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REGULAR ARTICLE

Direct effects of soil organic matter on productivity mirror those observed with organic amendments

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Abstract
Aims Organic amendments to arable soil build soil organic matter (SOM), which can increase crop yields. However, organic amendments can influence crop yields independently of SOM by providing nutrients directly to plants. The relative importance of native organic matter versus organic amendments is not well quantified. We experimentally manipulated both organic amendments and native SOM concentrations to quantify their relative importance to crop yields.
Methods We created OM concentration gradients by (1) diluting an organic-rich A-horizon with a mineral base and (2) amending compost to the same mineral base, generating OM concentrations for both treatments of approximately 2, 4 and 8%. We grew buckwheat and measured plant productivity and a range of soil fertility variables.
Results Higher concentrations of OM, whether native or amended, were associated with higher soil water holding capacity and nutrients, and improved soil structure. Consequently, increases in both native and amended OM were associated with strong positive but saturating impacts on productivity, though amendment effects were greater.
Conclusions Our results suggest that native SOM can support productivity levels comparable to those observed with organic amendments. Although our quantitative findings will likely vary for different soils and amendments, our results lend support to the idea that SOM stocks directly increase productivity.

Keywords Crop productivity · Crop yield · Soil health · Soil organic carbon · Soil organic matter · Soil quality · Sustainable agriculture

Introduction

Soil organic matter (SOM) is considered the key arbiter and indicator of soil fertility due to its impact on soil chemical, physical, and biological properties (Romig et al. 1995; Reeves 1997; Robertson et al. 2014). Soil organic matter increases aeration and water holding capacity, provides habitat for soil organisms that fuel nutrient cycling, and retains and provides nutrients critical to productivity (Brady and Weil 2007). The role of SOM in supporting and sustaining soil as a critical resource is gaining increased attention through initiatives promoting the concept of "soil health" (FAO 2005; NRCS 2012; Fine et al. 2017). A guiding paradigm of these initiatives is that adding organic matter to the soil creates resilient and fertile soils by improving soil properties. This, in turn, ensures more stable and long-lasting

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productivity, and decreases reliance on external inputs such as mineral fertilizers and irrigation (Reeves 1997; Robertson et al. 2014).

There is still substantial uncertainty, however, about how the amount or concentration of SOM influences yields (Herrick 2000; Loveland and Webb 2003; Edmeades 2003; Oldfield et al. 2015; Hatfield et al. 2017). The effects of additional SOM on crop productivity are inconsistent, with decreased, neutral, or increased productivity compared to soils with less SOM (Bauer and Black 1992; Johnston et al. 2009; Bhardwaj et al. 2011; Williams and Hedlund 2013). Furthermore, studies exploring the effect of SOM on crop yields are often confounded by the fact that SOM gradients among agricultural fields often result from differing rates and types of organic matter inputs. Inputs can directly influence both yields and SOM concentrations, making it difficult to tease out the independent effects of SOM from organic inputs on crop yield (Fig. 1). Specifically, the addition of inputs such as plant residues, compost, or manure can have effects on yields independent of SOM content (Baker et al. 2007; Powlson et al. 2014). For instance, retaining plant residues can increase soil moisture, which can help increase crop yields, especially in arid climates (Pittelkow et al. 2014). Manure can provide high concentrations of essential plant nutrients, but is also associated with nutrient losses and run-off from agricultural systems (Johnston et al. 2009). These effects raise the question as to the extent to which it is the inputs, versus the native SOM, that drive agricultural productivity (Fig. 1).

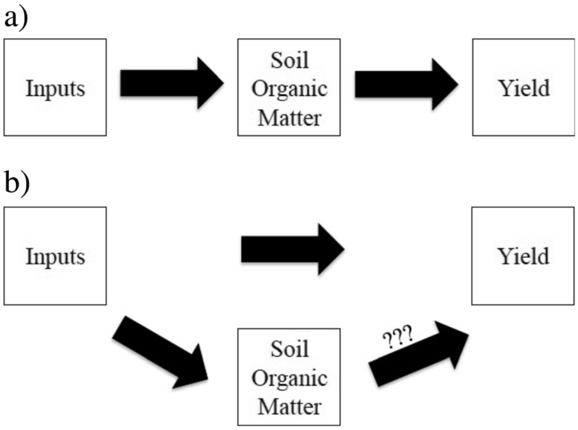


Fig. 1 Conceptual diagram exploring how organic inputs influence yields. (**a**) Traditional assumptions posit that inputs increase soil organic matter, which can increase yields; (**b**) however, organic inputs can have effects independent of SOM on crop yield. Studies exploring the effect of SOM on crop yields are often confounded by the fact that SOM gradients are a result of differing amounts and types of organic inputs. Inputs, therefore, can directly influence yields and SOM concentrations, making it difficult to tease out how SOM directly influences yields. Our study design explores, independently, how inputs directly influence productivity and how SOM directly influences productivity

Varying effects of native SOM versus inputs underscore the theory that different pools of organic matter contribute differentially to soil fertility. Soil organic matter can be conceptualized as a continuum of organic compounds that cycle at different rates largely due to decomposer access to SOM and its protection within the soil's mineral matrix (Lehmann and Kleber 2015). The more stable, slower cycling pool consists largely of mineral-sorbed, highly processed organic matter that is thought to confer soil fertility through water and nutrient retention. The more actively cycling organic matter pool is strongly impacted by fresh OM inputs and is thought to directly supply nutrients for crop growth (Janzen et al. 1992; Wander 2004). As such, native SOM and organic amendments may act through different pathways to affect crop yields.

The organic matter concentration within a soil is the resulting balance between formation and decomposition, and depends largely on interactions between inherent soil properties (e.g. texture and mineralogy), climate, management, and the nature of the inputs. All native OM necessarily comes from inputs, however, we expect a larger degree of native SOM to be derived from belowground inputs (Schmidt et al. 2011; Clemmensen et al. 2013), whereas compost is created from the decomposition of above-ground biomass. As such, one might expect that native OM should have a smaller proportion of actively cycling organic matter, and therefore fewer rapidly mineralizable nutrients to support crop growth than a soil amended with compost (Fortuna et al. 2003). Furthermore, applied as an amendment, we do not know what proportion of compost will ultimately go on to form stable SOM. Yet a foundation of sustainable management of agricultural lands is to build SOM contents, generating an important question where management is focused on increasing or maintaining yields. Specifically, when managing organic matter to maximize productivity, is it more effective to manage inputs or build up native SOM? This largely becomes a question of managing flows versus managing stocks. To help address this question, we examined the relationship between both native SOM and amended organic matter on resulting crop productivity. Further, we investigated a number of soil properties in an attempt to disentangle the mechanisms by which SOM and organic amendments influence yield.

Methods

Soil treatments and experimental set-up

The objective of our experiment was to estimate, independently, the direct effect that both SOM (as contained in resident native stocks) and organic inputs (as incorporated compost) have on crop productivity. We took two approaches to manipulating soils: (1) we diluted an organic-rich A-horizon with a mineral base of sand, silt, and clay; and (2) we added finished compost to the same mineral base. For both soil treatments, we created a gradient of organic matter (OM) with three different concentrations (low, medium, high) ranging from 1.25% to 8.5% (see Table 1). We note that the low, medium, and high OM concentrations were similar but not identical between the two different soil treatments (see Fig. 2). We procured both the A horizon and the compost from the Yale Farm in New Haven, Connecticut, USA (41°19′N, 72°55′W; 108.7 MAP, 11.3 °C MAT). The A horizon was from the top 10 cm of a perennial zone on the farm and had not received any supplemental inputs of organic matter for the past 7 years, and so resulting SOM concentrations are reflective of natural cycling of different pools of organic matter. The Yale Farm soil is a sandy loam classified as a Cheshire Urban land complex (mesic Typic Dystrudept) (NRCS 2016). The A horizon had an initial carbon (C) concentration of 10.1% and nitrogen (N) concentration of 0.66%. The compost was created at the Yale Farm from farm residues (non-harvested vegetables, root and aboveground biomass removed after harvest). The compost had an initial C concentration of 5.3% C and an N concentration of 0.42%. Both the A horizon soil and the compost were then mixed, independently, with a screened fill (primarily sand, silt, and clay with very low C and N concentrations) procured from a commercial landscaping company. The fill had an initial C concentration of 0.47% and N concentration of 0.020%. For clarity, we refer to these different soil treatments as "native-OM" and "amended-OM."

All soil materials (fill, A horizon, and compost) were homogenized and hand sorted to remove any large stones (>5 mm diameter), macrofauna, and large roots (> 2 mm). The soil materials were then mixed in specific ratios to achieve the organic matter (OM) gradients, homogenized, and placed in pots (17.78 cm height, 17.78 cm diameter). There were five replicates for each OM concentration (low, medium, high). All pots received the same volume of soil (2 L). Pots were then placed at the Yale Farm. The experimental pots were separated from the Yale Farm's annual vegetable operation, receiving no supplemental irrigation.

The experimental crop, buckwheat (*Fagopyrum esculentum* L.), was germinated in a potting mix (containing no mineral fertilizer) to its cotyledon stage and

Table 1 Soil property means

Soil variable	Experimental soil manipulation						
	None	Native OM			Amended OM		
	Base	Low	Med	High	Low	Med	High
Soil Organic Matter (%)	1.31 ± 0.04	2.24 ± 0.04	4.15 ± 0.09	8.79 ± 0.09	1.92 ± 0.03	3.52 ± 0.05	8.30 ± 0.07
Total soil C (%)	0.47 ± 0.02	0.79 ± 0.04	1.54 ± 0.04	3.18 ± 0.07	0.65 ± 0.02	1.20 ± 0.02	3.06 ± 0.06
Total soil N (%)	0.02 ± 0.0007	0.04 ± 0.0013	0.09 ± 0.0035	0.20 ± 0.0045	0.03 ± 0.0003	0.08 ± 0.0006	0.22 ± 0.0032
P-extractable (ppm)	4.98 ± 0.07	24.44 ± 0.83	84.32 ± 2.99	190.54 ± 4.10	17.24 ± 0.41	81.62 ± 2.00	261.80 ± 4.20
K-extractable (ppm)	42.0 ± 1.0	49.0 ± 1.87	59.0±1.14	108.0±3.03	60.6±0.68	163.6±2.29	584.4 ± 11.40
CEC (meq 100-g^{-1})	5.96 ± 0.12	8.48 ± 0.21	12.78 ± 0.13	23.18 ± 0.44	7.14 ± 0.12	11.36 ± 0.21	23.68 ± 0.20
pH	8.27 ± 0.14	7.94 ± 0.04	7.74 ± 0.02	7.26 ± 0.02	8.00 ± 0.03	7.64 ± 0.02	7.18 ± 0.02
Soil microbial biomass (μg-C g soil^{-1} h^{-1})	0.48 ± 0.01	0.55 ± 0.01	0.78 ± 0.02	1.15 ± 0.04	0.60 ± 0.01	0.86 ± 0.02	1.76 ± 0.14
Water holding capacity (%)	0.18 ± 0.01	0.19 ± 0.01	0.24 ± 0.01	0.41 ± 0.03	0.22 ± 0.01	0.27 ± 0.01	0.47 ± 0.03
Bulk Density (g cm^{-3})	1.23	1.13	0.93	0.79	1.01	0.97	0.70

Values (mean ± SE, $n = 5$) of measured soil variables for the experimentally manipulated soils. The base represents the mineral base that was combined with both the organic-rich A-horizon (native OM treatment) and the finished compost (amended OM treatment)

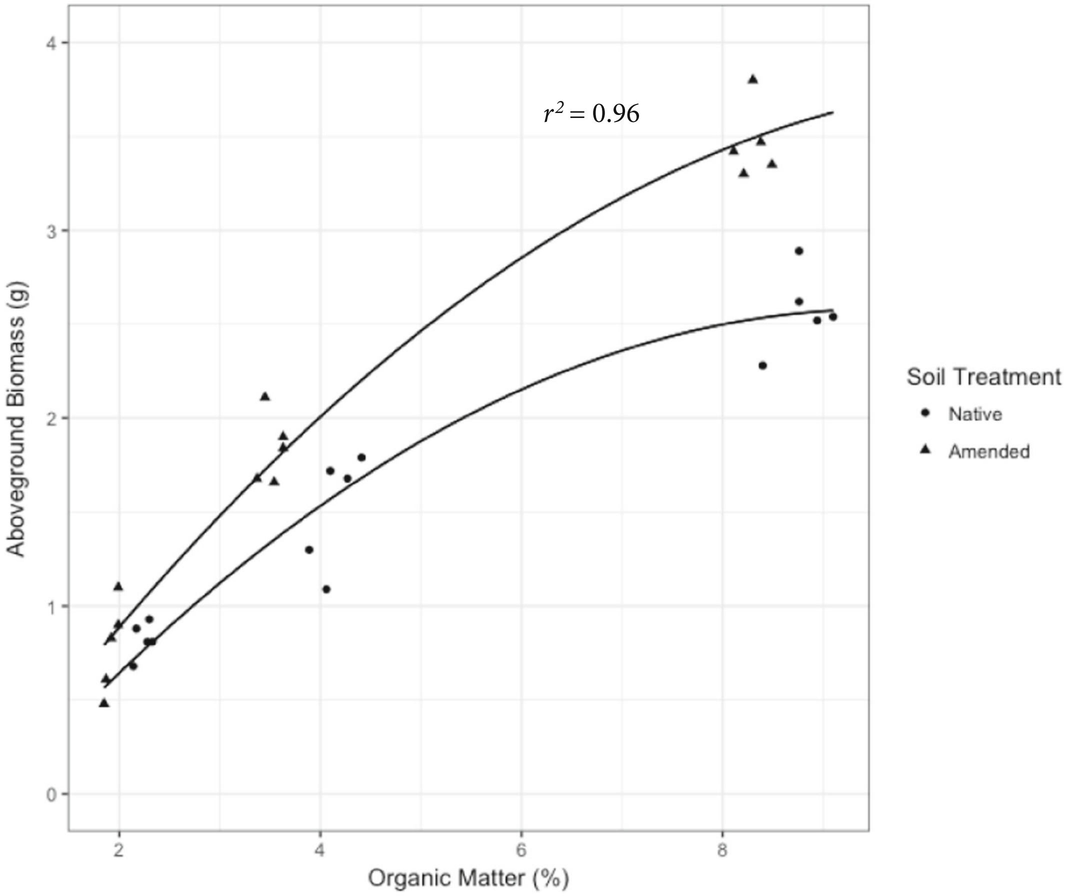


Fig. 2 Relationship between aboveground productivity and soil organic matter. We modeled the relationship between organic matter and aboveground biomass. The lines represent the mean regression lines for each treatment; each OM concentration had an *n* of 5

then transplanted into experimental pots. Each pot received three individuals of the same size (i.e. height and cotyledon number). We grew plants as monocultures as opposed to single plants since single plants grown in pots have been shown to respond to variables such as N availability in a manner inconsistent with monocultures and diverse communities (Poorter and Navas 2003).

Experimental measures

During the course of the growing season (approx. 6 weeks), we measured volumetric water content using a time-domain reflectometer (TDR) with 12-cm long rods (HS2 HydroSense Soil Moisture Probe, Campbell Scientific, Logan, UT, USA). At the end of the growing season, prior to senescence, plants were harvested to assess aboveground biomass. Plants were cut at soil level, dried to achieve consistent mass at 65 °C, and then weighed. After mass determination, aboveground biomass was ball-milled to a fine powder and analyzed for C and N concentrations using a Costech ESC 4010 Elemental Analyzer (Costech Analytical Technologies Inc., Valencia, CA). We calculated plant N concentrations as well as total N contents by mass. Both of these variables can be related to plant performance (Bradford et al. 2007). The total N content by mass is indicative of how much N each plant is able to acquire from the soil (Chapin et al. 1987), and N concentrations are indicative of the photosynthetic enzyme capacity of the plant (Hirose and Werger 1987).

After harvesting the aboveground plant biomass, soils were passed through a 2 mm sieve, and then measured for OM content, water holding capacity, bulk density, total C and N concentrations, and microbial biomass. Soil OM content was determined on oven dry soil (105 °C) by loss on ignition (375 °C, 16 h)

(Nelson et al. 1996). Water holding capacity was determined by wetting the soil to beyond field-capacity, allowing it to drip drain over filter paper for 2 h, before being weighed and then weighed again following oven drying (overnight at 105 °C). Non-sieved soil cores were air-dried and used to determine bulk density based on pot volume (depth by area) and oven-dry mass. Values were corrected for root and pebble (> 2 mm and up to ~5 mm diameter) volume and mass retained on a 2 mm sieve. We performed one bulk density measurement per treatment and OM concentration. For %C and N determinations, a subsample of the sieved soil was air-dried and then ball-milled to a fine powder prior to element determination as described above.

Microbial biomass was determined using a modified substrate-induced respiration (SIR) technique (Fierer and Schimel 2003). Substrate-induced respiration provides an index of microbial biomass by measuring rates of CO_2 efflux over a given incubation time. Soils (4 g dry weight equivalent) were incubated overnight at 20 °C, slurried with a 4-mL autolyzed yeast solution by shaking for 1 h, and then capped with an air-tight lid modified for gas analysis (Bradford et al. 2008). Samples were flushed with CO_2-free air, and after 4 h of incubation at 20 °C, headspace CO_2 concentrations were measured using an Infra-Red Gas Analyzer (Li-COR model Li-7000, Lincoln, NE, USA).

Soil samples were sent to the University of Massachusetts Soil and Plant Nutrient Testing Laboratory for analysis of soil extractable P and K as well as pH (1:1 water), and cation exchange capacity (CEC). Soil P, K, and CEC were measured by the Modified Morgan extraction method.

Statistical analysis

We fit a regression model to explore the relationship between OM concentration and aboveground biomass. Our model terms included organic matter concentration, soil treatment (native or amended), and their interaction. We included an interaction term to test whether or not the slopes of the regression line between OM and productivity were different depending on the soil treatment. We added a quadratic term for OM as it exhibited a nonlinear relationship with aboveground biomass. We had originally intended to take a structural equation modeling approach to explore causative relationships between measured soil properties and productivity. However, our experimental design (direct manipulations of OM to achieve a gradient) did not provide the independent variation needed to properly implement SEM (Kline 2012).

Exploring plant performance as it relates to N availability, we again used the same model structure using total N content by mass and N concentration of above-ground biomass (separately) as dependent variables and % OM, soil treatment, and their interaction as independent terms. The model for N mass (and not N concentration) contained a quadratic term for OM since N mass displayed a non-linear relationship with SOM concentration.

We also explored the relationship between measured soil properties and OM to try to understand the mechanisms by which native-OM and amended-OM influence crop productivity. We used a similar model structure as stated above, creating different regression models with the soil parameter as the dependent variable (e.g. water holding capacity, extractable P, extractable K, CEC, microbial biomass, and bulk density); however, we retained a quadratic term for OM in the model for extractable P only as that is the only variable that displayed a nonlinear relationship with OM.

To determine whether or not OM concentration had an impact on volumetric moisture across the growing season, we used a linear mixed effects model with date of measurement, OM, and soil treatment as fixed effects, and with pot as a random effect, to take into account the repeated measures per pot over the course of the growing season. All statistical analyses were performed using the "R" statistical program (version 3.3.1).

Data availability The dataset generated and analyzed during the current study is available through the KNB repository (https://knb.ecoinformatics.org/).

Results

SOM-yield relationship

The r^2 of our linear model for OM and above-ground biomass was 0.96, suggesting that our model captured the majority of the observed variation in the data. For native-OM soils, the highest organic matter soils had approx. 3-times (2.57 ± 0.10 g, mean ± SE) the amount of aboveground biomass than the lowest OM soils (0.82 ± 0.04 g, mean ± SE; Fig. 2). For amended-OM soils, high-OM soils had approx. 4.5-times the amount of aboveground biomass (3.47 ± 0.09 g, mean ± SE) compared to the lowest OM soils (0.78 ± 0.11, mean ± SE; Fig. 2). This greater relative response of biomass to increasing OM in the amended versus the native-OM soils likely explains why we observed a significant interaction between OM concentration and soil treatment (Table 2).

Plant nitrogen

Total plant N increased with OM concentrations (Fig. 3), indicating greater N availability with greater OM concentrations. Similar to above-ground biomass, amended-OM soils had a greater relative response of leaf N mass to increasing OM concentrations than native-OM soils (Fig. 3a). For amended-OM soils, leaf N mass was 6-times greater at the highest (108.30 ± 8.10 mg) OM concentrations versus the lowest (17.95 ± 2.24 mg). For native-OM soils, leaf N mass was only 3.4-times greater at the highest (63.15 ± 5.47 mg) OM concentrations versus the lowest (18.31 ± 1.20 mg).

Soil properties with increasing SOM

In addition to exploring how OM concentration and soil treatment affected above-ground biomass, we examined relationships between measured soil parameters, OM concentrations, and soil treatment. The majority of measured soil properties increased with increasing amounts of OM (Fig. 4). There were strong, positive relationships with OM for water holding capacity, microbial biomass, extractable P and K, total soil N, and CEC.

Table 2 Modeled regression coefficients, standard errors and *P* values for the OM-productivity relationship

Variable	Estimate	Std. error	t value	*P* value
Intercept	−0.52	0.260	−1.99	0.057
OM (%)	0.65	0.110	5.82	< 0.001
OM^2	−0.034	0.010	−3.54	0.002
Soil treatment	0.015	0.160	0.097	0.92
Soil treatment: OM	0.11	0.028	4.058	< 0.001

The output of our regression model exploring the relationship between aboveground biomass and organic matter for our two soil treatments. We modeled our soil treatments as categorical predictors with native-OM soil coded as the reference treatment. The r^2 of this model was 0.96

There were strong, negative relationships between OM concentration and pH, and with bulk density (Figs. 4g, h). For bulk density, we only measured one replicate per soil treatment by OM concentration, and so could not explore whether native versus amended OM had different effects. However for pH, there was again a significant interaction, with the effects of the amended-OM apparently being greater across the OM concentration gradient than the native-OM.

We measured soil volumetric water content across the growing season to capture dynamics of water retention. Volumetric soil moisture contents were fairly low across the course of the growing season for all soils, and did not differ among the different OM concentrations or soil treatments (Fig. 5). Heavy rainfall prior to the last measurement date resulted in higher volumetric moisture contents for all soils right before they were harvested for aboveground biomass determination.

Although we had intended to explore the causal mechanisms by which native and amended-OM affected plant yield and nitrogen contents, the strong responses of the majority of the soil properties to increasing OM concentrations meant that the majority of the variables were highly correlated. As such, it was not possible to identify a specific soil property, or set of properties, by which amendments versus native OM were acting on plant performance.

Discussion

Agricultural management is key to building and sustaining soil fertility. Additions of organic matter like compost represent exogenous inputs that are thought to primarily influence nutrient supply and soil tilth. Whereas systems that focus on cover crops or perennials to maintain root inputs tend to shift more toward endogenous organic matter cycling, with the intention of building up resident stocks of SOM that confer nutrient and water binding capacities (Janzen et al. 1992; Wander 2004). Given the differential pathways through which native and amended OM may impact soil fertility, it remains largely unanswered as to whether or not systems that receive OM exogenously or build OM endogenously have similar impacts on crop productivity when organic matter concentrations are comparable. Despite higher aboveground biomass and total nitrogen in amended-OM soils, our data suggest that the effects of increasing OM concentration have effects on plant

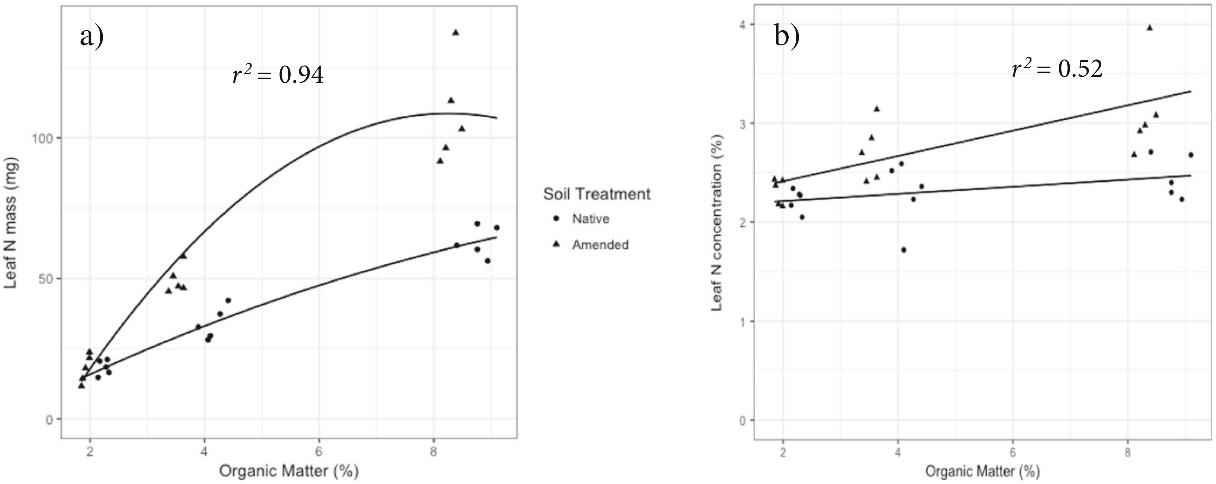
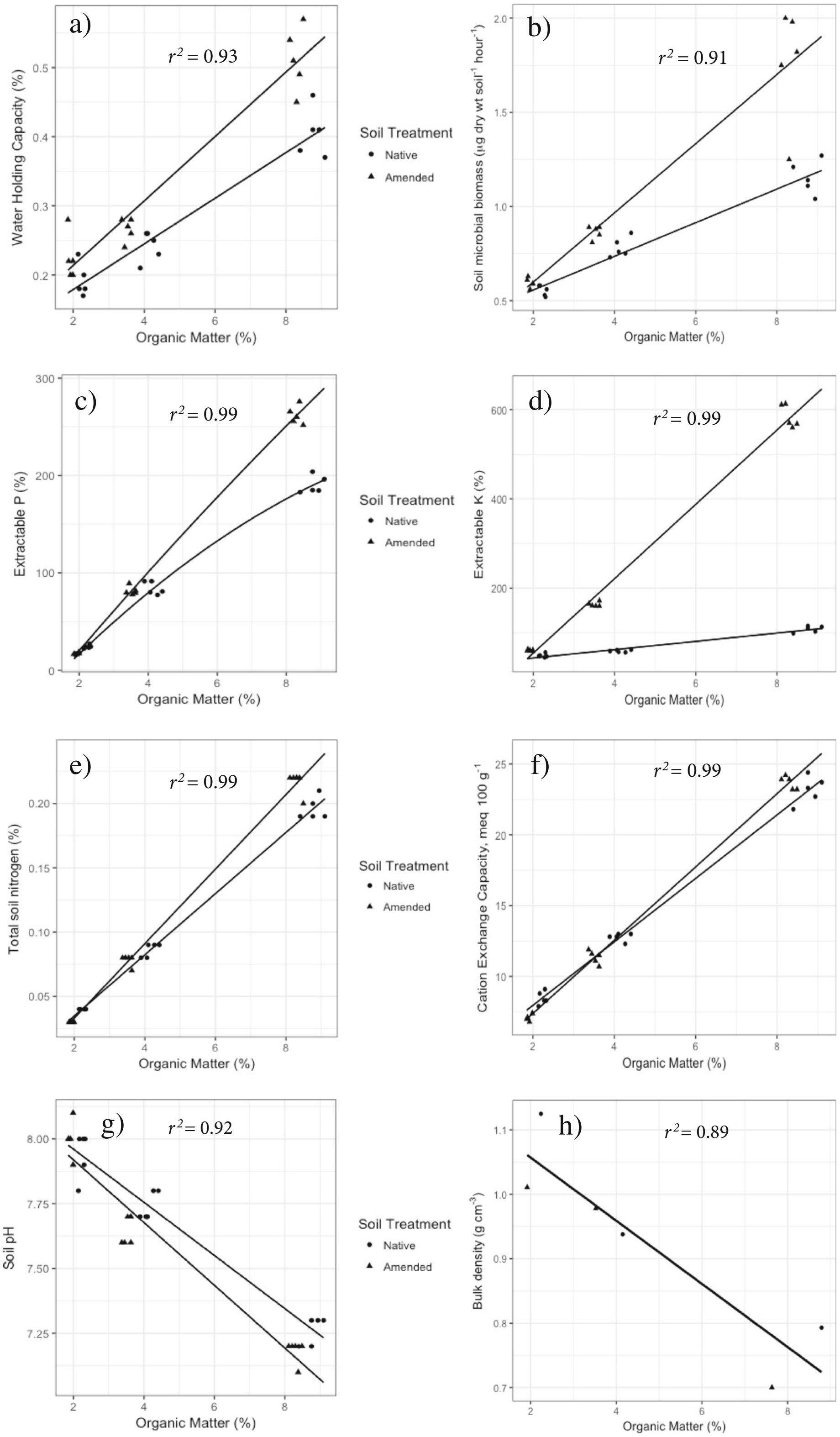


Fig. 3 Leaf N mass and leaf N concentration in aboveground biomass. We explored the relationship between organic matter and leaf N mass (**a**) and total leaf N concentration (**b**) in harvested buckwheat biomass. Both N measures provide an indication of plant performance: total N content by mass (**a**) indicates how much N plants are able to acquire from the soil while leaf N concentrations (**b**) are indicative of the photosynthetic enzyme capacity of the plant. For both native and amended OM soil treatments, as organic matter concentrations increased, so did N availability. Lines represent mean regression lines for each soil treatment; each OM concentration had an *n* of 5. See supplementary Table 1 for coefficients and *P* values

performance that are of similar magnitude for both amended and native OM (Fig. 2). Furthermore, we found no strong support for the idea that the effects of amended versus native-OM operated via different causal pathways, given the strong effects of both soil treatments on most soil properties, including water holding capacity, CEC, and extractable nutrients (Fig. 4).

Though there were differences in resulting biomass between native-OM and amended-OM soils at the highest OM levels, the qualitative patterns between the two soil treatments remain the same: as OM increases, so too does productivity. However, the relationship between inputs, organic matter, and crop productivity is dynamic and will likely vary depending on management, soil characteristics, climate, and the OM itself. For instance, we cannot directly compare results across our two different soil treatments due to inherent differences in the nature and composition of organic matter contained within each treatment. The similarity in response of both productivity and soil parameters to both native- and amended-OM in our study is dependent on the fact that the native-OM and amended-OM we used for this experiment had similar C:N ratios (see Methods). Had we used an amendment with a wider C:N ratio such as straw, wood mulch, or low quality plant residues, we would have seen very different effects on resulting plant biomass and soil properties. Our results, however, do confirm that native OM can directly impact yields, independent of recent amendments, and confirm findings that OM amendments can stimulate productivity (Johnston et al. 2009).

We attempted to tease apart the mechanisms by which organic matter influences productivity by measuring a number of soil properties. All soil properties increased with increasing organic matter, and so we could not untangle which of the soil properties had the most direct impact on resulting buckwheat productivity. We did see significant interactions between OM and soil treatment for almost all of the measured soil properties (Fig. 4, Supplementary Table 1). For all measured properties, these interactions indicated that the effect of the amended-OM became greater than that of the native-OM as OM concentration increased (Fig. 4). Specifically, at low OM (2%), soil property values were similar between the two soil treatments, but typically diverged as OM concentration increased, with the amended soil having higher values. However, the magnitude of the soil treatment effect (e.g. native versus amended OM) differed markedly among these soil variables. For example, amended-OM concentration very strongly affected extractable P and K but native-OM concentration did not (Fig. 4c vs. d). Differences in productivity at higher OM concentrations between amended and native OM treatments may then have been a result of an extra subsidy of plant available P and K in the amended soils. We might expect native-OM soils to contain lower


a)
$r^2 = 0.93$
Water Holding Capacity (%)
0.2
0.3
0.4
0.5
Organic Matter (%)
2
4
6
8
b)
$r^2 = 0.91$
Soil microbial biomass (µg dry wt soil^{-1} hour^{-1})
0.5
1.0
1.5
2.0
Organic Matter (%)
2
4
6
8
Soil Treatment
● Native
▲ Amended
c)
$r^2 = 0.99$
Extractable P (%)
0
100
200
300
Organic Matter (%)
2
4
6
8
d)
$r^2 = 0.99$
Extractable K (%)
200
400
600
Organic Matter (%)
2
4
6
8
Soil Treatment
● Native
▲ Amended
e)
$r^2 = 0.99$
Total soil nitrogen (%)
0.05
0.10
0.15
0.20
Organic Matter (%)
2
4
6
8
f)
$r^2 = 0.99$
Cation Exchange Capacity, meq 100 g^{-1}
10
15
20
25
Organic Matter (%)
2
4
6
8
Soil Treatment
● Native
▲ Amended
g)
$r^2 = 0.92$
Soil pH
7.25
7.50
7.75
8.00
Organic Matter (%)
2
4
6
8
h)
$r^2 = 0.89$
Bulk density (g cm^{-3})
0.7
0.8
0.9
1.0
1.1
Organic Matter (%)
2
4
6
8
Soil Treatment
● Native
▲ Amended

◀ **Fig. 4 Soil quality indicators and their relationship with organic matter**. Measured soil properties and their relationship with organic matter: (**a**) water holding capacity, (**b**) soil microbial biomass, (**c**) extractable P, (**d**) extractable K, (**e**) total soil N, (**f**) cation exchange capacity, (**g**) soil pH, and (**h**) bulk density. Generally, all measured parameters increase with increasing concentrations of organic matter, except for pH and bulk density. The lines represent mean regression lines for each soil treatment; each OM concentration had an *n* of 5. See supplementary Table 1 for coefficients and *P* values

proportions of plant available P since the majority of P in soils becomes quickly bound up in insoluble forms unavailable to plants. Likewise, native soils may have smaller amounts of plant available K because it is highly mobile and readily lost through leaching (Brady and Weil 2007). In contrast to P and K, CEC values between the two soil treatments were very similar across the range of organic matter. One might expect that native-OM would have greater CEC due to the reactive nature of organic colloids (Brady and Weil 2007), but our results did not support this expectation. It is feasible that other key soil properties that we did not measure might show different patterns, with native-OM having a stronger effect than inputs. For instance, while we did not measure erosivity, we might expect native-OM to have greater protective capacity than amended-OM. This is essential in terms of maintaining yield resiliency over long time-scales (Amundson et al. 2015).

Notably, the role that organic matter played in water retention is highlighted by results that show no statistically significant differences in volumetric soil moisture taken throughout the course of the growing season (Fig. 5), but very different water holding capacities across the varying concentrations of organic matter (Fig. 4a). The lack of difference between volumetric soil moisture contents among the different OM concentrations highlights that there was very little pore space taken up by water. This is not surprising given the drought conditions in New England during the summer of 2016. The buckwheat plants were rain-fed, and New England experienced a drought during the summer of 2016, with summer rainfall approximately 11 cm below the 100-year recorded mean (NOAA 2017). Our results suggest that most available water was likely held in

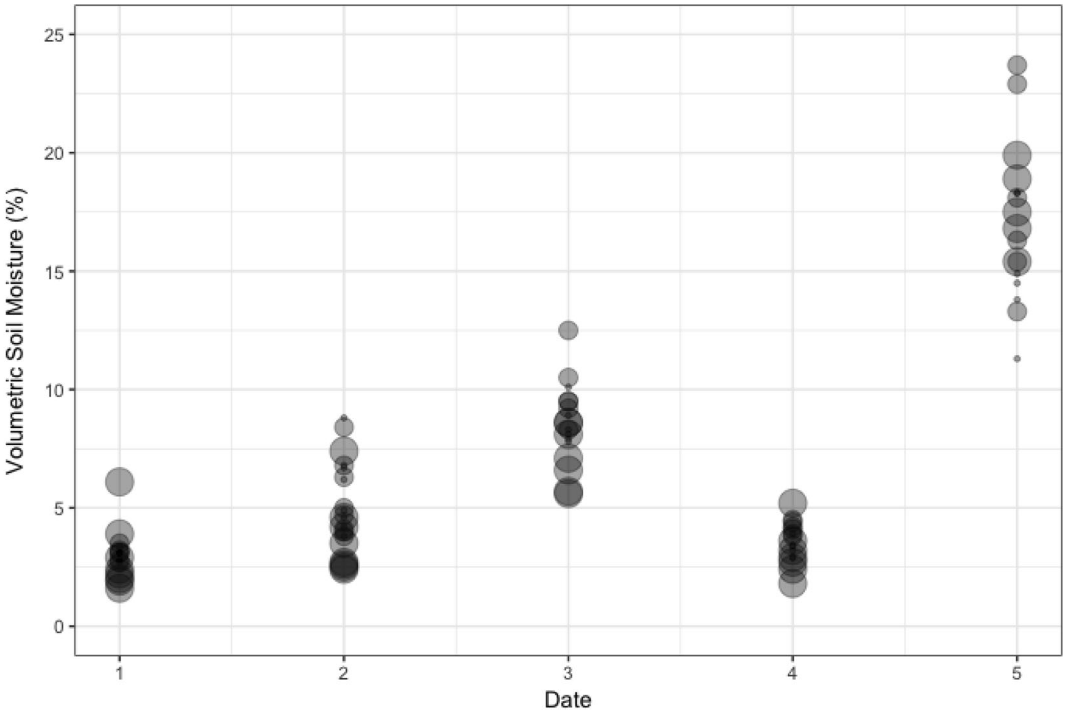


Fig. 5 Volumetric soil moisture across the growing season. Volumetric soil moisture content did not differ among soil treatments (native-OM or amended-OM; not shown) or across organic matter concentrations across the growing season. Circle size is proportional to organic matter concentrations. As New England experienced a drought in the summer of 2016 when plants were grown, these soils most likely held water against colloids versus in pore space. The increase in soil moisture on the last measurement date is a result of a rainfall event the day before

films against colloids versus filling pores, highlighting the importance of organic colloids – whether from native or amended-OM – in maintaining water availability under drought conditions.

There has been much research focused on the role of SOM as an outcome of specific management practices (Rasmussen et al. 1998; Grandy and Robertson 2007; Angers and Eriksen-Hamel 2008). Our project aimed to explore SOM as a driving variable, trying to tease apart the influence of both native organic matter and amended organic matter on resulting crop productivity. A foundation of conservation agricultural practices is to build SOM contents in order to create resilient soils capable of supporting higher and more sustainable yields. When managing for SOM, an important question is whether or not to manage inputs or to build up native SOM. Our results demonstrate that native and amended OM have similar effects on both productivity and soil properties, suggesting that native OM can sustain productivity to similar levels of a recently incorporated organic input.

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