Costs and Ecological Benefits of Organic Amendments Added to Erosion Control Structures



December 2023

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This material is based upon work that is supported by the National Institute of Food and Agriculture, U.S. Department of Agriculture, under award number 2021-38640-34723 through the Western Sustainable Agriculture Research and Education program under project number G322-21-W8614. USDA is an equal opportunity employer and service provider. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the view of the U.S. Department of Agriculture.

Executive Summary

This cost analysis approximates the labor, material, equipment and transportation costs associated with applying organic amendments to erosion control structures at five ranches located throughout New Mexico: two in Rio Arriba County, one in Mora County, one in Santa Fe county, and one in Eddy County. At each ranch, 18 erosion control structures (“rock run-downs”) were built at small headcuts. Mulch and compost were each applied to six structures at each ranch and half of the structures at each ranch were seeded with native grass seed in a full factorial design. The results of this analysis found that each structure alone cost ~$21 ($7-$28 range, depending on if rocks were on site and if heavy equipment was used). Mulch added upslope erosion control structures added $16 of cost, and compost upslope added $19 per plot. Seeding upslope cost approximately $7 per plot. There was little effect of adding organic amendments or seeding (biological management activities) to erosion control structures (physical management activities) within one year, so producers may not need to invest the additional cost because the rock structures alone were highly effective.

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Introduction

This report outlines the approximate financial costs and ecological effects of pairing biological interventions, such as organic amendments and seeding, to physical intervention erosion control structures on arid rangelands. It is intended to be used as a guide for other producers and land managers interested in improving the efficacy of erosion control structures on their land. We acknowledge that many of the factors contributing to the costs and outcomes may be unique to each region and ranch studied. This report, therefore, is meant to provide estimates, averages, and ranges to help land managers in decision making and budgeting for erosion control measures.

Study Motivation

Water and wind erosion degrade soil in ways that impact nutrient availability, water retention, plant community health, and forage production on rangelands, in turn posing threats to food security, human health, and agricultural communities.[1] Erosion can harden or remove topsoil, which decreases water penetrability and lowers nutrient levels, reducing the soil's overall ability to sustain plant growth. With less plant growth, there are less root structures in the ground to help hold the soil in place, which ultimately exacerbates soil loss and creates a perpetual cycle of worsening erosion conditions. Historically, soils in the American West have been depleted due to repeated misuse of land including uncontrolled grazing, mining, and pollution.[2] As the effects of historic and current erosion conditions begin to accumulate, steps to control erosion become increasingly more crucial. Retaining topsoil cover and increasing vegetation growth are two goals that work together to mitigate the impacts of erosion and prevent it from worsening.

New Mexico has 43 million acres of agricultural land in private farms and ranches, with many of these lands are at risk of wind and water erosion and in need of active intervention to restore soil health. Sheet-rill erosion is the number four top rangeland resource concern in New Mexico, and plant productivity is number one.[3] New Mexico had the highest average bare ground (37.0%) on non-federal rangelands in the United States and bare ground in the state increased at the highest rate (11.3%) from 2004-2015,

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[1] Edwards, B. L., Webb, N. P., Brown, D. P., Elias, E., Peck, D. E., Pierson, F. B., Williams, C. J., & Herrick, J. E. (2019). Climate change impacts on wind and water erosion on US rangelands. *Journal of Soil and Water Conservation*, *74*(4), 405–418. https://doi.org/10.2489/jswc.74.4.405

[2] Whitbeck, L. (2018, March 6). *An Introduction to Erosion Control*. Quivira Coalition. https://quiviracoalition.org/erosion-control/

[3] *Grazing Land Assessments | Natural Resources Conserv*ation Service. (n.d.). Www.nrcs.usda.gov. Retrieved September 4, 2023, from https://www.nrcs.usda.gov/ceap/grazing-lands

suggesting that the risk of erosion likewise increased and continues to do so.[4] Thus, finding cost-effective methods to mitigate the effects of erosion, build soil health, and support robust native plant productivity is especially important for improving ecosystem resilience and our pursuit of sustainable agriculture across the arid and semi-arid Southwest.

Several rock structure techniques such as one rock dams, Zuni bowls, and rock rundowns have shown promise for addressing erosion on rangelands.[5] Applying amendments such as mulch and compost may enhance the erosion-mitigating effects of the rock structures themselves. In this study, we characterize mulch as a woody material usually chipped or shredded and added as a surface dressing. Compost is decomposed feedstock such as food waste, manure, and woody material that retains active and abundant microbes such as bacteria and fungi. Organic amendments have been shown to decrease soil erosion through decreasing runoff, increasing soil's water holding capacity, and increasing water infiltration into the soil surface.[6] Previous studies have also shown that aboveground net primary productivity has increased when organic amendments were applied to rangelands through increasing the nutrient pool available to plants and reducing soil moisture loss.[7] Reestablishing plant communities and seed banks by spreading native seeds can also replenish native and climate-appropriate plant species and in turn establish root structures that help reduce erosion. Little is known, however, about how combining physical interventions (rock structures) with organic matter/biological interventions (mulch, compost/seeding) could accelerate soil health and reduce erosion.

In this study, we tested whether adding organic amendments and seeds to rock erosion control structures results in multiplicative benefits on arid rangelands at five ranches across New Mexico. Through these comparisons, this analysis hopes to serve as a guide for producers looking into pursuing erosion control with physical and biological methods (Table 1) and costs they may incur.

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[4] *National Resources Inventory Rangeland Resource Assessment*. (2018). https://www.nrcs.usda.gov/sites/default/files/2022-10/RangelandReport2018_0.pdf

[5] Maestas, J, Conner, S, et al. *Hand-Built Structures for Restoring Degraded Meadows in Sagebrush Rangelands Examples and lessons learned from the Upper Gunnison River Basin, Colorado.* (2018). https://www.wlfw.org/wp-content/uploads/2018/05/CO-NRCS_Range_Technical_Note_40_Gunnison_Zeedyk-Structures_5-18.pdf

[6] *Compost Utilization for Erosion Control.* (n.d.). Extension.uga.edu. Retrieved August 14, 2023, from https://extension.uga.edu/publications/detail.html?number=B1200&title=compost-utilization-for-erosion-control

[7] Gravuer, K., Gennet, S., & Throop, H. L. (2019). Organic amendment additions to rangelands: A meta‐analysis of multiple ecosystem outcomes. *Global Change Biology*, *25*(3), 1152–1170. https://doi.org/10.1111/gcb.14535

Rock rundowns to address headcuts

Headcuts are vertical or near-vertical drops along the beds of erosion channels. They are steep elevation changes caused by water erosion and expose bare soil, making it even more susceptible to future water erosion.[8] Rock rundowns are best utilized on low-energy headcuts (<1.5 ft tall) to prevent upstream erosion and stabilize the sites. When building the structure, it is important to modify the incline of the headcuts relative to surrounding soils so it is a stable angle (3:1 slope), and that the middle point is the lowest so that water runs through the structure and not around it. Live plant matter should be protected and the rocks should be placed as tightly as possible to avoid water contact with the soil of the head cut.[9]

Figure 1: Rock rundown structure

[8] Wyoming Game and Fish Department. (2022, January 20). *What is a Headcut and how does one form?*. YouTube. https://www.youtube.com/watch?v=rniHUi-KA8U

[9] Maestas, J, Conner, S, et al. *Hand-Built Structures for Restoring Degraded Meadows in Sagebrush Rangelands Examples and lessons learned from the Upper Gunnison River Basin, Colorado.* (2018). https://www.wlfw.org/wp-content/uploads/2018/05/CO-NRCS_Range_Technical_Note_40_Gunnison_Zeedyk-Structures_5-18.pdf

Compost

Compost has only recently started being applied to arid and semi-arid rangelands, and is more commonly used on crop lands and gardens in wetter climates. In general, compost has been shown to be more productive than applying raw organic materials since they have been converted to a pathogen-free material with soluble nutrients in a biological form that acts as a slow-release fertilizer.[10] It has been shown to increase soil nutrient content, water retention, structural soil stability, and plant biomass on semi-arid rangelands.[11] Compost can be produced onsite or purchased. It should consist of mostly carbon sources, known as brown matter, and a smaller ratio of nitrogen sources, known as green matter. If produced onsite, moisture and heat levels of the pile should be monitored closely for optimal decomposition. Based on the scale of application, compost can be applied using a wheelbarrow and shovel, with a manure spreader, or with a blower truck on broader landscapes. Please refer to the technical guide linked in Table 1 for more information on compost production and use on rangelands.

Mulch

Like compost, mulch can be produced onsite or purchased. Best practices suggest that the mulch should consist of 100% organic wood (or other organic material depending on availability and need) that has been mechanically cut using a wood chipper or other machinery. When applied correctly in certain contexts, organic wood mulch has been shown to be an effective and practical means of controlling erosion and runoff on disturbed land prior to vegetation growth. The material also helps to retain water, moderate soil temperatures, prevent crusting of the soil surface, and foster the growth of vegetation.[12] Mulch should not be applied too densely, as this prevents light and air from reaching the soil. The permeability, composition of material, and purpose of mulch application all impact how mulch should be applied. Please refer to Table 1 for guidance.

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[10] *Compost on Rangeland.* (2018). https://ucanr.edu/sites/soils/files/316038.pdf

[11] Leger, A. M., Ball, K. R., Rathke, S., & Blankinship, J. C. (2022). Mulch more so than compost improves soil health to reestablish vegetation in a semiarid rangeland. *Restoration Ecology.* https://doi.org/10.1111/rec.13698

[12] *Soil Erosion Control Mulches, Blankets and Mats.* (n.d.). https://www3.uwsp.edu/cnr-ap/UWEXLakes/PublishingImages/resources/restoration-project/soil%20erosion%20control%20mulches%20mats%20blanketsMETROPOLITAN%20COUNCIL.pdf

Native Seed Application

Applying native seeds to erosion control structures can help further reduce erosion through promoting plant establishment. Increasing the presence of a native plant community can create robust soil root structures, stabilize soil, create healthy underground microbiomes, and increase nutrient cycling in the soil.[13] Native and climate-appropriate seeds are overall more likely to germinate and survive in arid New Mexico conditions and also may have the root structures most conducive to stabilizing New Mexico soil types.[14] The addition of native seeds helps ensure the presence of a positive plant community around the structures and hastens the process of achieving native plant establishment.

Table 1: Educational and implementation practice resources for rock rundowns, organic amendments, and seeding.

Rock Rundowns	Mulch	Compost	Seeds	General Carbon Amendments
Erosion Control Field Guide by Quivira Coalition	Conservation Practice Standard Mulching (Code 484)	Rural Dryland Composting by Quivira Coalition	New Mexico Range Plants by New Mexico State University	NRCS Soil Carbon Amendment Conservation Practice Standard
An Introduction to Erosion Control by Quivira Coalition		Tipsheet: Compost - ATTRA – Sustainable Agriculture	A Field Guide to the Grasses of New Mexico by New Mexico State University	

Methods

Ranch Contexts

This study was conducted across 5 ranches located throughout New Mexico, four of which are situated in the Northern half of the state and the last in the Southeastern corner. The five participating ranches were selected because they all reported that they are struggling with past and ongoing soil erosion issues to varying extents. These participating ranches steward a total of ~62,000 acres across a variety of dryland ecosystems on private, leased

13 Vannoppen, W., De Baets, S., Keeble, J., Dong, Y., & Poesen, J. (2017). How do root and soil characteristics affect the erosion-reducing potential of plant species? Ecological Engineering, 109, 186–195. https://doi.org/10.1016/j.ecoleng.2017.08.001
14 Allison, C., & Ashcroft, N. (n.d.). New Mexico Range Plants Circular 374. https://pubs.nmsu.edu/_circulars/CR374_LG.pdf

and public lands. The following detailed ranch descriptions are included to help practitioners identify a ranch similar to their own and assess results as they may pertain to their operation and particular erosion issues.

Rio Arriba 1

Location: Tierra Amarilla, NM

The Ranch is a cow/calf operation on 1,500 private acres and 2,000 forest service acres in Rio Arriba County in northern New Mexico located north of the Carson National Forest. The private land has been managed by the family since the 1880's and they started raising cattle in the 1950's. The family currently manages 50 head of large frame Angus cattle, and are looking to explore smaller frames as a part of their future management plans. The cattle graze in the pastures where the erosion control structures are located from November to April and are fed hay in that area throughout the winter. In addition to raising cattle, the property also currently has 100 acres of irrigated hay fields. The ranch is a family-run operation and does not have any hired employees.

Set at about 7,000 feet of elevation, the property's soil is a heavy white and yellow clay with pockets of rock. Water does not easily penetrate this dense soil and topsoil runs off easily approximately one inch down. The ranch is located in a valley at the bottom of the rain catchment for the Rio Nutrias and Terrero Creek which then join the Rio Chama. Located at a transition from sage, juniper, and piñon to ponderosa pines and aspen trees, the property spans Crystalline Subalpine Forests (21b), Crystalline Mid-Elevation Forests (21c), Sedimentary Subalpine Forests (21e), and Sedimentary Mid-Elevation Forests (21f).[15]

In recent years, the ranch has been challenged by milder winters and unpredictable heavy rainfall. Instead of gradual, longer winter snow melts and runoffs, the ranch has experienced smaller pulse precipitation events both during the spring and summer monsoon rain season. Rainfall for the area averages 16.2 inches per year, and temperatures range from an average daily mean of 65˚F during the hottest months and 23˚F during the coldest months of the year. The area receives an average of 62.2 inches of snowfall per year. Ultimately, these changing rain conditions have reduced forage for wildlife and the cattle operation alike. A lack of plants and their stabilizing root systems has reduced soil stability and exacerbated existing erosion, which has left important ranch infrastructure at risk of damage from increased erosion conditions. The sites for the experiment were chosen due to their proximity to a nearby road in one section and area near an ephemeral waterway in another, which had been threatened by these erosion conditions.

[15] Griffith, G. E., Omernik, J. M., Mccraw, M.M., Muldavin, E., Jacobi G. Z., Canavan, C.M., Schrader, T.S., Mercer, D., Hil, R., Moran, B.C. (2007). *Ecoregions of New Mexico.*- https://upload.wikimedia.org/wikipedia/commons/b/b8/New_Mexico_EPA_ecoregions.pdf

Rio_Arriba_2

Location: Alire, NM

The ranch is a second generation operation. The property is located in Rio Arriba County in Northern New Mexico, just west of Carson National Forest. The ranch consists of over 20,000 acres of non-contiguous land which includes private land, leased land, Bureau of Land Management permits, and Forest Service property. The ranch maintains a cow/calf operation that currently has 200-250 head of medium-sized Black Angus cattle and employs short-term rotational grazing, prioritizing forage availability in order to fulfill the goal of holistic resource management.

Situated in the valley lands surrounding a stretch of the Chama River North of the Abiquiu Reservoir, the ranch touches the Foothill Woodlands and Shrublands (21d), Sedimentary Subalpine Forests (21e), and Sedimentary Mid-Elevation Forests (21f) US EPA Ecoregions.[16] These ecoregions are known to be largely comprised of pinyon-juniper, oak, Engelmann spruce, ponderosa pine, aspen, and Douglas-fir woodlands, with a diversity of understory of shrubs, grasses, and wildflowers interspersed between a mosaic of tree stands and meadows. The ranch's acreage includes a variety of forested areas, dry land, rolling hills, canyons and prevalent stream terraces.[9] The soil types on the property include medium-textured silt and clay soils with some salt and calcium carbonate deposits. Soil is well-developed in some areas, especially on top of stream terraces, while it is less developed and more erodible in other areas.

Overall, the property sits at about 7,500 feet of elevation, receives approximately 14 inches of rain and 2.5-3 feet of snowfall annually. Temperatures range from below-freezing temperatures in winter to about 85˚F in summer. Recently, summers have been hotter and more intense rains have passed through, but winter runoffs remain plentiful due to consistent snowfall. The experimental sites sit on the edge of a 300-foot deep stream terrace and were chosen in order to prevent erosion from worsening in the steep area below.

Santa Fe County

Location: La Puebla, NM

The Farm was homesteaded in the early 1950's from the Bureau of Land Management. The farm is located north of Santa Fe in Northern New Mexico. The BLM added a dam to the

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[16] Griffith, G. E., Omernik, J. M., Mccraw, M.M., Muldavin, E., Jacobi G. Z., Canavan, C.M., Schrader, T.S., Mercer, D., Hil, R., Moran, B.C. (2007). *Ecoregions of New Mexico.*- https://upload.wikimedia.org/wikipedia/commons/b/b8/New_Mexico_EPA_ecoregions.pdf

[9] Meter, K (2021, June 14) *Building Soil Health in New Mexico: Tools for Community Self-determination*. https://www.crcworks.org/nmsoilhealth.pdf

east side of the property in the early 1980s, reducing the land to 140 acres. 1-3 horses have been present since the mid 1980s-present. Chimayo chile was grown with drip irrigation for 3 years in the 1980s-1990s. Two calves were purchased as stockers in 2016 and reared until sold at auction; the property has been under a drought waiver since 2017 and new stockers were added in 2023.

The property sits at 5,900 feet of elevation. This site is characterized as part of the North Central New Mexico Valley and Mesa (22f) and is covered with scattered piñon pine, oneseed juniper trees, Blue Grama Grass, and Indian Rice Grass.[17] The soils Chupe-Riverwash complex, 1 to 3 percent slopes which are fine sandy loam in fan remnant landforms from sandstone layers.

The mean annual temperature is 52˚F and the site receives an average of 11.4 inches of precipitation annually, 7.4 of which falls in the warm months (May–October).[18] The road and remaining flat pastures are threatened by erosion in large rain events following drought. The erosion control structures were selected in sites to begin to protect the road system from the frequent erosion events that wash out the road to the house, as well as to protect an area of flat, level land that could be put into chile production in the future.

Mora

Location: Wagon Mound, NM

The Ranch located on 13,000 acres of leased land which includes private, Bureau of Land Management, and Forest Service allotments. The rancher runs a cow/calf operation with 220 head of primarily Black Angus and Black Baldy cattle. The cattle are grass-efficient and small framed, making them well adapted to the grass-fed operation. The rancher occasionally hires help for projects or hosts apprentices at her ranch, but has no consistent employees.

The property sits at about 6,000 feet of elevation and is generally rocky with only a few feet of soil above the parent material of Dakota Sandstone. The area is characterized by the Upper Canadian Plateau Southwestern Tablelands (26l).[19] In the area where the structures are located, the soil is a highly erodible sandy loam. The vegetation on the property includes Big Bluestem Grass and Blue Grama Grass.

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[17] Griffith, G. E., Omernik, J. M., Mccraw, M.M., Muldavin, E., Jacobi G. Z., Canavan, C.M., Schrader, T.S., Mercer, D., Hil, R., Moran, B.C. (2007). *Ecoregions of New Mexico.*- https://upload.wikimedia.org/wikipedia/commons/b/b8/New_Mexico_EPA_ecoregions.pdf

[18] *La Puebla, NM: Weather Forecast and Conditions* (2023). Accessed December 12, 2023, from https://weather.com/weather/today/l/La+Puebla+USNM1068:27:US

[19] Griffith, G. E., Omernik, J. M., Mccraw, M.M., Muldavin, E., Jacobi G. Z., Canavan, C.M., Schrader, T.S., Mercer, D., Hil, R., Moran, B.C. (2007). *Ecoregions of New Mexico.*- https://upload.wikimedia.org/wikipedia/commons/b/b8/New_Mexico_EPA_ecoregions.pdf

The property receives about 15 inches of annual rainfall, most of which falls during the monsoon season in late summer-early fall. Temperatures range from 90-95˚F in summer months to around 32˚F in winter months. Recently, winter snows have turned into spring rains and monsoons have been weaker than usual, causing drier conditions. Old trailing and sheep grazing on the property have also contributed to erosion on the ranch, and erosion is more prevalent where there is evidence of past roads or trails. The erosion control structures were all placed in areas impacted by trailing and were chosen to start near the house and work outward.

Eddy

Location: Queen, NM

The ranch spans over 25,000 private and BLM acres in southern New Mexico just north of Guadalupe Mountains National Park. Settled by the rancher's grandfather in 1913, the operation remains family run with no hired help. The ranch is a cow/calf operation and has approximately 200-300 head of large-frame Angus cattle. The cattle are monitored closely in a grazing area until about ½ the forage is gone, when they are then rotated to a new pasture. The ranch utilizes dirt stock tanks to catch water, so their grazing rotations depend on water availability. Each pasture is typically only grazed once a year, but that also fluctuates due to water availability. Historically, the ranch has raised goats and sheep, but the family sold their herd due to mountain lions 20 years ago. Evidence of past sheep grazing is still prevalent and contributes to erosion conditions. The property is littered with old mezcal pits from Mezcaleros and remnants of homesteaders, including dugouts and evidence of overgrazing, all of which have also contributed to current erosion conditions.

The ranch sits at about 6,000 feet of elevation, and has a mixture of dense clay and gravel soils, both highly erodible. The ranch consists of both desert and mountain regions and western side of the property has rocky canyons and more jagged topography. The land is characterized as Chihuahuan Basins and Playas (24a) and Chihuahuan Desert Grasslands (24b).[20] Some of the main plant species include Piñon, Alligator Juniper, and some Ponderosa Pines. The prominent grass species include Blue Grama, Side Oats, and Giant Sacaton. There are also cactus species like Century Plants, Blue Agave, Cholla, Yucca, and many more species.

The area's average rainfall is 13.4 inches, its average snowfall is 6 inches, and it has a yearly average temperature of 77˚F.[21] The property experiences wildfires approximately once every 5 years, some of which have destroyed fences and pipelines. Besides the risk of

[20] Ibid.
[21] Mission & Statistics | Eddy County, NM. (n.d.). Www.co.eddy.nm.us. Retrieved August 4, 2023, from http://www.co.eddy.nm.us/268/Mission-Statistics

damaging infrastructure, the fires have also prevented regrowth of key species for wildlife like Black Brush and Mountain Mahogany. Grasses and smaller forage species often regrow well after wildfires, but so do new weed species. Old growth trees often suffer and do not regrow easily for 15-20 years after a fire.

Inconsistent periods of heavy rain and drought have caused damage to ranch infrastructure, washed out areas on the ranch, and caused forage to weaken. During drought periods, forage tends to weaken and become very dry. Subsequent extreme rains then wash out land that has become vulnerable due to the weakened forage and root structures. After long periods of rain, the forage tends to grow back much fuller and stronger before it is dried out once again during the next drought period. These dramatic fluctuations have become more intense in recent years and cause damage to infrastructure such as roads and fire breaks, wash out areas on the property, and prevent consistent forage growth. The sites chosen for this study were relatively shallow arroyos compared to deeper headcuts and gullies on the property. They were chosen due to their proximity to a road both for convenience and to prevent erosion from damaging ranch infrastructure.

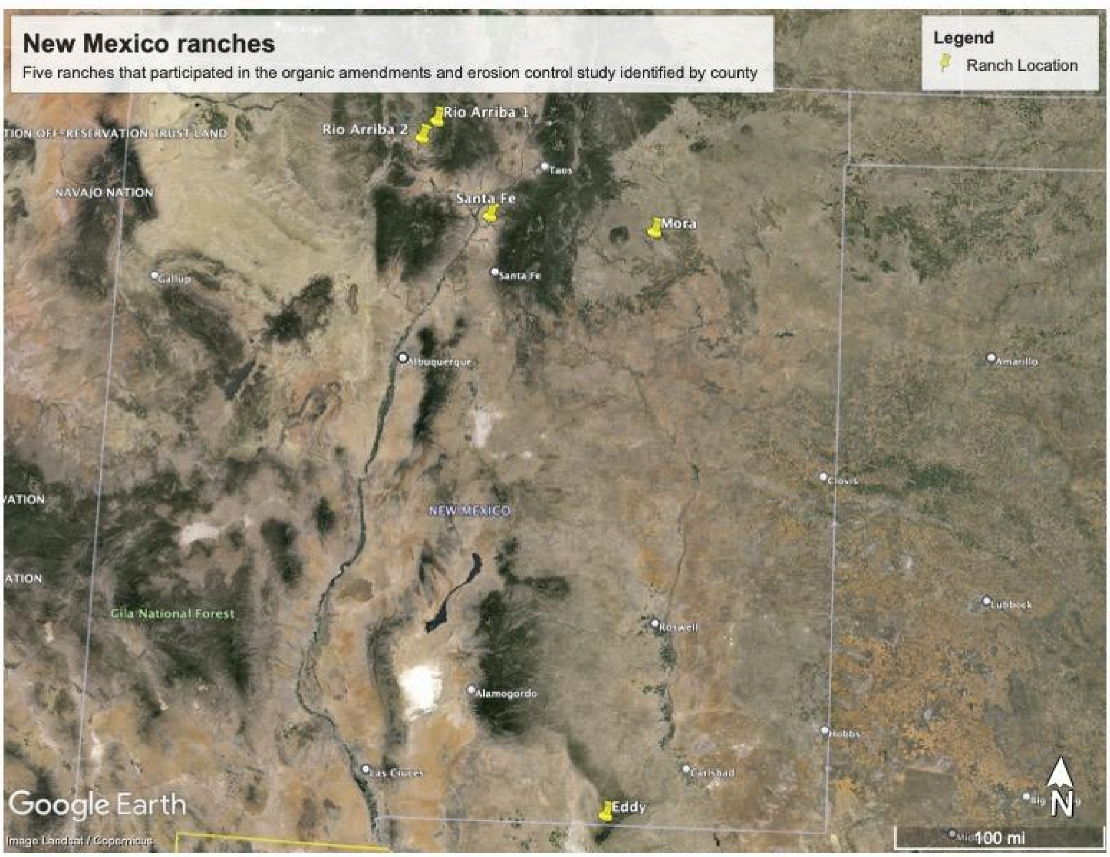

Figure 2. Location of ranches in the study identified by nearest town name in New Mexico.

Experimental Design

For this study, rock rundown structures were placed on 18 active erosion headcuts at each ranch (with the exception of the Mora county ranch, which used nine headcuts because we did not need to use a seeding treatment; see below). Producers suggested headcuts that were the most vulnerable to erosion damage, including areas that were at risk of damaging infrastructure.

On a 5m x 5m five meter wide area upslope of each structure, we added two treatments in a full factorial design: organic amendment (three levels: ¼ in of compost (¼ in depth), ¼ in of wood mulch (¼ in depth), and control) and seeding (two levels: native seed mix added and control) with three replicates per treatment combination. With this design, we could assess if a simple amendment like mulch (shredded woody material) or a more resource-intensive amendment (compost) would have an effect on soil and plant performance to more rapidly reduce the effects of erosion.

Premium Compost was purchased from Soilutions in Albuquerque, NM. The compost was composed of approximately 46% organic matter and it had a pH of 8. It had a ratio of .62 of Nitrogen, .31 of Phosphorous, and .71 of Potassium.[22] The compost was applied above the erosion control structure at about 1/4 inch depth and approximately .2 cubic yards were applied to each structure using a rake and wheelbarrow.

Wood mulch was purchased from Soilutions in Albuquerque, NM. The mulch consisted of chipped blonde wood. It was applied at approximately ¼ inch depth above the erosion control structure to create a blanket effect over the ground. Approximately .2 cubic yards of mulch was applied to each structure simply using a wheelbarrow and shovels.

[22]https://soilutions.net/collections/pick-up-compost-soil-mulch-at-soilutions/products/copy-of-premium-compost

Figure 3: Left: Truck loaded with approximately 1-1.5 y3 of compost. Right: Mulch pile ready to be applied to site

2.5 lbs of native seeds were dispersed between 9 structures at each ranch except for the Mora county ranch, where none of the structures required seeding due to a robust seed bank. One or more New Mexico native grasses were added to each ranch as follows: Rio Arriba #1: Sideoats grama and Slender Wheatgrass; Rio Arriba #2: Alkali Sacaton and Slender Wheatgrass; Santa Fe: Slender Wheatgrass; Eddy: Sand Love Grass, Sideoats Grama. The seeds were dispersed by hand evenly across the 5m x 5m plot into either the bare ground or any applied amendments.

Cost-Benefit Analysis Design

Preliminary cost and qualitative data are based on information gathered during the construction phase of the experiment, post-experiment interviews with each rancher, and a cost investigation phase used to create the necessary cost assumptions. Preliminary cost information was gathered by recording labor hours and gathering receipts from material purchases. Other costs were gathered through participant interviews, contacting suppliers, and making informed careful assumptions. Ranchers were also interviewed in order to gather qualitative information about their lived experiences throughout this study, their ecological observations, and any additional costs they accrued that may not have been noted in our documentation. After acquiring all possible cost information, applicable assumptions and calculations were created in order to determine a realistic cost per structure.

For this cost-benefit analysis, we weighed the costs of constructing the rock structures and the added costs of supplementing these structures with organic amendments and native seeds against the ecological benefits of erosion control. The evaluated costs include labor, materials, and delivery/transportation. These costs were added together and divided by the number of replicates in order to determine an average cost per plot for each amendment. We then compared these cost calculations to the cumulative ecological benefits of each treatment type to create an overall cost analysis for each amendment (compost, mulch, control). Ultimately, our goal with this analysis was to provide information about the most cost effective and beneficial treatments land managers can pursue to most impactfully reduce erosion on their land.

Ecological Monitoring

Baseline ecological measurements were taken at time of structure construction in fall/winter 2021. In order to examine rapid responses to erosion control activities at each replicate, the sites were re-measured one year later in 2022.

We assessed erosion control impacts on erosion/accretion of the downstream channel, soil characteristics, and plant community and vegetation.

- Erosion/Accretion: A profile contour gauge was placed approximately 1m below the rock structure to assess the continued erosion or deposition of sediment in the studied headcuts. As per Kornecki et al. (2008), the gauge is a linear instrument with sliding pins, that were placed perpendicularly across the headcut and the device's 19 pins were released to different depths to conform to the slope and depth of each headcut. From these pins, we measured each headcut's depth and slope at 19 points.[23]
- Infiltration rate: Infiltration rate is a measure of how fast water penetrates soil. Water infiltrates more rapidly in drier soils, and as water begins to replace air in soil's pores, the infiltration rate slows and eventually reaches a steady rate.[24] Infiltration rate is determined by soil texture, which is an inherent characteristic of the soil, and structure, which can change based on compaction, organic matter content, and other stressors. Infiltration rate was measured with a single ring infiltrometer (15 cm diameter) in a randomly selected interspace. 444 mL of water was added and the time for infiltration was recorded, then the process was repeated with a second 444 ml.

[23] Kornecki, T.S., Fouss, J.L., and S.A. Prior. A portable device to measure soil erosion/deposition in quarter-drains. *Soil Use and Management*, *24*, 401-408.
[24]Brouwer, C., Prins, K., Kay, M., & Heibloem, M. (1988). Irrigation water management: irrigation methods. *Training manual*, *9*(5), 5-7. https://www.fao.org/3/S8684E/s8684e00.htm#Contents

Figure 4: CRI Project Manager Garcia measures the infiltration rate of arid rocky soils.

- Aboveground biomass: We used a randomly placed 45 x 45cm PVC square to clip all plants to ground level. Material was placed in paper bags, dried at 60 C for 3 days, oxidized material was removed with forceps to capture material that was likely to have been alive in the previous 1 year, and weighed to 0.01 g.
- Vegetation transects: Vegetative species richness and proportion bare ground was captured using the line intercept method.
- Aggregate stability: Soil aggregate stability is a measure of a soil's capacity to facilitate air and water movement. Soils are an aggregated matrix of sand, silt, and clay, and the structure of soil matrices regulate the movement of air and water to plant roots. It is desirable for plants to have a matrix that is porous, but able to retain its shape when subjected to external forces. Aggregate stability was measured on 6 haphazardly collected surface samples using methods from Herrick et al. (2001).[25] This method would not capture soils that could not be collected on the sieve (category "0") but was consistent across all treatments.
- Soil Organic Carbon: Soil carbon was measured by taking one soil core in each study plot (2 cm diameter, ~12 inch depth) and soil samples were sent to Ward Laboratories (https://www.wardlab.com/) where soil organic and inorganic carbon levels were analyzed using the combustion method.

[25] Herrick, J. E., Whitford, W. G., De Soyza, A. G., Van Zee, J. W., Havstad, K. M., Seybold, C. A., & Walton, M. (2001). Field soil aggregate stability kit for soil quality and rangeland health evaluations. *Catena*, *44*(1), 27-35.

Results

Cost Summaries

Labor Costs
The time spent on labor in this study is based on the amount of time it took per person to transport and gather materials, build erosion control structures, and spread soil amendments. The time it took to spread seeds was negligible, so it was not calculated into the final cost per plot. Some ranches used equipment, such as a backhoe, during the process of building the erosion control structures. The difference in time it took to build the structures by hand compared to the time using machinery was noted. Time measurements were gathered through participant interviews, notes from time of construction, and mapping distances to travel between Soilutions in Albuquerque, NM (where amendments were purchased) to each property.

A wage rate of $16.61 was used to calculate labor costs. This rate was based on the U.S. Bureau of Labor Statistics' *May 2022 State Occupational Employment and Wage Statistic*s average hourly wage for New Mexico farm workers working with ranch animals.[26] Labor costs are considered both for construction and transportation and are based on the total hours worked and the number of people working.

Some ranches hosted a workshop during which up to 20 participants helped build the rock structures. In this analysis, we are considering every voluntary participant in building the structures to be a paid employee, and that volunteers worked about half of the total construction time reported by participating ranchers. So, for the purposes of estimating a consistent average cost per structure across all 5 ranches, we are choosing to include the labor costs of workshop participants, although in reality, voluntary participants were not paid to assist at the workshops. Hosting these educational events actually provided many hours of volunteer labor towards building the structures and could be a viable cost-saving mechanism for other ranchers looking to build rock rundowns on their land. Hosting workshops is also an effective way to share knowledge and build community between ranchers. This benefit is not quantified in this study, but is crucial to note nevertheless.

[26]New Mexico - May 2022 OEWS State Occupational Employment and Wage Estimates. (n.d.). Www.bls.gov. Retrieved May 13, 2023, from https://www.bls.gov/oes/current/oes_nm.htm

Figure 5: Participants learning how to construct rock rundown structures

Table 2. Data and calculated (green heading) costs of labor per structure for constructing rock rundown structures and adding either compost, mulch, and/or seeds at five ranches. A wage rate of $16.61 was used to calculate labor costs.

Ranch	Management	Total time to gather (h)	Total time to build/spread (h)	Labor cost per structure	Total time to transport (h)	Labor transport cost per structure
Rio Arriba #1	Rock	2	6	$7.38	0	$0.00
	Compost	0	3	$8.31	5.1	$14.12
	Mulch	0	3	$8.31	5.1	$14.12
	Seeds	0	0.25	$0.46	0	$0.00
Rio Arriba #2	Rock	1	6	$6.46	0	$0.00
	Compost	0	3	$8.31	5.1	$14.12
	Mulch	0	3	$8.31	5.1	$14.12
	Seeds	0	0.25	$0.46	0	$0.00
Santa Fe	Rock	1	6	$6.46	3	$2.77
	Compost	0	3	$8.31	3.2	$8.86
	Mulch	0	3	$8.31	3.2	$8.86
	Seeds	0	0.25	$0.46	0	$0.00
Mora	Rock	4	5	$16.61	0	$0.00
	Compost	0	1.5	$8.31	3	$16.61
	Mulch	0	1.5	$8.31	3	$16.61
Eddy	Rock	4	4	$7.38	0	$0.00
	Compost	0	3	$8.31	10	$27.68
	Mulch	0	3	$8.31	10	$27.68
	Seeds	0	0.25	$0.46	0	$0.00

Equipment Costs

Some of the ranchers used equipment that they had already owned, such as a backhoe. Costs associated with equipment ownership, such as equipment depreciation, will not be considered in this analysis since equipment was not used for more than one eight-hour work day. Instead, for the purposes of this study, we will be assuming all equipment was rented for a daily rate. To calculate this rate, the average cost to rent a small backhoe in Albuquerque, NM for one day was averaged from several suppliers. We derived an average rate similar to the daily rate of Home Depot as of July 2023, about $375 per day.[27] This does not include the cost to transport or deliver the equipment to the ranch property, but it does include small fees such as fueling.

In general, the usage of a backhoe did little to impact overall construction costs or reduce the hours required for assembly. For some properties, such as the Hibner Ranch, a backhoe was necessary to dislodge rocks embedded in the ground. Backhoes also reduce the amount of time and effort it takes to load and unload rocks. Otherwise, properties found that using equipment such as a truck or Four-wheeler was sufficient. Producers should determine what equipment to use to assemble structures based on how accessible rock is on the property, the distance rocks must be moved, the size of the rocks, and the number of workers available.

Figure 6: Backhoe transporting rocks to sites

[27] https://www.compactpowerrents.com/rental-equipment/tractor-loader-backhoe/tlb-micro-6-dig-depth/

Table 3. Data and calculated (green heading) costs of equipment per structure for constructing rock rundown structures and adding either compost, mulch, and/or seeds at five ranches.

Ranch	Management	Equipment cost total	Equipment cost per structure
Rio Arriba #1	Rock	$375.00	$20.83
	Compost	$0.00	$0.00
	Mulch	$0.00	$0.00
	Seeds	$0.00	$0.00
Rio Arriba #2	Rock	$375.00	$20.83
	Compost	$0.00	$0.00
	Mulch	$0.00	$0.00
	Seeds	$0.00	$0.00
Santa Fe	Rock	$0.00	$0.00
	Compost	$0.00	$0.00
	Mulch	$0.00	$0.00
	Seeds	$0.00	$0.00
Mora	Rock	$0.00	$0.00
	Compost	$0.00	$0.00
	Mulch	$0.00	$0.00
Eddy	Rock	$0.00	$0.00
	Compost	$0.00	$0.00
	Mulch	$0.00	$0.00
	Seeds	$0.00	$0.00

Transportation and fuel Costs

Fuel costs for transporting mulch and compost to the ranch properties were calculated using an assumed fuel economy of 18 miles per gallon (mpg) and the average cost for gasoline in New Mexico in 2021-2022, $3.50/gallon.[28] For each property, the mileage traveled started at Soilutions in Albuquerque and ended at each ranch. We did not account for depreciation or wear-and-tear on a vehicle in this analysis. Many rural areas do not have amendment suppliers nearby, so ranchers interested in implementing organic amendments would likely encounter large transportation distances until regional hubs or on-ranch/on-farm production become established. It is possible, however, that there may

[28] https://gasprices.aaa.com/?state=NM

have been suppliers closer to producers participating in this study, which would lower transportation costs. If it is accessible, we recommend utilizing the closest supplier or sharing transportation burdens with neighbors to reduce time and labor costs.

To calculate round trip transport costs, the mileage has been approximated starting from each property to Soilutions in Albuquerque, NM and returning to the property. The average round trip distance between Soilutions and each property is 361.2 miles and distances range from 192-654 miles round trip. Some materials were transported from Soilutions to multiple ranches in combined trips. For the purposes of evaluating a realistic cost to farmers, we are assuming that each ranch made a singular trip to and from the supplier.

Seed transportation costs were not included because no separate trip would need to be made; any of the trips to purchase compost, mulch, or rocks could include purchasing seed, or seed could be delivered for a minimal difference in cost.

Table 4. Data and calculated (green heading) costs of transportation of material per structure for constructing rock rundown structures and adding either compost, mulch, and/or seeds at five ranches.

Ranch	Management	Transportation distance (mi)	Transportation cost per structure
Rio Arriba #1	Rock	0	$0.00
	Compost	308	$9.98
	Mulch	308	$9.98
	Seeds	0	$0.00
Rio Arriba #2	Rock	0	$0.00
	Compost	306	$9.92
	Mulch	306	$9.92
	Seeds	0	$0.00
Santa Fe	Rock	50	$0.54
	Compost	192	$6.22
	Mulch	192	$6.22
	Seeds	0	$0.00
Mora	Rock	0	$0.00
	Compost	346	$22.43
	Mulch	346	$22.43
Eddy	Rock	0	$0.00

	Compost	654	$21.19
	Mulch	654	$21.19
	Seeds	0	$0.00

Material Costs
We estimated that we used an average of 0.15 cubic yards of rocks per structure. Rocks were only purchased for one ranch and it is recommended to source rocks onsite if possible. For all properties besides the Santa Fe county ranch, rocks were free and harvested onsite. If rock was sourced from the property, the only applicable cost for the rock structures themselves is labor, making the baseline cost for structures much less expensive.

The costs of compost and mulch were determined by an average volume spread per plot: 5 meters x 5 meters x .635 cm, thus for each plot, .21 cubic yards of amendments were applied. The compost was purchased for $50/cubic yard, and the mulch was purchased for $35/cubic yard.

Seeds cost $16/lb and ½ lb was spread at each plot.

Table 5. Data and calculated (green heading) costs of materials per structure for constructing rock rundown structures and adding either compost, mulch, and/or seeds at five ranches.

Ranch	Management	Cost per cu yard or lb	Materials cost per plot
Rio Arriba #1	Rock	$0.00	$0.00
	Compost	$50.00	$10.50
	Mulch	$35.00	$7.35
	Seeds	$16.00	$8.00
Rio Arriba #2	Rock	$0.00	$0.00
	Compost	$50.00	$10.50
	Mulch	$35.00	$7.35
	Seeds	$16.00	$8.00
Santa Fe	Rock	$125.00	$18.75
	Compost	$50.00	$10.50
	Mulch	$35.00	$7.35
	Seeds	$16.00	$8.00

Mora	Rock	$0.00	$0.00
	Compost	$50.00	$10.50
	Mulch	$35.00	$7.35
Eddy	Rock	$0.00	$0.00
	Compost	$50.00	$10.50
	Mulch	$53.00	$11.13
	Seeds	$16.00	$8.00

Total costs

Table 6. Total costs of labor, equipment, and materials per structure (red column heading) and additionally including transportation costs (labor and mileage; yellow column heading) for constructing rock rundown structures and adding either compost, mulch, and/or seeds at five ranches.

Ranch	Management	Total per plot excluding transportation costs	Total per plot including transportation costs
Rio Arriba #1	Rock	$28.22	$28.22
	Compost	$18.81	$42.90
	Mulch	$15.66	$39.75
	Seeds	$8.46	$8.46
Rio Arriba #2	Rock	$27.29	$27.29
	Compost	$18.81	$42.84
	Mulch	$15.66	$39.69
	Seeds	$8.46	$8.46
Santa Fe	Rock	$25.21	$28.52
	Compost	$18.81	$33.89
	Mulch	$15.66	$30.74
	Seeds	$8.46	$8.46
Mora	Rock	$16.61	$16.61
	Compost	$18.81	$57.84
	Mulch	$15.66	$54.69
Eddy	Rock	$7.38	$7.38
	Compost	$18.81	$67.68
	Mulch	$19.44	$68.31
	Seeds	$8.46	$8.46

Ecological Benefit to Cost Analysis

Overall, we did not detect a significant difference in several of the ecological measurements we monitored across our treatments (Figures 7, 8, 9). In general, we found rock rundowns, on their own, to be effective tools for reducing erosion in active headcuts on arid lands throughout New Mexico because generally the channel below the structure gained material (Figure 7, left column).

There were several sites with trends that increased costs of interventions led to a benefit in ecological response. For example, at Rio Arriba #2 and Santa Fe ranches, interventions of about $20 more per plot led to approximately half the amount of bare ground (Figure 9, left column). However, in other cases, additional interventions seemed to decrease a desired ecological characteristics, such as aboveground biomass at the Eddy county ranch (Figure 8, left column).

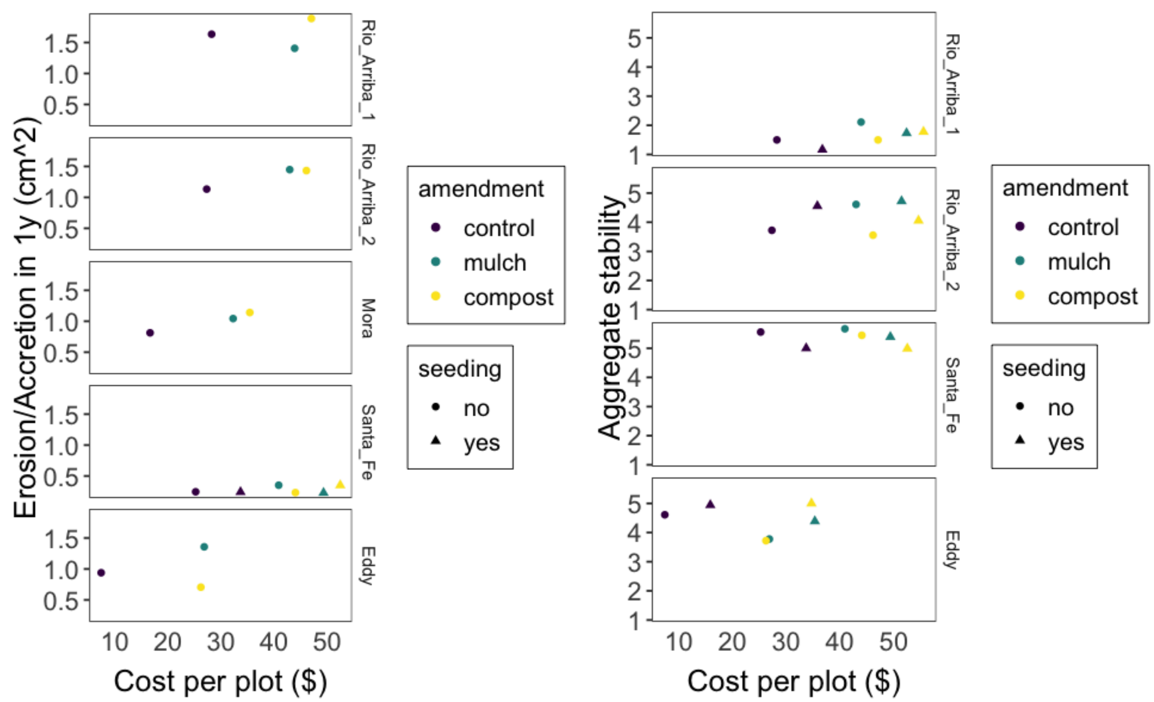

Figure 7. Cost of treatments (amendment = point colors and seeding = point shape) at each ranch. Left column: amount of soil that accumulated (positive numbers) or eroded (negative numbers) from the channel below the rock rundown structure in one year. Right column: aggregate stability (higher values are more resistant to disruption in water than lower values) of soil upslope of the erosion control structure after one year.

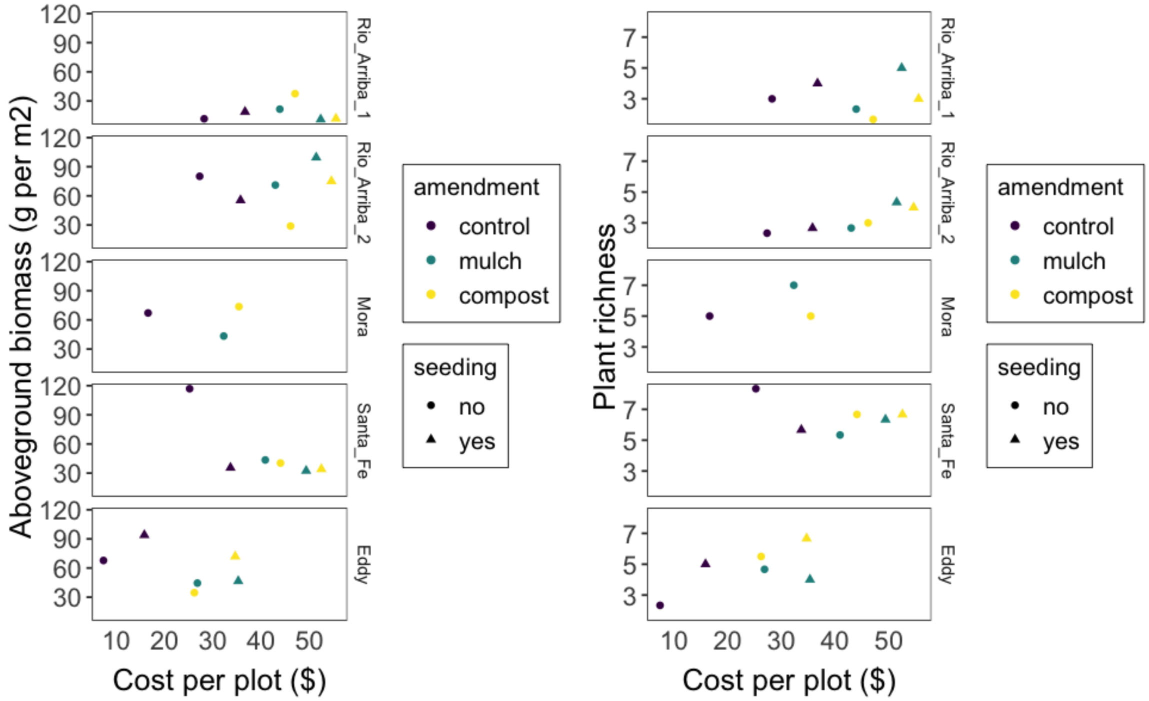

Figure 8. Cost of treatments (amendment = point colors and seeding = point shape) at each ranch. Left column: total biomass in plots upslope of the erosion control structure after one year. Right column: Plant richness (number of species encountered on the line intercept transect) in plots upslope of the erosion control structure after one year.

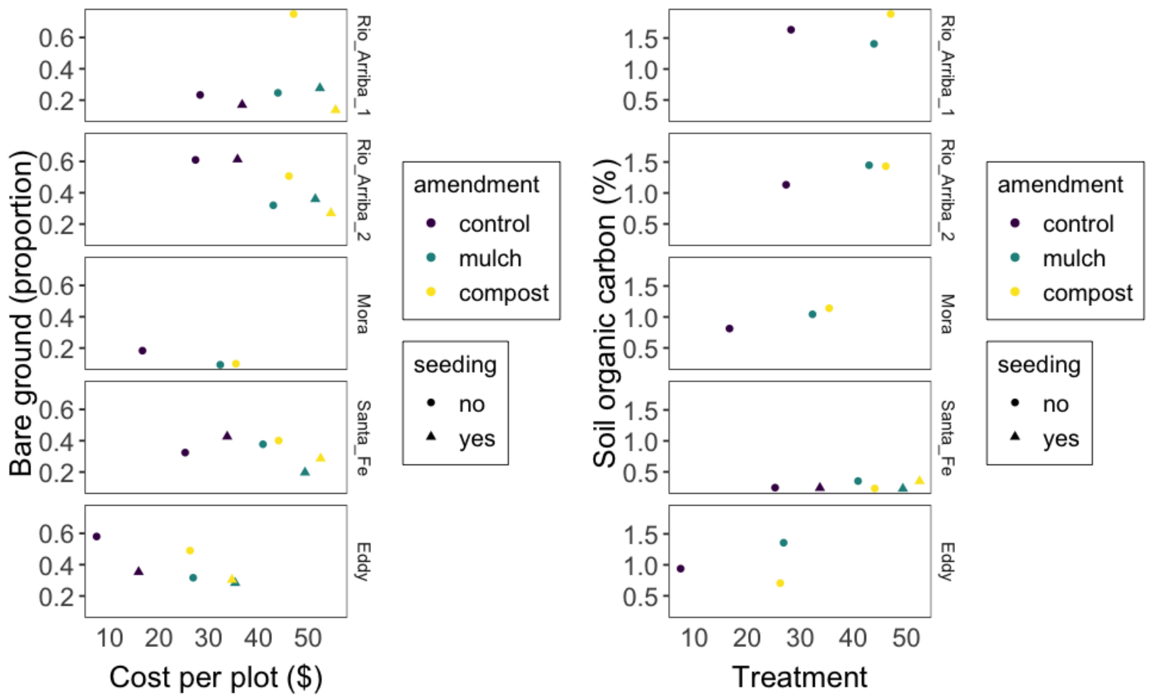

Figure 9. Cost of treatments (amendment = point colors and seeding = point shape) at each ranch. Left column: The amount of bare ground plots upslope of the erosion control structure after one year. Right column: Plant richness (number of species encountered on the line intercept transect) in plots upslope of the erosion control structure after one year.

Rancher Experience

After gathering qualitative data about the process of this study from interviews with producers, certain trends have been identified that are not reflected in the quantitative data. This helps to assess how viable erosion control structures with organic amendments are for producers that must make financially sound decisions for their operation. Including informal data collection from producers is an effective way to gather information in between scientific measurement periods, gain context of the operations, and understand producers' lived experiences throughout the study.[29] Overall, several qualitative trends became apparent throughout the interviews with producers.

No noticeable changes in plant cover were observed around structures.

[29]Woods, S. R., & Ruyle, G. B. (2015). Informal Rangeland Monitoring and Its Importance to Conservation in a U.S. Ranching Community. *Rangeland Ecology & Management*, 68(5), 390–401. https://doi.org/10.1016/j.rama.2015.07.005

With the exception of the Mora County, plant cover did not appear to have any visible increase in areas with the addition of organic amendments and seeds. On the two Rio Arriba ranches, there was no noticeable increase in plant growth. Both producers noted that this could be due to high winds blowing seeding away and is most likely associated with drought conditions after the structures were assembled. They both added that it would have been hard for the organic amendments to have much of an effect on the nutrient levels of the topsoil at these sites on their ranches due to the lack of rain. The Eddy county ranch, however, saw a huge increase in plant cover in the application zones with heavy rains, but according to casual visual observations, the organic amendment areas did not look noticeably different from the surrounding areas. In this case, the rancher attributes the rise in plant cover to rain conditions rather than the nutrients added from amendments. The plant growth both in and surrounding the application zones dried up once dry conditions returned. The Mora county ranch saw increases in the amount of visible plant cover and believes that this is due to increased water retention, biological activity, and physical protection of seeds from both the soil amendments and rock structures. It should be noted that this ranch already has a preexisting thriving seed bank and did not require any additional seeding.
Drawing from these observations, we can conclude that the conditions in which the amendments are applied may impact their effectiveness. From these interviews, we might surmise that it could be more effective to place amendments when and where there is some level of moisture and the winds are not too high.

Rock rundown structures alone are effective at reducing erosion.
Next, all of the producers saw reduced soil erosion below the structure and noticed soil accumulation within and above the structure. The ranches all noticed that any headcuts or eroding zones slowed or stopped completely and soil moved less around the structures in general. These observations signify that the actual rocks structures are effective at catching soil. All of the ranchers added that although the physical structures achieved the first step of reducing soil movement, increasing forage growth would help significantly in increasing water retention and replenishing degraded soil.

Rock rundown structures are a low maintenance erosion control option.
All of the producers also described the erosion control structures as generally low maintenance and easy to assemble. By taking either 1-2 full days or a week's worth of evenings, the producers were able to assemble 18 or more structures on their land. After that, none of the ranchers said they had to do more than move a rock back into place. A year and a half after construction, the producers said that the structures remain intact, effective, and embedded in the ground. The Rio Arriba #2 rancher said, however, that he

may reseed some structures since he believes increasing forage at the structures would significantly help to stop erosion completely. The Mora county ranch also noted that in the future she would apply amendments in areas that need increased water retention or nutrients. She also said that she would experiment with combinations of mulch and compost on the same plots. Reseeding and adding amendments would not take more than a few hours, especially if the materials are already onsite. Overall, the structures have reduced long term impacts of erosion and have required very little maintenance.

Erosion control structures can prevent more intensive large-scale solutions from being necessary.

The locations and topographies of structures vary from ranch to ranch. Generally, the structures are small and are on low grade declines, not on the steepest headcuts. All of the producers noted that they would replicate rock rundowns or another shape of rock structure to target other areas that may be more severe. At the Santa Fe and Rio Arriba ranches, the sites were all chosen to prevent erosion from damaging vulnerable infrastructure. The erosion has slowed or stopped in these areas and rock structures could be a viable way for producers to avoid much more expensive and large-scale repair jobs in the future.

Erosion control structures are adaptable to different sites and operative capacities among ranches.

All of the producers said they would implement this demonstration again and experiment with the best combination of structure shape and amendment based on the site. These structures can be made using as little or as much material and time as desired and are easily adaptable to different topographies. Besides challenges with seed germination and lack of visible increases in forage, the erosion control structures have qualitatively reduced soil movement in their areas and prevented erosion from continuing or worsening.

Discussion

There are several reasons why organic amendments may have not shown effectiveness on erosion structures in arid climates. Temperature and precipitation patterns in dry climates, for example, are highly variable within and between years, causing them to exert stronger controls on vegetation productivity and composition than human management actions. The influence of precipitation and temperature on rangelands implies that the climatic conditions which enable an organic amendment to function properly are not always guaranteed, and therefore may inhibit the amendments from having their intended impact.

[30] In dry landscapes, the limiting factor to achieving healthy soils and reducing erosion may not be a lack of soil nutrients or microorganisms, but rather lack of regular precipitation and moisture. Soil microbial biodiversity, for example, is extremely influenced by soil moisture and temperature, and decreases in total soil microbial biomass have been shown to coincide significantly with decreased rainfall.[31] The literature indicates that plant establishment rates in arid lands can be highly variable and contingent on annual rainfall and drought regimes.[32] The year we conducted our study, our participating ranchers communicated that rainfall seemed insufficient to establish new plant cover upslope from our erosion control structures; In Eddy county, rainfall during the duration was higher than average (18in), while in Rio Arriba county, rainfall was about average (18in). Besides the influence of dry conditions, there are many other physical factors that may influence the effectiveness of organic amendments to control erosion including soil composition, past soil disturbances, wind erosion, and other environmental and physical factors.

An additional explanation for the lack of effectiveness of organic amendments could be variance in site-specific characteristics for gullies, headcuts, and other erosion features. One study highlighted that treatments may have varied effectiveness on different sites, which impacts the cost effectiveness of implementing remediation strategies from site to site. The same study concluded that applying a one-size-fits-all mechanism towards erosion control can cause difficulty in addressing the nuanced issues presented by erosion. Additionally, economies of scale may be in play when implementing erosion control efforts, and the volume of erosion addressed may impact the remediations' cost effectiveness.[33] Based on these findings, we cannot rule out organic amendments as entirely ineffective at decreasing erosion when applied to erosion control structures. Under certain climatic conditions and erosion cuts, organic amendments may provide multiplicative benefits to rock structures, but additional research would be required to prove or negate their impact on different types of sites.

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[30] Gravuer, K., et al. Organic Amendment Additions to Rangelands
[31] Naorem, A., Jayaraman, S., Dang, Y. P., Dalal, R. C., Sinha, N. K., Rao, Ch. S., & Patra, A. K. (2023). Soil Constraints in an Arid Environment—Challenges, Prospects, and Implications. Agronomy, 13(1), 220. https://doi.org/10.3390/agronomy13010220
[32] FIND CITATION
[33] Rust, S., & Star, M. (2018). The cost effectiveness of remediating erosion gullies: a case study in the Fitzroy. Australasian Journal of Environmental Management, 25(2), 233–247. https://doi-org.coloradocollege.idm.oclc.org/10.1080/14486563.2017.1393465

Strengths and Weaknesses Summary

Ecological and economic factors are included in this comparison of the physical intervention (rock structures) and biological interventions (compost, mulch, and seeding).

Table 7: Strengths and weaknesses of treatment types.

Material	**Strengths**	**Weaknesses**
Rock Structures	-holds soil and amendments in place -disperses flow of water above structure -little to no processing of material or maintenance -low cost -reduce erosion and sedimentation on newly forming headcuts -lessens steep gradient of headcuts and thus reduces velocity of water flow	-no added nutrients to soil -labor intensive construction process -potential displacement of rocks from structures -resource not readily available on all ranches -rocks may move out of place over time -rocks must be placed correctly to be effective -equipment required to transport rocks around ranch
Compost	-slow release fertilizer -simple application -covers bare soil -can promote plant establishment -improves soil nutrient content -only required in small area above headcut -increases nutrient levels -increases water retention -reduces erosion through increased moisture, soil cover, and plant establishment	-nutrient composition of compost must suit soil nutrient deficiencies -costly material -ineffective in drought -requires periodic replacement -must be produced or transported to the property -potential nutrient oversaturation -may promote growth of undesired species
Mulch	-retains soil moisture by covering bare soil -reduces soil surface temperatures -slow decomposition process -simple application -promotes plant establishment -promotes microbial activity	-lacks of soluble nutrients at time of application -costly material -lightweight material susceptible to wind erosion -ineffective in drought -requires periodic replacement -risk of “overmulching” -may promote growth of undesired plant species

Native Seed Application	-low cost -promotes robust seed bank, replacing undesired species with endemic, drought-tolerant species - promotes plant growth -helps replenish plant communities in eroded areas -help reduce erosion through providing root structure in soil	-requires adequate growing conditions -may be eaten by animals -may blow or wash away with weather events -cost to establishment rate may not be effective -seed mix must be adequate for the local environment

Concluding Thoughts and Recommendations

Our ecological findings concluded that there was no statistically significant impact on erosion control or associated soil benefits with the addition of organic amendments to erosion control structures at newly forming headcuts within one year. For this reason, we recommend that producers utilize rock structures to manage erosion on their land, but it is not worth the associated costs to apply organic amendments as well if there are critical areas to treat over rapid time scales.

Appendix

Comparable Costs

The following tables outline the costs of materials utilized in this experiment in Albuquerque, NM as of August 2023. These may serve as resources for people interested in sourcing materials in the future or as examples of price ranges for these materials.

Table A1 : Comparable costs of local compost for sale 2023

Source	**Cost per cubic yard**[34]
Sandoval County[35]	$12.00
Bernalillo County Water Authority[36]	$10.00
Barela Landscaping Materials, Inc.[37]	$45.50
Soilutions[38]	$58.00
Reunity Resources[39]	$92.00

Table A2 : Comparable costs of local mulch for sale 2023

Source	**Cost per cubic yard**
Sandoval County[40]	$7.00
Pete's Landscaping and Materials, LLC[41]	$44.00
Barela Landscaping Materials, Inc.[42]	$33.50
Soilutions[43]	$43.00
Reunity Resources[44]	$42.00

34 Assuming 1 ton of compost equals 2.5 cubic yards.
35 https://www.sandovalcountynm.gov/departments/public-works/solid-waste/
36 https://www.abcwua.org/customer-service-compost/
37 http://www.barelalandscaping.com
38 https://soilutions.net/collections/pick-up-compost-soil-mulch-at-soilutions
39 https://www.reunityresources.com/soil-yard.html
40 https://www.sandovalcountynm.gov/departments/public-works/solid-waste/
41 https://www.peteslandscaping.com/materials
42 http://www.barelalandscaping.com
43 https://soilutions.net/collections/pick-up-compost-soil-mulch-at-soilutions
44 https://www.reunityresources.com/soil-yard.html

Call the local city or county solid waste department for current availability of free mulch. Many city and county public works departments in near Albuquerque, New Mexico offer recycled mulch at no charge.[45]

Table A3 : Comparable costs of local rocks for sale 2023

Source	Type and size	Cost per ton
Neumark Landscape Supply[46]	Mountainair Brown 2”-4”	$65.00
Canyon Stone and Gravel[47]		$10.00

Table A4 : Comparable costs of New Mexico native grass seed mixes for sale 2023

Source	Cost per pound
Curtis and Curtis Seed[48]	$24.00
Western Native Seed[49]	$14.00
Great Basin Seed[50]	$24.00
Rehm’s Nursery[51]	$37.00
Plant World[52]	$29.00

The prices included in this table are for New Mexico native or climate-appropriate grass seed mixes which include grass species applied at the test sites.

45 https://www.nmcomposters.org/compost-mulch-sources
46 https://rscmaterials.com
47 https://canyonstonenm.com/stone/
48 https://curtisseed.com/santa-fe-trail-native-grass-mixture/
49 https://www.westernnativeseed.com/mixesintro.html
50 https://greatbasinseeds.com/product/santa-fe-trail-grass-mixture/
51 https://www.rehmsnurserynm.com
52 https://store.plantworldinc.com/departments/grass-seed-|06|GSD.html