Considerations for Compost Application in Irrigated Pasture

Quick Facts

- We undertook a three-year study (2020-2023) in two locations in western Colorado to assess the **efficacy of compost on irrigated pasture on yield, soil organic carbon, and soil health**. We compared 1) compost to 2) synthetic fertilizer, 2) a combination of fertilizer and compost, and 3) controls (no nutrient amendment).
- **We did not detect differences among treatments in soil organic carbon or soil health** metrics after 2 years.
- **Compost plots were less productive** ($p = 0.008$; 1,585 lb./acre +458) compared to fertilized plots and were not different than controls (i.e., untreated) in Year 1. In Year 2 of the study, plots treated previously with compost were not different from other plots, regardless of subsequent management (i.e., return to commercial fertilizer, or if no commercial fertilizer was applied).
- **Salts were not an issue despite high application rates**.
- In irrigated pastures, the risk of invasives due to compost is presumably low since typical management involves nutrient additions and weed management. **There was no increase in invasive species due to treatments in our study.**
- **Results on the efficacy of a 1-time application of compost to increase yield, soil organic carbon, and soil health on irrigated pasture and rangeland** are mixed across many studies (Kutos et al. 2023).** Thus, there is risk involved in this practice as the costs are significant and may not produce comparable yields to fertilizer in irrigated pasture, and soil benefits may be slow to emerge.

Recommendations

- Whether or not compost is the right choice for an operation depends on context and goals of an operation.
- Soils change slowly, and soil health benefits may take longer to emerge than the 2-year timeframe of this study.
- To maximize the potential benefits and reduce risk, we recommend:
    - Timing the application of compost so that organic nitrogen in compost has time to mineralize and can be used by the crop (i.e., fall application for cool-season irrigated pasture in CO).
    - Incorporating compost, using harrowing, creasing, etc., in irrigated pasture to reduce losses.
    - Calculating the compost rate (lbs./acre) based on nitrogen demand of the crop, supply in the compost, presumed mineralization rates, and soil tests to supply the desired lbs./N per acre. If another nutrient (such as P or K) was more limiting than N, estimates could be based on that nutrient to meet crop needs.

Introduction

Why compost?

There is increasing interest in agricultural practices that reduce reliance on synthetic fertilizers, while enhancing soil health and increasing soil organic carbon. In past studies on rangeland, compost additions (Silver. et al 2018) have positively impacted soil characteristics, including soil organic carbon, while increasing yield compared to areas where compost was not used. Silver et al. (2018) and associated studies (Ryals et al. 2014 & 2016) were conducted in annual grasslands where increased productivity inputs due to compost led to increases in soil organic carbon. Increasing soil organic carbon is desirable because it is one of the most important constituents of soil. Soil organic carbon influences nutrient availability, water holding capacity, water infiltration and is the main source of energy for microorganisms. Finally, there is an abundance of carbon credit programs that are coming into the marketplace. Major companies are implementing compensation platforms to incentivize farmers/ranchers to implement practices that enhance soil organic carbon stocks. Soil carbon gains can be purchased, providing another source of farm/ranch revenue and influence rural economic vitality.

The efficacy of compost on soil organic carbon and yield has mixed results (Kutos et al. 2023). Additionally, few studies address the context of western Colorado. We undertook this experiment to evaluate the impact of compost on soil health and yield and help develop recommendations that are regionally relevant for using compost on irrigated pasture.

Research Objectives

1. Evaluate the effect of a 1-time compost application on grass productivity and species composition in irrigated pasture.
2. Evaluate how a 1-time compost application affects soil carbon and other soil health metrics in irrigated pasture.
3. Develop recommendations for compost application in irrigated pasture using results from our study, in conjunction with other studies.

How Would Compost Increase Soil Organic Carbon?

Vegetative growth of plants is the engine that drives below-ground soil organic matter, much of which is comprised of soil organic carbon. Compost application can contribute to net soil carbon accumulation by increasing inputs and/or reducing losses. Compost amendments can increase soil carbon through greater productivity inputs via either aboveground litter or belowground root carbon inputs. Compost could also ameliorate soil carbon loss if erosion or microbial decomposition is reduced. The effectiveness of compost application to increase soil carbon is dependent on the context, including climate and previous land-use history. Sites with a history of prior disturbance and depleted soil carbon stocks enable greater proportional increases of soil carbon pools following compost amendments. Additionally, extreme or variable temperature and precipitation patterns (e.g. drought-prone areas) can exert greater influence on vegetation productivity and composition than compost amendments.

If compost additions enhance soil carbon stocks, how long will it persist? This is another important consideration, especially in terms of understanding the longevity of benefits that may be realized. The fate of soil carbon is a function of the soil type (e.g. pH, texture), moisture, temperature, and the soil microbial community. Not all soil carbon is made equal, and different pools of carbon can be defined by how it forms, functions, and persists in the soil. Soil carbon that is unprotected (particulate organic carbon) is an important energy source for microbes but is also vulnerable to being lost either through decomposition (microbial respiration) or physical disturbance (e.g. tillage). Carbon that is associated to clay minerals (mineral-associated carbon) or trapped within aggregates is less accessible to microbial decomposers and can remain in the soil for much longer. Both forms of carbon (unprotected or protected) are important and understanding these distinctions can help inform soil health or climate mitigation goals if soil carbon gains are realized.

Risks of Compost

As with any agricultural practice, there are risks and benefits involved. Though our study focused on irrigated pasture, past long-term studies demonstrated risk on native rangeland on the Northern Colorado Front Range (Blumenthal et al. 2017). In this study, researchers documented significant increases in invasive annuals in plots where compost had been applied years earlier, and where cheatgrass was initially a low percentage of the cover. Even small amounts of nitrogen, combined with other nutrients (e.g., phosphorous) can encourage growth of undesirable species for years after compost is applied (Blumenthal et al. 2017). Colorado rangelands are dominated by perennial grasses (grasses that live more than one year). This grass-type is generally less adept at using nutrients compared with annual grasses. Thus, there is a risk of encouraging increases in annuals due to nutrient application, even in low nitrogen composts. Conversion from a perennial-dominated system to an annual dominated system would undermine carbon sequestration, forage production and other ecosystem goals. Thus, caution is warranted when choosing where to apply compost. Considering land type, land condition, goals and risks is essential. California rangelands are dominated by annual species, which reduces risk of compost since conversion from a perennial system is not a factor, as observed in Ryals et al. (2016). Underlying characteristics of a site/ region, such as timing and amount of precipitation, soil, topography and dominant plant groups account for much of the variability in results across studies. Thus, especially in rangelands, we stress the importance of considering the ecosystem type, state and potential unintended consequences of compost application.

In irrigated pastures, the risk of invasives due to compost is presumably low since typical management involves nutrient additions and weed management. Additionally, in well-management fields there is high plant and cover which lowers the opportunity for invasives to establish. Pastures can be renovated if needed, whereas restoration on rangeland following cheatgrass invasion is extremely difficult. Taken together, the risk of encouraging invasives due to compost application is low in irrigated pasture.

Applying Compost in Irrigated Pasture

Calculating rates, timing, and compost quality

There is a wide range of documented compost application rates and a lack of clarity on how to determine the application rate. We based the rate (tons/acre) on the nitrogen demand of the crop relative to the available nitrogen in the compost, and accounting for soil nitrogen availability (Table 1). We also used assumptions about nitrogen mineralization rates and availability in the compost (20% of total N estimated to be plant available in year 1 – (Ward Labs Soil Test Guide). We found that compost P & K concentrations exceeded forage requirements, and the C:N ratio of the compost was C:N = 18, which is within the desired range for grass hay (C:N 10 – 20 less plant available N short-term, but could supply longer-term(slow-release). The calculated amount of compost to achieve the desired N rate, may be quite expensive (discussed below), ranging from 10 -16 tons per acre (compost was $45/ton + delivery), with 6 tons per acre used in the fertilizer plus compost treatment.

Several sources are listed below for estimating compost application rates.

- Diagnosing Saline and Sodic Soil Problems
- Best Management Practices for Manure Utilization
- Interpreting Compost Analyses
- Choosing a Soil Amendment
- A Review of Soluble Salts in Compost
- Compost Application Rates for California Croplands and Rangelands for a CDFA Healthy Soils Incentives Program
- Assessing Compost Quality for Agriculture
- Ward Laboratories Guide

Site	Treatment	Compost Mass (tons/acre)	Compost-C (tons/acre)	Compost-N (lbs/acre)	Fert-N (lbs/acre)	P (lbs/acre)	K (lbs/acre)
Ridgeway	Compost	18.8	4.69	90	---	347	628
Fruita	Compost	10.4	2.60	50	---	193	349
Ridgeway	Fert+Compost	6	1.50	28.8	61.2	111	201
Fruita	Fert+Compost	6	1.50	28.8	21.2	111	201
Ridgeway	Fert	0	---	---	90	50	---
Fruita	Fert	0	---	---	50	40	40

Table 1: Calculated amendment rates used in our study. Note that compost amendments were optimized for forage N requirements (accounted for existing soil N and assumes 20% of org N is 'plant available in Yr1).

Compost quality may be of concern. For example, we tested our compost's Fungal:Bacteria ratio which was of interest to our stakeholders. Salts may be an issue if compost is applied repeatedly in areas where soils are saline, and compost is derived from manures. We recommended testing compost for salts and any other concerns (and comparing composts if more than 1 industrial-scale composter is available).

Effects of Compost on Yield, SOC and Soil Health

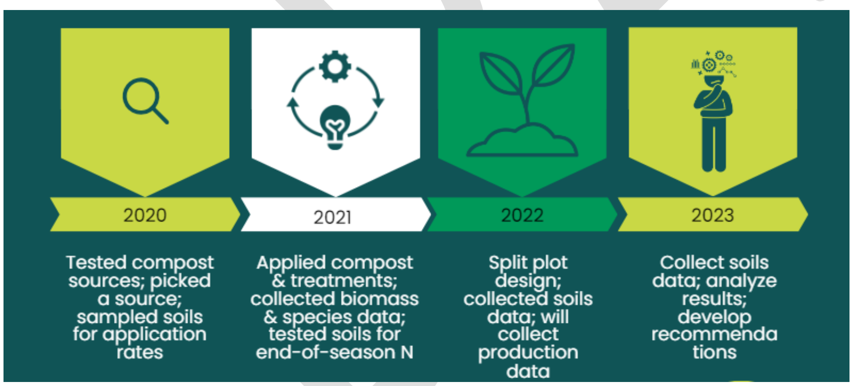

Figure 1: Timeline of the experiment described in this study.

Background

At two sites (fields in Ridgway and Fruita, CO), we established 4 treatments: compost, fertilizer, compost+fertilizer, and control (24 treatment plots across 2 sites, see Figure 2 below). We monitored these treatment plots over 3 years. As discussed above, compost, fertilizer and compost+fertilizer all had equal available N based on the assumption that 20% of the N in compost would be plant available in year 1 (Table 1). Treatments were applied in spring (March and April) 2021. Compost was not integrated, and only applied on top of pasture vegetation. We collected yield data at peak production before first and second hay cuttings in 2021 and 2022. We collected species composition data in 2021 and 2023. We collected soil cores with a hydraulic soil auger one and two calendar years after compost application (springs 2022 and 2023). Several soil cores were collected per treatment, and aggregated by horizon at depths 0-10 cm, 10-20 cm, 20-50 cm and 50-100 cm.

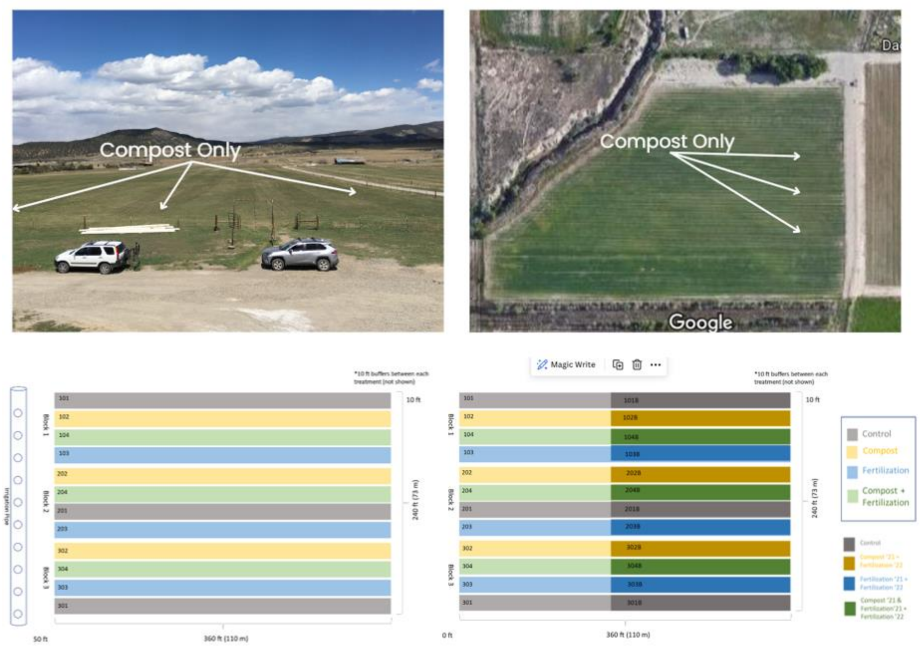

Figure 2: Diagram of treatment layout in our experiment. Each treatment was applied as follows: Compost Only x 3 @ 2 Sites | Compost + Fertilizer 3 @ 2 Sites | Fertilizer Only 3 @ 2 Sites | Control x3 @ 2 Sites

Results

Pasture Yield

- Compost plots were *less* productive (*p = 0.008*; 1,585 lb./acre ±458) compared to fertilized plots and were not different than controls (i.e., untreated) in year 1.

- However, any negative effect from compost was not apparent in year 2 (no differences among plots treated differently in Yr1 in Yr2).
- Plots where fertilizer was applied in Yr2 were significantly more productive than non-fertilized plots ($p = 0.001745$), but there was no difference among treatments from year 1.

Species Composition

- There were no differences among treatments in the proportion of exotic species pre and post treatment.

Soil Organic Carbon & Soil Health

- A 1-time application of compost did not increase soil organic carbon stocks. There were *no* differences among treatments at any depth sampled.
- We detected no treatment effects on total nitrogen stocks.
- Despite high application rates, compost did not increase soil salinity.
- There were no treatment differences among treatments in soil health metrics analyzed, which included:
  - Carbon (TC, SIC, SOC)
  - Nitrogen (NH4, NO3, TON)
  - Phosphorus (Olsen P)
  - POX-C (proxy for microbial/active carbon)
  - Water holding capacity
  - Beta-glucosidase (Microbial extracellular enzyme)
  - PH
  - Soil Respiration
  - Water Stable Aggregates
  - CEC (Cation Exchange Capacity)
  - Salts

Other Studies

When compared with other studies, compost on irrigated pasture and rangeland has mixed results. A 2023 synthesis (Kutos et al. 2023) reviewed studies on rangeland and found that in 15 out of 37 studies (40% of studies), compost did *not* lead to an increase in soil organic carbon compared to the control. In 22 out of the 37 studies (60% of studies), compost *did* lead to an increase in soil organic carbon compared to the control. The same review showed that yield was *not different* in compost versus control in 50% of studies (Kutos et al. 2023). More locally two studies from the Northern Colorado Front Range showed conflicting results on irrigated pasture (one study found an increase in soil organic carbon and the other found no increase - Mclelland et al. 2022 and Mikha et al. 2017, respectively) (Table 2). Given these results, our study was not anomalous. Collectively, these results suggest that compost may not always enhance soil organic carbon or plant productivity. Paying close attention to timing of application, amount applied and integration may increase success.

Table 2: Comparison of select studies on compost and impact on soil organic carbon.

Study	**Was there an increase in SOC?**	**Amount applied**	**How long did it take?**	Location of Study
Mclelland et al. 2022	Yes, in top 10 cm	4.9 T/Ac in Irr. Pasture ('12, '18) (109 N lb/acre)	Observed after 8 yrs	Northern Front Range, CO
Kutos et al. 2023	15 studies = No; 22 studies = Yes, difference between compost/ control = 59%	Various	Various, ranges from 1 yr to 5 yr	Various
Mikha et al. 2017	No	9.8 T/Acre and 4.9 T/Acre	2 years	Northern CO
Ryals et al. 2014	Yes	7 kg/m2 or 28 T/Acre; C:N 11	Observed after 3 yrs	California; various sites

Costs of Compost

Cost is always a consideration in agriculture. We estimated the costs of compost on our study compared to synthetic fertilizer (Table 3).

Table 3: Comparison of costs of compost and fertilizer used in this experiment.

Site	Treatment	Compost Added (tons/acre)	Compost (lbsN/acre)	MAP (lbsN/acre)	Urea (lbsN/acre)	Compost ($/acre)	MAP ($/acre)	Urea ($/acre)	Total ($/acre)
Ridgway	Compost	18.8	90	----	----	$362	----	----	$362
Fruita	Compost	10.4	50	----	----	$201	----	----	$201
Ridgway	Fert+Compost	6	29	----	61	$117	----	$54	$171
Fruita	Fert+Compost	6	29	----	21	$117	----	$19	$135
Ridgway	Fert Only	0	----	10.58	79.42	----	$15	$71	$85
Fruita	Fert Only	0	----	8.46	41.54	----	$32	$37	$49

Discussion & Recommendations

Given that results on composts' efficacy are mixed, there is risk involved in this practice as the costs are significant and may not produce intended results. Whether or not compost is the right choice for an operation depends on context of an operation, including crop N demands, dominant vegetation type if irrigated pasture or rangeland - i.e., annuals or perennial grassland, presumed mineralization rates, etc., and that operations unique goals (i.e., if they are willing to risk reduced yields in order to reduce reliance on synthetic fertilizers, or for other goals).

To maximize the potential benefits and reduce risk, we recommend timing of application relative to crop use so N in compost has time to mineralize before that crop needs the N. We also recommend some kind of incorporation, such as harrowing, in irrigated pasture to reduce losses. Manure-based composts can also be high in salts, so we recommend measuring soil and compost salinity and estimating the effect of compost amendments on soil salinity to make sure you are within the range of the crop/forage salinity tolerance.

Changes to soil carbon can be slow, and it is possible that differences would be realized given more time. Detecting small changes in soil carbon is difficult against a large background and spatially-variable carbon stock. Another challenge in quantifying soil organic carbon change is accounting for soil *inorganic* carbon, which is characteristic of arid and semi-arid climates with underlying geology that promotes high concentration of carbonates. For example, soil inorganic carbon accounted for the majority

(~75%) of total carbon stocks at our Fruita site. If detecting soil carbon change is the primary goal, we recommend maximizing the time in between sampling events (longer treatment duration) and using prior or existing data to account for spatial variability and to determine the number of samples required to maximize detection of change. The [Stratifi Soil Sampling App] can help address questions on the number and distribution of samples needed.

Summary Table: Risk and Benefits of Compost Associated with Various Land Types

Land Type	**Potential Risks**		**Potential Benefits**	**Considerations**
	Invasives	**Costs**		
Irrigated Pasture*	Low	Moderate	Yield: Moderate – mixed results. SOC: Moderate – mixed results. Soil Health: Moderate. Mixed results.	Risk tolerance, Timeline and timing of application, Incorporation potential, etc.
Rangeland**				
Degraded	If site is already invaded by annuals, risk is low.	Moderate. Expensive relative to forage gain.	Moderate. Some studies show increased production.	Consider what is causing degradation, and if that can be mitigated. State of the site and goals. In some cases, high N may inhibit the establishment of native bunchgrasses.
Not Degraded	Moderate-High. Annual invasives may increase over time.	Moderate. Expensive relative to forage gain.	Moderate. Some studies show increased production and increased SOC.	Dominant species on the site, presence of cheatgrass seeds and seedlings, and state of the site. In CO, perennials are dominant.

*Irrigated pasture definition

**Rangeland: Land dominated by native vegetation and managed extensively). Table addresses risks, benefits and considerations of compost as a land management practice. Ratings are based on this study and other studies.

Citations

1. Blumenthal, D. M., LeCain, D. R., & Augustine, D. J. (2017). Composted manure application promotes long-term invasion of semi-arid rangeland by Bromus tectorum. Ecosphere, 8(10), e01960.

2. Kutos, S., Stricker, E., Cooper, A., Ryals, R., Creque, J., Machmuller, M., ... & Silver, W. L. (2023). Compost amendment to enhance carbon sequestration in rangelands. *Journal of Soil and Water Conservation*, *78*(2), 163-177.

3. McClelland, S. C., Cotrufo, M. F., Haddix, M. L., Paustian, K., & Schipanski, M. E. (2022). Infrequent compost applications increased plant productivity and soil organic carbon in irrigated pasture but not degraded rangeland. *Agriculture, Ecosystems & Environment*, *333*, 107969.

4. Mikha, M. M., Widiastuti, D. P., Hurisso, T. T., Brummer, J. E., & Davis, J. G. (2017). Influence of composted dairy manure and perennial forage on soil carbon and nitrogen fractions during transition into organic management. *Agriculture*, *7*(5), 37.

5. Ryals, R., Kaiser, M., Torn, M. S., Berhe, A. A., & Silver, W. L. (2014). Impacts of organic matter amendments on carbon and nitrogen dynamics in grassland soils. *Soil Biology and Biochemistry*, *68*, 52-61.

6. Ryals, R., Eviner, V. T., Stein, C., Suding, K. N., & Silver, W. L. (2016). Grassland compost amendments increase plant production without changing plant communities. Ecosphere, 7(3), e01270.

7. Silver, W. L., Vergara, S. E., & Mayer, A. (2018). Carbon sequestration and greenhouse gas mitigation potential of composting and soil amendments on California's rangelands. California Natural Resources Agency, 62.

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