Assessing the Quality and Possible Functions of Compost Extracts in Organic Systems

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This article reviews popular wisdom surrounding compost extract (CE), defines terms and relevance to organic production, and presents the results of a project that explored the range of characteristics across different CE and their effects in a few controlled environments.

Compost as Inoculum

Compost and compost preparations are proposed as microbial inoculants with wide ranging benefits. The nutrient input benefits of compost are well understood, but if any gains are to be observed as an inoculant (disease suppression, nutrient cycling, weed suppression, increased plant growth), it has been suggested that a high quality compost with selected biological properties should be paired with a low quality soil.

Here are several examples to illuminate the concept of using compost as inoculum as they appear in popular press (Lowenfels & Lewis 2010).

- Protozoa, single celled organisms, eat bacteria releasing minerals from bactera in plant available forms. If a soil contains low protozoa diversity and abundance, a compost containing diverse protozoa would be selected and applied, even at very low rates, to introduce protozoa. They would multiply and take up residence in the soil.
- Different plants are favored by different points along the range of fungal to bacterial biomass ratio (F:B) in soil. This ratio can be shifted by introducing relatively small doses of compost with a desirable F:B which in turn will increase health of target plants, and suppress vigor of weeds.
- Plant pathogens must compete for space and food resources among other non-pathogenic organisms. When organisms from a compost are applied to a seed or leaf, competitive exclusion of pathogens is favored by compost microbes.

Such ideas are compelling conceptually, however, there is a wide gulf between something that ‘makes sense’ and something that reliably results in a desired outcome.

It is still unknown how to predict whether a particular compost preparation will work for a particular application. Applied research into compost tea and CE has mainly focused on disease suppression because promising efficacy is often observed. But the body of literature on the subject describes plenty of negative results as well. In other words, sometimes there is little doubt that the compost preparation helped, and other times there is little doubt that it did not. Composts vary quite a bit from one to the next, as do soils. So, the mixed research results could suggest a failure of pairing the correct compost with the system under study. Or it may reflect that some challenges cannot be solved by inoculation with compost, or that effects of CE are inherently unpredictable.

In any case, a starting point to untangling the unpredictability of CE as inoculum is to understand the variability across different CE; define breadth of differences that exist, then test efficacy of the same CE for solving various problems. We conducted such a survey, as well as a modest investigation of CE effects on lettuce seed germination, *Pythium* sp. damping-off suppression, and lettuce growth response to soils containing CE-inoculated fresh residues.

What is Compost Extract?

According to organic guidelines, a compost extract is a preparation of organic allowable compost, potable water, and any organic allowable additives used within one hour of mixing XXXXXX. It can be used, unrestricted, up to the day of harvest. This makes CE an attractive alternative to compost tea (produced with additives and a brewing process) for organic producers because it is governed by the same harvest restrictions as fresh manures unless an exemption is obtained through and application process and special testing of each specific brewing system and recipe.

How is Compost Extract made?

CE is simply any combination of compost and water. If intended as a fertilizer, strong concentrations of compost to water, up to 1:1 (v:v) can be used. Preparations as dilute as 1:100 or less may be intended as an inoculant, and these still fall under the definition of CE.

Preparing CE can be as easy as mixing worm castings in a bucket of water, or it can be made with expensive equipment designed to forcefully dislodge and suspend every compost particle smaller than half a millimeter. Any mesh size can be used to filter particulate from a compost, which introduces an additional source of variability in CE. A common approach is to hold compost in a filter bag and knead it in water, or let it be buffeted by air bubbles pumped into a basin of water.

How is Compost Extract Used?

CE can be applied directly to soil as a drench (a proven method to deliver modest amounts of nutrient). For inoculant purposes, it is sometimes suggested to apply as a seed drench or in furrow. Some growers apply low concentrations to plant surfaces in a spray or by dosing into pivot irrigation. Some nursery operations apply as a heavy spray, or by injection into irrigation systems, or using watering cans. CE may also be applied by spray or drench to soil, pasture, green manure, or cover crop residue.

Note: Intentions matter. An organic producer may make their own CE and apply it with the expectation of suppressing or preventing disease, but if CE were sold for the purpose of controlling disease it would be classified as a pesticide or biopesticide and subject to testing and regulation. For this reason, a class of agricultural input distinct from fertilizers or pesticides, called "biostimulants" is defined. Biostimulants include microbials, seaweed extract, trace minerals, humic and fulvic acids, as well as shelf stable CE, and packages of compost intended *for use in CE or compost tea. This class of inputs is fairly new, rapidly growing, and rules are in flux.*

When Should Compost Extract be Used?

There are remarkable anecdotes and compelling proponents touting the wide-ranging benefits of this simple technology. As long as the compost is compliant and the extract is not held longer than one hour after preparation, it's use is unlimited and assumed safe. There is certainly nothing wrong with trying something new, especially when it is cheap and simple.

When Can I Expect to Benefit from Compost Extract?

Few studies have endeavored to identify predictors of compost extract function. Disease suppression is the most researched among the proposed functions of CE. Neher et. al. (2017) found presence of certain enzyme activity in CE and hardwood bark feedstock to predict *Rhizoctonia solani* suppression *in vitro* (in petri dishes, not crops in the field).

Numerous studies have documented repeatable disease suppression from the same batch of compost. In other words, if you saw benefits from the a batch of compost before, you'll probably see the same benefit from that batch again, even if it's been stored for extended periods (Schüler et. al.). Aside from this limited case, it's a gamble, but hopefully an inexpensive one.

Original Research on CE

Extracts from ten diverse composts were tested for chemical properties, microbial community, and lettuce seedling germination. Of these, seven organic allowable CEs were tested for *Pythium* damping-off suppression when used as a cucumber seed drench. Finally three CEs were used in a greenhouse experiment to test their effects when applied to three different residues before soil incorporation.

Composts Used

Composts were selected for diversity of feedstock and process. Municipal sewage sludge (Biosolids) and an immature feedlot compost (ACN Inwood) were included because products like these are applied to many acres.

	Description	Availability	Approximate $/lb
Biosolids	Wastewater sludge from biodigester	bulk	$0.00
NPL Mushroom	Spent mushroom substrate	bagged	$0.11
Big Red Worms	Food/yardwaste vermicompost	bagged	$1.00
EKO Compost	Poultry manure/wood windrow	bagged	$0.32

David Johnson	Static Yardwaste vermicompost	backyard	-
Wiggle Worm	Vermicompost from organic grain	bagged	$1.15
Soil Dynamics	Municipal windrow	bulk	$0.02
ACN Inwood	Cow manure/corn stover windrow	bulk	$0.01
Home Worms	Household vermicompost	backyard	-
Mountain Magic	Cow manure/forest windrow	bagged	$0.11

Table 1: Name, short description, availability, and price of composts used.

Chemistry of Compost Extracts:

Provision of plant nutrition is well recognized to increase plant growth and health. Pant et. al. found that preparations similar to CE increased crop production and concluded that the primary mode of action at play was nutrient provision. Ward Labs (Kearney, NE) analyzed fertility content of CE produced by kneading 100 g dry equivalent of each compost in a 400 µm nylon mesh bag with 1000mL total water.

The Biosolids and ACN Inwood materials were immature as indicated by high ammonium content and odor. Their low C:N and knowledge of their production process indicated that they likely did not meet initial C:N ratio of 25-40:1 as required for organic use (*7 CFR 205.203(c)(2)(i), USDA, 2000*). Results from these CE are not reported.

Table 2 underlines the remarkably wide range of plant nutrients present in CE made with the same dry mass of different composts. Composts are known to vary greatly, and this research confirmed that their extracts are similarly variable; moreover, the chemistry of the solid compost closely matched that of its CE (data not shown).

	Total N (ppm)	Total P (ppm)	Total K (ppm)	Sulfur (ppm)	Calcium (ppm)	Magnesium (ppm)	pH	C:N
Low Compost	Mountain Magic	Wiggle Worm	David Johnson	Soil Dynamics	Soil Dynamics	David Johnson	Wiggle Worm	Soil Dynamics
	321	78	65	67	730	188	6.6	8.2
High Compost	Home Worms	EKO Compost	Home Worms	NPL Mushroom	NPL Mushroom	NPL Mushroom	EKO Compost	Mountain Magic
	1434	1271	1601	306	2463	566	8.8	27.9
Range/High	0.78	0.94	0.95	0.78	0.70	0.66	0.25	0.71

Table 2: Ranges of chemical parameters across 8 finished composts (biosolids and ACN Inwood were excluded due to immaturity and questions of compliance with organic standards). "Range/High" represents the ratio of range of observed values to the highest observed value.

Biological Tests

Sterilized composts or compost extracts have been shown to lose their disease preventing properties, suggesting that living biology plays a role in suppression (Neher et. al. 2017, El-Masry et. al. 2002). Likewise, expectation of supplementing the soil food web depends on living organisms in CE. So we attempted to characterize the microbial component of our panel of CE.

Several measures of microbial content of CE were tested. One objective of this project was to check agreement between methods attempting to measure the same thing. Total microbial biomass was estimated using Fatty Acid Methyl Ester extraction (FAME), the Soil Microbiometer® system, and direct microscopic observation according to the method of Dr. Elaine Ingham*. Correlations were calculated between methods attempting to measure the same microbial parameter.

Biological Tests - Results

As with chemical makeup, CE varied dramatically for microbial content (table 3). Moreover, the method used to estimate microbial parameter had a strong influence on the result, for example Wiggle Worm compost had the least total FAMEs (biochemical marker tracking closely with microbial biomass), but the greatest biomass estimated the Soil Microbiometer® system.

		Microbial Biomass (FAME, nmol/mL)	Microbial Biomass (Microsope, ug/mL)	Microbial Biomass (Soil Microbiometer®, ug/mL)	F:B (FAME)	F:B (Microsope, ug/mL)	Total Nematodes (number/mL)
Low Compost		Wiggle Worm	EKO Compost	NPL Mushroom	Wiggle Worm	NPL Mushroom	[several]
		6.496	413	157	0.088	0.019	0
High Compost		Home Worms	Home Worms	Wiggle Worm	NPL Mushroom	David Johnson	Home Worms
		23.24	4296	1054	0.279	0.72	22
Range/High		0.7204819	0.90386406	0.851043643	0.68458781	0.97361111	1

Table 3: Ranges of biological parameters across 8 finished composts (biosolids and ACN Inwood were excluded due to immaturity and questions of compliance with organic standards). "Range/High" represents the ratio of range of observed values to the highest observed value.

Our data can afford a "quick and dirty" estimate of agreement between methods that presume to measure the same parameter. Table 4 outlines R^2 values between pairs of measurements. Microscope count and FAME agree fairly well for bacteria and total biomass, but poorly for fungal biomass. The Soil Microbiometer®, a system designed for estimate soil microbial biomass, did not correlate well with FAME or microscope estimates of CE microbial biomass.

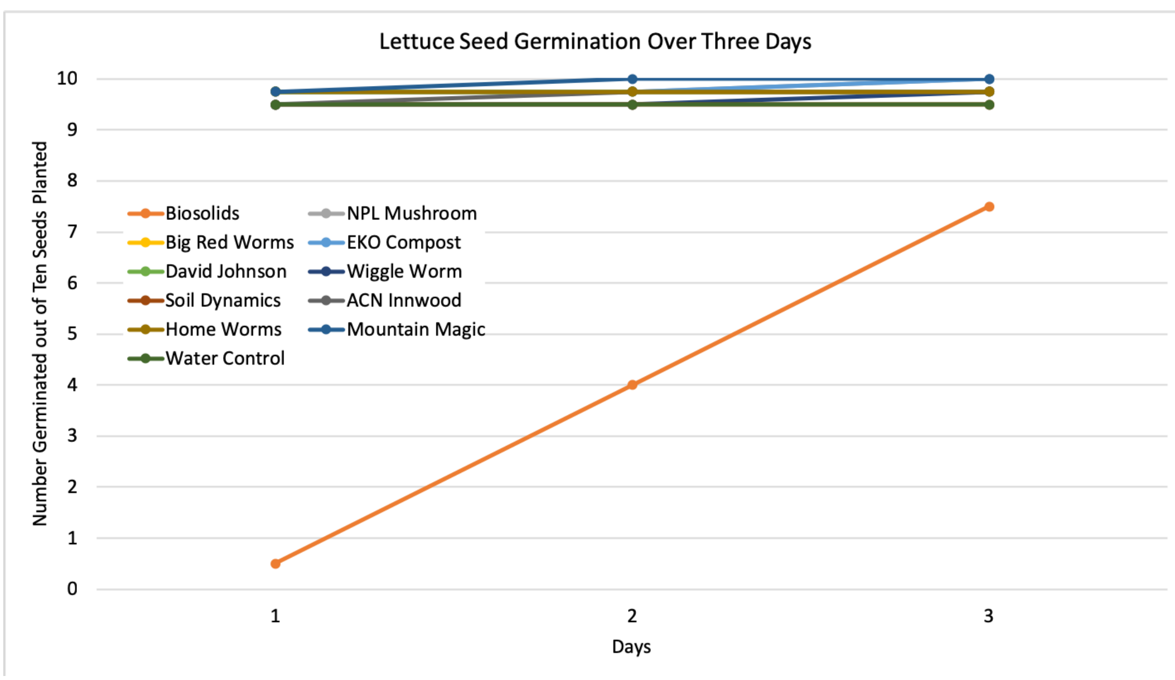
Parameter		R^2	# of CEs observed by both methods	Correlation direction
Total Microbial Abundance	FAME vs. Microscope	0.674	7	positive
	FAME vs. Soil Microbiometer	0.006	10	positive
	Microscope vs. Soil Microbiometer	0.242	7	negative
Fungal Abundance	FAME vs. Microscope	0.277	7	positive
Bacterial Abundnace	FAME vs. Microscope	0.722	7	positive

Table 5: Comparison between pairs of biological measurements that aim to estimate the same parameter. R^2 describes fidelity between methods, 1 being a perfect score.

Lettuce Seed Germination

In a speedy and simple phytotoxicity test, we germinated 10 lettuce seeds in petri dishes on filter paper moistened with CE. Four petri dishes were prepared for each CE and number of seedlings germinated was recorded each day for three days.

Only municipal biosolids slowed lettuce seed germination (Figure 1), and ACN Inwood markedly slowed root elongation (data not shown). These two composts had the greatest proportion of their total N present as ammonium, as well as relatively high CO_2 production when dried and rewetted, which are indicators of immaturity. They were excluded from further trials.



Pythium Damping-Off Suppression

Pythium Damping-Off Suppression – Introduction

Several studies have described suppression of *Pythium* damping-off by certain compost, and lack of suppression by others (McKellar & Nelson 2003, Scheuerell & Mahaffee 2005). We endeavored to describe *Pythium* suppressivity of our panel of composts

Pythium Damping-Off Suppression – Materials and Methods

Seed starting mix was inoculated with a *Pythium ultimum* isolate and left waterlogged to incubate at room temperature for one week and used to fill seed trays (50 cell 10”x20”). Cucumber (var. Marketmore ’76) seeds were soaked in seven compost extracts and a water control for one minute and planted into cells using a completely randomized design. Each CE was applied to 16-20 seeds. Trays were managed in the most conducive environment possible for damping-off, under humidity domes, and totally waterlogged.

Pythium Damping-Off Suppression – Results

“David Johnson,” “Home Worms,” and “Water” were significantly less suppressive from all the others (Figure 2). This result is contrary to the expectation that more fungal biomass as observed by microscopy would favor suppression.

Pythium Damping-Off Suppression – Discussion

These results might suggest that abundant fungal hyphae indicated CE conducive to Pythium damping-off. Another conclusion could be that using organic allowable CE with nursery seedlings is unlikely to hurt, and likely to help with damping-off. This would run contrary to the recommendation to keep nursery seedlings as aseptic as possible by using sterile media and avoiding compost in controlled environments.

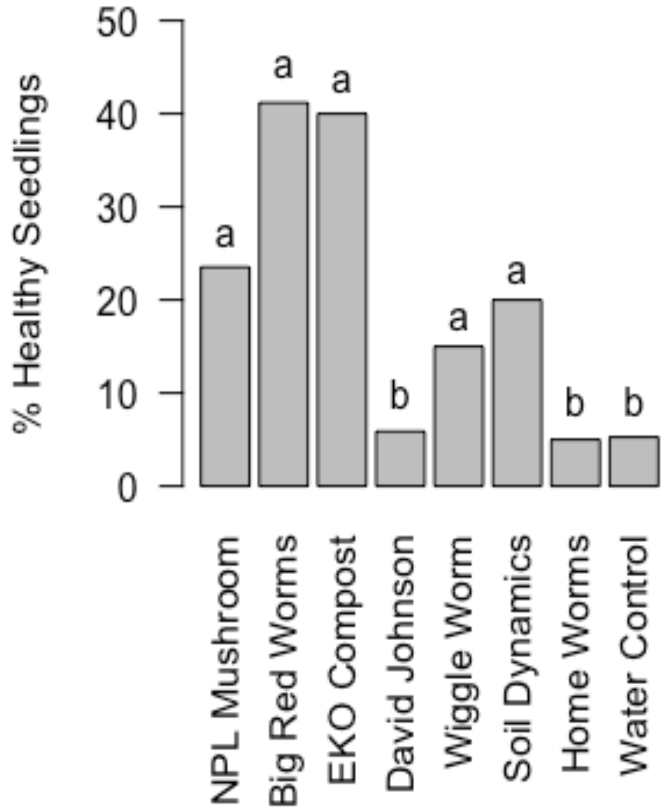


Figure 2: Percent healthy seedlings resulting from cucumber seeds soaked for one minute in various CE and water control, grown to one true leaf stage in media heavily infested with Pythium *sp.*

Treating Residues with CE

Treating Residues with CE – Introduction

Aside from disease antagonism, another expectation for CE is that it will cause a shift in the soil microbial community to the benefit of the system as a whole, favoring crop growth.

In soil microbial ecology, changes in the soil environment are powerful drivers of community change (Pankhurst et. al. 2002, Wortmann et. al. 2008). These effects are safely expected to be stronger than small introductions of novel "outsider" organisms, as introduced by dilute CE. When fresh plant residues enter the soil suddenly, as in a tillage event, the soil microbial community will undergo acute changes and divergent outcomes may be possible.

We speculated that applying CE as inoculum to fresh residues before soil incorporation could capitalize on this moment of instability and favor colonization of CE microbes in the soil. If this is true, and relevant in a production system, we expect to see subsequent plant growth responses to CE inoculation of residues at soil incorporation.

We were unable to find any scientific studies investigating pre-tillage CE application to crop residues as it effects subsequent crop growth, so we designed an experiment to simulate spraying a crop residue (oat straw), green manure (alfalfa), and biodegradable mulch (PLA/sawdust mulch) before soil incorporation.

Treating Residues with CE – Materials and Methods

Three of the ten CE described above were selected according to criteria in table 4. Using a randomized complete block design with six replicates, we applied CE to residues before mixing with steamed greenhouse media (peat, vermiculite, sand, and field soil) to simulate spraying the residues just before soil incorporation by tillage.

"Full Foodweb "	**"Typical Compost"**	**"Unimpressive Compost"**
High fungi relative to other composts	Medium fungi relative to other composts	Low fungi relative to other composts
High beneficial nematodes relative to other composts	low beneficial nematodes relative to other composts	No beneficial nematodes
abundant protozoa including flagellates, testate amoebae, naked amoebae	medium/low protozoa	low/no protozoa
Allowable for Organic Production		
Mature "finished" compost (<1% total N as ammonium-N)		
Non-phytotoxic (lettuce seed germination)		

Table 4: Target criteria of CE for use in greenhouse experiment of CE-treatment of residues before mixing residues with soil.

Biological characteristics of the three CEs selected for the greenhouse experiment are presented in table 5. These CE and a urea solution were applied to residues at standardized N rates such that each pot received 3 lb total N/acre (3.36 kg total N/ha), volume applied was 180-280 gal/ac (1630-2620 L/ha). A water control was included as well for a total of five sprays.

The residues were Alfalfa, Oat Straw, and PLA/Sawdust mulch. They were incorporated after spraying with CE at rates of 5, 2, and 1.67 tons/acre (11.2, 4.5, and 3.8 Mg/ha) respectively. Polypropylene geotextile was included as a positive control for effects of physical properties of residues, and a no residue control was prepared by spraying a small amount of soil with CE and incorporating it into the rest of the soil for each no residue pot.

	Compost Extract Name	Home Worms	Soil Dynamics	EKO Compost
Total Microbial Biomass / Indicator	FAME (nmol/mL)	23.249	12.101	9.216
	Earthfort Microscope Count (ug/mL)	11,935	19,840	10,380
	Light Microscope Count (ug/mL)	4,296	2,422	413
	Soil Microbiometer® (ug/mL)	551.5	235.7	909.5
Fungal Biomass / indicator	Fungal FAME (nmol/mL)	2.15	0.921	0.674
	Earthfort Microscope Count (ug/mL)	31.36	1.65	12.95
	Microscope Count (ug/mL)	750.7	80.4	0
F:B	FAME	0.18	0.13	0.11
	Earthfort Microscope Count	0.002	0	0.001
	Light Microscope Count	0.214	0.034	0
Beneficial Nematodes (number/mL)		22	1	0
Protozoa by dilution culture/ Most-Probable-Number calculation	Flagellates (number/mL)	5,754	46	139
	Amoebae (number/mL)	460,600	4,606	42,635
	Ciliates (number/mL)	426.4	8.4	0.6
Protozoa by Microscope Count	Flagellates (number/mL)	31,777	0	0
	Amoebae (number/mL)	74,148	0	0
	Ciliates (number/mL)	0	0	0
Allowable for organic production		✓	✓	✓
Ammonium N:Total N		0.02%	0.05%	0.07%

Mature "finished Compost	✓	✓	✓
Non-phytotoxic by lettuce seed germination assay	✓	✓	✓

Table 5: Biological measures of CE applied to residues. Additional microscope counts of bacterial and fungal abundance, and protozoa quantification by dilution culturing and most-probable-number calculation were ordered from Earthfort Laboratories (Corvalis, OR) for the three CE used in this experiment.

Five lettuce seeds were sown two weeks after residue incorporation and thinned to the one most vigorous seedling at the first true leaf stage. Dry above-ground weight was measured 42 days after planting.

<u>Treating Residues with CE –Results</u>

Main effects of residue were significant and dramatic (figure 3). Increased yield due to N-rich alfalfa, and reduced yield due to C-rich PLA/wood mulch and oat straw, suggest N dynamics to be a process strongly influencing lettuce growth in this experiment.

A contrast of urea versus all other CE in non-alfalfa pots was significant, confirming urea treatments produced slight yield increase in within these residues, further suggesting N limitation.

When CE effect is considered within each residue treatment individually, there were no significant differences due to any CE (including water and urea controls) within any residue treatment except in Alfalfa. Within the Alfalfa residue, there were hefty and significant yield increases under the Soil Dynamics and EKO Compost CE (both increasing yields by 53% and 80%, relative to water and urea, respectively). Home Worms, Urea, and Water were not significantly different from one another (figure 4).

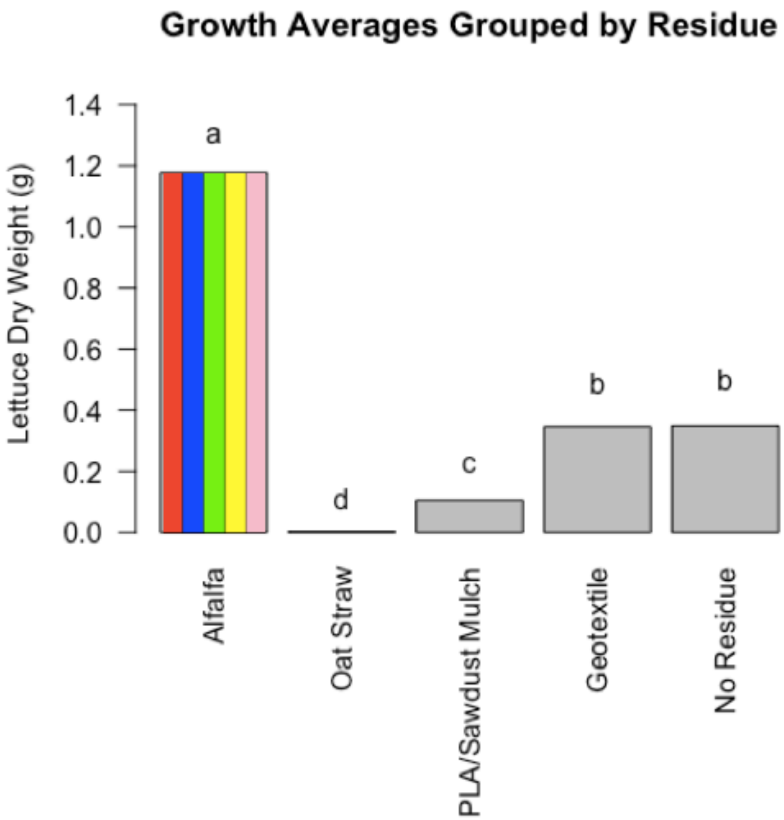
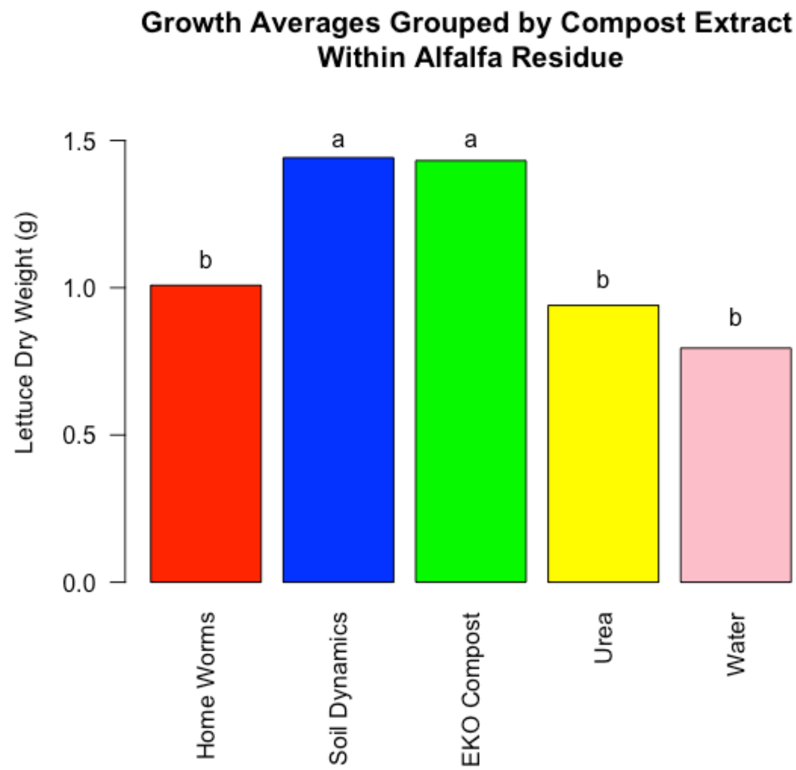


Figure 3: Significant main effects due to residue factor. Letters indicate significant differences between columns. Alfalfa column is colored to illustrate that it represents an average of the five extract treatments within the alfalfa residue, which are represented separately in figure 4.



Treating Residues with CE – Discussion

We were interested to see whether the abundant predators and fungi in "Home Worms" would overcome the expected nutrient immobilization due to the high C residues, oat straw and PLA/wood mulch. Protozoa and nematodes are known to accelerate nutrient mineralization by consuming and excreting bacteria and fungi. All three of our CE inoculations seem to have failed to mitigate N immobilization, and did not increase lettuce growth under these residues.

Furthermore, when applied to the relatively uncolonized environment of the steamed greenhouse mix alone or with inert geotextile, no CE had any inoculant effect leading to increased lettuce growth.

Alfalfa increased plant growth largely due to N input. Interestingly this effect was modulated by choice of CE. Our expectation of increased growth due to more fungi and predators (protozoa and nematodes) as measured in the "Home Worms" CE, was not confirmed. Rather the CE we expected to contain less desirable biological traits were the ones that increased growth by 53% over the urea N control.

We have shown that CE is highly variable when measured directly, and that in certain cases CE can cause changes in plant growth unrelated to nutrient input. However, we are unable to suggest tests or criteria for predicting CE effects.

Conclusion

Scientific research is continually revealing elements complex living system of soils, seemingly in response, a CE and compost tea generates more and more buzz in popular press and social media. The concept of restoring beneficial life to soil and plant surfaces resonates with those scientists, farmers, and gardeners who strive to connect with the fascinating ecosystem of life found in soil (Puigde la Bellacasa, 2014). To some growers, it just feels good to use CE.

Futhermore CE is allowable in organic systems and less restricted than compost tea, and a wide range of benefits are possible, but unpredictable.

If using CE for fertility, the well understood practice of matching the nutrient status of the crop or soil with nutrient content of input is dependably useful.

CE is allowed to be applied with the intention to prevent plant disease and promote plant health, but it can not be sold as a product to control disease.

Conceptualizing soil ecological systems is difficult! Our understanding of soil and compost microbes is strongly affected by the methods used to evaluate them. We showed that available methods for estimating microbial parameters of CE do not agree closely with one another, and we failed to find, in this work or in the literature, any dependable predictors of CE efficacy for any particular use. CE remains unpredictable, it often produces neutral results, but has been shown to effect surprising positive (and negative) results with disease prevention. This work showed that, at least in controlled environments, a non-nutrient effect of CE can influence crop vigor in the absence of disease. Further research or on-farm experimentation is warranted with application of CE to fresh green manures at the time of soil incorporation.

Acknowledgements

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