Pathways to Adaptation:

Nature-based Solutions and Conservation Perspectives of Agricultural Producers in a San Juan River Headwater Community

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Introduction

There is both reason for concern and substantive cause for optimism about the future of water resources in the Southwest. Currently, watersheds are becoming dissected, aquifers depleted, and floodplains disconnected as academic nomenclature replaces ‘drought’ with the less ephemeral ‘aridification.’ However, as explored throughout this paper, Nature-based Solutions (NbS) like agroforestry, rotational grazing, and organic soil amendments could be applied to conserve water, protect ecosystems, promote adaptive food systems, and support resilience. Understanding regionally specific limitations and nuances is foundational to the process of testing and integrating NbS, which are inherently place-based methods.

A research survey conducted in an arid region of Southwest Colorado gauged attitudes and limitations from agricultural producers about NbS, resources, and conservation. Through this project we hope to demonstrate how convergent research between academic institutions, local conservation entities, and agricultural producers can aid in informing adaptive transformation and pathways of communication between academic and non-academic sectors. The background, process, and results of this survey are detailed in Chapters 2 and 3.

The Southwest has seen a temperature increase of almost 2°F in the last hundred years, with some areas seeing greater temperature increases as headwater snowpack becomes less certain (EPA, 2021). Changes in hydrology from deforestation, soil depletion, and reduced snowpack from soils raising albedo are threats to the forests, streams, and food producing lands of the Southwest. On a global scale, one third of all agricultural land has been deemed unusable due to soil degradation, mostly from overgrazing, chemical pesticides and fertilizers, heavy tillage, and land clearing (Rhodes, 2012). Chapter 4 will explore the effects of industrial agriculture on a global scale to provide reference for the importance of localized farms and food systems for watershed and forest health, resilience to climate change, and safer food and production. Smaller farms can be more easily optimized for climate resilience than industrial food production systems, so understanding pathways to adaptability for these operations is necessary.

Even with modern climate challenges, the Southwest offers a landscape that has and can be tended for foods, medicines, and animal husbandry. Mindful integration of Traditional Ecological Knowledge (TEK) held by the Indigenous stewards of Southwest lands could be the most resilient and regionally adapted methods, but such knowledge should not be commodified. The region where the research survey was conducted is on the ancestral lands of Ute, Comanche, Arapaho, and Diné Nations. In Chapter One, Indigenous histories will be explored to provide an introductory background of the agricultural history of the region and honor the peoples to whom partnering with nature was and is a way of life.

Reimagining, adapting, and localizing food systems could mitigate challenges from climatic and social changes, wherein unsustainable massive-scale industrial systems of farming won't meet rising demand (Nabhan et al., 2020; Gremmen, 2022). Supporting conservation-based production decreases reliance on emission-heavy distribution and virtual water, bringing individuals closer to food sources with minds, bodies, and wallets. Exploring the place of NbS that promote conservation like agroforestry and building soil organic matter is a step toward protecting the waterways that give the Southwest life.

Table of Contents

CHAPTER ONE

The Interconnectedness Between Forestry, Agriculture, and TEK

Defining Terms

"Words without thought never to heaven go."

-Claudius, Shakespeare's Hamlet

While there are many terms for sustainability-focused agriculture and agricultural methods, important nuances exist. For example, agroecology has more of a social focus than does regenerative agriculture. It's foundational to use clear language and accessibly describe terms, especially given a goal of cross-disciplinary, convergent research that benefits communities. Considering the context of language is respectful to researcher, community, and reader. For example, 'regenerative agriculture' has been increasingly used by corporations like PepsiCo, and for rural communities, such language could represent the imminence of corporatization, and a loss of livelihood for small-scale growers who can't compete with highly integrated and wealthy corporations. In an academic context, using terminology that doesn't consider regional context could indicate epistemic misunderstandings on behalf of researchers. Furthermore, a feasible transition from conventional agriculture to regenerative methodology requires more than one leap, and implementing intermediary stops like conservation agriculture, focusing first on soil health and cover crops, could allow growers to experiment and integrate regenerative techniques like agroforestry and silviculture into current modes of production.

Below is a list of terms, some of which will be used in this paper, and others that are relevant to the topic but won't be explored at length, with brief definitions.

Agroecology- Processes and principles toward the transformation of global food systems based on localization, equity, participation, ecological restoration, and resilience (Tittonell et al., 2022).

Agroforestry- Adding climatically adapted woody perennial trees and shrubs to livestock and crop systems, creating a complex, multistory system with parts capable of supporting each other through structure, nitrogen fixing, or shade (Elevitch et al., 2018). A tree-based subset of regenerative agriculture that focuses on both socio-economic and environmental objectives (Castle et al., 2022; Schoeneberger et al., 2017).

Conservation Agriculture- Improving soil health through minimal disturbance and permanent cover while seeking to improve yields, retain water, and support ecosystem services (Dumanski et al., 2006).

Ecological Resilience- The ability of an ecosystem to adapt to disturbance without altering structure and processes within a survivable threshold of modification (Holling, 1973).

Food System- The network of production, processing, dispersal, consumption, and waste of agriculturally cultivated or harvested food products and the affected economic, social, and ecological environments (von Braun et al., 2021).

Nature-based Solutions (NbS)- Agricultural production solutions that mimic natural ecological systems: includes agroforestry, cover cropping, and development of healthier soil.

Natural Climate Solutions- Improvements to the management of agricultural or natural land through conservation and restoration for carbon storage (Fargione et al., 2018).

Permaculture- Coined by David Holmgren and Bill Mollison in the 1970's, 'permanent agriculture' aims to create a self-perpetuating system of perennial plant systems using little to no inputs, mimicking natural ecosystems (Rhodes, 2012).

Regenerative Agriculture- An adaptation to existing methods of food production that utilizes soil and land management to improve soil health, restore biodiversity and mitigate climate change, acknowledging farming and ranching as a holistic ecological system that relies on and exists within native ecosystems (Rhodes, 2012; Schreefel et al., 2020). Regenerative agriculture aims for closed nutrient loops, greater biodiversity, increased use of perennial crops, and reduced reliance on external resources (Elevitch et al., 2016). This method intends to improve ecosystem services on and around farmlands.

Traditional Ecological Knowledge (TEK)- The traditional knowledge held by Indigenous Nations about the natural environment, and specifically the relationship between humans and the natural environment (Finn et al., 2017).

Forestry, Water, and Food Production

(Why is this M.F. Paper About Agriculture and Perspectives of Ag Producers?)

In the Western U.S. forested land generates drinking water for almost 90% of people using public water, and over 90% of drinking water supply for cities like Portland, Oregon are supplied solely by forest sources (Liu et al., 2022). Forest management is watershed management, and the health of forests directly affects predictability and reliability of municipal water supplies. Globally, 70% of freshwater use is for farming while in parts of the West like California, agriculture represents 80% of developed water supply use (Cooley, 2015; Gebremariam et al., 2021). Water derived for agricultural use, especially in the Intermountain West, depends heavily on snowmelt from high elevation forests, which has been changing in response to climate changes (Qin et al., 2022).

Snow cover across mountainous regions of California, Nevada, Utah, Arizona, and New Mexico typically remains for six months or longer, supplying a reservoir that gradually melts during the early growing season (Elias et al, 2016). Food producing communities rely on these headwaters to supply flows to bring irrigation water to streams or reservoirs and eventually ditches or pipes. The EPA saw a snow water equivalent decline of 93% in snow telemetry (SNOTEL) network sites measured across the Intermountain West from 1955 to 2022, with an average snow water equivalent reduction of 23% across site areas (EPA, 2022). Dust blown onto snow is an accelerant for snow melt, decreasing albedo, the amount of light the snow can reflect. Melt acceleration from dust has been measured to bring melt-out as much as 31 days earlier than modeled based on snow amounts (Fassnacht et al., 2022).

Sustainable agriculture is food system adaptation and land and forest management. Directly, revenue from dairy and livestock ranching is often generated with the support of extensive forest rangelands, which could be managed responsibly as silvopasture systems, thus reducing fuel loads, and protecting from wildfire threat (Schoeneberger et al., 2017). Water used for irrigation makes its way to ecosystems through connected waterways, ephemeral flows, and soil water retention. Sometimes, nature’s life-giving systems are regarded as if they have very junior water rights—a questionable adjudication assignment. Alternative farming modalities like no-till, cover cropping, agroforestry, and soil building all have potential to increase biodiversity and connectivity of ecosystems. Understanding ag producers’ attitudes about conservation and what conservation methods are of high interest is as beneficial to longevity of farms and ranches as it is to forest and riparian/stream health. By targeting outreach and programs aligned with what producers are interested in, and engaging them in the process, time can be saved, and methods of production suited to changing climate and ecosystem wellbeing established.

Agroforestry, defined above, will be discussed at length in Chapter Four. Though it is a promising and sustainable growing system, the term could also be understood as a field of study, separate from forestry and agronomy. Expertise in how agricultural land management affects forest and stream health and, furthermore, how certain management practices can benefit ecosystems, is understudied, and needed. Productive land use doesn’t need to involve damage to the natural environment. Indigenous ways of growing food show that partnerships with nature could support subsistence agriculture that is ecologically neutral or beneficial, and uses patterns of nature, including forest structure, to grow food crops.

For example, the Three Sisters growing technique is an Indigenous method that uses the intercropping of beans, squash, and corn in mounds. The Three Sisters is reflective of nature-based food growing used in pre-colonial times and was the backbone of farming for North American Indigenous communities (Park et al., 2016). Each plant provides benefit for the others, with beans supplying nitrogen via nitrogen-fixing bacteria on roots, ground covering squash suppressing weeds and providing natural mulch to limit evaporation of water, and corn creating a trellis for beans (Ngapo et al., 2021). Furthermore, each food provides nutrients that others do not—corn is calorie-rich but missing essential nutrients, particularly amino acid lysine, which is found in beans and squash (Dunmire, 2004). The next section will explore more context about agriculture in the Southwest, through a very brief overview of pre- and post-colonial agricultural practices on the landscape. Before discussing the modern context and potential adaptations of agriculture in the Southwest, it's necessary to acknowledge the surveyed region's pre-colonial history of food growing and land management. Mindful and respectful integration of these practices could support adaptability and water conservation in the Southwest.

Brief Histories of Agriculture in the Southwest: Acknowledging the Land's Indigenous Stewards

Pre-Colonial Agriculture in the Southwest

Some origin stories of the Pueblo, Navajo, and Tohono O'odham peoples of the Southwest prominently include relations to food-producing plants (Guarino, 2021). Ancestral Puebloan peoples inhabited the southwestern United States prior to colonization for over a millennium, utilizing resources from pinyon juniper forests and eventually practicing subsistence agriculture especially during 1500 BC to AD 700 (Lentz et al., 2021). Crops of Indigenous farmers in North America during this time included corn, domesticated in tropical Mesoamerica and carefully cultivated over thousands of years (Herr, 2009). Radiocarbon dating has indicated that domesticated corn was being grown in the Colorado Plateau by 2100 BC, where it was grown in a wide range of climates and elevations in current day Arizona and New Mexico (Merrill et al., 2009). During the Late Archaic period, corn in the desert Southwest was grown by Ancestral Puebloans through a system known as water table farming, or planting in floodplains of ephemeral streams where sandy soil retains surface level moisture throughout the growing season, eventually evolving to earthworks diverting water to fields to support higher populations (Dunmire, 2004). Stone check dams spanned arroyos collecting storm runoff, detriment, and fine-grained soil ideal for planting (Dunmire, 2004). These dams both collected nutritious soil and slowed the rapid pace of desert rainwater runoff or ephemeral waterways to allow water to permeate more effectively.

Pre-colonial fields didn’t separate crop species into monocrops, but instead mixed companion plants onto mounds with troughs between rows, which created a water reservoir (Park et al, 2016). The aforementioned Three Sisters was more than an agricultural technique, but a culturally significant part of life that influenced customs, ceremonies, stories, and technology (Ngapo et al., 2021). In the Southwest region, a Navajo creation story features white corn as the oldest male ancestor and yellow corn as the most ancient female ancestor, indicating the deep spiritual significance of food producing plants in Indigenous cultures (Guarino, 2021). Corn was available in many varieties due to hybridization and selective breeding by Native peoples, and wild grasses were selected for edible seeds, with distribution of domesticated species used to track human dispersal pathways (Diehl, 2009; Park et al, 2016). Hohokam farmers of modern-day Southern Arizona cultivated little barley (*Hordeum pusillum)* which relied on no supplemental water (Dunmire, 2004). Some Hohokam were also cultivating large-scale agave on flood-farmed arroyos or hillside rock terraces (Dunmire, 2004). Symbiotic relationships existing within the natural environment were foundational to Indigenous food systems and ways of living.

Some cultures like Hopi continue the tradition of nature-based farming today. Descendants of Ancestral Puebloans, Hopi grow desert-adapted varieties of corn using traditional methods and no supplemental irrigation, though climate change and contaminated groundwater on Reservations threaten this legacy (Carson et al., 2020). Utilizing Traditional Ecological Knowledge (TEK), Indigenous wisdom, and methods of biomimicry could bolster future agricultural growth and transition in the Southwest, just as the same methods supported Indigenous populations for millennia (Nabhan et al., 2020). Approximately 60% of modern global food supply is linked to New World species, with many originating in North America like squashes, pumpkins, and possibly beans (Park et al., 2016). Acknowledging the Native peoples who originally cultivated these species and inquiry of place-based Indigenous and post-colonial histories of arid regions of the U.S. is the first step in mindful integration of TEK and Nature-based Solutions in modern day agriculture.

Post-Colonial Agriculture in the Southwest

By the late 1500's, Spanish colonizers were attempting to bring Old World crops and growing techniques to the Southwest (Hancock, 2022). Such methods were adapted to different climates and landscapes. Local Ancestral Puebloan peoples by this time had sparsely populated communities up to 100 miles apart (Mathers, 2019). Violent colonization by the Spanish further reduced Ancestral Puebloan presence in the region. This ultimately led to the Pueblo Revolt of 1680, during which an organized alliance of Puebloan peoples forced the Spanish out of the area and led to years of forceful attempts by the Spanish to reconquer (Romero, 2020). Land dispossession eventually took hold across the region, severing Indigenous connections to tribal history, relations to nature, and dramatically changing pre-colonial ways of life (Randall & Curley, 2023).

The Federal government enacted the Homestead Act in 1862 to supply land to colonial settlers for free, on the condition of five years of residency and agricultural cultivation on their land, granting approximately 10% of U.S. land to 1.6 million settler families and individuals (Edwards et al., 2017). Native tribes were pushed onto reservations after the 1851 Indian Appropriations Act was passed by Congress, partly to allot the federal government with land to support expansion policies (Randall & Curley, 2023). This led to immeasurable changes for Native people's connection to "land-as-culture," the food systems supported by ancestral land, and ultimately resulted in resounding physical and social health detriments for communities (Guarino, 2021). A modern food item common to the Southwest symbolizes this era; fry bread, which was made by utilizing nutritionally barren rations given by the U.S. government during forced relocation (Park et al., 2016). The severance from land-as-culture to land-as-cultivated was fast, and further intensified by the loss of TEK as younger generations chose career paths that didn't require traditional, place-based knowledge sharing from older generations (Schoeneberger et al., 2017). This is only a brief overview of the effects endured by Native communities, and not representative of the nuanced, ongoing challenges. Such an overview should be considered, however, before discussing nature-based solutions that are rooted in TEK of Indigenous people.

After colonization of the Southwest was underway, settlers practiced subsistence farming often in isolation; limited by canyon walls, climate, and soil quality, supplementing income by hunting furs like beaver (Freeman, 1953). The adjustment, especially without understanding of the landscape or established food growing traditions, was arduous. Interest in dryland farming in the early 20th century brought cash crops like potatoes and pinto beans to the area, which could be cultivated without irrigation (Dishman, 2008). Brought by advances in large irrigation systems, genetic modification technology, and increasingly modern farm equipment, large-scale farming in the Southwest has become, in some areas, a reality. In others, small- and medium-scale family-owned farms persist. Livestock production accounts for about 70% of farming sales in New Mexico and Utah and 40% in Arizona, with many crops raised for livestock grown on the same land (Steele et al., 2018). More than half of high-value specialty crops in the U.S. are grown in in the Southwest, dependent on irrigation and sensitive to temperature extremes and irregular hydrology (Schoeneberger et al., 2017). In Colorado two million acres of wheat is cultivated, a top commodity in the state, though 80% of it is exported, second only to beef exports (CO Department of Agriculture; Coleman, 2012).

As snowpack declines leading to reduced water availability and streamflow peaks earlier in the year, modern day farmers are experiencing less reliable hydrology (Elias et al., 2016, Overpeck & Udall, 2020). In 2013, many farmers using irrigation in New Mexico received 3 inches of surface irrigation water per acre compared to the usual 2 acre-feet (Ward, 2014). Especially for junior water rights holders, understanding how to capture or slow rainwater and optimize water retention of soils, as was done in pre-colonial agriculture, could be a step toward combatting a difficult, rapidly intensifying situation. Utilizing TEK-rooted, nature-based practices like agroforestry could provide shade to soils and livestock, reducing evaporation of water from soils and exposure to high winds.

Agriculture has shaped the tale of human history in the Southwest, and climate change poses challenges to mainstream methods of farming on the landscape. It is, however, an opportunity for innovation and adaptation to change. Prior to colonial settlement, desert food systems were adapted to regional climates and systems like the Three Sisters optimized water use, soil ecology, and limited space. Respectfully integrating modern technology and TEK could aid in climate adaptability for agricultural and ecological systems. Integrating TEK into modern agricultural practices should be considered with respect for these histories. The next section will outline a survey created to understand perspectives of modern farmers on the Southwest landscape, to gauge interest in nature-based and TEK-rooted solutions like agroforestry. This very brief, introductory overview of some of these histories is included to provide background and acknowledge the peoples to whom the surveyed region is ancestral land, including the Ute, Arapaho, Comanche and Diné, as well as Ancestral Puebloans.

CHAPTER TWO

Research Survey Background

In Soils as in Neighbors

Believing that they could understand the universe solely on logic, without experiment, ancient Greek philosophers proposed that plants gleaned all necessary elements from the soils they grew in (Rhodes, 2012). This was true as a generalization but left out important intermediary players. Protozoa, bacteria, insects, rodents, and fungi living at the top foot of soil could equal 11 tons per acre and are the creators and digesters of the mineral particles needed by plant roots (Bane, 2012). Fertile soil is a cornerstone of all ecosystems—to ensure survival, every animal and plant species depend on soil or that which grows in soil (Pimentel et al., 1997).

Building fertile, healthy soils is necessary for crop and livestock resilience. Of the elements that contribute to the conditions of agriculture like climate, water, landform and vegetation, soil is one of the easiest to modify (Bane, 2012). Bare, sun-exposed soils or those dependent on chemical fertilizers are dangerous for water quality from runoff and can lead to topsoil loss. By either abandoning tilling practices or focusing on rebuilding soil communities post-till, producers can increase water percolation and retention, allow for clean runoff water, and even sequester carbon (Elevitch et al., 2018). Adding compost or manure to soils can support ecosystem services by harboring diversity in invertebrate and microbial communities that increase nutrient cycling (Kremen & Miles, 2012). Other soil amendments, like biochar, could help improve soil porosity especially in clay soils common to the Southwest (Rasa et al., 2018).

Biochar is an example of TEK and integrating it in modern agriculture could lead to a low-cost soil amendment while honoring traditional ways of growing food.

Along with water retention properties, organic material content in soil is a major indicator of its productivity, and acts as an adhesive that maintains soil structure, allowing air and water to pass through while increasing moisture-holding capacity (Sampson, 1981). This structure is severely damaged by cultivation and tilling, with organic material losses of about 35% each time soil is cultivated unless organic material is proactively added (Sampson, 1981). Though evidence about no-till practices aiding in carbon capture is mixed, it does improve nutrient cycling, improves water infiltration while reducing evaporation, reduces erosion, and can conserve water (Ongle et al., 2019). Limiting or eliminating tillage of soils to build communities of organisms and organic material increases productivity and resilience, yet ploughing is usually a part of food cultivation.

Within communities, too, connection increases resilience. Increased resilience within communities can aid in more positive responses to political, socioeconomic, and environmental changes (Faulkner et al., 2018). Social capital is foundational and refers to connections based on trust and community norms that allow for cooperation leading to mutual benefit (Krasny, 2020). This includes environmental protection, as social capital can influence environmental behaviors and collective action toward a cause (Krasny, 2020). Increasing social capital through community engagement, outreach, and education can be compared to adding organic material to soils—increasing connectivity, building resilience, and contributing to environmental benefit. Imagining communities with ideological no-till practices could encourage increased social capital and more adaptability to change.

Filter Bubbles and the Importance of Understanding Perspectives

Breaking out of filter bubbles to share ideas with community members with diverse perspectives is one facet of resilient system building for both crops and neighborhoods. Filter bubbles are media-based algorithmic systems that considerably limit how often individuals encounter information counter to their beliefs and attitudes, effectively eliminating productive exchange of ideas, instead encouraging exclusivity and ideological polarization (Kaluža, 2021). Filter bubbles extend beyond the Internet, creating social environments where people feel dramatically separate from each other due to seemingly opposing values. This is a step beyond the idea that humans are separate from ecological systems and nature, which has contributed to damaged landscapes, pollution, and planetary scale changes to climatic patterns. As of writing, the notion of anthropogenic climate change is disputed, mostly by oil conglomerates who have been aware of the climate crisis for almost half a century (Hall, 2015). This has led to differences in belief about anthropogenic climate change, and serious beliefs about character attributes projected to “opposing” viewpoints. This needn’t be the case. Experiencing community with other people is a step closer to experiencing community with the natural world. Breaking out of filter bubbles, both on and offline, could lead to more comprehensive solutions to resource challenges.

While an online survey is a small step into holistically understanding ideas and attitudes, it is one of many. The convergent project development was conducted during workshops aimed at community-based watershed management and, specifically, conflict around water, hosted by a consensus builder and local conservation districts. These workshops allowed individuals with different stakes in the watershed to share ideas openly. In the end, statements given over several

3-day workshops contributed to a revised local river management plan. Agricultural producers often couldn’t attend 3 full-day workshops, but it was important to conservation districts that their perspectives were included in the plan. In collaboration with conservation district staff, this began the process of collaboratively constructing a survey instrument for agricultural producers about conservation perspectives and limitations. This survey took about 10-15 minutes to complete and focused on conservation practices including agroforestry methods like windbreak tree planting, perspectives, limitations to implementation, and climate challenges. The goal of this survey and the work of the conservation districts was to promote more consistent flows for an over-adjudicated river, floodplain connectivity to benefit surrounding forests, community cohesion and contribution, and support for farms and ranches in the area.

CHAPTER THREE

Conservation Perspectives of Agricultural Producers in a San Juan River Headwater Community of Southwest Colorado

Abstract

The Southwest region of the U.S. is integrated into local and widespread food systems, and establishing modes of adaptability to local, regional, and even global events is critical. For this work, producers in a San Juan River headwaters county in Southwest Colorado participated in a convergent research survey developed collaboratively with community partners. The objective of data collection was to inform conservation districts, local policy, and future research. The survey addressed perceptions about soil degradation, water laws, effects of climate, and ways to ease barriers to Nature-based Solutions (NbS). Respondents identified water availability and climate changes as most negatively affecting operations and had interest in agroforestry methods like windbreak trees and drought-resistant crops. Organic soil building was identified as already being used by almost half of respondents. Cost was selected as the leading perceived barrier to implementing nature-based agricultural solutions, with over half of respondents identifying that programs to subsidize or eliminate cost would improve willingness to try conservation methods. Focusing on soil building could serve as an introduction to NbS, and producers already utilizing this NbS could help establish regional protocols. The health of a community's watershed determines its wellbeing, especially in rural communities reliant on

functioning ecosystem services. We hope to contribute this model for wider applications in other regions to uncover place-based solutions to resource challenges.

1. Introduction

Navigating supported implementation of increasingly sustainable agricultural practices necessitates collaboration with a diverse range of stakeholders and a synthesis of community-rooted and research-based approaches. Understanding how convergent academic partnerships with non-academic organizations and communities could support adaptation to climate change while integrating and honoring the knowledge of agricultural producers, community members, Traditional Ecological Knowledge (TEK), generational ecological knowledge, and ecosystem services and systems are all themes of convergent processes. Alongside climate models and analyses, individuals whose livelihoods are being affected by aridification should be an integral part of finding solutions to complex and evolving challenges of food production in the Southwest. Maintaining a locally sourced food supply while reducing the contribution of irrigation on hydrologic unpredictability and reductions in stream and river flows necessitates diverse partnerships and regionally informed solutions.

Such solutions to aridification related challenges could be nature-based, mimicking adaptable ecological systems, and have roots in Indigenous food production and TEK, with some of the oldest agricultural traditions in North America having been in the modern-day Four Corners region (Dunmore, 2004). Nature-based agricultural practices utilize patterns of ecology while minimizing reliance on inputs like heavy irrigation and fertilizer application. Silvicultural techniques can be incorporated to protect crops from high winds with productive native-adapted trees (Gold & Garrett, 2009). Enriching soil with organic material reduces the need for fertilizers, and agroforestry practices like alley cropping reduce potential for runoff of topsoil into waterways (Elevitch et al., 2018). To comprehensively understand hurdles to integrating these practices, engaging with producers about place-based needs, observations, and limitations is foundational.

Fig. 1. The effects of 2021's water year; dry fields at Ute Mountain Ute Tribe Farm and Ranch Enterprise in Towaoc, near Four Corners in CO. Photo: Corey Robinson, *Colorado Sun.*

Convergent solutions are needed to ensure the resilience of farms for community wellbeing and food system security as data show trends of changing hydrology in the Intermountain West (Overpeck & Udall, 2020). Southwest Colorado is one of many regions experiencing increased aridification due to climate change (MacDonnell, 2021). Those with junior water rights to Dolores' McPhee reservoir in the Four Corners region received as little as 10% of adjudicated water during the 2021 growing season (Outcalt, 2021). The effects of 2021 on the Ute Mountain Ute Tribe Farm and Ranch Enterprise are shown in Figure 1. Dolores' Water Conservancy District had to impose penalties for water overuse, and the Dolores River lost a valuable rainbow trout fishery (Southwestern Water Conservancy District, 2022). Ecological and hydrological systems, Southwest Colorado's place in the food system, and community wellbeing are all affected by aridification. The water adjudication system of prior appropriation, almost 150 years old, is being stressed by this pressure too.

Fostering adaptability is beneficial, especially for small and medium-scale agricultural operations. Allowing agricultural producers to self-select adaptive methods that are of most interest could streamline efforts to connecting growers with resources and partnerships that aid in implementation. In the county surveyed, agriculture is dispersed and represented by small and medium-scale family farms. About 80% of the county's population is white, about 14% Native American, and about 13% Latino. In one watershed that was of particular interest to partnering conservation districts, the river is dynamic and responds quickly to changes in temperature as snow melts, changing flows rapidly over 12- and 24-hour time periods, supplying over 50 irrigation ditches to water rights holders. The river is small and, unfortunately, over-appropriated. Understanding what regenerative or conservation-based methods growers in this watershed are interested in could contribute to improved flows for this waterway. Building pathways for discourse between agricultural producers and academics is symbiotic and could contribute to food system resilience and uncover commonalities rooted in land ethic from diverse stakeholders.

2. Methods & Materials

2.1 Survey Development

The survey was developed through a collaborative process with partnering conservation districts to ensure that data ultimately met the needs of community-based projects, and the surveyed population was limited to agricultural producers in one rural county of Southwest Colorado. Objectives and goals were identified, taking into consideration uses for local policy and academic research. During the development of the survey, there was a gradient of questions primarily for conservation district purposes or shared objectives. Some questions, including Q7 about synthetic fertilizer use, were requested by conservation district staff to meet their data needs. The development of questions was a process that included literature review and meetings with conservation district employees. Coordinators at conservation districts provided insight to ensure clarity of questions, ideal survey length, neutral wording, and how to implement a local business-driven incentive. The perspectives and contributions of conservation district staff was extremely helpful, given extensive experience working with agricultural producers in the region, understanding of ecological nuances, and integration with the community. Conservation districts requested that their exact location be kept anonymous for uses outside of direct community outreach and internal NAU and Transformation Network meetings and correspondence. This aligned with the project's goals to be guided by the highest benefit of the watershed and community, as a convergent effort.

During the development of the survey, conservation districts hosted workshops to address watershed management policy that engaged local individuals and groups, including water rights holders and community members. The goal of these workshops was to create a plan for a river that is diverted for irrigation in the area, but that has been experiencing reduced flows. The creation of this river management plan informed topics included in the survey, and an overarching goal was for data to contribute to this plan and represent perceptions of agricultural producers in the area whose schedules couldn't accommodate long time commitments. Engaging farmers and ranchers while considering schedule limitations, especially during early irrigation and growing season, was an objective.

2.2 Survey Design

The survey instrument took 10-15 minutes to complete, with 16 questions including an open-ended final question for questions, comments, and suggestions. The paper version of the survey is included in Appendix A. To reduce survey length, as many multiple-choice questions as possible were molded into Likert scales. The survey was made available via Qualtrics and on paper by mail to accommodate any respondents without computer access. Survey recruitment was achieved through posters in local businesses with QR codes to the Qualtrics survey, emails from conservation districts to listservs, and distribution of paper surveys at meetings and events for farmers and ranchers. Producers in the small river watershed involved in the river management were targeted, with a higher volume of emails, posters, flyers, and community engagement taking place in that area. A five-dollar incentive to a local coffee shop was offered. Partnering with a local business was important to align with the project's goals of community benefit and focus. Data was collected in rural Southwest Colorado during Summer 2024, and most surveys were taken online via Qualtrics.

During data collection, an automated system ("bots") took the survey ostensibly due to the advertised incentive to a local coffee shop. By utilizing IP address data and analysis of response times/quality the data was conservatively cleaned and bot responses removed. This process is outlined at length in Appendix C.

3. Results

3.1 Demographic Results

In total, the survey had 60 respondents, 33 in the small, targeted watershed with less irrigators/producers. The total number of producers has been omitted as it may identify the region where the survey was distributed, but as seen in Figure 2, the scales of production of respondents is relatively low, which is accurately representative of the region, where agriculture is widely dispersed. The coded average of was 2.4, meaning the average farm size was about 20-79 acres.

Acres (Scale of Production) Code Values:

1=1-19 acres
2=20-79 acres (average)
3=80-119 acres
4=120+ acres

Figure 3 outlines the distribution of the top six uses for agricultural land in the surveyed county. The dataset used for the distribution chart is from the USDA National Agricultural Statistics Service (NASS) CroplandCROS Data Layer. This raster is published each year with annually updated satellite data, not farmer-reported data (USDA, NASS). This data does not include land use for livestock, which is significant, as 62% of survey responses identified producing livestock. In the region, forage and hay is often grown on the same land or in the same region, with imported hay being less common.

USDA's CroplandCROS raster data identified the sixth most common use for agricultural land in 2023 was fallow or idle cropland. 64% of agricultural land in the region is used for alfalfa or other hay, with 'other hay' representing other legume species grown for hay. 51% of survey respondents identified growing alfalfa or other hay.

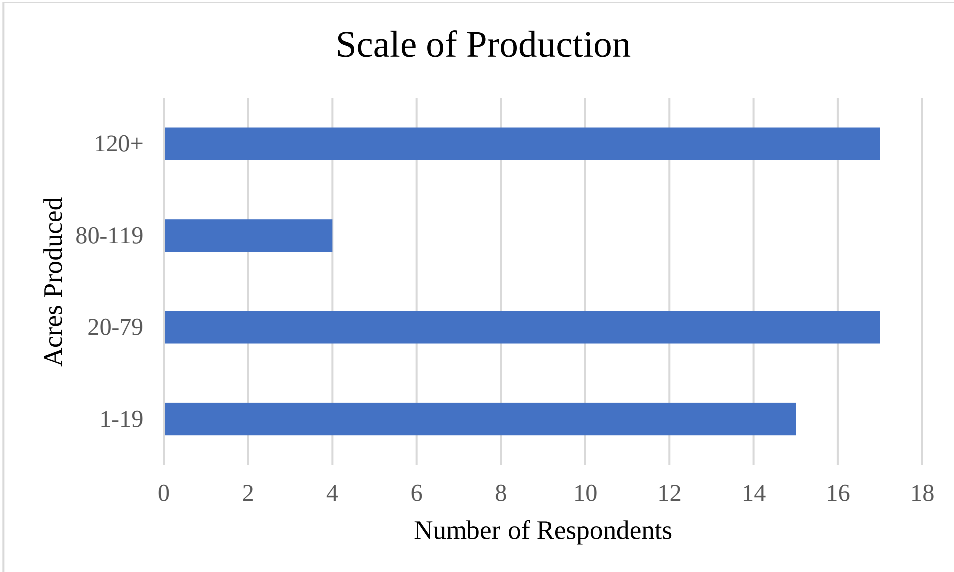

Fig. 2. Acres cultivated by respondents, illustrating the scale of production in the surveyed county of Southwest Colorado. Results from survey Q2.

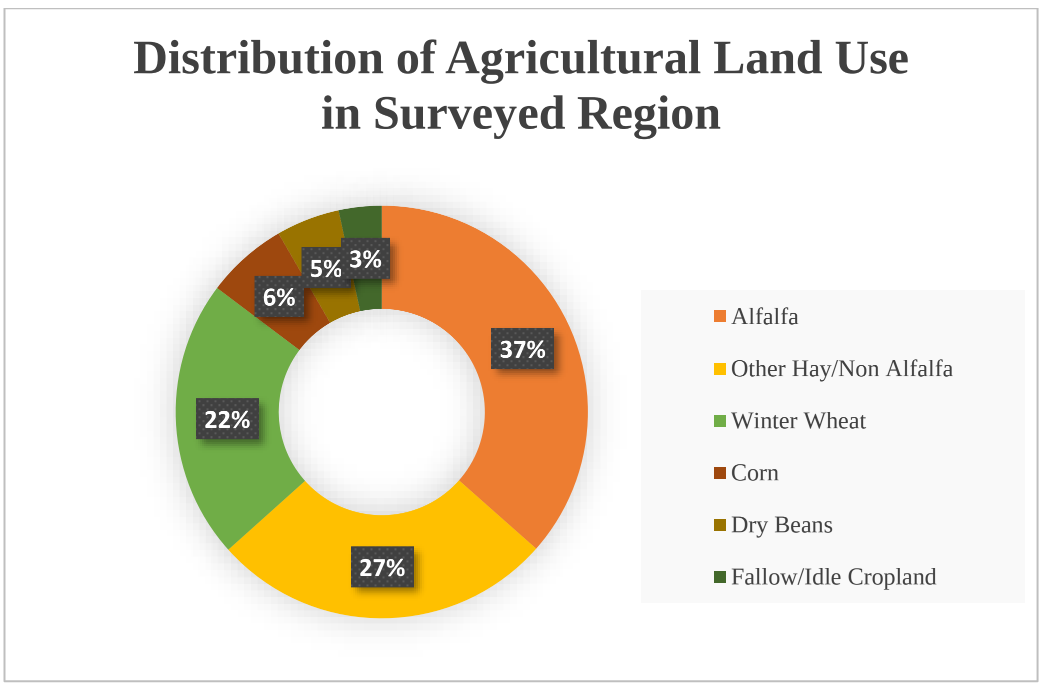

Fig. 3. Most grown agricultural products in the county surveyed in Southwest Colorado as measured by USDA CroplandCROS, NASS raster data.

3.2 Methods of Highest Interest

Understanding what methods are of interest and are already being used by producers in the county was gauged with a Likert scale on Question 9. Nearly half (45%) of respondents to the question identified already adding organic material to soil, and 41% of respondents identified already using rotational grazing. As shown in Figure 4, the highest 'extremely interested' methods were agroforestry methods windbreak and/or shade trees (34% of respondents) and drought-resistant crops (31% of respondents).

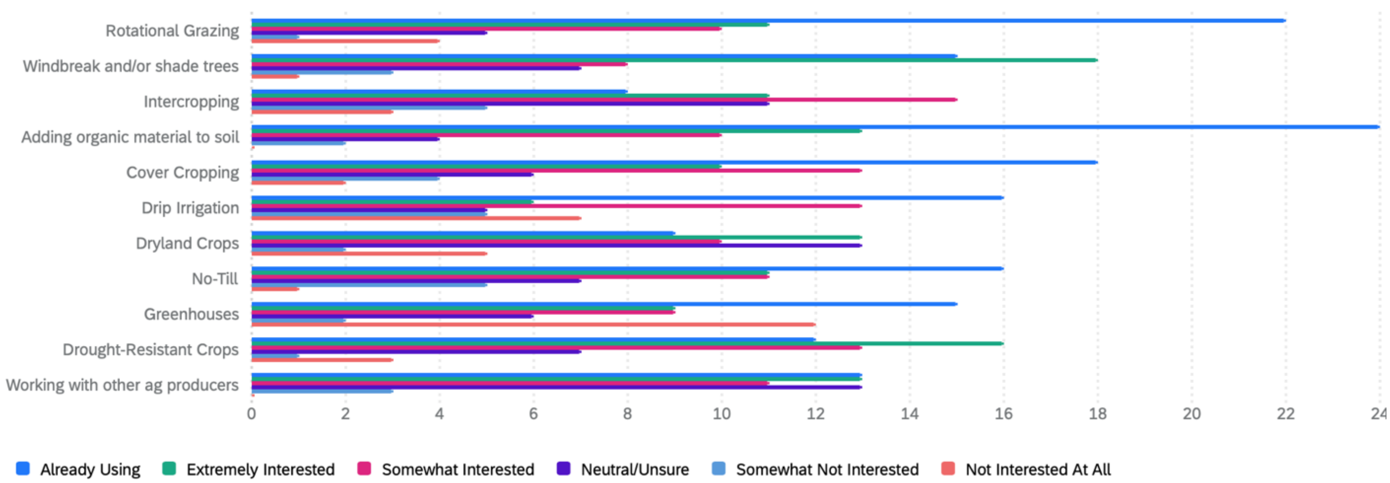

Fig. 4. Likert scale response results to Q9: How interested would you be in utilizing each of these methods on your land?

3.3 Perceived Barriers and Methods to Increase Willingness

To gauge climate-related challenges, producers were asked about how their production has been negatively affected by water availability, soil quality, and temperature or weather changes. Water availability and temperature and weather changes are related and received similar response rates. As shown in percentages in Figure 5, 42 out of 53 respondents identified water availability as a challenge, while 39 out of 52 identified temperature and weather changes as challenges. Almost half of respondents identified soil quality as a challenge.

Methods respondents identified to ease strain and increase willingness are shown in Figure 6. 60% of those who responded identified programs to subsidize or eliminate cost, and 58% identified workshops or training. 56% of survey respondents selected access to equipment, and the fourth highest selection (44% of respondents) was technical assistance.

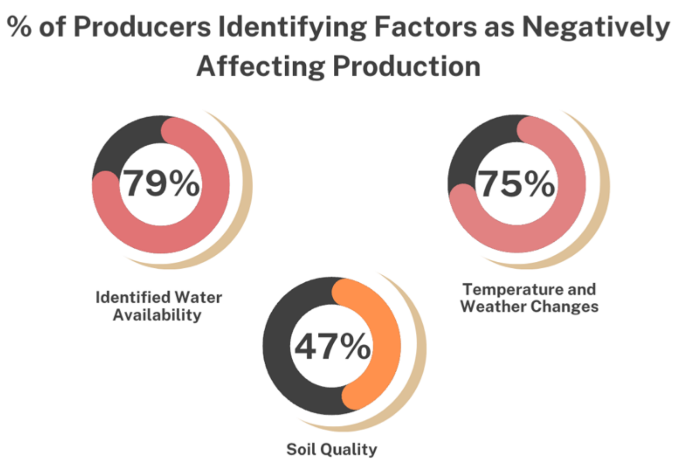

Fig. 5. Percentage of respondents who selected water availability, temperature and weather changes, and soil quality, respectively, as negatively affecting production.

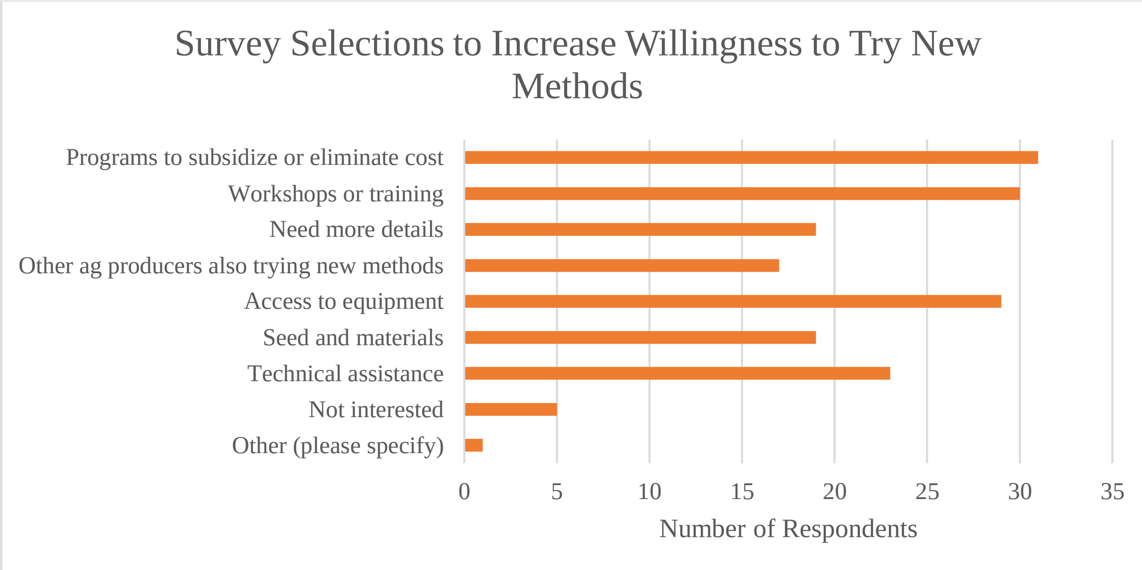

Fig. 6. Responses to Question 10: Would you feel willing to try new methods if there were (select all that apply).

3.4 Statistical Analyses

Using data from questions 2 and 13-15 (shown in Figure 6), statistical analyses were conducted to search for significant correlations (p-value <0.05) between variables. Scale of production and satisfaction with community resources were selected as potential moderating variables. Before searching for significance between variables to test for moderation or mediation between variables, each variable was quantified in Figure 8. ‘Acres’ had an average response value of 2.4, indicating that respondents operated on an average production area of 20-79 acres. ‘Community resources’ had an average value of 3.4 indicated a 68% overall satisfaction with community resources by respondents. ‘Irrigation’ had an average response value of 2.96, meaning a 59% rate of satisfaction with current irrigation equipment. ‘Water rights’ had an average response value of 4.1, indicating an 82% rate of familiarity of water rights.

In Figure 9, scale of production (acres) represents the independent variable while satisfaction with irrigation equipment (irrigation), familiarity with water rights (water rights) and satisfaction with community resources (community resources) were tested as a dependent variable. There was no statistically significant correlation between acres and irrigation or water rights, but the p-value between acres and community resources was 0.00948, indicating a significant correlation, shown in Figure 9. Community resources was then tested as an independent variable, with acres, irrigation, and water rights as the dependent variable, to search for significant correlations. All varieties of these variables as compared to satisfaction with community resources proved to be statistically positively correlated, as shown in Figure 10. Those who responded with more satisfaction with community resources produced at a larger scale, identified a better familiarity with their water rights, and were more satisfied with their irrigation equipment.

2. How many total acres of land do you produce on?

☐ 1-19 acres ☐ 20-79 acres ☐ 80-119 acres ☐ 120 or more acres

13. How satisfied are you with community resources available to you?

Not At All Satisfied ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Very Satisfied

14. How satisfied are you with your current irrigation equipment (diversions, headgates etc.)?

Not At All Satisfied ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Very Satisfied

15. How familiar are you with the water rights on your land?

Not At All Familiar ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Very Familiar

Fig. 7. Questions 2 and 13-15. Selections from these questions were used for statistical analyses in R Studio. Sample from paper version of survey.

Variable	**Average**	**Min**	**Max**	**Std. Dev.**	**Std. Err.**
Acres	2.4	1	4	1.212056079	0.167170237
Community Resources	3.4	1	5	1.188652989	0.164836512
Irrigation	2.96	1	5	1.30868371	0.18507583
Water Rights	4.1	1	5	1.08339161	0.16150249

Fig. 8. Average, minimum, maximum, standard deviation, and standard error values for variables represented in questions 13-16.

Variables Compared via Linear Regression	**Standard Error**	**P-Value**	**Statistical Significance (p-value <0.05)**	**Slope**
Acres, Irrigation	0.2091	0.111639	*No*	0.209389907
Acres, Water Rights	0.2435	0.146	*No*	0.241197183
Acres, Community Resources	0.3810	0.00948	**Yes**	0.364001146

Fig. 9. Variables analyzed in linear model analysis comparing acres (scale of production), with satisfaction with irrigation equipment, familiarity with water rights, and satisfaction with community resources, respectively.

Variables Compared via Linear Regression	**Standard Error**	**P-Value**	**Statistical Significance (p-value <0.05)**	**Slope**
Community Resources, Irrigation	0.1227	0.00645	**Yes**	0.349926072
Community Resources, Water Rights	0.3302	0.0462	**Yes**	0.330201342
Community Resources, Acres	0.3810	0.00948	**Yes**	0.364001146

Fig. 10. Variables analyzed in linear model analysis comparing satisfaction with community resources to satisfaction with irrigation equipment, familiarity with water rights, and acres (scale of production).

Discussion

Engaging local food producers about self-identified interests and concerns promotes a nuanced approach to supporting adoption of regenerative methods to bolster adaptability of growers to a changing climate and encouraging land management conducive to functioning ecosystem services. Furthermore, engaging with local entities for a convergent survey creation process can produce regionally informed and locally beneficial data. The goal of this anonymous survey was to understand agricultural producers' perceived limitations to, and preferences and perceptions about conservation topics including Nature-based Solutions (NbS) like agroforestry. Uncovering nature-based practices currently being utilized was an objective, especially because there are several multi-generational farms and ranches in the region, which likely hold generational ecological knowledge. Generally, results showed that producers in this area are invested in water conservation and interested in methods like agroforestry (windbreak trees) and drought-resistant crops. Out of 53 respondents to a question about values, 34 selected conserving water and water retention of soil as 'extremely important,' and no respondents selected 'not important at all,' which is a promising indicator for conservation in the surveyed region.

Focusing on adding organic material to soil or rotational grazing, both identified as already being used, could serve as a gateway to further NbS and processes of developing regional protocols for growers interested in implementation or tailor financial support programs. Rotational grazing focuses on optimizing grazing pressure on forage plants by moving livestock methodically to improve soil health, increase nutrition available to livestock, and maximize forage plant yields (Baronti et al., 2022). Using soil organic matter as an amendment can increase nutrient availability in soils (Gerke, 2022). Building soil organic carbon through nature-based land management can mitigate soil degradation, often a costly issue, and aid in water retention (Jordon et al., 2021).

In the survey, 24 out of 54 respondents identified already adding organic material to soil, and 22 out of 54 respondents identified already practicing rotational grazing. These are useful data to support potential producer-to-producer knowledge sharing in the surveyed region. In general, social relations and contexts are foundational to knowledge practices for agricultural producers (Thomas et al., 2020). Supporting this inherent framework of idea sharing could bolster adaptability to drought years and changing climate, as growers with knowledge of regionally specific rotational grazing practices share methods with interested producers. While water availability (79% response rate) and temperature and weather changes (72% response rate) were overwhelmingly identified by respondents as negatively affecting production, soil quality (47% response rate) was selected considerably less. This could be reflective of producers already using adaptive practices like rotational grazing and adding soil organic material as an amendment on fields.

Out of 60 total responses, nearly all respondents utilized the online Qualtrics version of the survey, which could indicate that a younger cohort of producers responded. Nearly ¼ of the county surveyed is 65 or older. Though 2022 Pew Research indicates that 75% of U.S. seniors over the age of 65 report using the Internet, a percentage which has been increasing year over year, this is considerably less than the 98% of 30–49-year-old Americans that are online (Pew Research Center, 2022). While this correlation can't be fully tested as age demographic data wasn't collected, it's useful to consider how this could affect response rates. Finding outreach methods that encourage responses from a diverse age range is important for a dataset that is representative of multi-generational perspectives.

Statistical analyses conducted to compare scale of production, understanding of water rights, satisfaction of irrigation equipment, and satisfaction with community resources showed that ‘community resources’ was significantly positively correlated when compared in a linear analysis to the other three variables tested. Those who responded with higher satisfaction with community resources produced at a larger scale, identified better understanding of their water rights, and were more satisfied with irrigation equipment.

This result suggests that community resources is a moderating variable to scale of production, satisfaction with irrigation equipment, and understanding of water rights. Comprehensive understanding of individual water rights is necessary, as the adjudication system is complicated, and misunderstandings could cause conflict among rights holders. The statistically significant correlation between scale of production and community resource satisfaction could suggest that those with more at stake take advantage of community resources at a higher rate. For larger scale producers, relative to the average reported production size of 20-79 acres in the surveyed area, this result proves that community outreach in the region is contributing to positive outcomes, measurably, in terms of irrigation equipment satisfaction and understanding of water rights. Not all agricultural products require large scale land use though, as in the cases of tomato and apple production (Poore & Nemeck, 2018). This correlation also could indicate that smaller scale producers don’t feel as accommodated or represented by community programs. Supporting small-scale production could aid in creating a foundation for a shortened supply chain, limiting how much virtual water is exported. Supporting a wide variety of sustainably, locally produced commodities can help aid in rural community coherence and limit distribution costs for growers (Anggaeni et al., 2022).

Conserving water in the Southwest is not a straightforward process in part due to water adjudication policy limitations and restrictions. In three watersheds in Colorado, C.R.S. § 37-92-305(3)(c) has been passed, an amendment protecting water rights if a rights holder chooses to allot some adjudicated water to land fallowing, water banking, or conservation (FindLaw, 2022). In the remaining four Colorado watersheds, water users may not use adjudicated water for conservation uses, and "use-it-or-lose-it" is the paradigm, meaning the full water right must be used to uphold it. The region surveyed is in one of the watersheds where C.R.S. § 37-92-305(3)(c) hasn't been implemented, so is limited in terms of how much water can be used for return flows to waterways or other conservation purposes. This policy challenge poses a significant roadblock to achieving buy-in from producers wanting to implement regenerative or conservation-based practices. Despite this limitation, understanding perspectives of agricultural producers and what regenerative methods are of highest interest will hopefully aid in expediting the C.R.S. § 37-92-305(3)(c) amendment, a goal of local conservation districts.

In Figure 3 describing most common uses for agricultural land in the area identified by USDA NASS raster data, fallowing is the sixth highest use. This could be interpreted in a few ways. Fallowing programs exist in the Southwest, incentivizing producers to fallow land for one or more growing seasons for conservation purposes. This could mean focusing irrigation water on other fields or, in places where policy protections are in place, reallocate water for conservation (Koch et al., 2021). Fallowed land, especially without the addition of agroforestry practices like windbreak trees that limit erosion, can contribute to dust on snow, a major contributor to changes in headwater snow melt hydrology.

Melt events in this region, as measured by SNOTEL telemetry sites across headwater snowpack locations, are occuring up to a month earlier than projected based on snow amounts, partly to dust on snow lowering snow's albedo and causing faster, earlier melt events (EPA, 2022; Fassnacht et al., 2022). Dust mitigation is an important and complex challenge in the Southwest, and understanding where and why land is being fallowed could inform mitigation strategies. These could include agroforestry to reduce wind erosion and planting cover crops to protect soil biodiversity and health (Jose et al., 2022; Elevitch et al., 2018; O'Connell et al., 2014). In the region surveyed, windbreak trees were of the highest interest, with a 33% response rate of 'extremely interested' on a Likert scale. Rotational grazing is another mitigation tool for soil erosion, which can occur from soil compaction due to overgrazing that encourages weed growth while killing forage plants and harming soil health (Baronti et al., 2022). Offering information sessions, training, and financial programs to implement mitigation methods could aid in limiting erosion of soil, limiting wind-carried dust loads on high elevation snowpack.

For small- and medium- scale producers, water adjudication laws limiting conservation uses and limitations identified in the survey like cost and access to training are significant barriers to transformation. Water use for alfalfa irrigation accounts for a significant amount of Colorado River water use. A 2024 water use accounting report listed cattle feed crops as consuming 90% of total water used by irrigated agriculture in the Upper Basin, more than three times the combined consumption of commercial, municipal, and industrial uses (Richter et al., 2024). Also, the global alfalfa hay market has grown immensely due to increasing demand for dairy (Research and Markets, 2018). 2023 USDA NASS raster data identified 64% of agricultural land in the surveyed county as being used for alfalfa or other legume crops cultivated for hay, and 51% of survey respondents identified growing alfalfa or other hay.

As restrictions on alfalfa cultivation start being imposed in other parts of the world, like the 2019 ban in Saudi Arabia, exporting the crop will become more lucrative and in demand

(Research and Markets, 2018). Protecting increasingly arid landscapes like the Southwest will rely on supported transition based on convergent methodology. The top three means identified by respondents to increase willingness to try new methods were programs to subsidize or eliminate cost (60%), workshops or training (58%), and access to equipment (56%). Support for programs like these, along with policy amendments to allow for conservation use of adjudicated water, could support increased flows in the Colorado Basin, where 52% of all Colorado River water is used for agriculture, representing 74% of direct human use (Richter et al., 2024). Implementing convergent research surveys to gauge perspectives, challenges, and preferences of agricultural producers is a preliminary step in protecting the Southwest's part in the food system and the waterways that give it life.

In a written response, one respondent said, "If we aren't taking care of the land, we aren't making a living, period that's it." The same respondent also said, "We have no problem with saving the environment, but it is being pushed at us around every corner." This illustrates the need for sustainability efforts that go beyond encouraging growers to be environmentally friendly, but instead works with communities to offer regionally relevant training and programs that support a transition to increasingly adaptive practices like NbS. Integrating researched methods into on-the-ground transformation requires community-rooted inquiry. Convergent research focuses on innovation and solutions to complex issues by bringing together people from many backgrounds, disciplines, and ways of life (Wilson, 2019). Much like diversity supports resilience in ecological systems, diverse perspectives can produce more adaptive, comprehensive, and regionally informed climate solutions.

When asked by Chris Outcalt of *Colorado Sun* how drought has impacted the Ute Mountain Ute Tribe, one of three tribes in the Ute Nation Indigenous to the Colorado Plateau, Tribal Chairman Manuel Heart said:

> "Eventually, what's projected is the drought is going to get a little bit worse than what it is. We need to look at it now. Not 20 years down the road. Time is of the essence."

CHAPTER FOUR

Alternatives and Implications

Agroforestry: Integrating Forest Wisdom into Agricultural Systems

In the research survey of agricultural producers in San Juan a headwater-dependent community of Southwest Colorado, the practice most selected as ‘extremely interested’ (18 selections) in a Likert scale gauging interest in utilizing different methods was windbreak and/or shade trees. Using trees to help mitigate effects of radiation from the sun and high wind events is one outcome of agroforestry. Alley cropping could provide shade and windbreak to farms and ranches trying to find solutions to such challenges, while offering a secondary crop of valuable or productive trees adapted to the region. Alley cropping, which gained the most traction during the Dust Bowl, involves planting rows of trees between crops, reducing runoff, soil erosion, increasing efficiency of nutrient uptake, sequestering carbon, and improving biodiversity (Jose et al., 2022; Elevitch et al., 2018). Trees can provide a buffer from runoff of fertilizer or topsoil, protecting waterways (Elevitch et al., 2018). Alley cropping can also mitigate winds if used as a windbreak or shelterbelt, creating a shaded microclimate (Gold & Garrett, 2009). Integrating natural ecosystem functions works with, instead of against, the landscape to solve challenges (Stojanovic, 2019). As climate change adds increased extreme weather events that can threaten topsoil, water retention of soil, and wellbeing of livestock, agroforestry offers a suite of solutions to build resilience on small and medium-scale agricultural operations.

For millennia, Native peoples across modern North America have practiced Indigenous methods of what's now identified as landscape-scale agroforestry (Rossier & Lake, 2014). Researchers have found edible plant hyperdominance (greater abundance and more extensive ranges) in the eastern Amazon of South America originally from polyculture agroforestry 4,500 years ago, proving the ability of such systems to endure without active management. (Maezumi et al, 2018). Before the Middle Ages in Europe, food crops were produced on cleared and burned plots with trees planted with or following harvest (King, 1968). In recent history, agroforestry planting as shelter belts and windbreak trees were done in Canada and the U.S., especially during the Dust Bowl in response to extreme topsoil loss (Jose et al, 2022). Unfortunately, more widespread uses of agroforestry strategies have decreased significantly as forestry and agricultural management research fractured into separate infrastructures, though an increased interest and understanding of agroforestry practices has occurred in the last 40 years (Shibu et al, 2022). Linking these research silos to consider holistic landscape management could support increased understanding between natural and agricultural ecosystems.

Considering cultivated land as a continuation of an ecosystem is a hallmark of NbS like agroforestry. After all, agriculture depends on ecosystem services ranging from hydrological function to the abundance of pollinator species, which is becoming more scarce. In the last two decades, some species of bumble bee have declined by 96%, and species important for pollinating crops are declining in many regions of North America (Nabhan, 2013). The importance of pollination in agricultural systems can't be understated, but agroforestry practices could generate biodiversity to support pollinator host species and support pollinator abundance needed for food production (Schoeneberger et al., 2017). Pollinators are typically three times more abundant in fields that are sheltered from wind than those that are exposed (Williams &

Wilson, 1970). Therefore, integrating windbreak trees could protect pollinators while encouraging increased pollinator presence in crop fields. Additionally, areas under and around windbreak trees could be managed to encourage pollinator insects by establishing plant species attractive to bees and other pollinators. Alongside pollinator insects, livestock species could benefit from protection from cold or harsh winds. Windbreak trees can be managed to produce timber crops, particularly hardwood species like oak (*Quercus*) and walnut (*Junglans*) (Brandle et al., 2022).

The benefits of agroforestry stand in contrast to high deforestation and forest disturbance rates associated with intensive conventional agriculture (Kadoya et al., 2022). Increasing overall diversity of crops could improve food security outcomes, as monocultures are less resilient and prone to severe degradation from pests and extreme heat (Nabhan et al., 2020). The still-detectable edible landscape started by Indigenous peoples of the eastern Amazon 4,500 years ago utilized low-severity fire management, closed-canopy spaces for planting, limited land clearing, and management of multiple annual crops, all of which led to food system resilience despite social and climatic changes (Maezumi et al., 2018). Integrating forest structures in agricultural practices to mimic ecological strategies could do have the same benefit today. While many of these methods might not be applicable to large-scale operations, the next section will discuss the broad importance of localizing food systems in place of ecologically damaging industrial-scale agriculture.

Along with environmental protection, support and benefit to human wellbeing is an important part of agroforestry (Nabhan et al., 2020; Shibu et al., 2022). Prioritizing a healthy agroecological system could have positive ripple effects in societal, environmental, and production spheres. Social forestry, or forest management by communities, can be promoted by agroforestry. This is being shown across Southeast Asia, where more than 7.3 million households are engaging with social forestry as of 2019, many of those having once relied on now-degraded nearby forests to support their livelihoods (Willmott et al., 2023). Increasing agrobiodiversity for forests used for products like oil palm or cocoa leads also to diversified and more secure income, livestock fodder, and food security (Willmott et al., 2023; Pratiwi & Suzuki, 2019). A diversified farm system can be ecologically identified by multiple intercropped species, planting of non-food species, and genetic diversity in livestock and crop species (Kremen & Miles, 2012). Diversifying pasture and croplands in the U.S. could prove to have holistic benefits while increasing crop resilience.

Silvopasture combines livestock, forage, and tree planting. Adding trees to historically deforested farm and rangelands can allow forage crops to reestablish, provide shade for animals, abate winds, and create an integrated system managed for both forest health and grazing (Gold & Garrett, 2009). Natural forest systems have evolved over millions of years to optimize efficiency, and agronomic design could only benefit from tapping into such systems (Gremmen, 2022). A study in the U.S. southern-Midwest showed that, compared to conventional methods, silvopastures led to lower temperatures for soil and livestock, more soil organic carbon, and higher water content, both benefitting animal welfare and improving soil quality (Amorim et al., 2023). Finding nature-based methods like silvopasture to regulate farmlands as temperatures rise and climatic patterns change will aid in reducing potential vulnerabilities of soil, crops, and livestock.

Agroforestry involves a degree of uncertainty and experimental trial-and-error on behalf of the agricultural producer. Lag between initial implementation and when producers see improvement using NbS is likely, especially in the case of tree-based methods. Technical assistance from Federal and State conservation programs could improve access to design methods and financial support as needed to aid in transition (Schoeneberger et al., 2017). Any agroforestry practices applied to farmlands should be carefully considered based on regional climate. Ultimately, just because technology is nature-based doesn't mean it is necessarily good for a particular landscape, and land managers should consider this 'natural fallacy' when viewing the bigger picture of environmental and agricultural transition toward Nature-based Solutions (Gremmen, 2022). Such considerations could be achieved through active engagement with other producers, community members, and academic institutions (Dumanski et al., 2006).

Sharing ideas and understanding challenges could ease conflict, improve outcomes, and lead to more comprehensive solutions. Usually, producers can't easily implement new systems while managing operations but could benefit from input about solutions from private or academic organizations focused on conservation or agronomy. Academic institutions can create regionally adapted and informed strategies for adaptation while monitoring rates of success of different adaptation strategies like agroforestry (Schoeneberger et al., 2017). Sharing functions of agroforestry and how those functions support adaptation and mitigation, as shown in Figure 11, could increase understanding among agricultural producers. Community members who hold stake in waterways may offer insight that is less production-focused but paints a nuanced picture of why conservation is important. Methods like windbreaks, silvopasture, and diversifying crop systems may help to increase sovereignty from external inputs, water crises, and even mitigate the intensity of effects of climate change on farmers and ranchers in the Southwest U.S. and around the globe.

Climate change activity	Major climate change functions	Agroforestry functions that support climate change mitigation and adaptation
Adaptation		
Actions that reduce or eliminate the negative effects of climate change or take advantage of the positive effects.	Reduce threats and enhance resilience.	• Alter microclimate to reduce impact of extreme weather events on crop production. • Alter microclimate to maintain quality and quantity of forage production. • Alter microclimate to reduce livestock stress. • Provide greater habitat diversity to support organisms (e.g., native pollinators, beneficial insects). • Provide greater structural and functional diversity to maintain and protect natural resource services. • Create diversified production opportunities to reduce risk under fluctuating climate.
	Facilitate plant species movement to more favorable conditions.	• Assist in plant species migration through planting decisions.
	Allow species to migrate to more favorable conditions.	• Provide travel corridors for species migration.
Mitigation		
Activities that reduce GHGs in the atmosphere or enhance the storage of GHGs stored in ecosystems.	Sequester C	• Accumulate C in woody biomass. • Accumulate C in soil.
	Reduce GHG emissions	• Reduce fossil fuel consumption: o with reduced equipment runs in areas with trees. o with reduced farmstead heating and cooling. • Reduce N_2O emissions: o by greater nutrient uptake through plant diversity. o by reduced N fertilizer application in tree component. • Enhance forage quality, thereby reducing CH_4.

C = carbon. CH_4 = methane. CO_2 = carbon dioxide. GHG = greenhouse gas. N = nitrogen. N_2O = nitrous oxide.

Fig. 11. Functions of agroforestry that aid in climate change adaptation and mitigation (Schoeneberger et al., 2017).

Drought-Tolerant and Climate Adapted Crop Species

In the research survey conducted in Southwest Colorado, the method that had the second most selections of ‘extremely interested’ (16 selections) was drought resistant crops. There is an opportunity to prove the profitability, feasibility, and water saving potential of plant species adapted to desert conditions. All crop species have unique temperature and water thresholds, and growing seasons are determined by these boundaries (Walthall et al., 2012). While some commonly grown crops like wheat and soybean have reduced ability to photosynthesize due to heat in desert climates, arid adapted species have adapted over millions of years to cope with high temperatures (Nabhan et al., 2020). Implementing arid adapted species as small pilot plots within existing agricultural fields could help test outcomes of different species in Southwest Colorado and other desert regions of the U.S. Southwest. Understanding the feasibility of growing crops in specific regions is warranted, and further investigation through academic research and partnership programs could contribute to transformation from less arid adapted crops dependent on temperate, predictable climate and consistent irrigation. This especially crucial as crop yields are being threatened by climate change, which is accelerating expansion of drylands in the Southwest (Nabhan et al., 2020).

Drought and dryland-adapted crop varieties could be immediately feasible to pilot plots within larger operations, growers not contractually or financially bound to growing certain crops, and those receiving State or Federal funding from programs promoting conservation. Otherwise, permaculture farms, academic institutions, and hobby farms could create protocols through trial and error to provide insight to growers who may not have the flexibility to try new crops. There are a few species that could be of interest in arid climates of the Southwest, with varying uses. Ultimately, food produced is guided by demand, so any change in species grown would rely on food markets to also begin transformation toward arid adapted, less common food items. Revitalizing local food systems to encourage dietary choices that benefit individual and community ecosystem wellbeing is an adaptive strategy worth campaigning for.

One drought-resistant crop, the commonly grown cereal grain sorghum (*Sorghum bicolor*), can use 8 inches of water per harvest season, compared to the average 21 inches used by high-yielding corn crops (Scott & Dreiling, 2019). A self-pollinated plant, sorghum pollination isn’t negatively affected by drought, and waxy coatings on leaves serve as protection and a means of mitigating water loss (Carter et al, 1989). Sorghum can produce higher amounts of grain per unit of water as compared to corn or soybeans which illustrates its potential value as an efficient crop in arid regions, where it could replace less water efficient forage crops like alfalfa (Rees & Irmak, 2012). Though often a feed crop in the U.S., sorghum is utilized for human consumption in other parts of the world, is gluten free, and contains more fat and protein than corn (Rice & Curtis, 2021). Integrating sorghum into U.S. food markets would be needed to truly increase demand for the grain, but raising awareness about its nutritional benefit could stoke buyer interest.

The legume chickpea (*Cicer arientinum*) is another drought tolerant species originally from southeastern Turkey and Syria (Walia & Chen, 2020). Chickpea has a deep tap root allowing for drought tolerance by using water deep in the ground, high nutritional value, and nitrogen fixing root nodules (Arif et al., 2020). Its nitrogen fixing properties could particularly be helpful in the case of degraded soils, regenerating depleted nutrients and improving soil biodiversity, supporting connectivity of important microbial communities in the wider ecosystem. Using legume species in a rotational crop system reduces weeds and improves soil tilth to aid with root penetration of future crops, too (Walia & Chen, 2020). *Cicer arientinum* is a cool season plant, with a tolerance for hotter temperatures at the end of its life cycle which could be an effective option in mountainous regions of the Southwest where growing seasons often begin later (Karalija et al., 2022). Chickpea is an indeterminate grower, allowing for longer growing seasons if summer weather patterns remain temperate (Rice & Curtis, 2021). In a research study comparing chickpea seed size to climatic adaptations, it was found that Desi type variants with smaller seeds matured more quickly and had higher yields in dry years (Walia et al., 2020).

Crops like chickpea are most efficiently watered using buried irrigation lines, and prefer well-draining, sandy, loam soils (Light et al., 2018, Walia & Chen, 2020). Buried irrigation allows the root zone to receive water more directly, reduce evapotranspiration, and improve water usage effectiveness by over 20% (Wang et al., 2021). Between 2007 and 2017, gravity irrigation in the Southwest declined by 12%, while use of drip irrigation systems increased by 71%, a promising trajectory for adaptation in the region (Mpanga & Idowu, 2020). Though farmers have cited complications like irrigation tape maintenance and startup costs (Wagner & McVicker, 2015), improving technology to ease such hurdles is a step toward sustainability of the Southwest's role in food production.

In hotter desert lowlands, options like yucca, agave, mesquite and amaranth could be considered, with most supporting insulin metabolism, potentially helping mitigate health effects of type 2 diabetes, cited as the most expensive nutritionally related disease in the region (Nabhan et al., 2020). The species has been introduced in 129 hot and semi-arid countries for its many services, but unfortunately some species like the fast-growing subspecies *Prosopis juliflora* have become prolific invasive species in parts of the world and even contribute to high rates of pollen allergy (Hussain et al., 2020). Mesquite was used by early cattle ranchers in Texas for livestock feed, and after overgrazing of grasslands and fertilization of mesquite by manure, surface root systems of the tree inhibited regrowth of grasses (Archer et al., 1995). Ranchers in Texas still battle with mesquite, which continues to propagate over grasslands and create densities over 10,000 stems ha^{-1}, leaving little or no forage grass (Felker et al., 2013). Any notion of introducing mesquite as a crop species would require significant ecological assessment of potential risk for overly prolific growth. In areas like Texas where mesquite has become a nuisance species, it is unlikely to transform it into a crop species, even with less prolifically growing subspecies, due to its reputation. Such regional contexts should be considered when planning drought-resistant crop species.

Mesquite was once a food staple for Indigenous communities in the Americas and the Indian peninsula, producing sweet flour with high sucrose and fiber content (Felker et al., 2013). The flour, made from crushing pods, can be eaten without cooking, and kept indefinitely (Smith, 1932). Mesquite is a nitrogen fixing leguminous tree and could offer agroforestry options like shade for livestock, especially because of the plant's preferred temperatures, growing fastest in soil temperatures between 80- and 90-degrees F (Lyons & Rector, 2009). Nabhan et al. outline a plant-based arid-adapted agroecosystem with mesquite that could include a shaded "understory of cacti, herbaceous perennials, and ephemeral annuals irrigated by active and passive rainwater harvesting systems" (Nabhan et al., 2020). The tree can tolerate highly alkaline soils, able to live in soluble salt content ranging from 0.54% and 1.0% and a pH up to 9.5-10.0 (Ellsworth et al., 2018). Mesquite, which represents 44 *Prosopis* (Fabaceae) species has edible pods and can be used for fodder (Meyer, 1984, Ellsworth, 2018). Examples of the diversity of mesquite pods is shown in Figure 12.

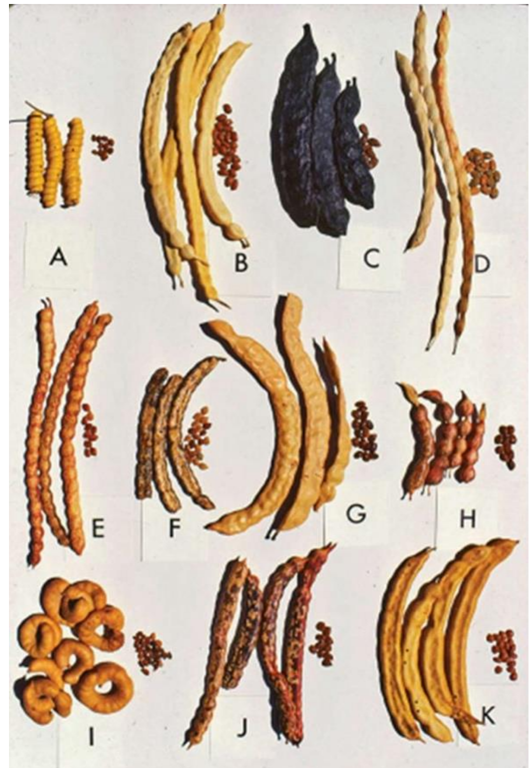

Fig. 12. *Prosopis* pods of various species from around the world, showing wide variety. (A) and (B) from U.S. California, (C) (E) (F) and (G) from Argentina, (D) from Baja California, (H) from New Mexico, (I) from Chile, (J) from south Texas, and (K) from Senegal, Africa. Photo by Taylor & Francis Ltd,

Mesquite, even in its native range, must be managed carefully, but its ability to grow so prolifically in desert environments is supportive of its potential as a food crop in water scarce regions. Limiting overgrazing of grasses to establish grasslands and then utilizing mesquite only as a monitored alley crop could be an outlet for its use. In recent years, some preparations of mesquite pods have begun finding their way into the U.S. food system and work from the USDA Western Regional Research Center has suggested uses of mesquite flour that are both useful and nutritious (Felker et al., 2013).

Without irrigation, Hopi farmers grew food crops in Arizona for over 2,000 years, utilizing less than 10 inches of precipitation annually (Kuzdas, 2019). This legacy supports the possibility of dryland farming of arid-adapted crops in the Southwest, with scalability being a main hurdle to overcome. As water resources become less consistent and irrigation not promised, especially to junior water rights holders, food growing operations will need to adapt. Proactively piloting arid-adapted crops like sorghum, mesquite or chickpea and experimenting with drip irrigation or other conservative watering regimes is the best way to ensure resilience of food production in the Southwest, and ultimately support higher instream flows with less irrigation diversion. Academic institutions can support this transition by researching new irrigation technology, a topic that producers in rural Colorado identified as of interest. Connecting with communities that self-identify interest in such methods could increase chances of success. For researchers, supporting adaptability could include continuing to uncover the most productive variants for regional climates while collaborating with food producers to fill gaps of knowledge inherent between farmer and academic.

Bringing it All Back Home:

The Importance of Adaptive Small-Scale Agriculture and Why 'Big Ag' Won't Work

Outlining the effects of industrial scale agriculture can help contextualize the importance of supporting smaller, community-integrated farms with a connection to land ethic. Furthermore, it's important to separate small-scale producers from the outsized negative effects of industrial-scale agriculture. In the Southwest, water conservation in agriculture is a necessity, and implementation of lower water-use methods is needed to preserve flows to within the Colorado Basin. This is much more feasible than retrofitting hugely consumptive, industrial-scale agricultural operations. Massive scales of production support cheaper food products and allow for increased accessibility to food but are unsafe by many micro- and macro-scale metrics—creating a complex an urgent challenge.

As it became predominant in the U.S. the 1950's, industrial scale agriculture didn't come about solely for the maximization of corporate profits, though that certainly has been one effect (Lam et al., 2016). Despite these farming methods only existing for about 70 years, modern diets reflect industrialized production of cereal grains, and a reduction in vegetables, nuts, and fruits (Rhodes, 2012). Since this form of agriculture has allowed for low-priced commodities to be produced at a massive scale, developing countries have had more access to well-stocked grocery stores (Boody & DeVore, 2006). At the same time, human population and therefore need for food is growing at a rapid rate, with demand being projected to double between 2012 and 2050 (Kremen & Miles, 2012). Though the cost of food may be subsidized by industrial scale agriculture, the environmental cost is incredibly high. As mentioned earlier in this text, monocrops are less resilient to climate change than nature-based or more diverse systems and have negative impacts on soil health. To maximize profits and productivity, food is grown as pesticide and fertilizer-dependent monocrops and livestock in confined animal feeding operations (CAFOs) that create huge amounts of waste in “manure lagoons” (Wartman, 2012). A huge portion of these become runoff into waterways and even contribute to air pollution (Boody & DeVore, 2006).

Fertilizer runoff, particularly nitrogen and phosphorous, contribute to eutrophication (excessive richness of nutrients in waterways) that causes toxic algae blooms and “dead zones” in waterways from low dissolved oxygen (Conley et al., 2009). These algae blooms can have devastating effects on ecosystems, like the 2018 *Karenia brevis* bloom in Florida, initiated by agricultural and urban runoff and increased temperatures (Dobson et al., 2019). *Karenia brevis* releases brevotoxins that are dangerous to human health and caused significant fish kill, along with seabird, sea turtle, and manatee deaths (Dobson et al., 2019). In the Chesapeake Bay, cyanotoxins from cyanobacteria blooms have caused bird and fish kill events, along with human health events, leading to persistent beach closures on the shores of North America’s largest estuary (Tango & Butler, 2008).

Intensive, industrial-scale agriculture is also changing, fracturing, and damaging forest ecosystems on a global scale (Kadoya et al., 2022). The threat to forest health is significant and alternatives like agroforestry that contribute to improvements in biodiversity should be considered for mitigation. Current agricultural practices account for ten percent of global greenhouse gases, and 38% of Earth's landmass is used for agriculture, so agricultural land management changes could be profound for forests and ecosystems (Stojanovic, 2019). The food system, including post-farm processing and distribution, accounts for 26% of total greenhouse gases (Poore & Nemecek, 2018). The distribution of this footprint is broken down in Figure 13. A quarter of emissions from food production end up as food waste, either from losses in the supply chain or by consumers (Gustavsson et al., 2013). Localizing food systems and supporting sustainable scales of agriculture could be a step towards limiting these emissions and losses. Shortening food chains could also limit virtual water, or that which is used in one region and exported to another. Furthermore, small-scale food producers shouldn't have to compete or pay monopolies like Walmart that control about 1/4th of all groceries sold in the U.S. (Wartman, 2012).

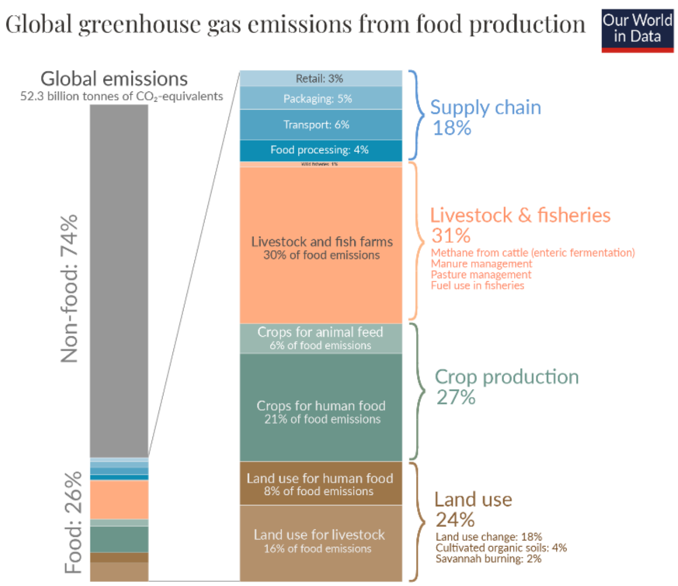

Fig. 13. Food's environmental impact. Data: Poore & Nemeck, 2018. Image: Ritchie, 2022.

Agriculture with a scale driven solely by commodity requires complicated responses to initiate environmentally beneficial change, necessitating weighing global supply chain demand and ecosystem services (Kremen & Miles, 2012). On the other hand, small-scale agriculture driven by a desire to support ecosystem services and ensure long-term sustainability of food systems has more flexibility in initiating beneficial change. Maximizing and subsidizing practices that are already ecologically sound is more straightforward than retrofitting sustainability to industrial, extractive operations whose function is inherently different from natural dynamics. Focus needs to be placed on supporting localized, community-based food systems.

In the county surveyed, no industrial-scale agriculture exists, only small and medium sized farms and ranches. Production is family-owned, and often multi-generational, with land management practices passed from one generation to the next. An over-adjudicated river in the region surveyed will benefit from water conservation, and land ethic should always be a central tenet of land management. ‘Industrial agriculture’ referred to here can be imagined as a single, genetically modified crop spanning thousands of acres, massive and possibly automated farm equipment, seeds that are patented and illegal to grow elsewhere, farm workers with gas masks to protect from myriad chemicals, and class action lawsuits in the billions. These are elements of corporatized, industrial scale agriculture.

The process of food production by industrial agriculture is damaging to the environment, and the foods produced similarly dangerous to human health. Foods grown industrially, as opposed to on small-scale or organic farms, are less healthy and pose risks by exposing consumers to pesticides, growth hormones, and even foodborne illnesses from unsanitary factory practices and lacking regulation (Wartman, 2012). These illnesses include malnutrition, immunodeficiency, malaria, chronic disease, and occupational injury and poor health (Hawkes & Ruel, 2006). Sources include agrochemicals like pesticides and antibiotics used for livestock, mycotoxins from poor post-harvest practices, and potentially unregulated genetically modified foods (Bhat, 2008). Pesticide residue can be measured in a disturbing number of common foods and beverages like fruit juices, animal feed, cooked meals, wine, and even water (Nicolopoulou-

Stamati et al., 2016). Though some pesticides have been banned due to health implications, consumers shouldn't have to serve as test subjects ahead of regulatory policy.

Changing this dangerous, unsustainable system is not a straightforward process. Most industrial food production is under the control of a few powerful corporations, who make small-scale farming increasingly difficult by producing low-cost food (Wartman, 2012). These corporations enjoy extremely integrated production chains that make it easier to distribute food than smaller, less powerful farms (Lam et al., 2016). However, USDA has guidelines for farms of all scales for reducing emissions, including "stabilized" fertilizers that result in less runoff, and some guidelines some topics explored in this paper, like cover cropping in the winter, utilizing no-till to reduce fossil fuel use by farm equipment, and realizing the potential of soil as a carbon sink to neutralize past emissions (Parton et al., 2011).

Organic material to fertilize fields need not be from faraway factories or supply stores but can be sourced locally. In Southern Arizona, about $200 million per year is spent by agricultural producers for inputs to food producing operations, while $300 million is sold as forage and other products, meaning that external inputs consume 2/3 of the value of food produced (Nabhan, 2013). In the research survey conducted in Southwest Colorado, 38% of respondents indicated applying synthetic fertilizer as needed, and 16% indicated applying synthetic fertilizer yearly. In some cases, food production systems can become reliant on expensive inputs that require consistent application to provide consistent nutrition to crops. Instead of relying on inputs shipped from far away, compost or other organic material can be sourced locally to promote soil health and water retention.

Though not accessible to all consumers, those who can afford to support local or organic farms can use their dollars to begin the shift toward a consumer-driven food system that's safe and sustainable. For agricultural producers, understanding how to take advantage of methods that are better for their respective watersheds and utilizing conservation-minded practices like agroforestry could support this shift, though industrial-scale producers should be held accountable for outsized contributions to land degradation and greenhouse gas emissions. As shown in Figure 14, sustainable agriculture seeks to empower communities through value addition, protection of ecosystem services, improvements to livelihoods, and adaptive governance. Through community-rooted convergent research efforts, feasible solutions can be implemented and tested to increase adaptability of food systems in the Southwest.

Fig. 14. Principles of sustainable agriculture. From the Food and Agriculture Organization of

Conclusion

Warming temperatures and less predictable hydrology are already impacting food producers in the Southwest and finding ways to integrate Nature-based Solutions (NbS) can support adaptability and resilience especially during dry, hot years. While challenges continue to evolve as the U.S. Southwest experiences aridification, allowing agricultural producers to identify adaptive methods that are of interest is a first step in successful implementation. Utilizing convergent research methodology, a survey of agricultural producers in a San Juan headwaters region of Southwest Colorado produced results that can help inform local entities as well as academic institutions. Understanding limitations to implementation could inform federal and state organizations about how best to support producers seeking to implement Nature-based Solutions. Integrating land ethic as a foundational framework to food production systems, including NbS like agroforestry, can promote adaptive agricultural systems.

Community-scale agriculture and forestry management issues call for community-scale response and action, like focusing on improving livelihoods while creating pathways to transform operations to biodiversity-friendly production (Kadoya et al., 2022). Engaging with producers through outreach should include both economic and ecosystem benefits and implications (Schoeneberger et al., 2017). Increasing access to programs to subsidize or eliminate cost was selected by 60% of survey respondents to increase willingness to try NbS. Agroforestry methods like windbreak and shade trees and drought-tolerant crops were identified as of the highest interest. Understanding climate challenges should be balanced with implementing solutions, and through convergent methods, finding ways to grow food in a changing world.

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My mom, dad, and husband Callen, who supported this project in all the other ways.

The Southwest landscape for teaching me lessons that can’t be learned in a classroom.

Afterword

Food can be viewed as a production item, a commodity, a necessity. An exchange, a point of contention: as per grade school biology, a vehicle for cellular energy. A product to be grown somewhere, measured, weighed, paid for, digested, and forgotten. Food can be a scarce resource; nutritious foods are not distributed fairly. Food can also be a facilitator of warm family reunions—a grandmother's cookie recipe, familiar and comforting. Food is multi-dimensional, ideological, and deeply sacred: a manifestation of the entanglement between human ingenuity and nature's wisdom. As confusing as it is miraculous. Whole careers can be spent studying the relationships between food systems and the economy, or human evolution, or global politics. The very cells of our bodies are constructed from nutrients inherent in our planet's soil and rains from our atmosphere. Some people recognize the spiritual domain of agriculture and respect nature's role in cultivating crops. The shift from reverence to commodification has not happened everywhere.

Food, and the way we grow it, carries a deep truth: how we care for our bodies and communities reflects how we care for our environment. Even in climate-controlled buildings and vehicles, in cities and paved paradises, we are as deeply connected to the symbiotic nature of our biome as ever. There's no boundary separating our bodies and the planet. What we consume can poison or heal us, and this is as true for our gut microbiota as for ecosystems. Humans exist within, not separately from, the vast network of plant, animal, and fungal life. This means that regeneration of soil and plant communities extends to rehabilitation of human communities, too. The opportunity for integration of the frenetic pace of industry is ripe for restorative advancement. Industrial growth has beneficially furthered our species' potential, but it's taken a devastatingly expensive toll on our relations and host planet. One can expect accountability without devoting too much cognitive disk space, arguably a non-renewable resource, to overthinking about this reality.

Growing up on Maryland's Chesapeake Bay showed the wide-ranging effects intensive agriculture can have on ecosystems. Fertilizer runoff led to dangerous algal blooms and bacterial outbreaks, closing beaches, and even harming bodies of immune-compromised watermen and women in my community, sickening our beloved estuary and those who worked on it. As a young person I gravitated toward books and documentaries about food systems—my mom reminds me that she still can't buy white sugar due to my intense lobbying after watching *Food Inc*. Learning about agriculture, consciously or not, helped contextualize this confusing lived experience. I understood early on that few corporations had iron fist control over seeds, pesticides, and methods of food production. What an insurmountable force, and a painful reality, that most of the food at my neighborhood grocery store was grown with a sole, insidious intention: greed. Even at a time when modern science showed us the importance of nutrient-rich diets, it seemed the appetites of corporate bank accounts had won. Getting unbleached sugar, as far as I was concerned, was the least we could do.

Some years have passed since being introduced to the corporate realm of agriculture. Becoming acquainted with permaculture, the power of local farms, regenerative agriculture, and Traditional Ecological Knowledge (TEK) in recent years has allowed me to reimagine the current food system as a substrate for community empowerment and connection. Generally, from where seems dismal and hopeless are beacons of hope. Re-learning how to work with the land instead of against it honors Indigenous wisdom and can heal some of the damage our planet has endured in the name of industrial progress. Even at an individual level, there's something about getting to know the soil in your backyard that feels empowering, like a quiet protest.

I once heard a rancher ask another if he'd heard about integrated grazing in orchard systems. "You're talking about letting the animals *in* the orchard? I think I've tried that once or twice, by accident," he said, laughing. I've seen how quickly a few unplanned llamas can defoliate fruit trees. Without context, especially after a lifetime of conventional food growing, some nature-based solutions can seem a bit strange. With intention, though, animals have the potential to till and fertilize soils, keep invasive species at bay, and enrich food production. There aren't many large-scale applications yet, but family farmers could benefit from mimicking nature and ecological systems.

The Southwest region, notoriously defined by conflict and stress over water resources, is ripe for integration and implementation of such methods. When Indigenous people were displaced, wisdom of food growing and spiritual connection to these valleys was lost, too. Partnering with nature is a return to the notion of connected wisdom, and Indigenous food growing methods may well prove to be the most resilient and climate adapted. Terms like 'permaculture' and 'regenerative agriculture' are, in my view, a sort of rebranding of how food was grown before European agricultural models were applied to unfamiliar landscapes. It's necessary to acknowledge and hold this fact. The excitement of new technology and ideas could distract from the reality that mitigating climate change will involve re-learning and integrating some very old, sometimes ancient, ways of living and growing food.

> *"I used to think the top environmental problems were biodiversity loss, ecosystem collapse, and climate change. But I was wrong. The top environmental problems are selfishness, greed, and apathy. … to deal with those issues we need a spiritual and cultural transformation – and we scientists do not know how to do that."*
>
> -*Gus Speth, former Dean of the School of Forestry & Environmental Studies at Yale*

Appendix

Table of Contents

Appendix A. Full Research Survey

[redacted]

INTERMOUNTAIN WEST TRANSFORMATION NETWORK

[redacted]

NAU NORTHERN ARIZONA UNIVERSITY

[redacted] County Agriculture Survey

Your responses will help inform the [redacted] Stream Management Plan, Conservation District planning for funding toward ag programs, and a research project. Please see attached information. Thank you for your time and contribution.

1. How many years have you been an agricultural producer?

☐ 0-5 years ☐ 6-14 years ☐ 15-19 years ☐ 20 or more years

2. How many total acres of land do you produce on?

☐ 1-19 acres ☐ 20-79 acres ☐ 80-119 acres ☐ 120 or more acres

3. Where do you get water to support your production? Select as many as apply.

☐ Reservoir ☐ Stream Ditch ☐ Well Water ☐ Prefer not to say

☐ Other (Please Specify): ____

4. Are you in the [redacted] watershed?

☐ Yes ☐ No ☐ Unsure ☐ Prefer not to say

5. During your time producing in the area, has your production been negatively affected by:

Water availability? ☐ Yes | ☐ No | ☐ Unsure

Soil quality? ☐ Yes | ☐ No | ☐ Unsure

Temperature/weather changes? ☐ Yes | ☐ No | ☐ Unsure

6. What do you produce? Select as many as apply.

☐ Livestock ☐ Alfalfa or Other Hay ☐ Winter Wheat

☐ Vegetables ☐ Fruit (Orchard) ☐ Dry Beans

☐ Other (Please Specify): ____

7. Do you use synthetic fertilizer on your crops?

☐ Yes, yearly ☐ Yes, as needed ☐ No longer use ☐ Never used

8. How important are each of these topics to you? Check one box for each.

	Extremely Important	Somewhat Important	Neutral/ Unsure	Somewhat Not Important	Not Important At All
Quality of Crops and/or Livestock					
Water Retention of Soil					
Production Cost Savings					
Nature and Wildlife					
Knowledge of Water Rights					
Watershed Health					
Working With Community					
Erosion Control					
Sustainability					
Conserving Water					

9. How interested would you be in utilizing each of these methods on your land? Check one box for each.

	Already Using	Extremely Interested	Somewhat Interested	Neutral/ Unsure	Somewhat Not Interested	Not Interested At All
Rotational Grazing						
Adding organic material to soil						
Cover Cropping						
Drip Irrigation						
Dryland Crops						
No-Till						
Greenhouses						
Drought-Resistant Crops						
Working with other ag producers						
Windbreak and/or shade trees						
Intercropping						

Please list any other conservation practices you use or are interested in:

____

____

10. Would you feel willing to try new methods if there were (select all that apply):

☐ Programs to subsidize/eliminate cost ☐ Workshops or training ☐ Need more details

☐ Other ag producers also trying new methods ☐ Access to equipment

☐ Seed and materials ☐ Technical assistance ☐ Not interested

☐ Other (Please Specify):____

11. Do you currently use methods to conserve water on your land?

☐ Yes, always have ☐ Yes, started recently ☐ No, but used to ☐ No, never

☐ No, but would like to start

Please list water conservation method(s):____

____

12. Would you like to see more information being shared about (select all that apply):

☐ Colorado Water Law ☐ How to use irrigation systems ☐ New irrigation technology

☐ Methods to conserve water ☐ Incorporating ditch users into a ditch company

☐ None of these

13. How satisfied are you with community resources available to you?

Not At All Satisfied ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Very Satisfied

14. How satisfied are you with your current irrigation equipment (diversions, headgates etc.)?

Not At All Satisfied ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Very Satisfied

15. How familiar are you with the water rights on your land?

Not At All Familiar ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 Very Familiar

16. Do you have questions, comments, or suggestions? Feel free to attach a separate sheet.

____

____

Thank you for participating. Please email your preferred mailing address to sgm254@nau.edu to claim your $5 Gift Certificate to [redacted] Coffee.

Appendix B.

Survey Results

Likert Scale Results

Q8: How important are each of these topics to you? Check one box for each.

#	Field	Extremely Important		Somewhat Important		Neutral/Unsure		Somewhat Not Important		Not Important At All		Total
1	Quality of Crops and/or Livestock	79.25%	42	16.98%	9	1.89%	1	0.00%	0	1.89%	1	53
2	Water Retention of Soil	65.38%	34	25.00%	13	5.77%	3	1.92%	1	1.92%	1	52
3	Production Cost Savings	38.46%	20	46.15%	24	11.54%	6	0.00%	0	3.85%	2	52
4	Nature and Wildlife	48.08%	25	30.77%	16	15.38%	8	3.85%	2	1.92%	1	52
5	Knowledge of Water Rights	55.77%	29	30.77%	16	11.54%	6	0.00%	0	1.92%	1	52
6	Watershed Health	58.49%	31	30.19%	16	7.55%	4	1.89%	1	1.89%	1	53
7	Working With Community	36.54%	19	40.38%	21	17.31%	9	5.77%	3	0.00%	0	52
8	Erosion Control	44.23%	23	42.31%	22	7.69%	4	5.77%	3	0.00%	0	52
9	Sustainability	61.54%	32	23.08%	12	9.62%	5	1.92%	1	3.85%	2	52
10	Conserving Water	64.15%	34	24.53%	13	5.66%	3	5.66%	3	0.00%	0	53

Showing rows 1 - 10 of 10

Q9: How interested would you be in utilizing each of these methods on your land? Check one box for each.

#	Field	Already Using		Extremely Interested		Somewhat Interested		Neutral/Unsure		Somewhat Not Interested		Not Interested At All		Total
1	Rotational Grazing	41.51%	22	20.75%	11	18.87%	10	9.43%	5	1.89%	1	7.55%	4	53
2	Adding organic material to soil	45.28%	24	24.53%	13	18.87%	10	7.55%	4	3.77%	2	0.00%	0	53
3	Cover Cropping	33.96%	18	18.87%	10	24.53%	13	11.32%	6	7.55%	4	3.77%	2	53
4	Drip Irrigation	30.77%	16	11.54%	6	25.00%	13	9.62%	5	9.62%	5	13.46%	7	52
5	Dryland Crops	17.31%	9	25.00%	13	19.23%	10	25.00%	13	3.85%	2	9.62%	5	52
6	No-Till	31.37%	16	21.57%	11	21.57%	11	13.73%	7	9.80%	5	1.96%	1	51
7	Greenhouses	28.30%	15	16.98%	9	16.98%	9	11.32%	6	3.77%	2	22.64%	12	53
8	Drought-Resistant Crops	23.08%	12	30.77%	16	25.00%	13	13.46%	7	1.92%	1	5.77%	3	52
9	Working with other ag producers	24.53%	13	24.53%	13	20.75%	11	24.53%	13	5.66%	3	0.00%	0	53
10	Windbreak and/or shade trees	28.85%	15	34.62%	18	15.38%	8	13.46%	7	5.77%	3	1.92%	1	52
11	Intercropping	15.09%	8	20.75%	11	28.30%	15	20.75%	11	9.43%	5	5.66%	3	53

Showing rows 1 - 11 of 11

no

It is suggested to increase the use area of drip irrigation

I've reached out to the local USDA office in [redacted] for assistance but am on a waitlist

I like the idea of being able to let ag producers have their voice heard. I applaud you for creating this survey and taking on the challenge of this hard headed community. However, the ways these questions and answers were worded it sounded as though there was an agenda connected to it. We have no problem with saving the environment, but it is pushed at us around every corner. If we aren't taking care of the land, we aren't making a living, period that's it. Therefore, yes we are doing what we think is best for our place, our family and our budget. Once again, I recognize the hard work that was put into this survey, but I don't see any way for it to help ag producers that operate on a large scale.

Multiple-Choice Results

Format: Selection, percentage of respondents, total respondents.

Q1: How many years have you been an agricultural producer?

0-5 years	17%	9
6-14 years	33%	17
15-19 years	12%	6
20 or more years	38%	20

Q2: How many total acres of land do you produce on?

1-19 acres	28%	15
20-79 acres	32%	17
80-119 acres	8%	4
120 or more acres	32%	17

Q3: Where do you get water to support production? Select as many as apply.

Reservoir	68%	36
Stream Ditch	57%	30
Well Water	8%	4
Prefer not to say	4%	2
Other (please specify)	13%	7

Q4: Are you in the [omitted] watershed?

Yes	61%
No	28%
Unsure	13%
Prefer not to say	2%

Q5: During your time producing in the area, has your production been negatively affected by water availability?

Yes	79%	42
No	21%	11
Unsure	0%	0

Q6: During your time producing in the area, has your production been negatively affected by soil quality?

Yes	47%	25
No	45%	24
Unsure	8%	4

Q7: During your time producing in the area, has your production been negatively affected by temperature or weather changes?

Yes	75%	39
No	19%	10
Unsure	6%	3

Q8: What do you produce? Select as many as apply.

Livestock	62%	33
Alfalfa or Other Hay	51%	27
Winter Wheat	19%	10
Vegetables	43%	23
Fruit (Orchard)	36%	19
Dry Beans	9%	5
Other (please specify)	23%	12

Q9: Do you use synthetic fertilizer on your crops?

Yes, yearly	16%	8
Yes, as needed	38%	19
No longer use	10%	5
Never used	36%	18

Q10: How important are each of these topics to you?

	Extremely Important	Somewhat Important	Neutral/Unsure	Somewhat Not Important	Not Important At All
Quality of Crops and/or Livestock	42	9	1	0	1
Conserving Water	34	13	3	3	0
Water Retention of Soil	34	13	3	1	1
Production Cost Savings	20	24	6	0	2
Nature and Wildlife	25	16	8	2	1
Knowledge of Water Rights	29	16	6	0	1
Watershed Health	31	16	4	1	1
Working With Community	19	21	9	3	0
Erosion Control	23	22	4	3	0
Sustainability	32	12	5	1	2

Q11: How interested would you be in utilizing each of these methods on your land?

	Already Using	Extremely Interested	Somewhat Interested	Neutral/Unsure	Somewhat Not Interested	Not Interested At All
Rotational Grazing	22	11	10	5	1	4
Windbreak and/or shade trees	15	18	8	7	3	1
Intercropping	8	11	15	11	5	3
Adding organic material to soil	24	13	10	4	2	0
Cover Cropping	18	10	13	6	4	2
Drip Irrigation	16	6	13	5	5	7

Dryland Crops	9	13	10	13	2	5
No-Till	16	11	11	7	5	1
Greenhouses	15	9	9	6	2	12
Drought-Resistant Crops	12	16	13	7	1	3
Working with other ag producers	13	13	11	13	3	0

Q12: Would you feel more willing to try new methods if there were (select all that apply).

Programs to subsidize or eliminate cost	60%	31
Workshops or training	58%	30
Need more details	37%	19
Other ag producers also trying new methods	33%	17
Access to equipment	56%	29
Seed and materials	37%	19
Technical assistance	44%	23
Not interested	10%	5
Other (please specify)	2%	1

Q13: Do you currently use methods to conserve water on your land?

Yes, always have	53%	28
Yes, started recently	9%	5
No, but used to	9%	5
No, never	2%	1
No, but would like to start	9%	5
Please list water conservation method(s):	17%	9

Q14: Would you like to see more information being shared about (select all that apply).

Colorado Water Law	47%	25
How to use irrigation systems	47%	25
New irrigation technology	64%	34
Methods to conserve water	55%	29
Incorporating ditch users into a ditch company	23%	12
None of these	9%	5

Written Results

All responses submitted in questions where typed (Qualtrics) or written (paper survey) responses were available.

Q3: Where do you get water to support production? (Location-identifying responses omitted)

Non-irrigated. Rely on what falls out of the sky.
The schools
dryland
City

Q8: What do you produce?

Summer pasture for neighbors cattle

Trees

Seeds and medicinal crops

Biomass for livestock forage

Flowers

Pasture for horses

forest products

Honey, eggs

Quality Horse Hay

Nursery stock

Biomass for livestock forage

Q12: Please list any other conservation practices you use or are interested in.

Pest control measures: Use organic pesticides or biological control to control the propagation and spread of pests and reduce damage to crops.

I don't have enough time to manage all this

Build some fences, plant some trees, prepare for water shortages

The greatest impact on the Mancos watershed is all of the people moving into the area and subsequent development.

No misuse of chemical fertilizer

Crop rotation

Biostimulants

Integrated pest management

Monitoring soil quality and biomass production

Soil quality monitoring, biomass production monitoring, plant diversity

Matching soil types together with the most beneficial plant species to improve soil health.

Farm animals like earthworms to protect the soil

stream-side vegetation, buffer strips, hedgerows, and cover crops.

Add organic matter to soil

no

machine operation

Add greenhouses

Not yet

horse manure

forest management

Invasive plants

Q16: Do you have any questions, comments, or suggestions? (Location-identifying responses omitted)

I like the idea of being able to let ag producers have their voice heard. I applaud you for creating this survey and taking on the challenge of this hard headed community. However, the ways these questions and answers were worded it sounded as though there was an agenda connected to it. We have no problem with saving the environment, but it is pushed at us around every corner. If we aren't taking care of the land, we aren't making a living, period that's it. Therefore, yes we are doing what we think is best for our place, our family and our budget. Once again, I recognize the hard work that was put into this survey, but I don't see any way for it to help ag producers that operate on a large scale.

I would like to seexa water manager thatnhandles all ditches...right now there is no standardized protocol in invoicing water users, established procedures when there are water disagreements, etc.

I'd like to see the results of the survey

Nrcs not much help with most of my questions

none

Farm animals like earthworms to protect the soil

In the face of natural disasters, you can help us more

no

I want to learn more about farm management

Although there is little we can do to prevent the influx of people into this county that originated as farming ranching, logging and mining, it is extremely important educate newcomers of property rights, livestock laws, water rights and local customs. Realtors also need to be knowledgeable in these areas

NO

None

I could use help with gathering and analyzing data.

No

None

I hope the government can increase support

Hope to have more opportunities for training

no

no

Appendix C. Bot Response Mitigation

While the survey was open, after the second recruitment email was sent from partnering Conservation Districts, several clear bot responses were identified. This was the protocol for managing these responses and ensuring all responses were from the region, beginning when the responses began to be recorded.

Initial Mitigation

1. Identify bot responses were being recorded through daily Qualtrics response overview. Over 100 responses were recorded in a single day after a second email recruitment, which was highly unlikely for this region.
2. Close survey immediately, check to ensure security measures offered through Qualtrics were on.
3. Add a CAPTCHA to beginning of survey.
4. Reopen survey.

5. Despite all security measures being on and a CAPTCHA added, bots continued to submit responses.
6. Qualtrics version of survey was permanently shut down to avoid future non-local responses. The final weeks of recruitment encouraged respondents to utilize paper surveys.

Post-Data Collection

1. Identify ‘blocks’ of responses, often several taken around the same time, usually during odd hours like late at night or very early morning in the survey region (MDT).
2. Scan responses for duplicate written answers or written answers which were not relevant to agriculture or other survey topics.
3. Finally, utilize generalized IP address data to identify responses that were recorded outside of the U.S. Southwest.
4. Label responses as high-, medium-, and low-confidence, outlined below.

Confidence Level	**Criteria**	**Strategy**
High	1. Respondent’s generalized IP address within U.S. SW 2. Written responses coherent and relevant to survey topics 3. Survey completed in normal amount of time	Keep all high-confidence responses.

Medium	1. Either no written responses OR written responses were somewhat relevant 2. Generalized IP address was in the U.S.	Consult with Conservation Districts, thoroughly scan response for any criteria included in low-confidence response. Remove any responses with criteria included in low-confidence response.
Low	1. Written responses completely irrelevant or incoherent 2. Generalized IP address was outside the U.S.	Bot response, remove from dataset.

5. Delete responses that met low-confidence criteria.
6. Meet with Conservation Districts and NAU TN team to discuss handful of medium-priority responses and scan for any low-confidence criteria.
7. Keep original dataset for records, utilize cleaned dataset for future work.

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