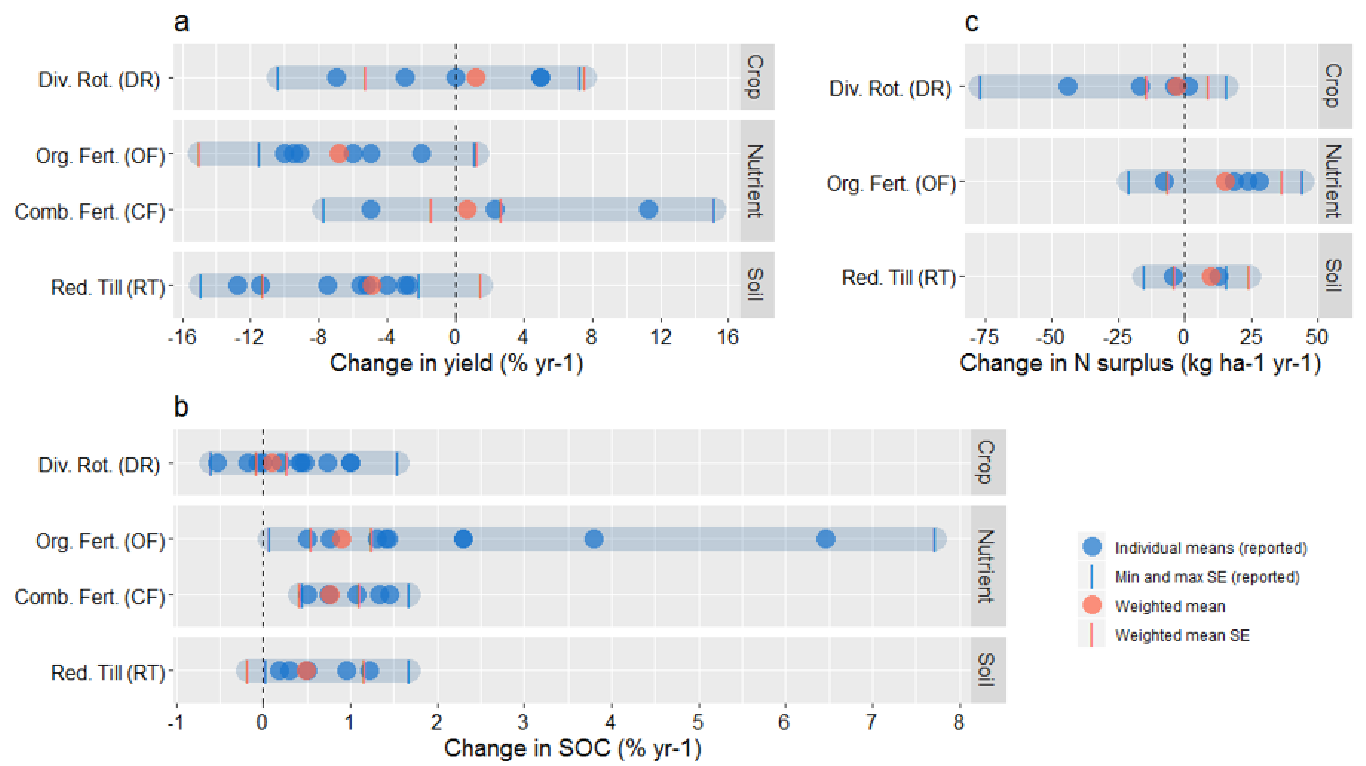

Figure 2: Annual changes in yield (a), SOC (b), and N surplus (c) based on inverse variance-weighted means of multiple meta-studies. Blue points are means for effect sizes reported in individual studies, blue error bars represent the range in standard error reported, and in red are the weighted means and their standard error. OF: organic versus mineral fertiliser; DR: diversified crop rotation by addition of a cover crop, legume crop, extra crop species, crop residue incorporation, or green manure into rotation; CF: combined organic and mineral fertiliser versus mineral; RT: reduced or no tillage versus conventional tillage, or no tillage versus reduced. Results are based on effect sizes from: (Aguilera *et al.*, 2013; Angers and Eriksen-Hamel, 2008; Cooper *et al.*, 2016; Han *et al.*, 2016; Hijbeek *et al.*, 2016; King and Blesh, 2018; Ladha *et al.*, 2011; Pittelkow *et al.*, 2015; Spiegel *et al.*, 2014; Tonitto *et al.*, 2006; Van den Putte *et al.*, 2010; Zavattaro *et al.*, 2017).

uptake in plant matter. There is little data in literature in general for some indicators such as N surplus as well as a lack of consistency in reporting by field studies (Eagle *et al.*, 2017). Due to the fact that studies often report in various units (e.g. percentage versus absolute change), N surplus is presented in absolute change (Fig. 2c). Estimations in this study may be biased due to the limited number of studies.

Combined and organic fertiliser had a significant effect on SOC (Fig. 2b: OF, CF). This indicates potential value in integrating meta-data together for well-studied practices, as well as further investigation on the effect of local site factors. On the other hand, the majority of the estimations have error bars that overlap with zero (9 out of the 11 means reported), indicating that overall effects are insignificant. Some variation can be related to the fact that various practices are aggregated together. For example, cover cropping, extra crop species, green manuring, different types of organic sources, and different groups of less intensive tillage practices are common distinct categories in other studies (Haddaway *et al.*, 2017; Hijbeek *et al.*, 2016; King and Blesh, 2018).

The initial estimates of this study will be improved through (1) a more detailed synthesis of meta-analysis literature, including a focus on site properties assessed, and (2) a multiple regression study allowing for a more robust analysis of the influence of soil, crop, climate and other site or experimental factors (Fig. 1c). Although most results here are based on effect sizes from long-term experiments, changes are reported as annual averages in order to make comparisons between different indicators. However, the evolution of SOC in particular should be analysed over longer time frames and experimental duration is an important moderator for multiple regression studies on SOC (Haddaway *et al.*, 2017).

4. Conclusion

Improved or recommended management practices have trade-offs, or conflicting effects, on farm productivity (crop yield) versus impacts on soil quality (SOC) and environment (N surplus). This is reflected in the results presented when applying organic or combined fertiliser, diversified cropping, and reduced tillage in place of the conventional practices of mineral fertiliser, monoculture cropping and tillage. Although results should be interpreted with caution in view of the uncertainties, a first estimation from multiple meta-studies shows that combined fertiliser is beneficial for both farm productivity (yield) and soil quality (SOC), while diverse rotations are beneficial to all aspects, including environment (N surplus). Organic fertiliser only as well as reduced tillage practices have overall contrasting effects with regards to the different indicators. The overall significantly positive or negative effect sizes reported for organic fertiliser on SOC (+0.9%) and combined practices for SOC (+0.8%) as a weighted mean of multiple studies shows promise for integration into a decision-making framework.

A future outcome of this study is to evaluate management measures based on distance of indicators to target values and critical limits (Fig. 1d). The end goal is an integrated assessment of management suitability, taking into account overall trade-offs and synergies between the different impacts (Fig. 1e) under various site conditions (Fig. 1c). This approach allows for the future integration of additional management practices and indicators.

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