Evaluation of Compost Application in Mediterranean Climates and The California Healthy Soils Program Demonstration Projects

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ABSTRACT

The California Healthy Soils Program (HSP) prioritizes the goals of reducing greenhouse gas emissions (GHG) and improving soil health to increase agricultural productivity. There is limited research looking at compost application in CA and the outcomes of the compost only component of HSP. Approximately a third of the demonstration program grant funding ($40.5 million) is allocated towards compost application. Compost application improves the soil's ability to retain water and cycle nutrients. A literature review confirmed that compost application improves soil's ability to retain water and cycle nutrients. Compost application demonstration sites via HSP have led to more GHG sequestration in California. Participants are also skeptical about the reduction in GHG compost application as there are many additional factors that counteract the carbon sequestration abilities; two thirds of the interviewees agreed that in theory compost application can reduce GHG reductions. However, participants are not seeing any statistically significant changes in overall soil health within the three year span of the program because significant change doesn't occur in such a short time period. More information and research is needed to conclude any long term benefits from the HSP.

KEYWORDS

Healthy Soils Program (HSP), compost application, organic carbon, soil health, Greenhouse Gas Emissions (GHG)

INTRODUCTION

Scientists predict that the increasing population size of the United States will require crop yields to double to meet demand, while the land area farmed will not change much. This will consequently lead to a higher need for sustainable land management techniques and the prioritization of soil health. Soil quality can greatly impact agricultural productivity. If the soil doesn't contain enough nutrients or is incredibly compact, the crop growth can be stunted. Roots are unable to develop fully leading to underdeveloped crop outputs. Healthy soil has been defined as "soils that enhance their continuing capacity to function as a biological system, increase soil organic matter, improve soil structure and water-and nutrient-holding capacity, and result in net long-term greenhouse gas benefits," (M. Tahat et al. 2020).

Soil is a carbon sink, storing 75% of Earth's carbon (Ecological Society of America 2000). Soil plays a vital role in Earth's biogeochemistry and the progression of climate change (Melillo 2021). When evaluating soil's potential role in climate change mitigation, both the carbon stocks present in the soil (including amounts of organic and inorganic carbon) as well as the fluxes of greenhouse gasses are important. Soil health indicators are quantitative metrics (soil carbon and cation exchange capacity) to evaluate soil health. GHG fluxes from carbon dioxide and nitrous oxide are recorded in soil samples. The greater the release of CO_2 into the atmosphere, the greater the concentration of the gas in a soil sample (Melillo 2021). Nitrous oxide is a detrimental greenhouse gas because one molecule of N_20 released into Earth's atmosphere can contribute almost 300 times more to climate change than one molecule of CO_2 (US EPA 2015). Some microbes live in the agricultural soils that release N_20 making the compound a critical component of soil monitoring.

Compost application is a direct manipulation of soil health indicators, especially carbon. By composting, there is a direct input of organic carbon which improves the soil structure. When the physical structure improves, the soil's capacity to hold and transport nutrients throughout the system improves due to the increase in the soil's cation exchange capacity (Jorge-Mardomingo et al. 2015). Composting also contributes to climate change mitigation by improving the Earth's ability to stabilize carbon and increasing plant growth, ultimately pulling more carbon dioxide out of the atmosphere (Gravuer 2016). Compost application helps retain nutrients in the soil andprevent leaching. Many benefits arise when a farm incorporates compost into its land management practices. Not only do the plants thrive, but there is a positive global impact.

Increasing the adoption of compost applications leads to an uptick in demand for manure and other organic waste products. This demand stimulates the need to produce more compost and leads to the diversion of organic waste from landfills (Gravuer 2016). By removing organic matter from typical waste management facilities there is a substantial decrease in methane.

The California Healthy Soils Program was established in 2016 to improve soil health and increase carbon sequestration. California is covered in diverse agricultural landscapes such as vineyards, rangelands, orchards, and other farms.The CA HSP is a government funded and operated by the California Department of Food and Agriculture (CDFA). The HSP was established because many institutions were not implementing consistent sustainable practices. The program is designed to incentivize practices with sums of grant money. There are two types of projects with the HSP - demonstration (research-based) and incentives (less restrictive for participants). My project will focus on demonstration programs because participants are required to track and report quarterly predicted organic carbon and present findings to the public. This will aid my research and allow me to analyze qualitative and quantitative variables to gauge a better understanding of the perceptions of awardees in the HSP. The demonstration programs are funding projects for universities, resource conservation districts (RCDs), and nonprofits to implement healthy soil practices and conduct research (Healthy Soils Program 2021). Practices include but are not limited to cover-cropping, no-till, reduced-till, mulching, compost application, and conservation plantings. As of 2023, compost application projects receive one third of the CDFA HSP overall budget (Healthy Soils Program 2021).

In this research study, I analyze soil carbon as the primary soil health indicator to track improvements in soil health over the three years of compost application. Additionally, I analyze how compost application in California alters carbon content. A key component of the CA Healthy Soils Program is to reduce GHG and create a cleaner, more sustainable California. Through this research, I look at compost application systems in California and the incorporation of the concept in the CA HSP to determine if the systems are promoting the reduction of GHG emissions and improving overall qualitative soil health. I then determine how the HSP compost application component is benefiting farmers, soil, and the environment. I examine how program participants' composting practices affect GHG emissions and soil health. Through interviews Igain a clearer understanding of how the HSP is operating, and detail participants' program perceptions.

RESEARCH FRAMEWORK

The primary goal of this research project is to determine why improving soil health through compost application is an important strategy to mitigate climate change and a priority of the CA HSP. This is achieved through a three-stage process: qualitative systematic literature review, secondary data analysis, and participant interviews. There is a current overarching assumption- compost application leads to healthier soil and a reduction in GHG emissions. However, addressed later in this research, there are some nuances to this assumption.

More research is necessary to fully understand the biogeochemical processes in agricultural soils. Kate M. Scow, a professor in soil microbiology, outlined the biogeochemical properties of soil and concluded that the total organic matter does not reflect changes in the composition and potential fertility (Scow et al. 1994). They emphasized that more research and experimentation are needed to better understand soil nutrient cycling. Chemical soil properties are altered by all agricultural practices (Scow et al. 1994). Dr. Getinet Adugna authored a review on soil compost and outlined the importance of sustainable compost application counters Scow's initial theories regarding compost. Agunda describes that compost is essential to increase soil and agricultural productivity. Carbon improves the soil's ability to retain water and nutrients and reduces the soil's susceptibility to erosion (Adugna 2018). Ultimately, making the soil more fertile. Adguna outlines the difference between immature and mature compost through their research. Mature composts increase soil organic matter more than immature composts due to their higher concentration of stable Carbon (Adugna 2018).

In this thesis, primary research was conducted through interviews and surveys to gauge perceptions regarding the HSP. The research completed by Cheryl Wachenheim inspired the methods for qualitative data collection. Dr. Wachenheim is a professor and researcher at North Dakota State University in Applied Economics and Agribusiness. Most of their published papers revolve around perceptions and consumer relations with agriculture. The research was conducted with two staged random samples that are stratified by geographic region (Wachenheim and Rathge 2000). This research provides statistical best practices to obtain perceptions data that I used to model my research. Additionally, it outlines why identifying perceptions is important in research because those that are misled, can be quickly addressed by the researcher and serve as a key finding.

The research paper “Farmers' Perception about Soil Erosion in Ethiopia" was key when structuring interview questions. The author Zerihuyn Nigussie is a professor in Agricultural Economics and describes that farmers are knowledgeable about soil erosion and are trying to be more sustainable (Nigussie et al. 2017). This demonstrates a great opportunity for a partnership between farmers and sustainable practices, which follows the strategic plan of the CA HSP. Community-level discussions are the next step in conversations about soil health and the CA HSP Demonstration projects aim to take that first step. Nigussie’s article greatly helped inform my research topic as it not only examines the environmental impacts of soil erosion but also investigates the social implications.

The rationale for this project is to gain a deeper understanding of what compost application looks like in Mediterranean climates and how compost application is a vital component of the CA Healthy Soils Program. The HSP is a new program considering it has been active for less than seven years and analyzes the practices of many different experimental techniques. The long-term outcomes of each type of sustainable practice are convoluted and there are only reports published that illustrate the overall outcomes. The HSP is being interpreted as a successful program even though only vague results are being published. Now, other institutions in the United States are also adopting similar grant programs to promote sustainable farming practices and reduce GHG emissions i.e. New Mexico and Washington (Shobe et al. 2020). This study approach will allow me to determine the current program status and view systems through the lens of the awardees.

METHODS

Qualitative Systematic Literature Review

CA experiences a Mediterranean climate. I conducted a qualitative systematic review to determine the effect that compost application has on the Mediterranean climate because there was limited information on compost in California. The procedure of this particular literature style was modeled after systems from Campbell Collaboration and direction from Dr. Timothy Bowles (University of California, Berkeley). The object is to gain a fundamental understanding of compost's ability to act as a climate change mitigation system and understand why the HSP may be investing millions of resources in the compost programs specifically (Table 1). Seventeen articles were reviewed.

I selected peer reviewed sources that were published in academic journals. Information was reviewed and synthesized into a table format. I looked for information that fell into the following categories: Compost as a conservation practice, compost and GHG reductions, and composts effect on sites carbon content. The goal of this process was to identify why compost is a key system to reduce GHG emissions. This process gave me a better understanding of the composting systems, the processes, and why the HSP is investing millions of dollars into the program.

Data Analysis of Program Structure/Outcomes

To analyze current program outcomes, I used the program website and I extracted the following information: funding year, project type, recipient (organization), grant amount, implementation practice(s), total implementation acreage, CO_2 reductions, county, start date, end date, and farmer outreach ("CDFA - OEFI - Healthy Soils Program" 2023). Estimated CO_2 reductions is an estimation that is derived from the GHG calculator, Comet Planner, that was completed as a part of the grant application assessed by HSP. The individual land managers did the estimated CO_2 calculations. The Farmer outreach value is determined when the project is completed. The farmer outreach value is a numerical value that outlines how many agriculturalists participants attended to inform about project outcomes and benefits community demonstration events. The data was filtered to only include composting participants. These are participants that are involved in the following composting application methods with varying carbon to nitrogen ratios (C/N): C/N < or = 11 from a composting facility, C/N < or = 11 on-farm produced, C/N > 11, on-farm produced, and C/N > 11 purchased from a composting facility, aerated compost tea, and vermicompost.

I extracted additional information regarding the application process, grant awardees, and program operation was pulled from the available HSP report. For example, California Climate and Agriculture Network (CalCAN) published a progress report from December of 2020 to detail the HSP outcomes for the first few years since installation (Shobe et al. 2020). The literature review prior to this step, provided in depth descriptions regarding a broad overview of all program current states.

I conducted analysis using multiple visualizations. I plotted all types of composting methods together to visualize the geographical locations of the projects in addition to the

variation in grant amounts using ArcGIS. Other visualizations to determine trends and correlation were completed using RStudio. I plotted Compost Grant amount Vs CO_2 Reductions in Figure 2 and Outreach vs Compost HSP Awarded Grant Amount in Figure 3. These are represented as scatter plots (see results for more information).

Qualitative Interview Analysis

To answer the question regarding program participation perceptions, I conducted 20 minute interviews with compost HSP compost application participants. A list of active projects and the organization was acquired through the CDFA program listing site. Information was paired down to a list of 27 composting participants. Each organization was reached out privately in order to obtain a point of contact, an individual knowledgeable about the HSP and their ongoing compositing projects. Points of contact were then privately emailed in order to schedule a 20 minute interview to discuss their organizations participation. All participants received the list of interview questions via email prior to the interview. They had the option to skip questions if they did not feel comfortable sharing any information. All participants answered questions to the best of their knowledge, none skipped any questions.

Five questions were asked during the conservation leaving space for additional probing questions. These questions were used to gather information, key motivations and collect additional qualitative information that is often glossed over by the reports. The goal of this component of the research project is to see if other participants are having comparable experiences with their demonstration cities. The questions are listed below:

1. Could you describe your demonstration project?
2. What are some key results from your project so far?
3. How have you been informing and reporting program outcomes?
4. Since implementing this compost application method what changes in adoption have you seen?
5. What does successful compost use look like in California?

There are currently 27 ongoing or completed unique participating organizations in the compost application demonstration projects. Of the 27 participants, I conducted 10 interviews. Participants were all lead principal investigators / primary points of contact for at least one of the organization's demonstration projects prior to the interview. I asked all participants the same five main questions and included time for additional follow up and probing. Participants were given a

list of the five questions prior to the interview. I included interviews from at least one of the following compost demonstration sites: vineyard, orchard, farm, and rangeland.

In order to analyze the information collected before the interviews, key themes were outlined in a table. Interview transcripts were then reviewed. The emergence of relevant themes were tallied in a table. I looked particularly at whether they saw statistically significant changes in their soil health via carbon or any other important indicators- participants are required to perform statistical analysis on their projects. I also looked for what their program feelings were.

RESULTS

Best Compost Application Practice

Table 1 highlights 10 of the most crucial findings from the literature review. The contribution of GHG and storage of carbon from the agricultural sector is becoming more widely known and analyzed in research. Although some results remain unclear.

In the articles examined, authors consistently agree that compost application is an effective soil conditioner. All of the articles reviewed articulated the impact that compost has in retaining water and nutrients. Therefore, compost improves the physical qualities of the soil. Multiple research papers confirmed that compost application improves soil's ability to retain water and cycle nutrients (Ramasamy Coolen et al. 2021).

Carbon is found in lower layers of soil samples. The literature alludes to compost applications' ability to make soil a more effective system to store carbon (Takakai et al. 2020). Carbon is sequestered in soil by plants through photosynthesis and can be stored as organic carbon. Compost improves plant efficiencies which then in turn improves carbon storage (Adugna 2018).

Carbon is stored for a finite amount of time. Compost, if applied regularly, will reach an equilibrium storage capacity and improves GHG amounts. All carbon will only be stored for about 100 years (Favoino and Hogg 2008). It also releases greenhouse gasses through the aging process which reduces the overall benefit of compost and GHG reductions. Animal based compost releases more gasses and there are many negative perceptions regarding the transfer of potential pathogens and the effect the manure has on native plant life. This piece of research was particularly important when generating a list of questions for the interviews. A key theme that I aimed to capture as a result of this literature review is the effect that compost has on GHG

emissions. This article helped articulate the impact and in addition gave me an area to ask interviewees about whether they feel their demonstration program compost application is reducing GHG emissions.

Ultimately, more research is needed to determine long term impacts that compost application has on the surrounding environment. Research that analyzed farmers' perceptions of compost consistently resulted in the concern that the application may have on the native plant life (Majbar et al. 2021).

There is a clear consensus that there are many positive impacts that compost has resulting in greater agricultural productivity. This provided me with the knowledge needed to better understand why it is a critical component of the HSP. This research also was important to compare key literature themes with common perceptions that HSP Demonstration program participants had.

Table 1. Compost Application in Mediterranean Climates Literature Summary. Information was compiled and synthesized from a qualitative systematic literature review analyzing compost application in mediterranean climates.

Source	Location of Research	Purpose	Type of Source	Summary Points
(Al-Madbouh et al. 2019)	Palestine	To identify what the farmers' perceptions in Palestine (mediterranean climate) are in regards to incorporating composting methods in order to re-purpose Palestine's organic waste.	Primary Research	There is a willingness to incorporate compost. Less willing to compost from their own sources. Creating a community will increase adoption practices.
(Favoino and Hogg 2008)	n/a	Why it is becoming more important to look at policy changes for climate mitigation measures via compost application.	Literature Review	Carbon is sequestered through compost application but is only sequestered for 100 years. Compost is a good technique that should be utilized to decrease targeted GHG reductions as it reduces the need for synthetic fertilizers and leads to an increase in ag. productivity over time.
(García-Gil et al. 2000)	Spain	To evaluate the changes in microbial activity that took place in an agricultural soil at two different rates over a nine year period and to compare a manure treatment, a mineral fertilization and a non-amended control.	Primary Research	Soils amended with municipal solid waste (MSW) compost can improve soil quality, increasing the organic matter content of degraded soils and improving soil biological and biochemical properties. The wide variety of substances such as heavy metals and other potential pollutants in municipal solid wastes limits the use of these residues in compost.
(M. Tahat et al. 2020)	n/a	To examine the role of soil health in intensive crop production systems and identified factors to consider when assessing soil health components in sustainable agricultural systems.	Literature Review	Organic systems increase soil nutrient mineralization, and microorganism abundance and diversity as well as soil physical properties. Interestingly, organic fertilizer sources (plant- or animal-based) can potentially affect microorganism abundance and crop yield. Animal based compost can reduce the microorganism counts.
(Ramasamy Coolen et al. 2021)	Mauritius	To determine an ideal mix of household wastes to ensure aerobic decomposition and prevent methane emissions.	Primary Research	The results showed that moisture content remained within the range that will allow composting to occur throughout the process in all four cases. It was also concluded that equal parts kitchen and garden waste is the ideal composition for compost.

(Rath et al. 2022)	United States	To analyze the effects of multiple different carbon storing techniques over a 7 year span.	Primary Research	Through the use of both composting and cover cropping researchers recorded that nutrients penetrated the soil further. There was also an increase in soil carbon transfer due to increased hydraulic conductivity. More research is necessary to further understand cycling.
(Scow et al. 1994)	United States	To determine if soil nutrient and biological parameters change during the transition from conventional to low-input or organic farming systems.	Primary Research	More research is necessary - soil fertility may be problematic during the transition period.
(Takakai et al. 2020)	Japan	To verify what the effects of long term compost application is on rice fields.	Primary Research	Long term application derived from cattle manure increased GHG emissions.
(Thomson et al. 2022)	Canada	To outline the potential scope for recapturing and recycling metabolic CO_2 gas from composting of residual biomass and organic wastes.	Secondary Data Analysis	The release of gasses like CO_2 from compost is dependent on the composition of the compost. Notice that the release of CO_2 is also dependent on the season. Additional research is needed to better understand the metabolic processes of soil nutrient cycling

CA HSP Current Outcomes and Trends

The geographic placement for each of the compost demonstration programs range in location from the San Diego area to just north of Sacramento. Sites occur in the central valley and coastal regions of California. Study site locations are centralized around many of California agricultural hubs such as the central value and the San Joaquin River delta. In addition, many sites are along coastal California. In Figure 1, Dot size represents the study site acreage and the color depicts the grant amount. The more red the dot the more money they receive (upwards of $200,000) while the more yellow the dot the less grant funding the site was allocated (the most yellow dot received $50,000).

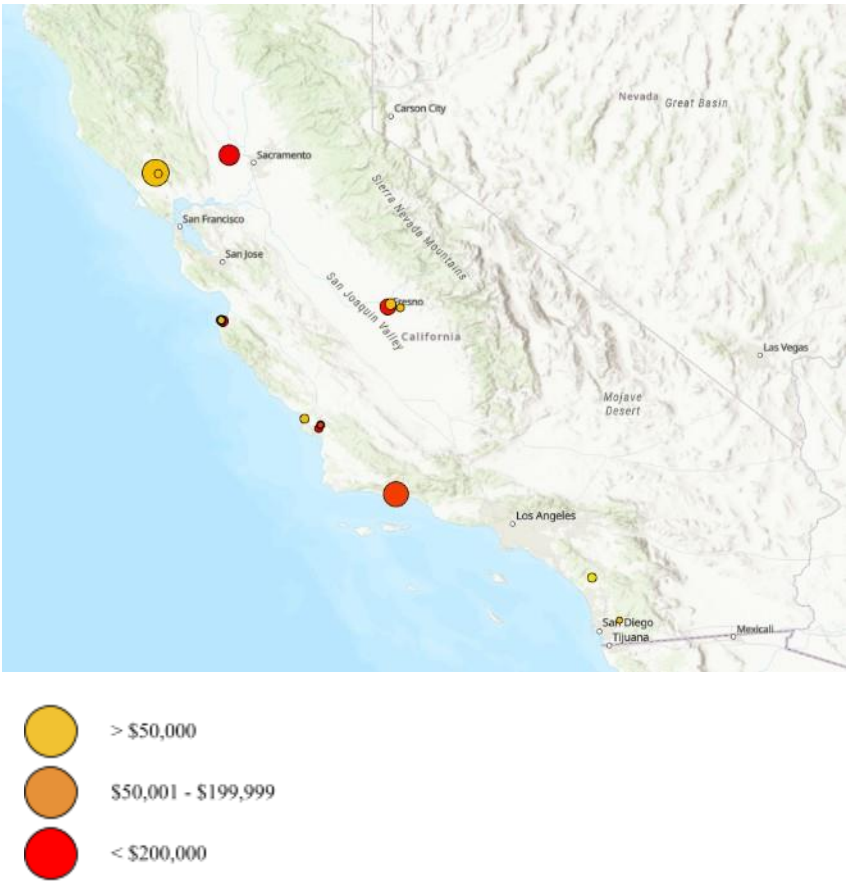

Figure 1. CA HSP Completed and Ongoing Demonstration Program Grant.

A CA agriculture region that is missing and not represented in the HSP composting application projects is the Imperial Valley.

The healthy soils program aims to reduce the GHG emissions in California and reduce the environmental footprint. The project's estimated CO_2 increases with the HSP grant amount.

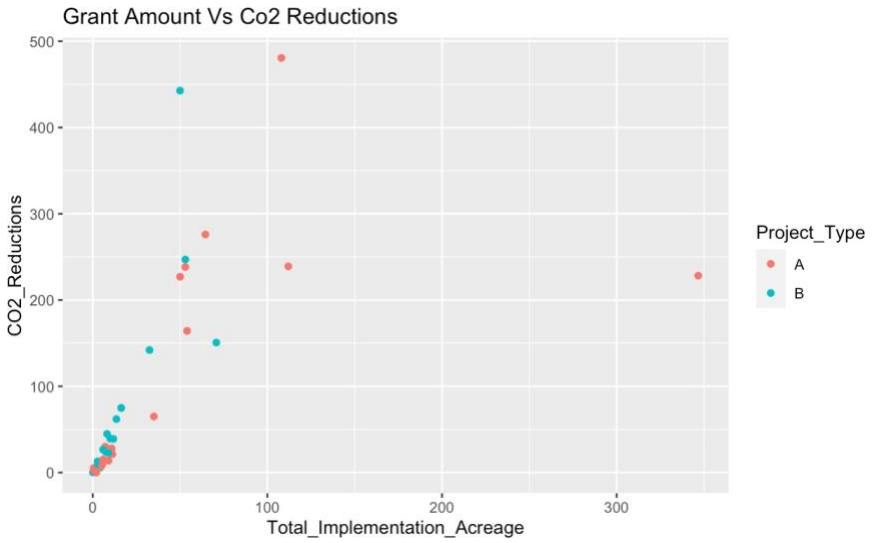

Figure 2. Compost Grant amount Vs CO_2 Reductions.

There is a clear trend that the more funding the program obtains the more CO_2 reductions they are estimated to achieve. Type A projects demonstrate a conservation management measuring GHG emissions and conduct an analysis of the project (Gravuer 2016). These tend to be larger research institutions such as UC Davis and Cal Poly. Type B projects are implementing a management practice and are not required to track explicit GHG emissions and also have to conduct an analysis of the project (Gravuer 2016). These are often but not always smaller institutions such as resource conservation districts. Type A and B Projects are predicting similar amounts of CO_2 reductions. B is predicting slightly more reductions. The red marker on the far right of the graph, is an outlier in the analysis. This study site is the only area analyzed that is a combined practice with rangeland planting only. However, I was unable to get in contact with the PI from this program to find more information.

A major requirement of the HSP demonstration awardees is to participate in community outreach. All participants need to invite industry professionals to the study site and promote their outcomes.

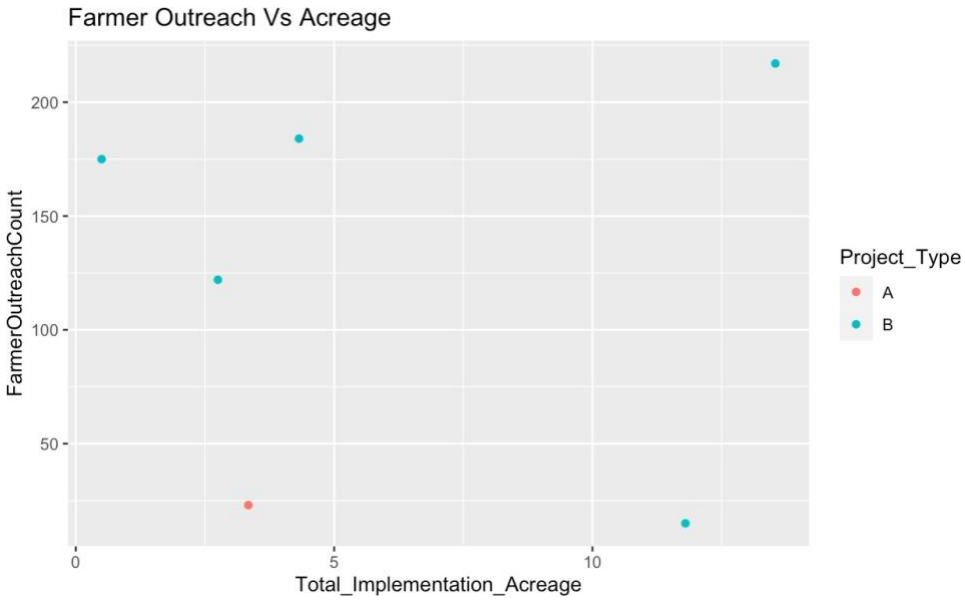

Figure 3. Outreach vs Compost HSP Awarded Grant Amount.

There is no definite trend in Figure 3. Larger funding is given to more recent projects so there is no outcome regarding how many farmers/ranchers they were able to reach. Figure 3 shows that larger implementation acreage and large acreages have the most and the least amount of outreach. The reason behind this becomes more clear through the interview. This may be because the larger farms have greater name recognition so it is easier to attract outsiders to see the demonstration sites. Other larger areas are research centers and universities. So they may be attracting less people to their study sites because they have a greater emphasis on the research.

Demonstration Program Interview Outcomes:

Through conversations, participants frequently discussed that there is no significant soil health impact overall after three years of participating in the HSP. Participants that continued to utilize composting application methods after the program ended started to see improvements in soil health 5 or more years post initial implementation.

Table 2. HSP Demonstration Program Awardees Interviewed Characteristics. Breakdown of sampled compost application interviewed project characteristics.

Characteristic	Count
1 compost application demonstration site	5
2+ compost application demonstration sites	5
Perspective for rangeland study cite	6
Perspective for vineyard study cite	1
Perspective for orchard study cite	2
Perspective for farm study cite	5
Grant amount > $100,000	5
Grant amount < = $100,000	5

Participants recorded a significant increase in soil carbon content. This carbon was an analysis of the upper layers of the soil. There is lower penetration when compost is applied for a longer period of time. Participants stated that those who applied compost for more than the allotted grant period of three years reported a lower penetration of carbon in the soil.

Table 3. HSP Demonstration Program Awardees Interview Key Themes. Information was compiled and synthesized from twenty minute one on one conversations.

Key Theme	Number of Responses	Illustrative Quote
There is no significant soil health impact after three years of participating in the HSP	7	"Hard to make conclusions because it was a small amount over a short period of time" -Interview 5
Participants recorded a significant increase in soil carbon content	7	"There were higher average total carbon areas with compost. Areas that didn't receive compost still showed a small increase." -Interview 5
Compost application is contributing to the reduction of GHG emissions	7	"I do believe it is. I just think we need to get better at the infrastructure side of things. More needs to be distributed and there needs to be more notable biomass sites." -Interview 8
The HSP is increasing the adoption of compost application in California	6	" The Healthy Soils Program is leading to an uptick in compost use. There is more money coming in… especially now, fertilizer rates are a lot more expensive due to covid and supply chain issues" -Interview 7
Compost application is difficult to adopt due to technology, labor, and the upfront cost	10	"Budgeting is an issue - it is an expensive product to use. If it was less expensive there would be an increase in compost use" -Interview 10
Struggled with the demonstration component	5	"Big part was the demonstration- community hub of education. Our site owner was not comfortable hosting large groups of people." -Interview 2
Informing outcomes beyond the required CDFA reports and public demonstration	5	"We do share outs with the community and are making a manuscript that will be published. Also we spoke at the Last CRCC presentation." -Interview 1
Unsatisfied with program / communication with the CDFA	4	"CDFA's funding was a little restrictive with extensions, modifications, and other things… Accommodations were not being made by the CDFA" -Interview 9
Did not receive adequate funding for long term changes	4	"Major difficulty - Budgets. Farmers are paying out of pocket and then getting reimbursed. They are getting confused and it is not an efficient system." -Interview 7

According to the interviewees, compost application is contributing to the reduction of GHG emissions. Interviewees often said "yes" to the question about compost reducing GHGs in general, but they often stated that there is a need for a better infrastructure. When compost is trucked great distances, more fossil fuels are burned and the potential positive impact that compost application has is negated by the additional factors (Interview 8).

There was a general agreement that the HSP is increasing the adoption of the compost application practice. However, participants described that compost application was reported to be difficult to adopt due to the costs and tools necessary to successfully apply. An interviewee mentioned in passing, that on their site it was very difficult to get the compost to the land and then spread it because the environment was uneven and very hilly. Ultimately, the process took more time and compost application spiked labor costs to an amount that they were not anticipating (Interviewee 5). The participant stated that inorder to remain in the program allocated budget, the study site land was reduced significantly.

Half of the interviewed participants struggled with the demonstration component of the HSP. They saw that this struggle increased when COVID hit and the CDFA didn't give many recommendations. One participant, Interview 6, describes that it was difficult to communicate with the CDFA, "CDFA wanted to have too much going on at the same time. Trying to have research and demonstration projects at the same time. It is not compatible on a short time scale." (Interviewee 6). Not all participants vocalized issues with the CDFA. Some who worked with larger, more established agricultural sites encountered fewer communications issues with the CDFA.

Fewer than half (four) of those interviewed are informing the public on their research outcomes. All completed the required CDFA reports and public demonstration events as they are required to report quarterly to the CDFA and bring the community to the study site. However, many are not going above and beyond to report outcomes. Some, such as Interviewee 5, are writing formal reports that they are publicizing on their websites and presenting findings at conferences. They are also adding information and updating a CA RCD Program tracker. While others are simply only fulfilling program requirements to maintain funding. They did this because they wanted to take a more active role in distributing information within the agricultural community (Interviewee 5).

Four interviewees expressed explicit dissatisfaction with the HSP program and communication with the CDFA. They also were the same participants that overlapped with

themes stating they did not receive adequate funding for long term changes. A common characteristic among these participants was that they were smaller demonstration sites. These RCDs and nonprofit organizations were working with much smaller local farmers who did not have access to adequate labor and technology which made the budget more constraining.

DISCUSSION

Through the research I have evaluated three main themes. The first major theme is that compost improves overall soil quality. However, the quality of the compost makes a difference. Compost quality is something that was often overlooked and not emphasized enough in the literature. We saw from the secondary data analysis that there is no correlation between funding amount and demonstration site acreage. The funding amount is correlated with the practices that are implemented in the areas. The acreage is correlated with more GHG reductions.

Soil Quality and Compost Quality

The findings from the literature review emphasizes the impact that compost application has on the soil quality. Based on conversations with the HSP compost grant awardees, compost application is leading to some improvements in agricultural productivity. Participants often quoted that agriculturalists that were implementing compost application on their land saw positive changes. Many participants did not see any statistically significant changes in CO_2 and N_2O emissions. However they saw many qualitative changes to their land. Ranchers often stated that they saw an increase in plant forage. “For Grazing land, ranchers saw an increase in productivity on those soils” (interviewee 10). Although these are not scientifically proven or tracked, there is reason to believe that compost application may result in denser forage.

It is important to emphasize that these positive changes only occur when there is a compost quality control aspect. It was brought up in conversation with Interviewee #2 that there are changes in legislation across California to incentivise the production of compost. California compost law SB 1383 requires the separation of organic material from garbage (“California Compost Law 2022” 2022). This would ultimately make compost cheaper and more accessible for smaller farms.

There is a great risk that with the mass production of compost, the quality will decrease

greatly. Interviewee #3 stated that they are already seeing a dramatic decline in compost quality. “Issues we did see is that the compost that we were receiving contained a small amount of plastic pollutants. This could create another environmental problem. You can see it by walking and looking at the ground. About 3-4 mm in size”(interviewee 3). Through the literature review there was no research or recommendations regarding poor quality compost. Especially, no research outlining the impact that compost with plastic may have on the surrounding environment. If this continues, the positive impacts that compost application may have on agricultural productivity will be negated and there could be a damper on increased adoption. The primary research conducted by Al-Madbouth et al. concluded that as of this moment there is a willingness from farmers to incorporate compost application (Al-Madbouh et al. 2019). One cannot help but fear that if compost quality becomes widely known as contaminated (with plastics or other substances that are not biodegradable) this willingness will disappear. There is great need for these legislations to pass and increase compost availability, but production and sourcing needs to be monitored carefully as well.

GHG Reductions

The secondary data analysis demonstrates that the more acreage available for a demonstration program the more greenhouse the more CO_2 is sequestered. This verifies the findings from the literature review that GHGs are released from the soil (Ramasamy Coolen et al. 2021). It can be concluded that the more soil available the greater storage potential. HSP participants agree with this as 7 of the participants agree that compost application has the potential to reduce GHG.

Some of these participants followed up by stating that it is not that easy to determine if compost directly reduces GHG in CA specifically, with current production systems. There are additional factors such as the soil's ability to store carbon is not unlimited and it is not forever. Soil can store carbon for about 100 years before it is re-released into the atmosphere (Favoino and Hogg 2008). This tells us that compost application is only a temporary way for CA to reduce their carbon footprint. Since the primary goal of the program is to reduce the amount of GHG in California in the long term, compost application may not be the best long term solution.

There are many factors that can lead to more GHG releases that are a part of the production. Participants often brought up the distribution of compost. “Making and transporting

was not easy and drove up costs" (Interviewee 1). Trucking compost large lengths leads to more released GHG than soil can sequester. Also, the literature review leads us to believe that the type of compost is crucial. Animal based compost releases more gasses through the aging process (Tahat et al. 2020). In California, a lot of the compost utilized for HSP is sourced from dairy and cattle ranches - animal based compost. There are not adequate systems in place at this moment that can lead us to conclude that there is a significant reduction in GHG due to Compost application. It is more likely that there is a net zero effect. However, more research is necessary to determine where CA and compost currently lie.

Limitations

There are few limitations worth noting about the extent of this research. First, data and findings were derived mostly from publicly available information that CDFA published. Organizations contacted were ones that were listed as public compost grant participants. It is possible that information is dated or misreported. A second limitation to this research is that data that estimates the GHG reductions is reported through a model simulation. In order for participants to qualify for the grant funding, they must submit their predicted outcomes from the program simulator, CometPlanner. This estimator is operated by the CDFA. The reported reductions by CDFA are likely overestimates. Project awardees mentioned that study plots were sometimes reduced in size or plans were changed when the implementation problems occurred.

A final limitation worth noting is that the grant programs only run for three years. Then the participants can choose to continue their projects or stop using the experimental practice. However, they will not continue to obtain funding. This ultimately means that soil health metrics are not tracked longer after three years. It is difficult to make statistically significant conclusions over such a short period of time. In order to draw more conclusive results the grant program needs to provide funding and track results for at least five years.

HSP Recommendations

Through the literature review, secondary data analysis and speaking with program participants, I would recommend funding the HSP demonstration program compost application component provides funding for five years or more. Participants interviewed discussed that any

sort of long term impact that compost has cannot be seen in such a short time. Interviewee 6 stated that if the program ran for a minimum of five years, they would see more results that we can draw more clear conclusions from. Currently, not all those who participate in the program for the three years continue implementing compost application. This is because they did not see any meaningful changes in their agricultural landscape and did not want to continue to fund the practice with their own resources. By providing more funding for a longer period of time, participants will have more financial resources and can invest in the proper technology and labor needed to apply the compost. There may also be changes in long term adoption from the farmers. An additional HSP program suggestion that arises from this research, is placing quality control restrictions on the compost utilized. There is not enough literature that outlines the potential impact that compost has on the surrounding native plant landscape. Therefore, it is important to ensure that the compost applied through the program is processed adequately to reduce the potential exposure of pathogens and reduce the risk of negative environmental impacts. In addition, compost applied should not have non-biodegradable substances such as plastic mixed throughout which is the norm seen on some farms (Interview 3). Along with a compost quality emphasis, there should be restrictions on how far the compost can be purchased and transported. Trucking compost large distances negates the potential positive impact that compost application has on GHG reductions. Therefore, if HSP participants are trucking compost hundreds of miles to get to their fields, there may not be a positive GHG impact from composting.

In order to ensure the longevity of the HSP compost application demonstration programs, there needs to be changes in program administrative functioning, funding and more regulations on what compost is applied to the California agricultural landscapes.

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