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REGULAR ARTICLE

Do organic inputs matter – a meta-analysis of additional yield effects for arable crops in Europe

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Abstract
Background and aims Organic inputs have a positive effect on the soil organic matter balance. They are therefore an important asset for soil fertility and crop growth. This study quantifies the additional yield effect due to organic inputs for arable crops in Europe when macronutrients are not a limiting factor.
Methods A meta-analysis was performed using data from 20 long-term experiments in Europe. Maxima of yield response curves to nitrogen were compared, with and without organic inputs, under abundant P and K supply.
Results We were surprised to find that, across all experiments, the mean additional yield effect of organic inputs was not significant (+ 1.4 % ± 1.6 (95 % confidence interval)). In specific cases however, especially for root and tuber crops, spring sown cereals, or for very sandy soils or wet climates, organic inputs did increase attainable yields. A significant correlation was found between increase in attainable yields and increase in soil organic matter content.
Conclusions Aggregating data from 20 long-term experiments in Europe, this study shows that organic inputs and/or soil organic matter do not necessarily increase yields, given sufficient nutrients are supplied by mineral fertilisers. Results show the relevance of some environmental factors for additional yield effect of organic inputs, but no simple relation between organic inputs and crop growth.

Keywords Soil fertility · Soil organic matter · Organic inputs · Crop yield · Food security · Soil carbon sequestration

Abbreviations
SOM Soil organic matter
SOC Soil organic carbon

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Introduction

Soil organic matter (SOM) is often considered the most important indicator of soil fertility (Johnston et al. 2009;

Reeves 1997). It contributes to each of fertility's three dimensions: the physical (structure, aeration, water retention), the biological (biomass, biodiversity, nutrient mineralisation, disease suppression) and the chemical (nutrient supply) dimension. On this basis, maintaining SOM is an important strategy to maintain crop productivity (Lal 2004). SOM contains about 50 % organic carbon (Pribyl 2010), making it's increase a potential means to mitigate greenhouse gas emissions (Smith 2016). Because of this positive contribution to climate change mitigation and food security, a voluntary action plan has been proposed at COP21 to increase SOM in all soils, called "*the 4/1000 initiative: Soils for Food security and Climate*" (UNFCCC 2015).

In some cases however, yield effects of SOM seem smaller than expected. Reviewing the literature, Loveland and Webb (2003) found it difficult to establish a critical level of SOM for temperate regions. They also did not find evidence for an adverse effect on crop yields where SOM contents in the soils of England and Wales were reduced. Similarly, comparing potential yields of winter wheat and spring barley across a large range of SOM contents in Denmark, Oelofse et al. (2015) found no significant effect on yields of winter wheat and only a small effect on yields of spring barley.

The mentioned studies compared the effect of actual SOM content, they did not assess specific management practices used to increase SOM. In arable soils, SOM can be increased by increasing organic inputs or reducing organic outputs (Freibauer et al. 2004). Increasing organic inputs can be done by increasing returned biomass (roots, litter) via higher yields or adding additional organic inputs such as compost, animal manure or crop residues. Decreasing organic outputs can be done by changing the moisture content of the soil or by using reduced or no tillage, although the effect of the latter two remain disputed (Govaerts∗ et al. 2009). Actual increase in SOM depends on a number of factors, such as the current amount of SOM, type of organic input, and environmental factors such as temperature, soil texture, and humidity (Smith et al. 1997).

Studies assessing the effects organic inputs on crop yields show mixed results. A recent meta-analysis of 32 long-term experiments in China compared the combined use of organic inputs and fertilizers with either only organic inputs or only fertilizers (Wei et al. 2016). The average yield increase of combining organics and fertilizers on wheat, maize and rice was found to be 8 % compared to using only fertilizers. In a different case however, (Dawe et al. 2003) found no improvement in grain yield trends with application of either manure or straw in intensive rice systems.

How do these contrasting insights compare? Although previous research has found a positive effect of either organic inputs or SOM on crop yields (Monreal et al. 1997; Wei et al. 2016), Oelofse et al. (2015) argue that in these studies the effect of nutrients is seldom separated from other effects. In fact, Wei et al. (2016) also mention this as the largest limitation of their study.

To circumvent this limitation, we have assessed the effect of organic inputs in a system without macronutrient limitation. In such a system, any effect of organic inputs on yield can be attributed to improved soil structure or soil life (the other two components of soil fertility). In our study, effects of organic inputs (also called organic fertilisers, organic manures or organic amendments) on attainable crop yields were examined in 20 long term experiments across a variety of soils and climates in Europe. To exclude the effects of macro-nutrients, the yield effect was analysed under abundant phosphorus (P) and potassium (K) supply and varying rates of nitrogen (N). Using this approach, we answer the following research question: Do organic inputs increase attainable yields? Previously, any effect of organic inputs or SOM on crop yield which are not related to macro-nutrients has been called the "*additional yield effect*" (Janssen 2002). Our objective is: to find the additional yield effect of organic inputs, beyond the macro-nutrients supplied.

Materials and methods

Literature search

To find data on long term experiments in Europe, two databases with metadata were used: the EuroSOMNET metadata on 110 long-term experiments and a database compiled in a recent European research project (CATCH-C (2015)) containing 377 long-term experiments. Promising experiments were selected and publications were searched using online search engines (Google scholar, ISI Web of knowledge). When more publications were available for one treatment, only yield data from the most recent publication was included.

The following selection criteria were used to select experiments: (1) at least 4 increasing levels of N applications without organic inputs; (2) at least 4 increasing N application levels with organic inputs; (3) P and K applied in ample amounts on all fields; (4) at least 5 years of yield data; (5) if crops are grown in rotation, yield data available for at least 2 rotations; (6) yield data reported for individual crop types (mean yield values averaged over rotation were excluded).

Data from 20 experiments was found adhering to these selection criteria (Fig. 1 and Table 1). Following, 107 distinct data sets were created, each representing a single combination of experiment location, crop type and organic input type, covering a number of years of yield observations. All data was processed in R 3.0.0 (R Core Team 2015).

Calculating additional yield effect of organic inputs for each set of data

Crop yields are known to steeply increase at lower levels of N application while levelling off or slightly decrease at high levels of N application. When yields are known at different levels of N application, response curves can be fitted (Cerrato and Blackmer 1990). For each set of data in our meta-analysis, two yield response curves were drawn: one with and one without organic inputs (Fig. 2). To fit the curves, the following formula was used (George 1984):

$$\text{yield} = a + b*0.99^{N} + c*N + \varepsilon \qquad (1)$$

In formula 1, N is nitrogen added as mineral fertiliser (kg N/ha), a, b and c are parameters to be fitted and ε is the error term. The maximum of each curve was calculated by setting the first-order derivative equal to zero and inserting the optimal N rate in Eq. 1. As P and K were applied in ample amounts, at the maximum of each curve N, P and K (the macro-nutrients necessary for crop growth) are not a limiting factor for crop yields. Accordingly, the maximum of each curve was regarded as the attainable yield for local environmental conditions and management. The additional yield effect of organic inputs was calculated by taking the difference between the attainable yield with and without organic inputs.

For each data set, response curves might fit the data points better or worse, creating an error in the estimation of the additional yield effect. To correct for the goodness of fit of each curve, the delta method (Oehlert 1992) was used, giving a variance for each data set. The inverse of the variance was used as a weighting factor for the calculated additional yield effect of each data set. To enable comparisons among crops, the relative difference was chosen as the response variable in the meta-analysis, expressing the additional yield effect of organic inputs as percentage of attainable yield with only mineral fertiliser. Fig. S1- S3 in Online Resource 1 show the individual response curves, while Fig. S4

Fig. 1 Overview of locations of long term experiments included in the meta-analysis (20)

Table 1 Details of experiments (20) included in the meta-analysis. For each experiment, clay content, percentage SOM at start, CGIAR-CSI Global Aridity Index, starting time, crops included in analysis and references used are given. For Vienna, additional data was provided by Heide Speigel (AGES). For Muencheberg, data was provided by Dietmar Barkusky (ZALF). For Grabow, data was provided by Dorota Pikuła (IUNG). For Bologna, additional data was provided by Guido Baldoni (University of Bologna). For Puch, additional data was provided by Matthias Wendland (Bayern LFL)

Experiment	Clay content (% < 2 μm)	SOM at start (%)	CGIAR-CSI Aridity index	Starting time	Crops	Types of organic inputs	References used
Bad Lauchstadt	21	3.56	0.68	1978	p,s	FYM, GM, straw	Eich et al. 2013; Pfefferkorn and Körschens 1995
Bologna 1	-	1.3	0.75	1966	m,ww	FYM, slurry, straw	Giordani et al. 2010; Triberti et al. 2008
Grabow	2	1.29	0.73	1980	m,p sb,ww	FYM	-
Iasi	39	-	0.61	1984	m,s	FYM, straw & BL	Hideborn Alm and Dahlin 2007; Mogârzan et al. 2007; Vasilica et al. 1997
Ivanovice	33	-	0.7	1984	wb,ww,	FYM, straw & BL	Hideborn Alm and Dahlin 2007; Vrkoc et al. 1996
Keszthely	21.3	1.4	0.72	1984	wb	FYM, straw & GM	Hoffmann et al. 1997; Kismányoky and Tóth 2012
Limburgerhof	10	1.29	0.72	1987	m, ww	straw & GM, straw & GM & slurry	Lang et al. 1995
Lukavec	15	3.3	0.84	1984	p,wb	FYM, straw & GM	Káš et al. 2010; Vrkoc et al. 1996; Vrkoč et al. 2002
Madrid	27	1.19	0.31	1985	sb,ww	FYM, straw	López-Fando and Pardo Fernández 2008; López-Fando et al. 1999
Methau	14.8	3.3	0.81	1966	p,sb,s,ww	straw	Albert and Grunert 2013; Körschens et al. 2014
Muencheberg	4.05	0.99	0.75	1962	sb,s,wr,ww	FYM, straw	-
Novi Sad	-	2.62	0.64	1984	m,s,ww	FYM, straw & BL, straw & BL & slurry	Starčević et al. 2005; Starčević et al. 1997
Oldenburg	6.19	2.84	1.09	1984	s,wb,ww	slurry, straw & GM & BL	Klasink and Steffens 1995
Prah Ruzyne	33	-	0.62	1984	s,wb,ww	FYM, straw & GM & BL	Vrkoc et al. 1996
Puch	23	1.86	1.22	1984	m,s,	slurry, straw, FYM, straw & BL, straw & GM & BL, straw & GM & slurry, straw & slurry	Hege and Offenberger 2006
Rauischholz-hausen	17	2.24	1.06	1984	s,wb,ww	straw & GM & BL	Von Boguslawski 1995
Speyer	8.9	1.24	0.8	1984	s,wb,ww	FYM, straw & GM & BL	Bischoff 1995
Sproda	6.3	2.2	0.68	1966	sb,s,ww	FYM, straw	Albert and Grunert 2013; Körschens et al. 2014
Tartu	7.7	1.71	1.05	1989	p,sb,sw	FYM, straw & BL	Kanal et al. 2003; Kuldkepp et al. 1996
Vienna	25.2	2.55	0.71	1986	s,wb,ww	FYM, slurry, straw & GM & BL	Hösch and Dersch 2002; Spiegel et al. 2010

m maize, *p* potatoes, *s* sugar beet, *sb* spring barley, *wb* winter barley, *wr* winter rye, *ww* winter wheat, *FYM* farm yard manure, *GM* green manure, *BL* beat leaves

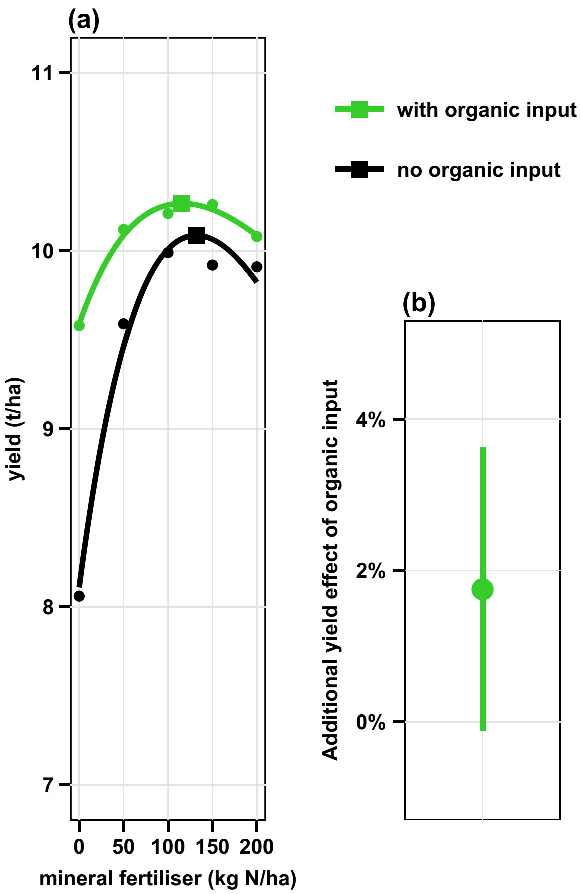

Fig. 2 Example of yield response curve to mineral fertiliser-N under sufficient P and K supply with and without organic inputs. **a** Black line is the response curve without organic inputs. The green line is the response curve with organic inputs. Squares indicate the maximum of each curve. The difference between the two maxima is due to the additional yield effect of organic inputs. **b** Green circle is the relative difference between the two maxima. Green line indicates the 95 % confidence interval due to the goodness of fit of the two curves. Yield data is from maize grown in Novi Sad between 1996 and 2003, with and without farmyard manure

in Online Resource 1 gives the additional yield effect and related 95 % confidence interval for each data set.

Removing of outliers

Yield effects were checked for outliers by assessing the point cloud across different variables and constructing a funnel plot. If a data point was located outside the point cloud and P and K could not be excluded as yield limiting factors in the treatment without organic inputs, the data was removed from the meta-analysis (This was only necessary in one case).

Assessing influence of co-variates

To assess the influence of environmental factors, crop characteristics or type of organic input, factors and co-variables were identified. Two grouping factors were used: type of organic input and crop type. In some cases, a combination of organic inputs was used, for example straw and slurry, where one of year straw was applied and the next year slurry. Each combination of organic inputs was included as a separate category.

In addition, for each dataset the following information was obtained from the literature: clay content, percentage of SOM content at the beginning of each experiment, amount of carbon in organic input, SOM change during each experiment and duration of each experiment. When numbers were given in percentage of soil organic carbon (SOC), they were multiplied with the conventional factor 1.724 (Pribyl 2010; Waksman and KR 1930). Duration of each experiment was multiplied with yearly carbon applied to give the total C added over the years. Geographical coordinates of each experiment were used to find the CGIAR-CSI Global Aridity Index (Trabucco and Zomer 2009).

To assess the effect of the grouping factors and co-variates, a mixed effects model with a hierarchical structure (Konstantopoulos 2011) was used. Mixed effect models allow for incorporation of random effects, which is important when observations are not from a stratified or random sampling design as is typical in meta-analyses (Gurevitch and Hedges 1999). The following two random effects were incorporated in the analysis: (1) Experiment: As a single experiment may produce multiple data sets, experiment was used as a random factor. (2) Treatment without organic inputs: Within a single experiment, multiple treatments with organic inputs can exist (for example one treatment with farmyard manure and one with crop residues) which are all compared to the same treatment without organic inputs (with only mineral fertiliser).

Group means for crop type and type of organic input were estimated with R-package lsmeans (Lenth 2015). To find the marginal effect of each co-variate on the additional yield effect of organic inputs, a separate model was made for each co-variate using the function lme (linear mixed-effects model) of package nlme (Pinheiro et al. 2015). Within these models, log-likelihood was maximized and yield effects were weighted by the inverse of the variance. Interaction between crop type and co-variate were checked on significance. Only SOM change had a significant interaction with crop type.

Model selection

To assess which combination of co-variates and factors could best explain the difference in the additional yield effect of organic inputs, multi-model dredging was performed using the dredge function in the R-package MuMin (Barton and Barton 2015). This function constructs a list of models by combining the given co-variates and then gives a ranking according to the corrected Akaike Information Criteria (AICc), an indicator commonly used to assess model fit (Bozdogan 1987).

Two model selections were run. In the first model selection, only data from experiments was included for which information on both percentage of clay and SOM content was available (15 out of 20**)**. For the second model selection, only experiments were included for which data on SOM change was available (8 out of 20).

Sensitivity analysis

For some sets of data, maximum yield was not reached within the N applications of the experimental set-up. These maxima had to be estimated beyond the experimental set-up resulting in a higher uncertainty. When analysing the data, these points could be either included or excluded, with each choice having its own advantage. Excluding these data points gives a dataset with more certainty on each individual estimate, but including them increases the size of the total dataset. Because a greater uncertainty results in a larger variance, meaning a smaller weight is given to a yield effect which is calculated with a maximum yield outside the experimental setup, we chose to include these data sets in the meta-analysis. To see the effect of including or excluding the maxima outside the experimental set-up, a sensitivity analysis was done on the main results.

Results

The mean additional yield effect of organic inputs across all 107 data sets is not significant in our meta-analysis (1.4 % ± 1.6 (95 % c. i.)). When excluding maxima estimated outside the experimental set-up, the mean yield effect is slightly higher: 1.9 % ± 2.0 (95 % c.i.), yet still not significant.

Additional yield effect across type of organic inputs, crop types and time of sowing

Comparing different types of organic inputs, the yield effect is roughly similar, but only the mean additional yield effect of farmyard manure is significantly positive (2.2 % ± 1.8 (95 % c.i.) – Fig. 3a). Yet we did find effects on specific crops. For potatoes the mean yield increase is 7.0 % ± 4.9 (95 % c.i.). In addition, our results show that maize, a crop with a less developed root system than wheat or barley, also benefits significantly from organic inputs (mean yield effect of 4.0 % ± 3.7 (95 % confidence interval) – Fig. 3b).

Across the 20 experiments, cereals sown in winter do not benefit form organic inputs in our meta-analysis (Fig. 3c). On the other hand, spring sown cereals do

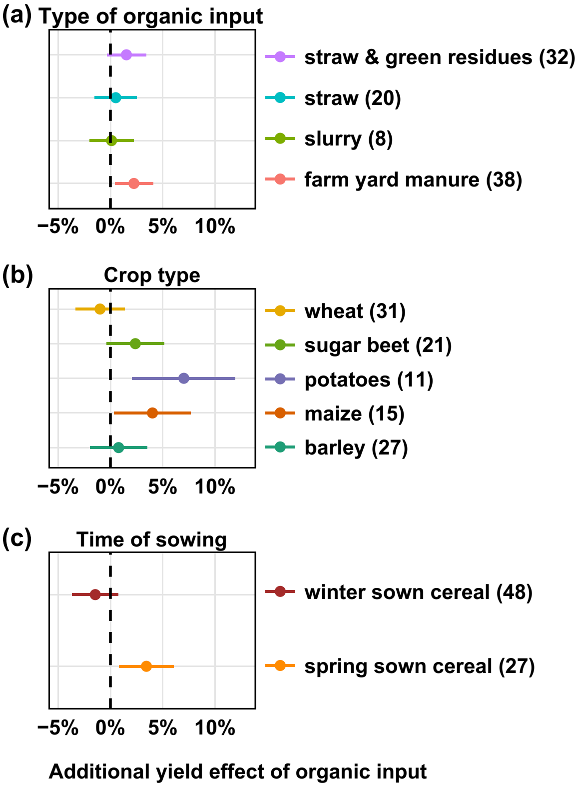

Fig. 3 Influence of type of organic input (**a**), crop type (**b**) and time of sowing (**c**) on additional yield effect of organic inputs. Circles are mean additional yield effects, lines the 95 % confidence interval. Numbers in brackets are the number of data sets in each group. Only groups with at least 8 data sets are shown. Green residues are either green manures or beet leaves. Groups with less than 8 data sets and results of the sensitivity analysis are shown in Fig. S5 of Online Resource 1

benefit (3.4 % ± 2.6 (95 % c.i.)). Spring sown crops have a shorter time frame to develop their root system which is needed to acquire sufficient nutrients and water (Johnston et al. 2009). Organic inputs, by improving soil structure, might facilitate this process, resulting in larger yields.

Influence of soil, climate and amount of C added

Crops grown on more sandy soils show a positive yield effect of organic inputs, while more clayey soils show neutral or negative yield effects (Fig. 4a). Relatively sandy soils normally have a poorer soil structure, which can be improved by adding organic inputs. Soils with low SOM content would also be expected to benefit more from organic inputs, but this is not apparent in our results (Fig. 4b).

For each experiment, we expressed climate in terms of aridity using the CGIAR-CSI Global Aridity Index (Trabucco and Zomer 2009). Lower values indicate lower temperatures with more rainfall while higher numbers indicate higher temperatures with less rainfall. In our study, crops grown in wetter climates benefit more from organic inputs (Fig. 4c).

Experiments differ in the type and the amounts of organic inputs applied annually, and in their duration. After converting all organic inputs to total C (ton C/ha, cumulated over the years), no significant relation was found between total C input and the yield effect (Fig. 4d).

Relative increase in SOM

For a subset of experiments, percentage increase in SOM during the experiment could be calculated. When running a model selection, combining the relative increase in SOM content with crop type gives the largest explanation of variance in the additional yield effect of organic inputs (Tables S1 and S2 in Online Resource 1). The magnitude of the effect is shown in Fig. 5a.

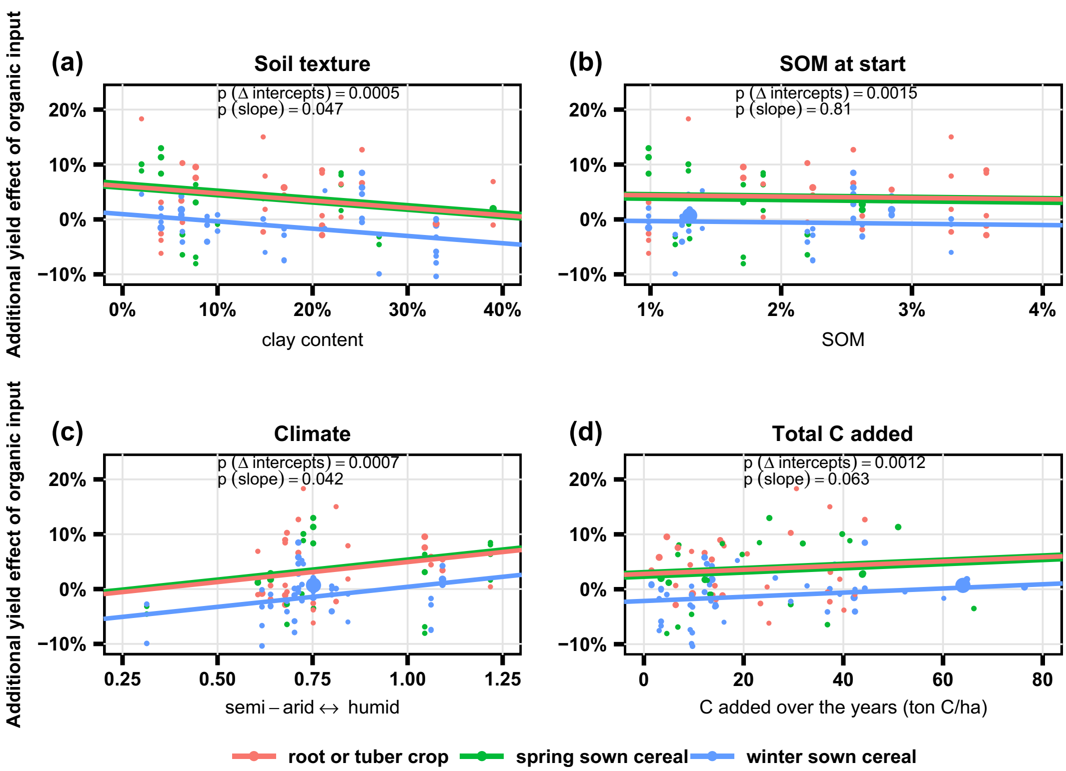

Fig. 4 Influence of soil texture (**a**), SOM content at the start of the experiment (**b**) climate (**c**) and amount of C applied over the years (**d**) on the additional yield effect of organic inputs. Clay content is expressed as the percentage of particles <2 μm in the soil. Climate is expressed as the CGIAR-CSI Global Aridity Index. Larger points have a smaller variance and therefore a higher weight. P (Δ intercepts) is the probability for the intercepts to be equal. P (slope) is the probability the common slope is equal to zero

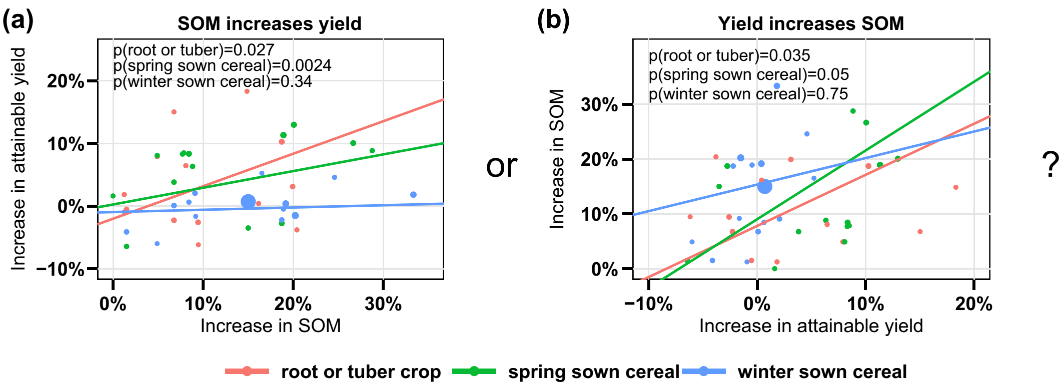

Fig. 5 Relation between increase in SOM and yield increase. **a** Increase in yield related to increase in SOM. x-axis: increase in SOM between the treatment with only mineral fertiliser and the treatment with organic inputs added. y-axis: difference in maximum yield between the treatment with only mineral fertiliser and the treatment with organic inputs added. **b** axes vice versa from a. Larger points have a smaller variance and therefore a higher weight. P (Δ intercepts) is the probability for the intercepts to be equal. P (Δ slope) is the probability for the slopes to be equal

Discussion

When discussing possible benefits of organic inputs and soil organic matter beyond nutrients supplied, it has been suggested that root or tuber crops might benefit more than cereals (Haan 1977; Verheijen 2005). The reason being that root and tuber crops depend more on soil structure for their successful cultivation and harvesting. Our study confirms this suggestion with a mean yield increase for potatoes of 7 %.

Crops grown in both very dry or very wet conditions could potentially benefit from organic inputs as SOM increases water holding capacity in dry climates (Díaz-Zorita et al. 1999) and prevents soil compaction in wet climates (Soane 1990). In our study, crops grown in wetter climates do benefit more from organic inputs. As expected for a meta-analysis over Europe, most of our experiments (16) however have a humid climate (index >0.65), with three experiments having a dry sub-humid climate (index 0.5–0.65), one a semi-arid climate (0.2–0.5) and none arid or hyper arid climates (index <0.2). As very dry climate were not included, this could be the reason why we could not confirm whether organic inputs have additional yield effects in dry climates.

Very weathered soils, mostly occurring in tropical regions, were also not included in our meta-analysis. Weathered soils often have very low cation exchange capacity (Palm et al. 1997) and lack a number of micro nutrients necessary for crop growth (Gupta et al. 2008). On weathered soils therefore, yield effect of organic inputs could be larger when related to treatments with only N, P and K supplied. A recent global database suggests experimental set-ups as used in our meta-analysis do not exist outside temperate regions (ISCN 2015), establishment of such long term experiments would therefore be recommended.

Before analysis, percentage of SOM at the start of each experiment was expected to be the largest influencing factor. Yet, no significant difference was found comparing experiments with different SOM contents (Fig. 4b). There is however uncertainty associated with comparing SOM contents across 20 experiments. When available, measurements of the upper soil layer or plough layer (often 24–30 cm) were included in the analysis, yet depth of measurement was not always explicitly stated. In addition, measurements of SOM are known to deviate, depending on methods used (Hoogsteen et al. 2015). Even though some error in SOM measurements might be involved, our finding does correspond well with a recent study in Denmark comparing yields of winter wheat across a large range of SOM contents (Oelofse et al. 2015), with similarly no effects found.

Figure 5a seems to indicate that more so than the total SOM at start (Fig. 4b) or the total C added (Fig. 4d), it is the percentage of fresh SOM in the soil which makes a difference. If so, this finding corresponds well with suggestions of Loveland and Webb (2003) that the proportions of fresh SOM is more important than the total pool of SOM. On the other hand, higher yields also have an effect on SOM by returning more crop, root and stubble residues (Glendining and Powlson 1995). One could therefore question if larger yields in our analysis are the result of the increased SOM content (Fig.5a), or vice versa (Fig. 5b)? In practice, both possibilities might be true and – if so – can be mutually reinforcing: in some cases more SOM gives somewhat higher yields, which adds more organic matter to the soil which in turn gives higher yields, which then again gives more SOM.

Limitations of study and broader contextualization

This meta-analysis did not find a significant mean additional yield effect of organic inputs. When assessing the use of organic inputs on a farm or regional level however, other aspects might also be relevant. Organic inputs can promote the buffering function of soil in years with less favourable conditions, thereby reducing yield variability (Pan et al. 2009). In our experiments, variability in attainable yields was not lessened with organic inputs (data not shown), but this could be tested further under more extreme climates.

Using organic inputs can also have environmental effects. Soils with higher SOM contents for example might create a more flourishing habitat for soil biota (Chang et al. 2007). Maintaining SOM contents can therefore contribute to biodiversity conservation.

Combining organic inputs with mineral fertilisers can decrease the demand for mineral fertilisers which can have positive effects such as a decrease in demand for fossil fuels (Wood and Cowie 2004). In our meta-analysis, the savings of mineral fertiliser N with organic inputs are substantial (Fig. S6 and Table S3 in Online Resource 1). The savings in mineral fertiliser N however do not outweigh the total N in the organic inputs and mineral N added for growth of green manures or decomposition of straw. Consequently, organic inputs might affect the extend of nitrate leaching, nitrous oxide or ammonia emission. For nitrate leaching, both positive (Leclerc et al. 1995) and negative cases (Basso and Ritchie 2005; Oelofse et al. 2015) are known. It has been suggested that the number of years of application is crucial and that over the long-term, if nutrients are applied attuned to crop requirements, organic inputs have no significant effect on nitate leaching (Maeda et al. 2003).

Even though the mean additional yield effect across all data sets was not significant, a large variance exists between data sets. Using grouping factors (crop type, type of organic input) and co-variates (clay content, aridity), some variance was explained, but large parts remained unknown. In some individual cases, organic inputs did increase attainable yield significantly (Fig. S4 in Online Resource 1). In others, organic inputs might have had little effects on soil structure, either because soil structure was already very good or because it was beyond simple repair. These type of nuances can be tackled in-depth in single experiments, but are difficult to disentangle when aggregating larger data sets. Combining meta-analysis with more in-depth studies is therefore vital for more thorough understanding of processes and mechanisms involved.

Conclusions

Using organic inputs to increase soil organic matter is often seen as a win-win situation for food security and climate change mitigation, such as in the recently proposed "*4/1000 initiative*" at COP21 (UNFCCC 2015). Using organic inputs to sequester carbon might be a viable option to buy time for developing technologies for reducing industrial emissions (IGBP 1998), this meta-analysis however shows that benefits for crop yields cannot be assumed to follow directly. On sandy soils, in wet climates and for certain crops (some root or tuber crops and spring sown cereals) organic inputs can increase yields beyond the nutrients they supply. In those cases, increases in attainable yields vary mostly between 3 to 7 %. In the majority of cases however, supplying only mineral fertiliser gives similar yields.

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