Rodale Institute
Final Report
Field Evaluation of Designed Compost Extracts for Organic Weed Suppression

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1. Project Summary

Aimee and John Good, like most organic vegetable growers, are interested in effective weed management techniques that allow them to reduce the frequency of in-season cultivation to manage weed pressure while, enhancing soil health and crop yields. Partnering with the Goods, an experimental and demonstration field trial was established in Kutztown, Pennsylvania in July 2016 to evaluate the effectiveness of chemically- and microbially-designed compost extract (CMD-CE) on weed management in cabbage during the fall season. In a randomized complete block design with four replications, CMD-CE was applied either post-planting or pre- and post-planting and compared to the grower's standard treatment (in-season cultivation). A no treatment control (no cultivation or compost) was included. Results showed that soil bulk density (1.07 g/cm^3) did not vary between treatments. Penetrometer readings were greater in soils that received compost extract (27.58 cm and 28.75 cm; post-planting and pre- and post-planting, respectively) compared to grower treatment (20.04 cm) in cabbage beds. Results showed that applications of compost extracts reduced mean weed biomass by 50% and 28% in post-planting treatment and pre- and post-planting treatment, respectively, when compared to the grower's standard treatment. Compost extract applications provided comparable cabbage yield to the grower's standard method. Cabbage yield declined as weed biomass exceed 11 g/cm^2. Chlorogenic acid, a polyphenol compound was found in compost, compost extracts and soil. Applications of CMD-CE can serve as an alternative tactic to replace in-season cultivation to conserve soil and reduce weed expression. Project results were shared with over 158 people in person including vegetable growers, students and interested clientele during visits and field tours. Web and magazine articles were produced based on the results of this project. Online postings of the articles were viewed by more than 550 people and printed copies were distributed to 6,500 members.

2. Introduction to Topic

Growers rank weeds as the number one obstacle to organic crop production [1]. In early stages of crop growth, weeds compete at a faster rate for water and nutrients [2,3] and impact crop yields later in the season [4]. Organic vegetable producers rely on mechanical cultivation and hand weeding for weed management. Frequent cultivation and hand weeding are labor intensive, time consuming, costly [5,6,7], decrease soil health [8,9]; and reduce yields and growers' profits.

Organic vegetable growers need reliable, cost-effective and practical tools that reduce the severity of weed problems and enhance crop yields and soil health.

In 2014, Dr. Zinati performed proof-of-concept experiments, funded by a private foundation, using CMD-CE to suppress weed seed germination under controlled conditions. Results showed that applications of compost extracts low in nitrate levels and high in nematodes compared to protozoa reduced lambsquarter seed germination by 32% [10, 11] as compared to those without extracts. Other trials showed that pigweed seed germination was suppressed by 20% when compost extracts had lower nematode-to-protozoa ratios [12]. Effectiveness of CMD-CE for weed control has not been tested on growers' farms and compared to growers' management practices on a large scale. Collaborating farmers Aimee and John Good face a variety of weed problems during spring and fall seasons. For example, in spring, they consider foxtail and galinsoga to be the major weed species that compete with crops grown without plastic mulch, whereas in the fall, pigweed is a major weed problem. It was very useful to partner with growers such as Aimee and John Good to evaluate whether the adoption of designed-compost extract would work as an alternative to hand weeding and cultivation and improve soil health and crop yields in spring and fall seasons.

3. Objectives Statement

The objectives of this project are to:

1) Identify and quantify the phenolic acids and flavonoids in designed compost extracts to pinpoint the phytochemicals that are potentially involved in the suppression or enhancement of weed germination,
2) Demonstrate and evaluate the efficacy of field applications of the DCE at two rates on weed suppression, soil health and crop yield when compared to the grower's standard method (hand-weeding and cultivation) for growing cabbage,
3) Identify and quantify the phenolic acids and flavonoids in soils samples that received DCE versus those treated without DCE,
4) Predict yield losses in relation to weed density in various treatments,
5) Disseminate the results at Rodale's Annual On-Farm Field Day, CSA field tours, and via a web article.

Measurable outcomes for each objective include:

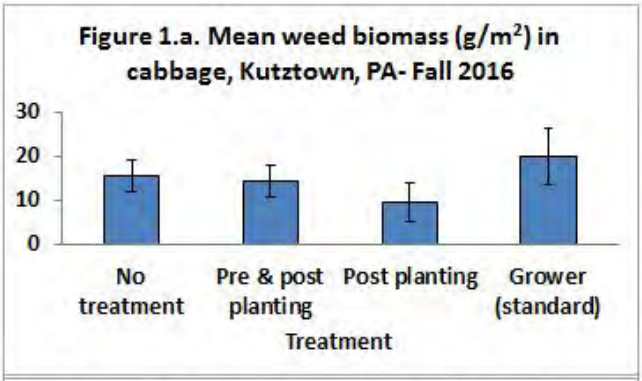
1) Determine the types and amounts of phenolic compounds that exist in DCE and contribute to weed suppression.
2) Determine whether the application of DCE will alter the types and amounts of phenolic compounds in soils and soil biology when compared to those without compost extract (water only) and those which have undergone multiple cultivations and hand-weeding.
3) Demonstrate and evaluate the impact of using extracts, containing chemical allelopathic compounds, as an alternative tactic to improve organic weed control, soil quality, and crop production while reducing dependence on seasonal cultivations and hand-weeding in the field.
4) Develop a model that predicts yield losses due to weed density and relate that to energy and labor costs.
5) Increase the awareness of vegetable growers, scientific groups, and agriculture educators to alternative tools that can be integrated into soil and weed management systems to enhance soil health, reduce cost of labor and energy, and improve growers' livelihoods.

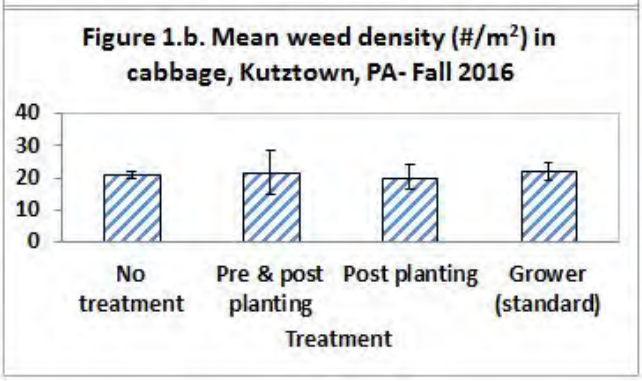
4. Educational Approach

It was imperative to conduct field experimental trials at the grower's field site to assess the success of the proof-of-concept experiments using designed compost extracts for reduction of weed expression and conserving soil health.

In partnering with Aimee and John Good, we were able to demonstrate and assess cabbage yields, weed density and biomass, soil physical, chemical and biological properties and estimate the cost of using designed compost extract for weed management when compared to in-season cultivation.

The Goods were involved in the execution of each step of the process from establishing crop beds, cultivation, applications of compost extracts, and cost analysis. Dr. Zinati coordinated these steps through emails and phone calls to ensure timely execution of field activities and addressing project objectives.





5. Project Results

Weed biomass, density and diversity: Although not statistically different, results showed that applications of compost extracts reduced mean weed biomass by 50% and 28% in post-planting treatment and pre- and post-planting treatment, respectively, when compared to the grower's standard treatment (Figure 1.a). Similarly, there was no significant decrease in mean weed density among treatments (Figure 1.b). The weeds were diverse and mainly included broadleaf weeds such as Pennsylvania smart weed, plantain, smooth galinsoga, and aster (**Photo 1**). In no treatment plots, pigweed and smooth galinsoga were the major weeds. All treatments except the grower's standard treatments had grasses and nut-sedge weeds. This could be attributed to in-season cultivation that reduced grass and nut-sedge population.

In comparison to lettuce and turnip crops that were grown at the same time with cabbage, results showed that using the designed compost extracts reduced mean weed expression by 43 percent when compared to no treatment and by 11 percent when compared to hand-hoeing (grower's) treatment in turnip and similarly, in lettuce, by 19 percent and 34 percent, respectively, compared to the grower's treatment and no treatment [14].

Crop yield: Cabbage heads ranged between 30,000 and 35,000 with no significant difference between treatments (Figure 2.a). Treatments that received compost extract applications had similar mean cabbage yields as those in the grower's standard treatment (ranged between 11,570

kg/ha and 13,790 kg/ha), however, they were significantly different from cabbage yield in no treatment (Figure 2.b).

Soil health properties: Mean soil bulk density was similar in all treatments and it was 1.07 g/ cm^3. Mean penetrometer readings for soil compaction were 20.04 cm in grower treatment (in-season cultivation) and no treatment (21.33 cm) and were significantly different from penetrometer readings taken in soils that received compost extract (27.58 cm and 28.75 cm; post-planting and pre- and post-planting, respectively). These results illustrate that using in-season cultivation for weed management increases compaction after only one growing season when compared to soils that receives compost extract, as an alternative method for managing weeds. Soil chemical properties: No major changes in soil nutrients except in phosphorus and potassium. Mean soil phosphorus concentration (ranged between 71 and 82 ppm) at the end of the season was greater by 15% in all treatments than that at the beginning of the season (ranged between 60 and 67 ppm). However, mean potassium concentration at the end of season decreased by 43% from that at the beginning of the season (ranged between 146 ppm and 161 ppm).

Results showed that soils collected from plots that received compost extracts had mean values of soil biological properties not different from those in grower standard treatment. Total microbial biomass ranged between 4,368 in post-planting to 5,468 in pre- and post-planting and were not different from grower's treatment (4,935). However, these values were lower in no treatment (3,888). Soil total bacteria biomass followed similar trend and ranged between 2,147, 2,544, 2,722, and 1,961 for post-planting, pre- and post-planting, grower's standard, and no treatment, respectively. Soil total fungi biomass was lower than bacteria biomass but followed a similar trend as that of total biomass. Soil total fungi biomass ranged between 423 and 629. Protozoa biomass was 38 in post-planting and 44 in pre- and post-planting treatments and not different from grower's treatment (55). These values were different from no treatment (32). These results showed that treatments with multiple applications of compost extract increased microbial biomass when compared to no treatment and were close to those in grower's standard treatment. Thus, the use of pre- and post- planting compost extracts as an alternative to the grower's standard method can be beneficial for weed management and conserving soil biological properties.

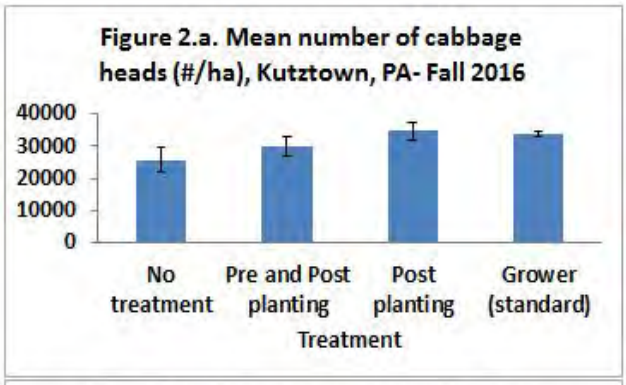


Figure 2.a. Mean number of cabbage heads (#/ha), Kutztown, PA- Fall 2016

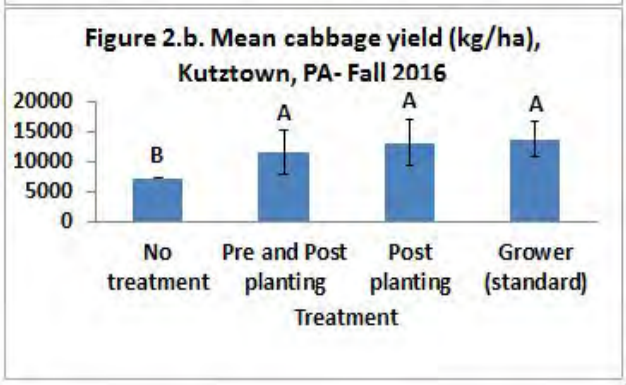


Figure 2.b. Mean cabbage yield (kg/ha), Kutztown, PA- Fall 2016

Economic analysis: In this project, we demonstrated the use of designed compost extracts as alternative tool to in-season cultivation to conserve soil health and reduce weed pressure without negatively impacting cabbage yields.

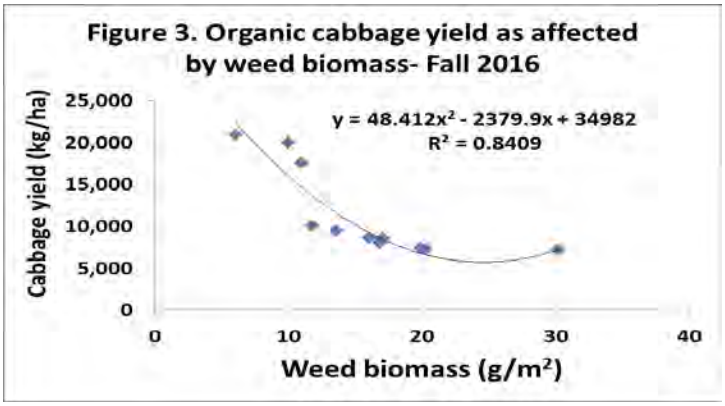
The economic analysis was based on certain assumptions such as grower's easy access to compost, the cost of fuel and time spent for in-season cultivation is $80 for an area of 250 m^2 as well as the wage per person is $15 per hour for compost extract preparation and application. In our study, it took one person two hours (backpack sprayer) to apply compost extract over an area of 250 m^2.

While the use of designed compost extracts at 1:3 dilutions can serve as an alternative method for weed management and can be considered a cost effective system for fall-season turnip production followed by lettuce (Zinati, unpublished data), this approach can be only cost effective in weed management and conserve soil health in cabbage production when compost extracts are applied over three times per season.

Table 1. Weed management cost per treatment for cabbage production in 250 square meters.

Weed management treatment	Cost ($)
Grower's standard (In-season cultivation)	83
Pre- and post- planting DCE applications (4 times per season	120
Post-planting DCE application (3 times per season)	90

Yield losses due to weed biomass: A model was developed to show the relationship between weed biomass and cabbage yield: The data set from all treatments were plotted and fitted to a polynomial curve with an equation of $Y = 48.412X^2 - 2379.9X + 34982$ with $R^2 = 0.8409$ (Figure 3). Once weed biomass exceeds 11 g/m^2 cabbage yield declines sharply.



Phytochemical analyses: Phenolic acids and flavonoids in compost, compost extracts, and soils: Samples from mature compost were collected and freeze-dried for analysis. At time of preparation of compost extracts, compost samples were collected fresh from the pile and diluted to 1:3. Samples of compost extracts were then collected and split into two portions. One portion was autoclaved, froze and stored at -20C and the other portion was immediately stored at -20C. The samples were autoclaved to learn about whether these chemicals may vary with temperature. Soil samples were collected at the end of the season and were immediately stored at -20C. All samples were sent frozen on dry ice via overnight shipping to Dr. Barickman's laboratory at Mississippi State University for analysis.

Contrary to our expectations, compost extract and soil samples did not contain either phenolic acid or flavonoids. However, these samples contained another type of polyphenols. They

contained chlorogenic acid, a natural compound that found in a wide array of plants. Chlorogenic acid is an important intermediary compound in plant metabolism and has a broad range of antimicrobial properties. It is a phytochemical and antioxidant found in high concentrations in coffee and sunflower.

The presence of chlorogenic acid in compost extracts and soil can be explained by the inclusion of sunflower plants in the feedstock when the compost pile was prepared. Mean value of chlorogenic acid in compost samples was 0.235 mg/g dry weight. Mean value of chlorogenic acid in non-autoclaved compost extracts was 1.680 mg/g dry weight and in autoclaved samples was 1.623 mg/g. Soil samples in all treatments have 0.110 mg/g mean value of chlorogenic acid.

An article documenting parts of the results has been published in BioCycle magazine, July 2017 issue, and three copies of this magazine have been mailed to the OFRF office. For more information regarding online access to this article, see Section 7 on Outreach.

6. Conclusions and Discussion

Project results indicate that the application of compost extracts can be effective in managing weeds and used as an alternative approach to mechanical cultivation as well as reducing soil compaction and producing comparable crop yields to the standard grower's method. The approach of using CMD compost extract can benefit all organic vegetable growers including new and younger growers facing financial, labor, and/or equipment limitations. Further studies are warranted to investigate the impact of compost extracts on weed management in no-till organic vegetable production. Our partners Aimee and John Good considered the project results are rewarding and opened their eyes to new technology that can be adopted in the near future in their organic farming system.

It is not fully clear how chlorogenic acid impacted weeds and their expression. These findings showed that further investigation is warranted to explore the use of compost extracts that contain chlorogenic acid at various concentrations and their impact plant growth. It will be also interesting to investigate, in addition, how designed compost extracts rich in chlorogenic acid can be used to increase levels of antioxidants in various vegetable crops.

7. Outreach

Outreach and educational plans included demonstrations, hands-on experience, and dissemination of results to seasoned and new growers, university students and interns at field day, tours, web articles, online news, and a publication in trade magazine. Along with Dr. Zinati, Aimee and John Good participated in the outreach and educational events by demonstrating the use of designed compost extracts and their uses as one tool in the tool box for weed management and no-till production for organic cabbage production. The information and results were shared with visitors at the field day (110 people) on July 15, 2016, the CRAFT tour program (35 apprentices) on July 26, 2016, and growers from Alabama and New York (8) between September 9 and October 4th, 2016.

Over the span of the project, five interns were trained on preparation and application of compost extracts (**Photo 2**); and collection of weed and yield data. A project-related web article was

posted on Rodale Institute's website on June 15, 2017 *and it had 37 page views between June 15 and July 30, 2017,* http://rodaleinstitute.org/use-of-chemically-and-microbially-designed-compost-extracts-for-managing-weeds/ and *205 page views on Rodale Institute's Facebook page.* In addition, an article was published in BioCycle trade magazine in the July 2017 issue, https://www.biocycle.net/2017/07/05/compost-effects-weed-suppression/ and *it was viewed by 315 people and 6,500 copies in print of the BioCycle July issue were distributed until July 30, 2017. Three copies of the magazine are being mailed to your attention.*

8. Financial accounting

Rodale Institute was awarded a grant of $14,991 from OFRF for this project work for the period May 1, 2016 through August 1, 2017. Grant funds were spent as follows:

Grant Expenses through 8/1/2017	$ Amount
Salaries	$6,208.00
Fringe Benefits	$1,481.00
Supplies	$1,552.00
Travel	$22.00
Analysis	$4,167.00
Shipping	$561.00
Farmer Stipends	$1,000.00
Total Project Expenses	$14,991.00

9. Leveraged resources

Additional funding of $14,728 was received from Northeast SARE to investigate the use of designed compost extracts on weed management and crop yields of lettuce and turnip.

10. References

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11. Photos and other addenda

Photo 1. Weed expression in fall-planted cabbage. Treatments from left to right are: Grower's standard treatment (in-season cultivation), pre- and post-planting compost extract, and post-planting compost extract.

Photo 2. Research summer interns getting hands-on experience on preparation and application of designed compost extracts in cabbage.