

Microbial Responses to Compost Amendments and
Water Pulses in Degraded Dryland Soils

by

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ABSTRACT

Dryland ecosystems are integral to the global agricultural system and play an important role in soil carbon (C) storage. Despite their importance, drylands are currently facing many challenges including climate-change induced rainfall variability and soil degradation. These challenges are predicted to have effects on the soil microbial communities in drylands. Compost, an organic soil amendment, is a land management strategy that has been proposed to increase soil C storage as well as improve soil conditions in drylands, specifically in restoration and agricultural sites where degradation has affected soil properties like microbial biomass and respiration. Compost additions and rainfall variability may interact to affect soil moisture, an important catalyst for microbial activity. Assessing microbial activity responses under compost applications and variable moisture will aid in understanding how land management strategies will be affected by climate change in the future. This study investigates how soil microbial activity from a degraded dryland restoration site is affected by different compost applications amounts and variable soil moistures. A laboratory incubation study was conducted in a controlled environmental chamber for 60 days. Soils were amended with different treatments of compost (0, 0.35, and 0.70 g cm⁻²) and water pulses (5, 10, and 15 mm) in a full factorial design. Each treatment received the same cumulative amount of water throughout the incubation, but pulses were administered in different frequencies (every 5, 10, and 15 days). Soil respiration and soil water content were measured daily, and microbial biomass was measured at

the end of the incubation to assess treatment effects on microbial activity. Microbial respiration and soil water content increased with increasing compost additions and water pulse sizes. Microbial biomass did not have consistent increases with compost additions or water pulse size. Cumulative microbial respiration was highest with the large-infrequent pulse size and smallest with the small-frequent pulse size. These results suggest that microbial activity and carbon dynamics in soils where compost amendments are used will respond to future changes in precipitation variability. The results of this study can aid in understanding how microbial activity is influenced by compost applications, which will be critical in making informed management decisions in the context of climate change.

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TABLE OF CONTENTS

	Page
LIST OF TABLES	iv
LIST OF FIGURES	v
INTRODUCTION	1
Study Overview and Hypotheses	6
METHODS	8
Experiment Overview	8
Collection Site	9
Expetimental Design.....	11
Expetimental Treatments.....	12
Soil Water Content	14
Microbial Respiration	14
Microbial Biomass.....	16
Statistical Analyses.....	17
RESULTS	18
Soil Water Content	18
Microbial Respiration	20
Microbial Respiration vs Soil Water Content.....	24
Microbial Biomass.....	26
DISCUSSION	28

	Page
Key Results	28
Soil Water Content	28
Microbial Respiration	29
Microbial Biomass.....	32
CONCLUSION	34
REFERENCES	35

LIST OF TABLES

Table	Page
1. Physical and Chemical Properties of Soil and Compost.....	11

LIST OF FIGURES

Figure	Page
1. Environmental Chamber at ASU	8
2. Collection Site	9
3. Rainfall Pulse Treatment Schedule	13
4. Photos of Watering Apparatus	13
5. Flux Puppy	15
6. Graph of Daily Soil Water Content	19
7. Soil Water Content Means and Significance Groups	20
8. Graph of Daily Microbial Respiration	22
9. Graph of Cumulative Microbial Respiration.....	23
10. Microbial Respiration Means and Significance Groups.....	24
11. Graph of Microbial Respiration vs Soil Water Content	25
12. Graph of Microbial Biomass	27

INTRODUCTION

Land degradation threatens the world's ecosystems, currently affecting over 25% of the planet's land area. Land use and climate changes are the primary causes of land degradation in drylands (Olsson et al., 2019; Mirzabaev et al., 2019). Drylands are terrestrial ecosystems characterized by low precipitation, where moisture losses through potential evapotranspiration exceed mean annual precipitation (FAO, 2004). Globally, drylands cover ~45% of all land surface (Právělie, 2016) and are expected to expand as aridity increases in many parts of the world (Mirzabaev et al., 2019; Právělie, 2016). Drylands are vital to the global agricultural system, responsible for nearly 80% of global cereal production (Mortimore, 2009) and producing 50% of the world's livestock (Allen-Diaz et al., 1996). Because drylands are so extensive and provide critical ecosystem services (Mirzabaev et al., 2019; White & Naeem, 2003), it is essential that effective management strategies, such as organic soil amendments, be developed to address land degradation in these ecosystems.

Soil degradation affects the viability of dryland ecosystems for agriculture. It is estimated that 10-20% of dryland soils are currently degraded (White & Naeem, 2003; Safriel et al., 2005). Land use change (including vegetation removal, conversion to agriculture, cropland abandonment, and urban expansion) and climate change are the two main causes of degradation (Mirzabaev et al., 2019). Symptoms of soil degradation often include salinization, aeolian and fluvial erosion, vegetation loss, organic matter depletion, loss of plant-available nutrients, and soil compaction (Mirzabaev et al., 2019;

Dregne, 2002). These occurrences can lead to reductions in crop and livestock productivity, lower biodiversity, decreases in ecosystem services and health, and increased water stress in dryland communities (Mirzabaev et al., 2019; FAO 2004).

Due to their global extent, drylands store an estimated 46% of terrestrial carbon (Safriel et al., 2005), with ~20% of that amount in soil organic carbon (SOC) (Lal, 2004). The amount of SOC stored in drylands is due to the large amount of area they cover globally, as they have low SOC per unit area compared to mesic systems. Degradation in drylands has led to the depletion of the already-low SOC concentrations in dryland soils (FAO, 2004). Because SOC in drylands is low, there is a high potential for additional carbon storage in the future, which could be beneficial for climate regulation (FAO, 2004). Land management strategies that reduce degradation from land use change and climate change may have the potential to store additional SOC in dryland soils (FAO, 2004). Soil organic amendments like compost are one potential management strategy that directly affects SOC and may enhance carbon storage in drylands (Ryals et al., 2015; Ryals et al., 2014, Silver et al., 2018), although the usefulness of large-scale SOC storage as a climate solution is highly debated (Schlesinger & Amundson, 2018).

With drylands threatened by current and future degradation, their importance for agriculture, and their potential to aid in climate mitigation efforts through carbon soil storage (FAO, 2004), it is imperative to understand how dryland soils will be affected further by the rapidly changing climate. It has been predicted that drylands will face an increase in rainfall variability that includes more extreme rainfall events and more

frequent, intense droughts (Collins et al., 2013; Zheng et al., 2018; Maestre et al., 2012). Several studies project both increases and decreases in precipitation depending on the region (Bates et al., 2008; Giorgi et al., 2019). However, even in areas where precipitation is forecasted to increase, the expected rise in temperature and evapotranspiration rates may negate positive effects of enhanced precipitation on soil moisture. Overall, soil moisture is projected to decrease by 25% in most global drylands (Bates et al., 2008; Collins et al., 2013). These changes can impact many soil processes and properties, including soil respiration, SOC storage, and microbial activity (Brevik, 2013; Humphrey et al., 2021).

Research has been inconclusive on whether dryland soil processes and properties, including soil respiration and microbial biomass, will respond positively or negatively to increased rainfall variability due to the complex interactions and counteracting effects of predicted changes. While organisms in dryland ecosystems are known to be well-adapted to variable and unpredictable rainfall, there is a possibility that climate change will exceed their adaptive capacities (Mirzabaev et al., 2019). A study in the Chihuahuan Desert found that increased variability (in the form of larger, less frequent events) increased productivity and soil respiration (Thomey et al., 2011). A laboratory study found that, at high levels of added cumulative precipitation, more frequent pulses led to increased decomposition (Joly et al., 2017). One study showed a decrease in moss-lichen soil crusts and an increase in cyanobacterial crusts in response to altered rainfall, leading to an overall reduction in microbial biomass (Zelikova et al.,

2012). One 5-year study found that both soil warming and drying led to a 32% reduction in soil C (Link et al., 2003). A study in a semiarid grassland found increasing soil respiration and soil moisture in response to increasing pulse size (Post & Knapp, 2021). Overall, these studies show that responses to variable precipitation differ greatly and seem to depend on factors including annual mean precipitation (Gherardi & Sala, 2019). A synthesis study on the impacts of altered precipitation regimes on dryland soils found that changes in the amount and frequency of precipitation can influence soil CO₂ emission and microbial community composition. The researchers concluded that there is an existing knowledge gap on dryland soil responses to rainfall variability, and that more research is needed to better understand how changing precipitation will affect dryland soils, including effects on microbial activity and carbon dynamics (Nielsen & Ball, 2015). Broad generalizations are difficult to make as dryland ecosystems are not uniform across the globe, but it has been shown that precipitation pulse size and the length of time between pulses are a more important determinant of soil respiration than cumulative precipitation (Austin et al., 2004).

With drylands facing the combined threats of climate change and land use change, sustainable land management is becoming increasingly important. National and international programs consider dryland restoration integral to future sustainability (Bureau of Land Management, 2001), but despite the widely recognized importance of drylands, restoration success rates in these ecosystems are generally low (Carrick & Kruger, 2007). Restoration efforts typically focus on managing vegetation cover and soil,

and different management methods can be combined to reinforce benefits and improve carbon storage that aids in climate change mitigation (Olsson et al., 2019). Integrated soil fertility management is an option that uses chemical and organic amendments such as manure, biochar, and compost to increase soil organic matter content. Organic amendments can increase microbial activity, soil organic carbon, and water-holding capacity in soils, all of which help to maintain plant production (Ryals & Silver, 2013).

Compost is a type of organic soil amendment made by decomposing organic materials in large, moist, well-aerated piles (Weil & Brady, 2017). Programs that collect waste and produce compost have been adopted by many different municipalities (Otten, 2001) and are seen as a method of diverting waste from landfills and creating low-cost amendments that are suitable for agricultural purposes (Wolkowski, 2003). Compost has been shown to increase C mineralization (Brempong et al., 2019), water holding capacity and crop yields (Hargreaves et al., 2008), aggregate stability, enzyme activity, aboveground net primary productivity, and plant tissue nitrogen (Gravuer et al., 2019). One study found that a single application of a high rate of compost (50 Mg ha⁻¹) to semi-arid degraded soils resulted in increased soil organic C and microbial biomass C (Reeve et al., 2011). Recent studies have proposed that compost may be useful in restoring degraded drylands by increasing soil organic matter, which will increase soil water content and water-holding capacity, as well as increasing carbon soil storage to mitigate climate change (Ryals et al., 2016; Ryals et al., 2015; Ryals & Silver, 2013).

Published studies have primarily considered either the relationship between rainfall variability and soil processes, or the relationship between organic amendments and soil processes. However, one recent laboratory incubation study looked at interactions between rainfall variability, soil processes, *and* organic amendments. The study looked at the greenhouse gas emissions of semi-arid soils under variable compost application rates and soil water contents (Brempong et al., 2019). The researchers found that carbon dioxide emissions increased by 59% as soils transitioned from dry to normal moisture (5% to 7% water filled pore space) and increased 15% as soil moisture increased from normal to wet (7% to 14% water filled pore space). The researchers concluded that greenhouse gas emissions depend more on soil moisture than on compost (Brempong et al., 2019). The results of this study indicate that dryland soil processes are heavily dependent on moisture, which is affected by rainfall frequency, pulse size, and organic matter additions. Due to the more variable rainfall conditions predicted in the future, it is important to further study how compost additions will affect soil under different moisture regimes.

Study Overview and Hypotheses

The main objective of my research was to determine how compost and variable water pulses interact to affect dryland soil processes. I wanted to know whether compost additions to drylands could help restore degraded soils and potentially mitigate further harms that the effects of climate change, including altered precipitation

patterns, may cause. The questions that I aimed to answer were: 1) What are the effects of adding compost to dryland soils on microbial respiration and microbial biomass C? and 2) What are the effects of varying water pulse treatments on microbial respiration and microbial biomass C in dryland soils with different amounts of compost added? To answer these questions, I conducted a soil incubation experiment. I amended a degraded dryland soil with different treatments of compost and variable water pulses and measured soil respiration, soil water content, and microbial biomass C.

I tested the following hypotheses: 1) Microbial biomass C will increase with compost additions and pulse size because microbes require carbon and water for activity 2) Microbial respiration will increase with compost additions and pulse size due to increases in microbial biomass C, and 3) Soil water content will increase with compost and increasing pulse size because compost will slow evaporation, allowing elevated soil water retention. I also predicted that small-frequent pulses would cause higher cumulative respiration at the end of the experiment than large-infrequent pulses, because more frequent pulses allow accumulation of soil moisture between pulses.

METHODS

Experiment Overview

To test my hypotheses, I conducted a 60-day incubation experiment in a controlled environmental chamber (Figure 1) at Arizona State University. The chamber was kept at a mean temperature of $26 \pm 0.5^{\circ}\text{C}$ and a mean relative humidity of 40% during the incubation (Kestrel Drop D2AG, Nielsen-Kellerman, Boothwyn, PA). I incubated soil and compost in Mason jars and treated them with water pulses of different sizes at different frequencies throughout the 60 days.



Figure 1. Environmental chamber at ASU.

Collection Site

The soil was collected from the North Altar Watershed Area (Figure 2a-2c), a research site located near Brawley Wash on King 98 Ranch, an abandoned agricultural field in Pima County, USA (32°01'41.4"N 111°22'14.2"W). The site was previously used for a biochar and compost study at the University of Arizona. The site has been intermittently farmed since the mid-20th century and has been impacted by plowing, episodic flooding, erosion, and sedimentation. Many surfaces in the area are devoid of vegetation. In 1995, the Altar Valley Conservation Alliance was formed to work to restore the Altar Valley for agricultural use for future generations, namely focusing on brush management and erosion control (<https://altarvalleyconservation.org/>). In 2020, the site had a mean daily minimum of 12.9°C and a mean daily maximum of 28.3°C, and received only 10.6 cm of precipitation (NCEI, 2020). When the soils were collected in April 2021, the site had been without a rainfall event exceeding 2 cm for over a year.





Figure 2b. Location of collection site (marked with black point) with reference to nearby cities and highways (USGS National Map).



Figure 2c. Example of degraded soil and lack of vegetation at soil collection site.

Experimental Design

At the collection site, surface soil was collected at 0 to 5 cm depth using a shovel. After transportation back to the laboratory at ASU, the soil was air-dried at 30°C for 24 hours and passed through a 2 mm sieve. The compost used for the study was from Tank's Green Stuff in Tucson. This compost is Seal of Testing Assurance (STA) certified by the U.S. Composting Council and meets all federal, state, and local regulations. Tank's compost was previously used in the University of Arizona field studies at the soil collection site. The compost was dried for 24 hours at 30°C and passed through a 4 mm sieve. The soil and compost were analyzed for physical and chemical properties before the start of the experiment (Table 1) at A&L Western Laboratories in Modesto, California. In each 43 cm² glass Mason jar, 200 g of soil was placed first, and then the layers of compost were carefully placed on top to avoid mixing. All jars were treated with factorial combinations of three compost treatments (no compost, 15 g compost, or 30 g compost) and three watering pulses (5 mm, 10 mm, or 15 mm). Every water pulse treatment received the same cumulative amount of water over the span of the 60-day incubation. There were 9 replicates of each treatment.

Properties	Compost	Soil
Texture	Not determined	Silt loam
pH	7.3	7.7
Organic Matter (%)	34.35	1.6
Water-Holding Capacity (%)	Not determined	35%

Table 1. Physical and chemical properties of soil and compost.

Experimental Treatments

A field study conducted by the USDA on a California rangeland used 0.635 cm of compost on the soil surface (Bullard & Smither-Kopperl, 2020), which is the application rate I decided to use for the study. After converting the rate from height to mass, I found that 0.635 cm of compost is equivalent to 14.18 g, which was rounded up to 15 g, and 1.27 cm of compost was rounded to 30 g. Therefore, compost treatments included a soil-only treatment with 0 g of compost, a low treatment with 15 g (0.35 cm^{-2}) of compost, and a high treatment with 30 g (0.70 g cm^{-2}) of compost. After drying and sieving, compost layers were carefully added on top of the 200 g of soil in each Mason jar.

Dryland precipitation events are classified as small events ($<5 \text{ mm}$) and large events ($>5 \text{ mm}$) (Huxman et al., 2004; Sala & Lauenroth, 1982). This classification was used to generate three water delivery treatments that differed in pulse size and frequency. The small-frequent pulse treatment received a 5 mm rainfall equivalent (21.5 mL distributed across the 43 cm^2 surface area) of DI water every 5 days of the incubation (Figure 3). The intermediate treatment received a 10 mm rainfall equivalent (43 mL) of DI water every 10 days, and the large-infrequent treatment received 15 mm (64.5 mL) every 15 days. Thus, the three treatments received the same total water (30 mm month^{-1}) throughout the experimental period. Water pulses were added by carefully pouring pre-measured water from a test tube into a 150 mL syringe attached to a Buchner funnel (Figure 4). The Buchner funnel was used to ensure even distribution

across the soil surface so that the compost and soil layers were not disturbed. The jars were left open for the entire incubation to allow for evaporation.

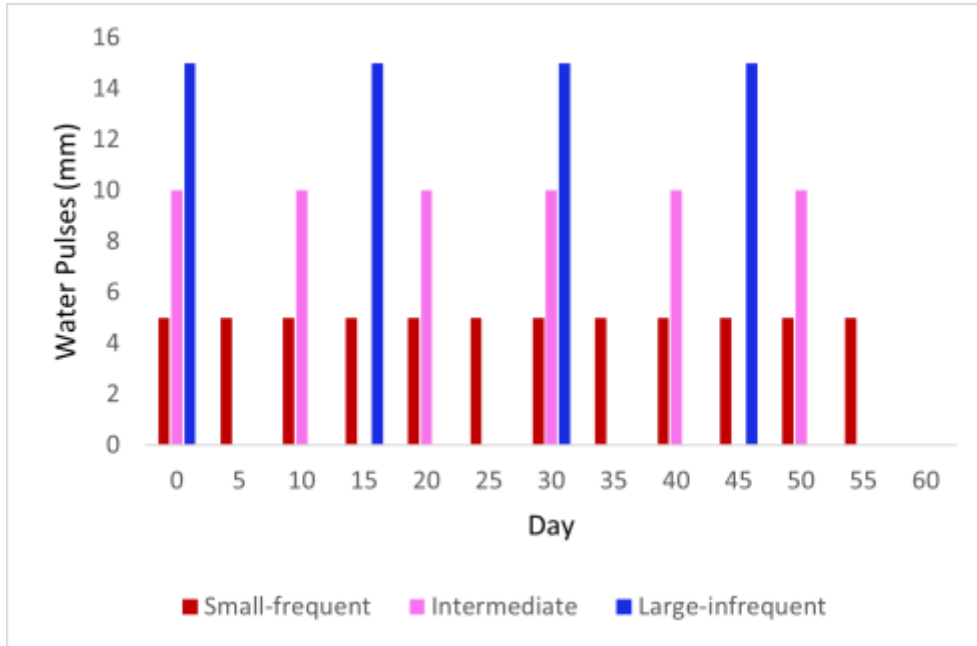


Figure 3. Rainfall pulse treatment schedule for the 60-day incubation.



Figure 4. The Buchner funnel attached to a syringe used to administer watering treatments.

Soil Water Content

The jars were weighed each day on a portable field balance to track the change in mass throughout the experiment. On each watering day, the microbial respiration and mass of each jar was measured before watering. Then, the jars receiving a treatment were watered in the evening after the day's respiration measurements, weighed again, and allowed to sit overnight to control for the Birch effect (Birch, 1964) before being measured for respiration again the next day. After the conclusion of the incubation, the jars remained in the chamber for several days to completely dry. They were then brought to the lab and destructively harvested. The compost was carefully removed from the soil surface, and then soil and compost were placed separately in clear plastic bags until further analysis.

Microbial Respiration

I used an infrared gas analyzer (LI-COR 820, LI-COR Biosciences, Lincoln, NE, USA) every day of the 60-day incubation to measure the rate of microbial respiration. The LI-820, along with several other components including an air filter (9922-05DQ, Parker Hannifin Corp, Lancaster, NY, USA) and a pump (Boxer 12K, Boxer GmbH, Ottobeuren, BY, Germany) were housed in a clear plastic case (Figure 5). The IRGA was connected to software called Flux Puppy that allows the IRGA data output to be visualized and saved onto a laptop (Carbone et al., 2019). The apparatus was connected to a Mason jar lid via Bev-A-Line IV Tubing (2140505 Thermoplastic Processes, Georgetown, DE, USA) with gas

inlet and outlet ports on the lid. A computer fan attached to the inside of the lid ensured well-mixed headspace air. Every day, the lid was attached to each of the 99 treatment jars and the CO₂ concentration was recorded for 3 minutes using the Flux Puppy software. Two additional treatments served as controls for CO₂ measurements: 9 replicates of a 'dry' control consisting of 200 g of soil with the different compost applications and no water additions, and 9 replicates of a 'blank' control consisting of empty jars. The changes in CO₂ concentrations (ppm) through time were converted to microbial respiration ($\mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$).



Figure 5. Flux Puppy setup.

Microbial Biomass

It is difficult to determine microbial community size by direct observation via microscopes in large samples (Paul et al., 1999). Instead, microbial biomass can be extracted from soil in the form of dissolved organic carbon (DOC). I used a chloroform fumigation extraction method (Jenkinson, 1996) to analyze five replicates of each treatment for DOC. The soil was brought to 50% WHC to maximize success of the technique (Oren et al., 2018), so water was added directly to the soil storage bags. They were shaken and massaged until all the water was evenly incorporated. The bags were resealed and allowed to sit overnight. The next day, rewetted soil from each sample was separated into beakers, specimen cups, and metal weigh boats. The weigh boats were put into an oven at 60°C for a wet-dry mass correction. The samples in the specimen cups were extracted with 0.5 M potassium sulfate for the initial measurements, to be compared later to the samples undergoing fumigation. First, 50 mL of potassium sulfate was added to each cup and shaken for an hour, and then mixtures were filtered through Whatman #1 filter paper into scintillation vials and stored in the freezer at -80°C.

The beakers with soils were fumigated in a vacuum desiccator with 30 mL of ethanol-free chloroform for 5 days. After the fumigation, those samples were also extracted with 0.5 M potassium sulfate and filtered into scintillation vials. All samples were then stored in the freeze to await DOC analysis. After thawing in the refrigerator for 2 days, the extracted samples were transferred to glass vials and acidified by adding concentrated hydrochloric acid until the pH was under 2. The samples were run on a

Shimadzu Total Organic Carbon Analyzer (TOC-10V, Shimadzu Corporation, Kyoto, Japan) for DOC. DOC was converted to microbial biomass by dividing mg of DOC per kg of dry soil by an extraction constant of 0.45 (Jenkinson et al., 2004).

Statistical Analysis

All statistical analyses were performed using R version 4.1.0 (R Development Core Team, 2021). I assessed differences in microbial respiration, microbial biomass C, and soil water content between compost and water treatments. I calculated mean cumulative soil respiration and mean soil water content for each of the 99 jars over all 60 days of the experiment. I performed a two-way analysis of variance with interaction effects (ANOVA) and assumed significance of $P < 0.05$. I tested ANOVA assumptions using the Levene's test for homogeneity of variances and the Shapiro-Wilk test for normality. I used the Tukey-Kramer test for all post-hoc analyses.

RESULTS

Soil Water Content

I found that the highest soil water content (SWC) over the 60-day incubation was in the large-infrequent water pulse treatments (15 mm) for all compost applications (Figure 6). A Tukey's post-hoc test found that pulse size significantly changed SWC in all compost treatments (Figure 7). Doubling the amount of compost from 15 g to 30 g significantly increased SWC in the intermediate and large-infrequent pulse sizes, but not in the small-infrequent pulse size. A two-way ANOVA revealed that there was an interaction between the effects of compost and water ($F_{4,72} = 34.62$, $p < 0.05$). The jars treated with 30 g of compost maintained higher SWC post-pulse at all watering levels, as SWC never returned to the level of the dry control. In the treatments with 15 g of compost, the SWC returned to the level of the dry control after pulses in the beginning of the experiment, but towards the end of the experiment also began to stay slightly elevated above the dry control. In the soil-only treatments, the SWC returned to the dry control level after every water pulse.

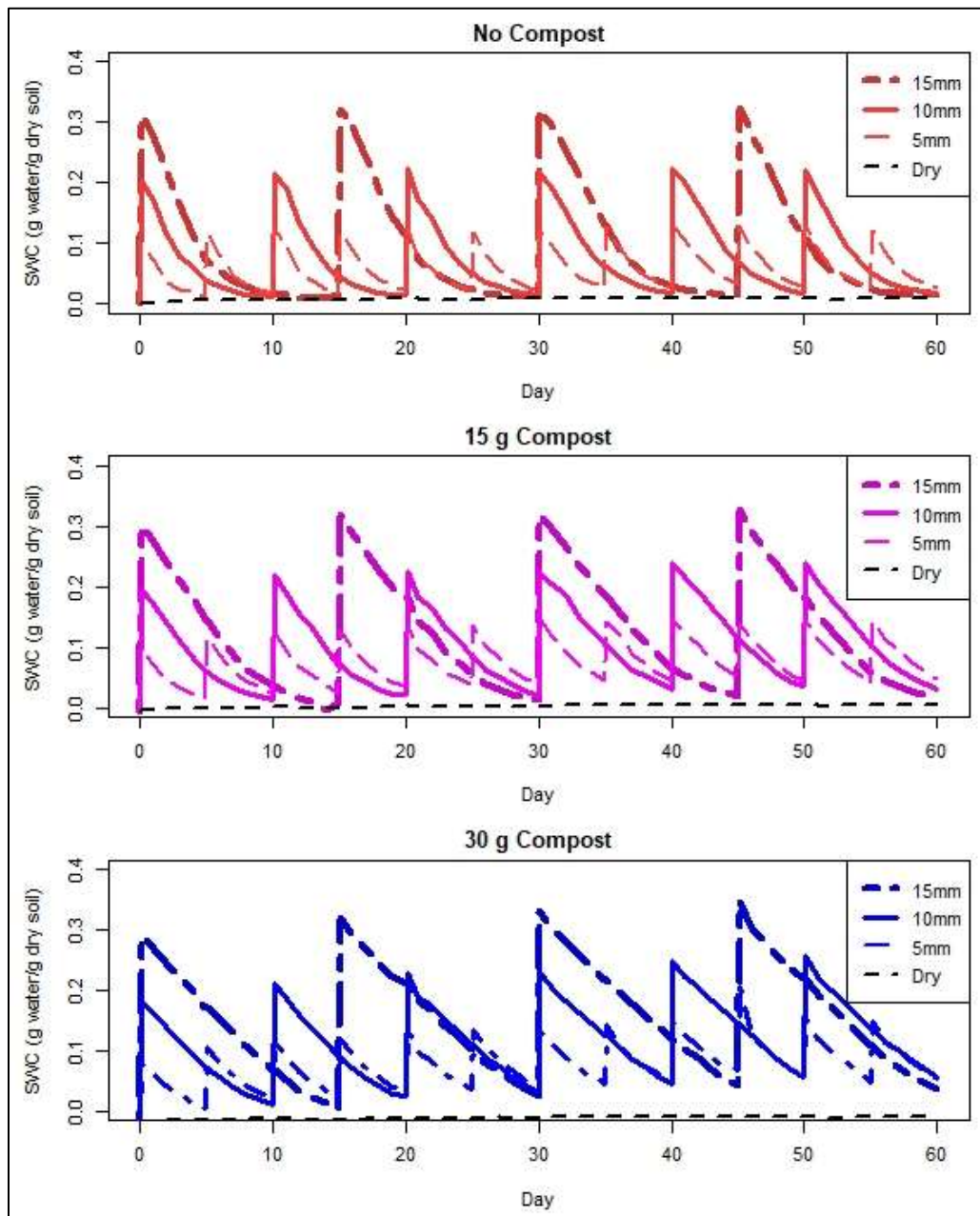


Figure 6. Daily soil water content separated by compost treatment. Values are means of the 9 replicate jars from each treatment combination for each day.

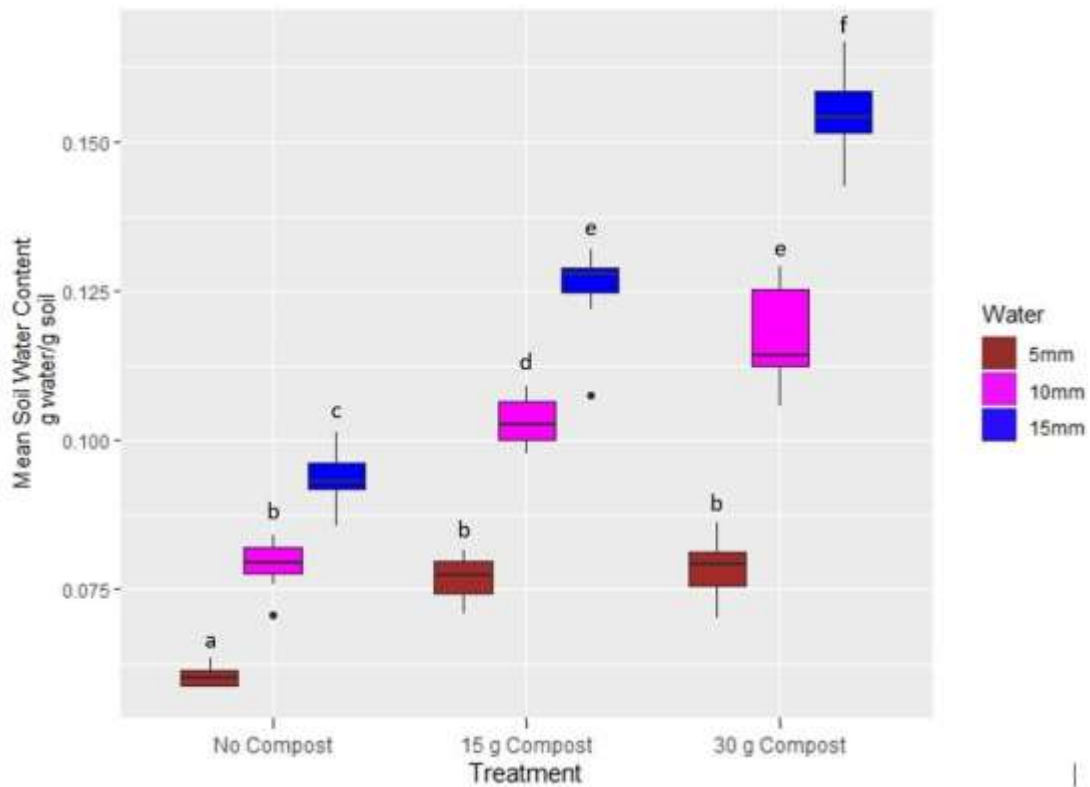


Figure 7. Soil water content separated by treatment with significance groups from post-hoc test. Values are means of the 9 replicate jars from each treatment combination over the 60-day experiment.

Microbial Respiration

On Day 1 of the experiment, the microbial respiration of most jars was very close to 0. After the initial watering event, there was a very high microbial respiration peak for all treatments (Figure 8) that was not seen again for the rest of the incubation. In the soil-only treatment, the large-infrequent pulse went from nearly $0.004 \mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ on Day 0 to $2.302 \mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ on Day 1. Similarly, in the 15 g compost treatments, the large-infrequent treatment jumped from $0.117 \mu\text{mol CO}_2 \text{ m}^{-2} \text{ s}^{-1}$ to $1.942 \mu\text{mol CO}_2$

$\text{m}^{-2} \text{s}^{-1}$, and the 30 g compost from $0.026 \mu\text{mol CO}_2 \text{m}^{-2} \text{s}^{-1}$ to $2.162 \mu\text{mol CO}_2 \text{m}^{-2} \text{s}^{-1}$. I analyzed the effect of compost treatments and water pulse treatments on the cumulative microbial respiration of each jar. The analysis revealed that there was an interaction between the effects of compost and water ($F_{4,72} = 10.26$, $p < 0.05$). I found that in the jars with the large-infrequent pulse, the soil-only samples did not reach peaks as high as either the 15 g or 30 g compost treatments. All large-infrequent pulse treatments had the highest cumulative microbial respiration for all compost treatments (Figure 9). At each watering level, the 30 g compost treatment had a higher cumulative microbial respiration than both the 15 g compost treatment and the soil-only treatment. A Tukey's post-hoc test found that the cumulative microbial respiration was significantly different between several groups (Figure 10). In the soil-only treatments, precipitation size did not significantly change respiration. Adding 15 g compost increased respiration compared to the control, but only with the intermediate and large-infrequent pulse sizes. Doubling the amount of compost increased respiration at all pulse sizes compared to the control, and increased with pulse size, but was only higher than the 15 g at the intermediate and large-infrequent pulse size.

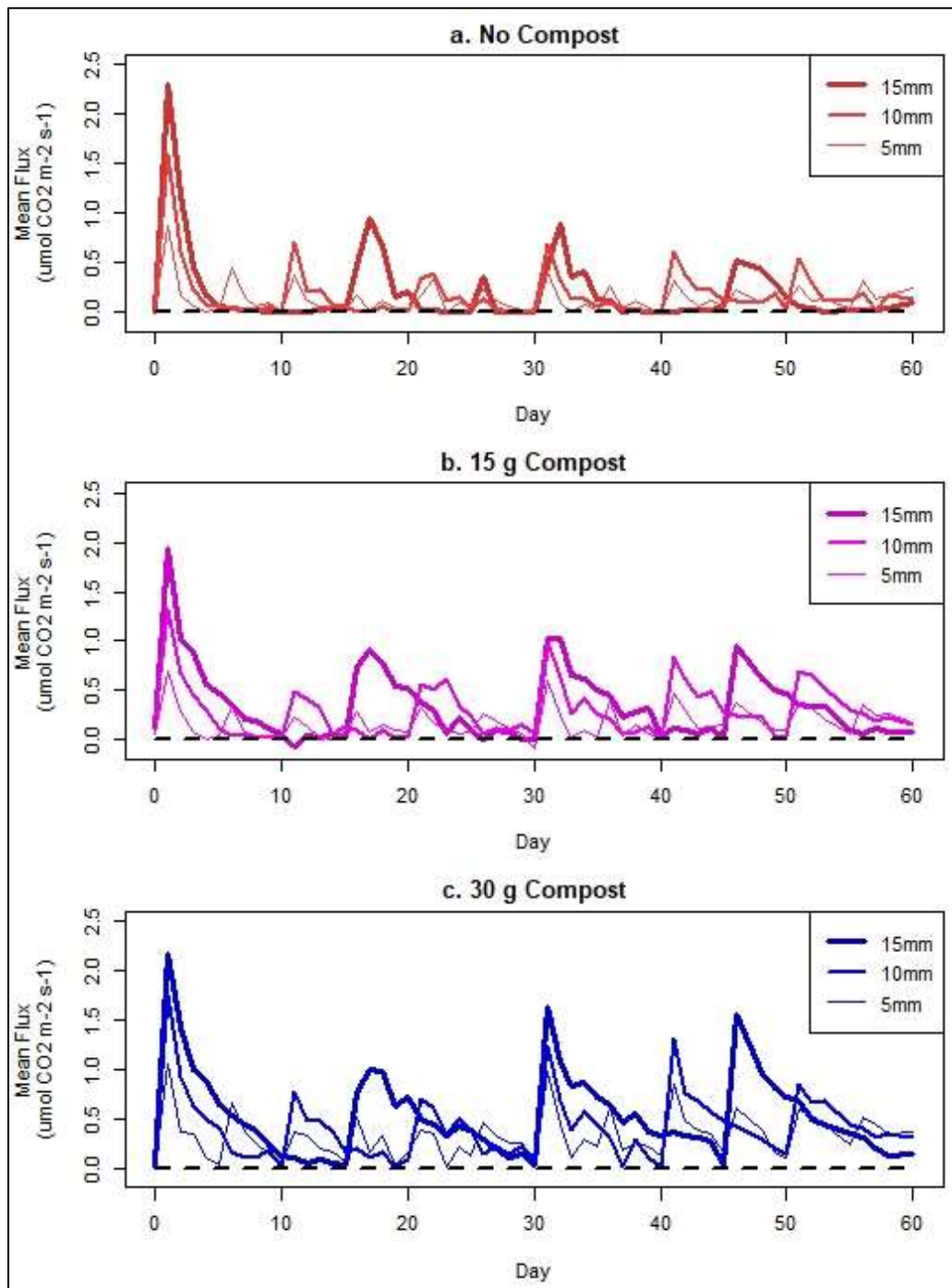


Figure 8. Daily CO₂ measurements separated by compost application. Values are means of the 9 replicate jars from each treatment combination for each day. Dashed line represents $y = 0$.

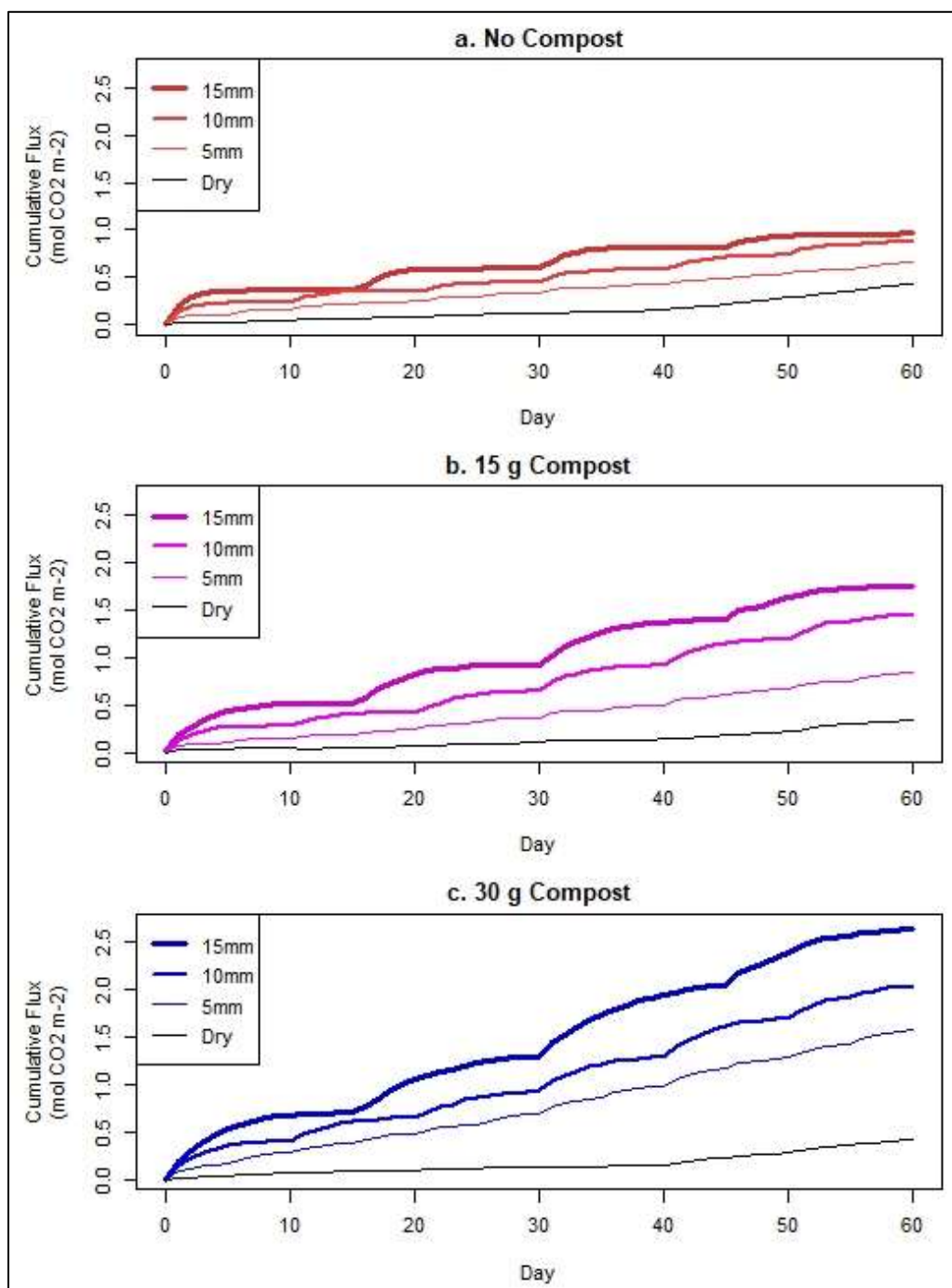


Figure 9. Cumulative microbial respiration added up over the 60-day experiment, separated by compost application. Values are means of the 9 replicate jars from each treatment combination for each day.

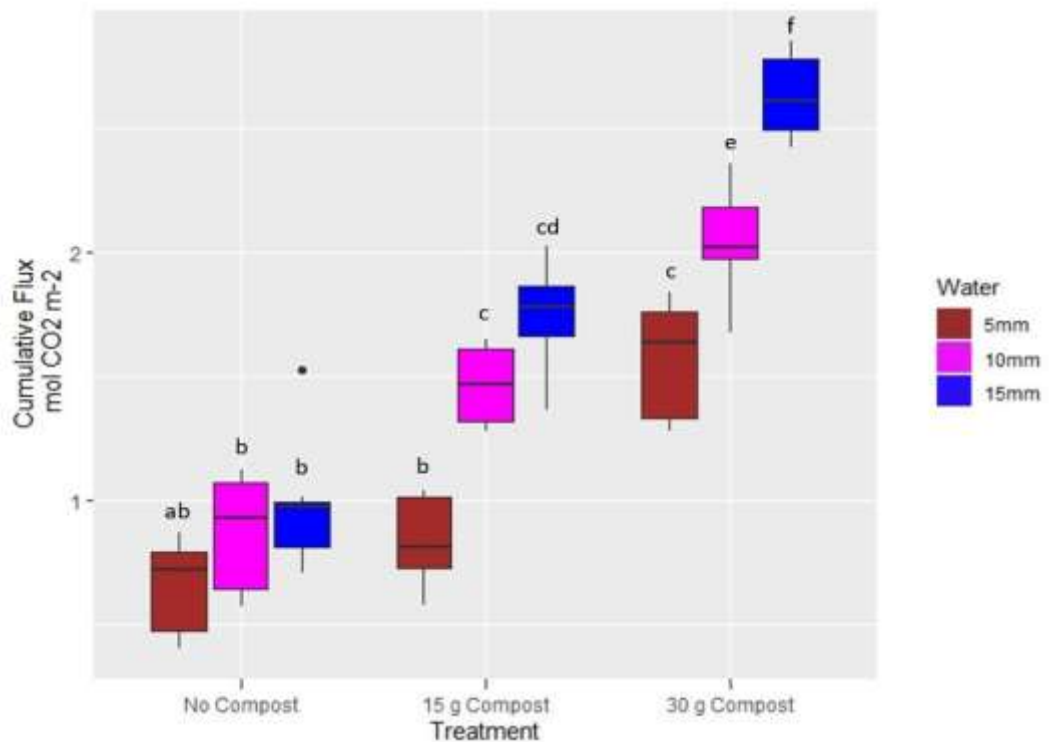


Figure 10. Final cumulative microbial respiration at the end of the incubation, separated by treatment with significance groups from post-hoc test. Values are means of the 9 replicate jars from each treatment combination.

Microbial Respiration vs Soil Water Content

There was a positive linear relationship between microbial respiration and daily soil water content (Figure 11). The slope increased with increasing compost additions, with the soil-only treatment having the lowest slope of 3.31, and the 30 g compost treatment having the highest slope of 4.14. Data points were highly concentrated on the bottom left of each graph in the soil-only treatment but began to spread out towards the right of the graph as soil water content values increased with the 15 g and 30 g compost additions.

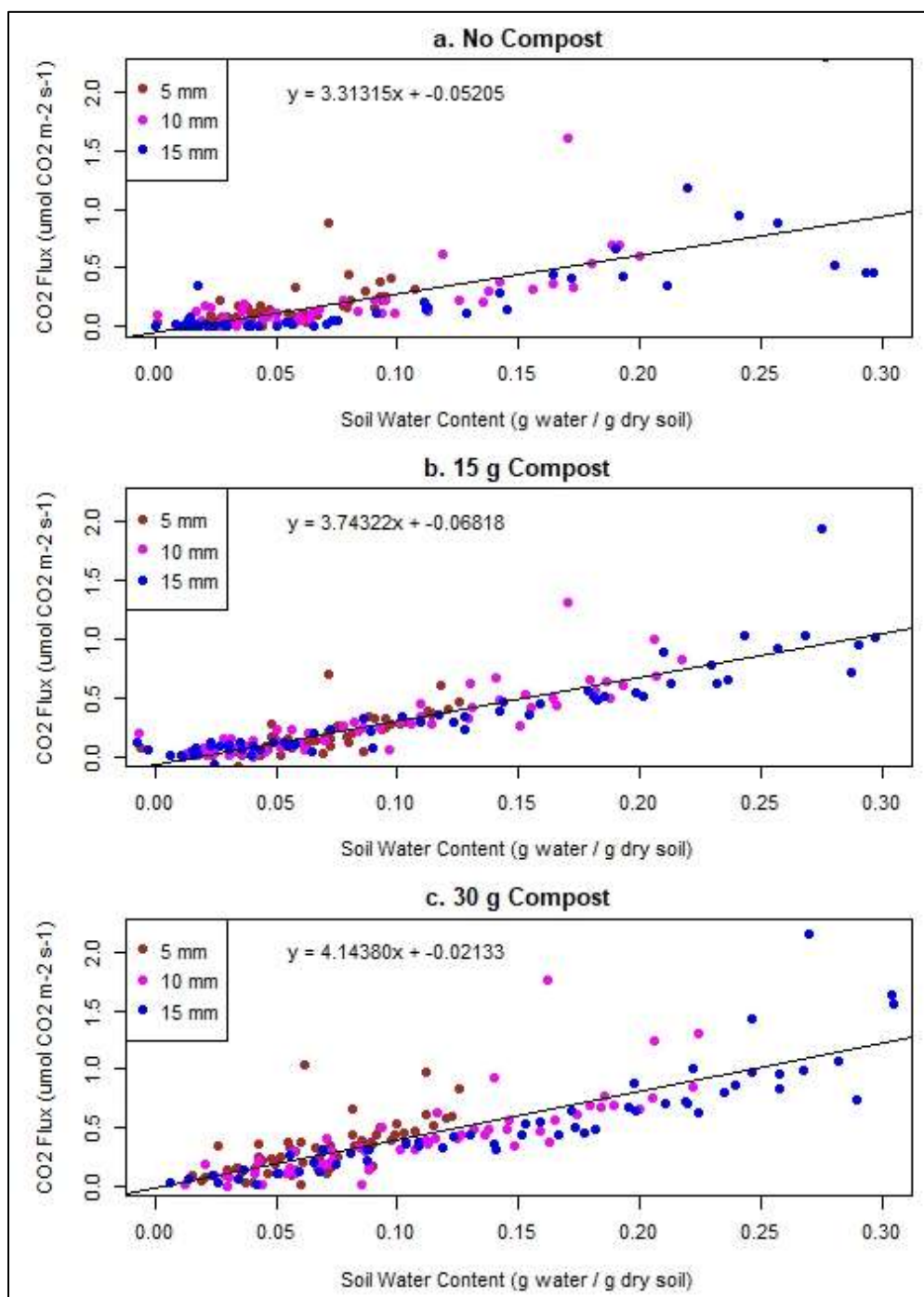


Figure 11. Soil water content vs microbial respiration, with regression lines and equations included in each plot.

Microbial Biomass

For the soil-only treatment, microbial biomass C was highest in the small-frequent watering pulse (5 mm) and lowest in the large-infrequent pulse (15 mm). This is a complete reversal from the results for 15 g compost, where the highest microbial biomass C was in the large-infrequent treatment (Figure 12). For the 30 g compost treatment, the highest value was for the large-infrequent pulse size, and this value was also the highest out of all treatments. In the 5 mm watering treatment, microbial biomass decreased in the 15 g compost application and increased with the 30 g compost addition. In the 10 mm treatment, biomass remained the same between all compost applications. In the 15 mm treatment, biomass increased with increasing compost applications. An ANOVA revealed that there was an interaction between the effects of compost and water ($F_{4,35} = 3.4984$, $p < 0.05$). However, the microbial biomass was not significantly different between most groups. There was only a significant difference between the 15 g compost x small-infrequent pulse treatment and the 30 g compost x large-infrequent pulse treatment ($p < 0.05$), and the soil-only x large-infrequent treatment and the 30 g compost x large-infrequent pulse treatment ($p < 0.05$; Fig 12).

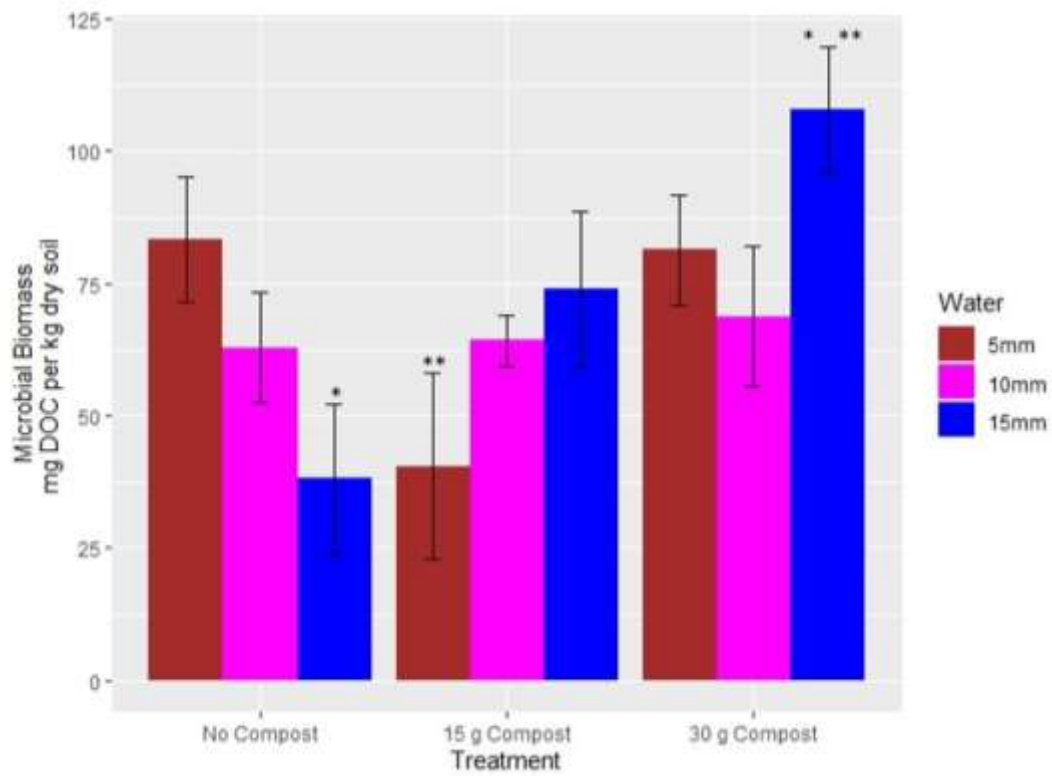


Figure 12. Microbial biomass separated by compost treatment and grouped by water pulse size. Values are means of the 5 replicates from each treatment combination. Bars with a singular asterisk (*) are significantly different from one another, and bars with a double asterisk (**) are significantly different from one another.

DISCUSSION

Key Results

My hypotheses were that microbial biomass, soil water content, and microbial respiration would increase with both compost additions and increasing water pulse size. Microbial respiration and soil water content did increase with increasing compost additions and water pulse sizes, so these hypotheses were supported. Microbial biomass did not have consistent increases with compost additions or water pulse size, so my hypothesis was not supported. Cumulative microbial respiration was highest with large-infrequent pulse size and smallest with small-frequent pulse size, which did not support my hypothesis.

Soil Water Content

My results support my hypothesis that soil water content would be higher after treatments with large-infrequent pulses compared to small-frequent pulses. This is because adding more water to soil leads to higher soil water content. Similarly, Sponseller (2007) found that with increasing rainfall, soil water content remained higher for longer periods of time. My results also supported my hypothesis that the addition of compost would increase soil water content compared to soil-only treatments. Jars with the 30 g compost addition did not return to baseline soil water content levels in between pulses like the soil-only treatments did but remained elevated above the dry control. For example, in the 30 g compost treatment, the small-infrequent pulse dried

out to 0.005 g water g soil⁻¹ on day 5 before watering, but only to 0.04 g water g soil⁻¹ on day 55 before watering. As time went on, jars with compost additions retained more and more water in between pulses, causing an accumulation of water that led to higher SWC. This is likely because the compost layer on top of the soil reduced evaporation rates and improved retention of soil water, which has been found in other studies as well (Movahedi Naeini, & Cook, 2000; Serra-Wittling et al., 1996). In my study, I found that the SWC in the low compost application of 15 g was only slightly elevated above the dry control, if at all, whereas in the 30 g compost treatment there was a much more obvious difference. This is likely because the small layer of 15 g of compost did not aid in reducing evaporation rates as much as the 30 g of compost, which may be significant when discussing the appropriate amount of compost to add to agricultural sites in drylands.

Microbial Respiration

My results supported my hypothesis that microbial respiration would increase with increasing water pulse sizes. This is likely because water pulses activated microbial activity, since microbes remain inactive in the soil until a rainfall event (Orgiazzi et al., 2016). Larger water pulses likely extended microbial activity for longer time periods than smaller pulses. Research has shown that soil water content has a positive effect on microbial respiration (Epron et al., 1999; Davidson et al., 1998; Cook & Orchard, 2008), which would explain why larger water additions cause higher microbial respiration.

Sponseller (2007) found that CO₂ production following rainfall events increased with the length of time between events, which could also explain why respiration was higher in large-infrequent treatments. However, studies have found that microbial activity saturates at a certain pulse size (Huxman et al., 2004, Joly et al., 2017). I did not find a similar threshold in my study, as microbial respiration did not saturate at the intermediate or large pulse size but continued to increase. I do think that at pulses exceeding the highest amount of 15 mm that I used for my study, I may have found a saturation threshold. This would likely occur because my jar conditions would have been flooded above a 15 mm pulse size, causing anoxic conditions and inhibiting microbial activity and respiration (Post & Knapp, 2021).

The large peak seen in all treatments on the first day of the experiment can be explained by the extended period of drought the soil had been subjected to. The site where the soil was collected had not seen consistent rain in over a year. The soil was dried further in an oven when it was brought to the lab. In soils that have not had rainfall for some time, where physiological activity is essentially zero, rainfall first initiates a burst of microbial respiration, caused by several mechanisms including the physical displacement of CO₂ stored in soil pore spaces and microbial respiration (Huxman et al., 2004; Birch, 1964). This is likely what occurred in my soils, which is why I did not see similarly high peaks throughout the rest of the experiment.

I also found that microbial respiration increases with increasing compost additions, likely because compost added more carbon to the soil, which is an energy

source for microbes. Other studies have found that microbial respiration increases with compost additions (Borken et al., 2002; Ryals & Silver, 2013; Zhen et al., 2014) in drylands, but it is typically as a response of stimulated microbial biomass. In my study, I did not find that my microbial biomass results coincided with my microbial respiration results, which may indicate that the elevated microbial respiration in the compost treatments was from the compost itself, and not only from additional microbial activity occurring in the soils.

I found that small-frequent events did not have a higher cumulative microbial respiration at the end of the experiment than large-infrequent events, which did not support my hypothesis. My prediction was based on the fact that frequent rainfall events allow soil moisture to accumulate between events, which can lead to greater infiltration depths and a longer period of activity, including soil respiration, than any single large precipitation event (Schwinning and Sala, 2004). In the soil-only treatments, small-frequent events were not frequent or large enough to allow soil moisture to accumulate, as jars completely dried out within 12 hours of the next watering pulse. In soils amended with compost, jars did not completely dry out between the small-frequent events (Figure 9). This caused the cumulative microbial respiration in the compost treatments to be greater than that of the soil-only treatments (Figure 10). However, the cumulative microbial respiration of the small-frequent pulse treatments was still not great enough to surpass the cumulative microbial respiration of the large-infrequent pulse treatments within compost treatments. Zhao et al. (2021) found that

more extreme precipitation patterns greatly enhanced cumulative soil respiration, which may explain why my large-infrequent pulse treatments showed the highest cumulative microbial respiration. Larger precipitation events stimulated microbial activity more than smaller events.

Microbial Biomass

My microbial biomass results from compost additions varied from my expectations. In the large-infrequent watering treatment, microbial biomass increased with compost additions, supporting my hypothesis that higher compost additions would result in higher microbial biomass. This is supported by studies that link organic matter additions to increases in microbial biomass (Reeve et al., 2011). However, in the other two watering treatments, microbial biomass either decreased or stayed the same with increasing compost additions. Studies have shown that microbial biomass is positively correlated with soil moisture, and that microbial biomass is often constrained by available moisture (Bell et al., 2009; Xu et al., 2013). This led me to hypothesize that large pulse sizes would result in higher microbial biomass. However, in the soil-only treatments, the small-frequent water pulse showed the greatest microbial biomass compared to the other two watering treatments, which does not support my hypothesis that larger water pulses would cause higher microbial biomass.

One potential explanation is that stagnant flood conditions decrease microbial biomass (Unger et al., 2009). Perhaps in the soil-only treatments, with no compost to

absorb the additional water, the jars became water-logged and created anoxic conditions. Thus, large water pulses decreased microbial biomass. However, this was not reflected in the microbial respiration results, so it is unlikely. Another explanation is that soil microbes are concentrated within the top few millimeters of arid soils (Garcia-Pichel & Belnap, 1996), so perhaps there was some sampling error when separating soils for DOC analysis. It also may be the case that there were more microbes in the compost than the soil underneath, or that microbes were concentrated in the soil immediately underneath the compost layer. This may have affected sampling. However, samples were mixed when being transferred from jars to storage bags, so this also seems unlikely.

CONCLUSION

The results from this study suggest that compost amendments and variable water pulses have significant effects on microbial activity in degraded dryland soils. There is a positive relationship between soil water content and microbial respiration, which means any future changes in rainfall patterns will influence microbial respiration rates. Soil water content is influenced by compost additions, with highest compost applications allowing elevated soil water content, which could be important in the context of future drought caused by climate change. Compost may be able to alleviate problems caused by drought, which would be especially important in agricultural sites and restoration sites. Overall, the results of this study can be used to inform future practices for compost applications to agricultural and restoration sites and help land managers understand how future practices may need to evolve based on the variable precipitation changes predicted in the future.

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