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Portugal to New Mexico: Investigating the Applicability of Syntropic Agriculture to a Semi-Arid Continental Climate

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SIT Study Abroad

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Abstract

Conventional industrial agriculture has numerous detrimental effects on the environment including high carbon emissions, pollution and overconsumption of water, soil degradation, and reduction of biodiversity (FAO, 2018). Large-scale alternatives are needed to combat these negative consequences and provide climate solutions. Syntropic Agriculture is a promising farming alternative especially in arid systems subject to degraded soils and desertification. New Mexico is a semi-arid continental climate in a prolonged period of drought and predicted to experience worsening agricultural conditions due to desertification, wildfire intensification, and exacerbated water scarcity. In an area with similar agricultural challenges, a project in Mértola, Portugal (Terra Sintrópica) is implementing Syntropic Agriculture with beneficial outcomes. This paper investigates the feasibility and potential benefits of applying Syntropic Agriculture to New Mexico as exemplified by the case study. As there are few existing examples of Syntropic Agriculture in continental climates, this study seeks to address the knowledge gap of whether this method is viable outside of tropical and Mediterranean climates. The example of Terra Sintrópica is extrapolated to comparable regions of New Mexico through the comparison between each region's agricultural, environmental, and climate contexts. The findings of this research suggest that Syntropic Agriculture is presently feasible on a small-scale in New Mexico and would benefit from further experimental and applied research in the region in the form of educational pilot projects.

Keywords

Agroforestry, Alentejo, Continental Climate, New Mexico, Soil Regeneration, Syntropic Agriculture

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Introduction

State of Conventional Agriculture on Land and Society

Agriculture, which occupies half of all habitable land globally, is a fundamental source of environmental degradation, but it is also a crucial site to address climate change (Ritchie, 2019). Industrial farming practices have a range of negative impacts including pollution, erosion, over-consumption of water sources, and reduction of biodiversity (FAO, 2018). According to the United Nations Food and Agriculture Organization, agricultural production is responsible for one of the largest percentages of greenhouse gas emission at 17% of the global total. Research indicates that conventional, chemical-intensive agricultural methods used today present threats to 86% of the world's endangered species (Rukikaire, 2021). Not only do these methods pose a fatal threat to biodiverse species, but their continued practice threatens the ability of the human population to feed future generations. Presently, nearly one in ten people globally experience food insecurity or undernutrition and a meta-analysis of 57 global food security predictions anticipates that food demand will increase by 35% to 56% between 2010 and 2050 (Ritchie et al., 2023, van Dijk et al., 2021). This is especially dire considering that the United Nations Food and Agriculture Organization reports that already 33% of soil is degraded which could increase to 90% of soil by 2050 if the same agricultural methods continue to dominate food production (UNDRR, 2023). There is an urgent need to find alternative ways to produce food while supporting ecosystems and counteracting climate change. Regenerative agriculture is the broad and increasingly discussed category of farming and grazing with the aim of reversing climate change through soil restoration (Cummins, 2015). Specific practices are being developed worldwide including the method of Syntropic Agriculture.

Syntropic Agriculture

Syntropic Agriculture is a method based in tangible practices and guided by a philosophy of learning from the forest. It falls under the umbrella of agroforestry, the combination of raising crops or livestock on the same plot of land as trees. It is also a form of regenerative agriculture for its ability to sequester carbon. Syntropic farming is based on the concept of syntropy as opposed to entropy; entropy is the dispersal of material and energy whereas syntropy is the (re)use of all matter within a system. These terms in relation to society can be thought of as a linear economy versus a circular economy. In a linear economy, produce ends in waste while in a circular economy all material has a role and remains within the system (refer to figure 1).

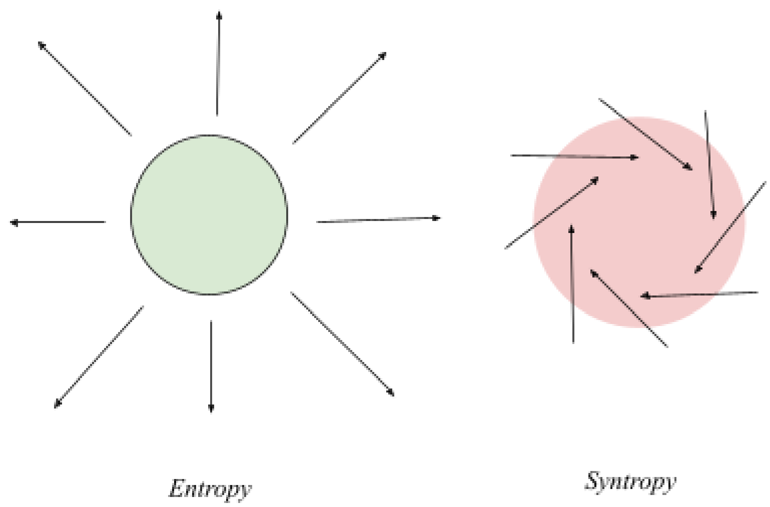

Figure 1: Entropy vs Syntropy adapted from Ulisse Di Corpo of Syntropy.org

Syntropic Agriculture was first developed and implemented under this name by Ernst Götsch, a farmer originally from Switzerland. He was working as a researcher on the genetic enhancement of plants when his trajectory was altered by the question, “Wouldn’t we achieve greater results if we sought ways of cultivation that favor the development of plants, rather than creating genotypes that support the bad conditions we impose on them?” (Götsch, n.d.) This inspired him to transition to field experiments where he observed the principles of forests which now compose the techniques of Syntropic Agriculture. In 1984 he bought a farm in Brazil called Fugidos da Terra Seca (Escapee from the Dry Land). The land had been left bare and deserted due to the prior owner’s intensive logging operation. (Calgaro, 2017) Within a decade, Ernst Götsch entirely reforested the 1,200 acres of land using the techniques which came to be called Syntropic Agriculture (Lugar da Terra, 2017). As of 2023, he continues to cultivate his land, exporting highly-prized organic cacao and training other farmers in this method. The farm is now renamed Olhos D’Água (Tears in the Eyes) in reference to the forest’s beauty. (Calgaro, 2017)

The primary goal of Syntropic Agriculture is the restoration of ecosystems by actively restoring soil. Soil, as opposed to dirt which refers only to the mineral component, contains in productive samples on average 100 million to 1 billion bacteria per 5 milliliters (the quantity of a teaspoon) (Hoorman, 2016). These bacteria and other soil microorganisms in the rhizosphere are essential to establishing a diversity of plants. In order to build soil from simple dirt to increasingly complex systems, Syntropic Agriculture aims to replicate and accelerate forest conditions which have supported the evolution of soil microbiology for milenia.

Two techniques to achieve this goal are succession and stratification. Succession refers to the evolution of plants following the evolution of soil conditions (Pasini, 2018). For an area of degraded soil (due to any kind of disturbance ranging from farming to wildfire), species reappear in stages of growing diversity; complex plant communities replace previous species after these simpler species have contributed to the progression of soil conditions (see example in figure 2) (Witynski, 2021). This is a familiar concept in ecology, though despite agriculture being a form of applied ecology, most agricultural practices rarely incorporate this knowledge; in fact, the predominant form of agriculture, monoculture, forces the opposite of natural succession in which complete species simplification leads to soil erosion and the loss of organic matter, biodiversity, pollination, and the replenishment of groundwater (Pasini, 2018). Another difference is that monoculture, and even many forms of organic and regenerative agriculture, solely focus on the horizontal placement of plants. Syntropic Agriculture also factors in vertical stratification which considers the luminosity, height, and life cycle of plants. The result of focusing on succession and stratification together is a highly diverse and densely planted plot where each element of the environment plays a collaborative role in restoring the land rather than as assumed competition.

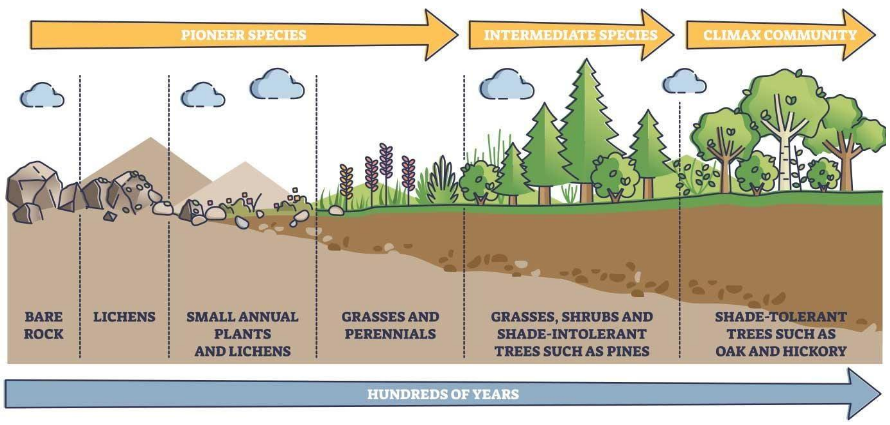

Figure 2: Ecological succession (University of Chicago News, n.d.)

Syntropic farmers can support and accelerate the benefits of succession and stratification by covering and feeding the soil. Pruning is one of the defining practices of Syntropic Agriculture. While seemingly simple, this practice is crucial to the consequent benefits that Syntropic Agriculture uses no pesticides and requires minimal to no irrigation. When a tree is pruned, the resultant biomaterial is immediately returned to the system as a soil cover. This benefits the ecosystem in three parts. First, when pruned, trees increase the amount of sugar released through their roots (Chesney & Vasquez, 2007). This additional sugar feeds the soil bacteria and accelerates the process of building the soil rhizosphere. The second benefit of pruning is that it allows more light to enter a system which can be important during different seasons. Finally, pruning creates biomass that, when spread directly around the plants, serves its own multifaceted benefit. This biomaterial increases water retention by slowing the evaporation rate, reduces soil erosion from wind and water, manages weeds, and as the biomaterial decomposes, it becomes nutrients for the soil like a natural fertilizer. This practice of pruning is inspired by the phenomenon in forests of leaf litter or high winds breaking branches which create a form of "composting-in-place". The philosophy of this practice is about returning more to the soil than what is extracted. Conventional forms of agriculture, from industrial to organic, are extractive and leave soils more degraded each year (Watts, 2018). In Syntropic farming, the soil becomes healthier each subsequent year due to the addition of more biomaterial than what is taken from the system.

Syntropic principles are of high relevance to the global challenges of climate change and desertification. As an excess of carbon builds in the atmosphere, the climate is warming and causing a series of environmental crises. As part of the cycle of climate change and its consequences, many arid and semi-arid landscapes are suffering from degradation and desertification, essentially the lack of carbon in soils (Zhang et al., 2022). By sequestering carbon, trees provide a solution to bridge the two substantial issues of too much carbon in the atmosphere and too little in the soil. The benefits of Syntropic Agriculture pertain directly to United Nations' Sustainable Development Goals 2: Zero Hunger, 3: Good Health and Well-Being, 6: Clean Water and Sanitation, 12: Responsible Consumption and Production, 13: Climate Action, and 15: Life on Land (UN Department of Economic and Social Affairs, 2015). Therefore, increasing research into agroforestry and specifically Syntropic Agriculture is an important aspect of addressing climate change and other global issues. Since Ernst Götsch's initial observation and project with syntropic principles, other farms have (re)introduced syntropic principles in Costa Rica, Mexico, Greece, Brazil, Portugal, Germany and Switzerland, though there is potential for its implementation anywhere where trees grow (Humintech, 2022).

New Mexico Climate Context

New Mexico is a state with a large variation of ecosystems, but like many places, climate change poses a significant threat to the environment. New Mexico traditionally has a semi arid to arid climate with low humidity, frequent sun, and high altitude. (New Mexico Museum of Natural History and Science, n.d.) It encompasses extremely diverse ecosystems and life zones. At the lower altitudes of 3,000 to 4,500 ft above sea level there is the desert and basin ecosystem. At roughly 4,500 to 5,500 ft are grasslands or the plains-mesa ecosystem, between 5,000 to 7,000 ft are piñon-juniper woodlands otherwise known as juniper-scrub ecosystem, at 6,500 to 8,500 are ponderosa pine forests, and from 8,000 to timberline (above which trees do not grow) is the alpine conifer ecosystem with mixed conifer and spruce-fir forests. There are riparian habitats interspersed (Albuquerque Public Schools, 2022, New Mexico Museum of Natural History and Science, n.d.).

Already climate change has had an impact on New Mexico with at least a one degree Fahrenheit increase across the state over the past century. New Mexico is predicted to warm another ten degrees Fahrenheit in the following century (Food & Water Watch, 2023). Climate change is predicted to have a continued impact on increased intensity and frequency of wildfires, decreased access to water, temperature induced changes to ecosystems, and changes to soil quality (United States Environmental Protection Agency, 2016).

2022 was a significant year in illustrating the state of New Mexico's water crisis. Many areas were impacted by the largest wildfire in state history and 90% of the state was under a severe drought. For the very first time, the Bureau of Reclamation published a water shortage declaration for the Colorado River while for the first time in 40 years, the Rio Grande River ran dry (Food & Water Watch, 2023). Industrial agriculture is deeply implicated in New Mexico's water crisis. These industrial farms consume 80% of the state's water, the equivalent of 774 billion gallons each year, despite contributing only 3% to the state's GDP. Of these outsized consumers, one of the biggest is mega-dairies or factory farms which not only consume roughly 32 million gallons of water daily but also contaminate groundwater with overflow manure. The other two industries responsible for extreme water consumption are pecans and the state's biggest crop, alfalfa, produced to feed cattle (Food & Water Watch, 2023). The combined lack of water, increasing temperatures, and extreme wildfires threaten desertification of prior forests and grasslands (United States Environmental Protection Agency, 2016). As these climate threats increase, it is necessary to consider how New Mexico can adapt.

Because of the highly diverse ecosystems, elevation, and climate of New Mexico, this paper will narrow the scope of analysis to the agricultural potential of two Sunset Climate Zone regions in New Mexico. Sunset Climate Zones were developed as a more comprehensive version of the U.S. Department of Agriculture's Plant Hardiness Zones Map which solely factors winter lows into growing recommendations. Sunset Climate Zones consider the complete factors of a climate including the date range of the growing season, details of rainfall, range of temperatures, wind, humidity, and altitude (Sunset Western Garden Collection, 2012). This paper will specifically focus on the Sunset Climate Zones 3A and 10 of New Mexico.

Zone 3A of New Mexico includes the towns of Los Alamos, Santa Fe, and Farmington and is of interest to this study because trees are a crucial element of this landscape. It is thought to be ideal for deciduous fruit trees, ornamental trees, and shrubby plants, as well as vegetables during the long, warm summers. (Sunset Western Garden Collection, 2012) The ecosystems of this zone in New Mexico span forests and woodlands, desert scrub, and grassland (Foxx, 2002). Most of Zone 3A ranges between 5,000 to 7,000 ft above sea level, situating it in the piñon-juniper woodland. The temperatures of Zone 3A have minimum averages from 15 to 25°F and extremes of –8 to –18°F placing it in the USDA Plant Hardiness Zone 6b (Gardening Know How, 2022). The growing season without frost ranges from 150 to 186 days (Sunset Western Garden Collection, 2012).

Zone 10 of New Mexico includes much of the southern and eastern parts of the state with the towns Roswell, Clovis, and Las Cruces among others. Elevation falls within roughly 3,300- to 5,000 feet, on the lower end for New Mexico (Sunset, 2004). Similar to 3A, strong winds and sun are present, according both challenges and opportunities for trees in this region. This zone is primarily composed of grassland, some desert scrub, and small areas of forest and woodland (Foxx, 2002). The growing season can last 225 days and the temperature lows range from 32°F to 22°F in extreme temperatures placing it in the USDA's Plant Hardiness Zone 7b to 8a (Sunset Western Garden Collection, 2012).

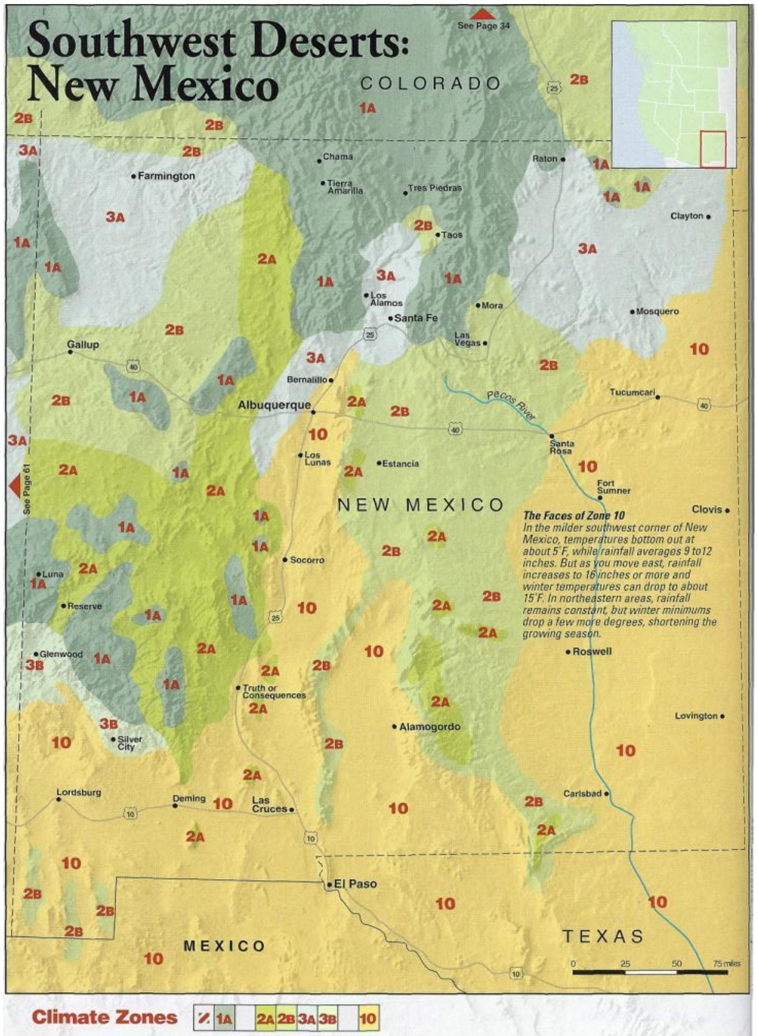

Figure 3: Climate Zones of New Mexico (Sunset Magazine, 2004)

Alentejo as a Potential Learning Lesson

Successful case studies of Syntropic Agriculture exist in Alentejo, Portugal which has climate and agricultural challenges comparable to New Mexico. The Alentejo region is located in the Iberian Peninsula in the southern half of Portugal. Like New Mexico, it has a semi-arid climate though it is Mediterranean compared to New Mexico's primarily continental climate. Alentejo is categorized under Portugal Hardiness Zone 10a for lows of 33°F to 35°F (.6°C to 1.7°C) ("Portugal Plant Hardiness Zone Map," 2012). The highs for this region can exceed 100ºF (37.8°C).

The agricultural history of the area is of intensive, monoculture cereal. Agriculture has long been the primary economic sector which required the import of water due to low rainfall. Beginning in the 19th century, plans for dam and irrigation construction were implemented to the extent of the country's economic ability. With the introduction of the dictatorship, these plans led to the domination of irrigated crops such as maize and rice in dryland conditions. The spread of these crops combined with drought from climate change have caused dangerously low reserves of water in the reservoirs and aquifers (Faísca, 2022). Additionally, monoculture farming has created degraded soils. Like New Mexico, Alentejo is at high risk of desertification which has inspired the introduction of certain regenerative practices such as Syntropic Agriculture.

Objective

Though Syntropic Agriculture has only been implemented in seven countries, it is hypothesized that syntropic principles can be relevant to any degraded landscape where trees grow or have survived previously (Hall, 2022). The aim of this paper is to investigate if Syntropic Agriculture would be an applicable, sustainable farming method for New Mexico given current and expected effects of climate change. Using a case study of Syntropic Agriculture in Portugal's Alentejo region, this paper will analyze if New Mexican farmers and environment would reap similar benefits to those in this comparable, though distinct landscape. Syntropic Agriculture has primarily been implemented in Mediterranean climates though the ecological issues it helps to address such as degraded or poor soil and water scarcity are becoming increasingly common globally and are prevalent agricultural concerns in New Mexico. There currently exists no studies on the topic of applying Syntropic Agriculture to a continental climate. This research aims to fill the gap in the literature by providing detailed predictions and strategies for the benefits and challenges of Syntropic Agriculture in a semi-arid continental climate.

Methodology

Case Study

This paper examined syntropic potential for New Mexico by extrapolating lessons from the case study, Terra Sintrópica in the Alentejo region. Terra Sintrópica's Center for Agroecology and Regeneration for the Semi-Arid Region (CARES) was co-founded by António Coelho and Dayana Andrade and visited by Ernst Götsch for consultation. It was the first example in Europe of Syntropic Agriculture in the semi-arid and is on the front line of climate change and desertification. Located at Horta da Malhadinha in Mértola, it is a "living laboratory" for experimenting with syntropic techniques to build knowledge of regeneration in this context. The goal is also to provide mentorship and education to aid in this much needed "agroecological transition" (Terra Sintrópica, 2022). The case study was selected both because of its highly relevant applied model of Syntropic Agriculture in a semi-arid climate and also for its existing capacity to share live findings. This paper applied the case study by conducting a comparison between the pedoclimatic conditions and typical agriculture structure of Alentejo and New Mexico. From there, the example of Terra Sintrópica was able to be projected onto similar realities of New Mexico and the differences provided opportunities for theorizing alternate strengths and weaknesses for Syntropic Agriculture in New Mexico.

Process of Data Collection and Analysis

The first step in designing the project was a literature review of existing work on Syntropic Agriculture. This involved finding and compiling relevant material, assessing the knowledge gaps, and locating potential case studies. "Agenda Gotsch" is the official website that distributes written and audiovisual material about the method developed by Ernst Götsch. There are only a few articles published in academic journals about Syntropic Agriculture including the most cited article written by the primary contributors to Agenda Gotsch (Andrade et al., 2020). One paper which studied Syntropic Agriculture outside a Mediterranean climate documents a project of testing Syntropic Agriculture in a temperate climate (Cossel et al., 2020). The constraints faced by the present paper precluded implementing a demonstration plot as done in the study of a temperate climate, necessitating an existing case study from which to draw insight.

For reasons described in the above section, Terra Sintrópica was selected as the case study and arrangements were made for a site visit. Data about Terra Sintrópica was collected during this field visit and through continued communication with collaborators and coordinators at CARES. The primary goal of this research was to understand the practices and philosophy of Syntropic Agriculture as performed in this location. The methods included observation and informal interview. The primary data of the theories, practices, and results observed at Terra Sintrópica was then supplemented with secondary data from scholarly sources to provide additional context and support to the claims of Syntropic Agriculture. The content gathered was then compiled into two tables for comparison between the pedoclimates and agriculture trends in the broader Alentejo region and New Mexico. The findings were then synthesized into a SWOT analysis which highlights the main strengths, weaknesses, opportunities, and threats to applying Syntropic Agriculture to New Mexico. To further understand the feasibility and considerations of this proposal, an agriculture expert in New Mexico was consulted in a semi-formal interview style. This interview subject was chosen for his role as a New Mexico Food and Agriculture Policy Officer and for his experience as a member of the Navajo Nation and farmer in the 3A climate zone. The information obtained through this interview was incorporated into the SWOT analysis and can be used for further research into the implementation of pilot projects in New Mexico.

Ethical Considerations

The initial project proposal was reviewed and approved externally by the School for International Training Institutional Review Board. The ethical considerations of this research pertain primarily to the interview process. All questions were written with the intention of allowing interviewees to respond openly and without influence to a particular end. All interviewees were informed of the subject matter and purpose of the interview prior to their participation. Oral consent to include information provided by participants was obtained for both interviewees. The final results of the project were reviewed and approved by experts in the field for assured validity.

Results and Discussion

The following tables (Table 1 and Table 2) are compiled to provide an overview into the local realities of New Mexico and Alentejo in terms of the climate, soil, land use, and agricultural contexts. The case-study of Terra Sintrópica was also included, when data was available, to further compare it against New Mexico and Alentejo. Those data can be used to predict the environmental and social effects of implementing Syntropic Agriculture in New Mexico.

Table 1: Comparison of New Mexico to Alentejo and Case Study (Climate and Land)

	New Mexico	**Alentejo**	**Terra Sintrópica** (Case study of Syntropic Agriculture located in Mértola, municipality of Alentejo)
Rainfall	Southern (Las Cruces) Annual total: 232 mm in 47 days Central (Santa Fe) Annual total: 325 mm in 64 days Northern (Farmington): Annual total: 202 mm in 62 days (Current Results, 2023)	High: Dec (83mm) Low: Jul & Aug (7mm) Annual total: 496mm* in 116.6 days (Weather Atlas, 2023) *Predicted to drop 20% to 40% in the coming century (Barahona, 2023)	High: Oct (60 mm) Low: Jul (1 mm) Annual total: 413 mm* in 45 days ("Mértola Climate", 2021) *predicted to drop to 288 mm in 2100 (Cortegano, 2021)
Average Temperature (high and lows)	Southern (Las Cruces) Low: Jan & Dec (29 °F/-2ºC) High: Jun & July (95 °F/35ºC) Central (Santa Fe) Low: Jan & Dec (17 °F/-8ºC) High: Jul (86 °F/30ºC) Northern (Farmington) Low: Jan (20 °F/-7ºC) High: Jul (90 °F/32ºC) (Climate New Mexico, 2010)	Low: Jan (36 °F/2ºC) High: Aug (85 °F/29ºC) (Weather Atlas, 2023)	Low: Jan (49.9 °F/10ºC) High: Aug (79 °F/26ºC) ("Mértola Climate", 2021)
Type of Soil	Low in organic matter	Low in organic matter	High in organic matter

	(“Soil Health, 2022) Sandy loam -43-85% sand -0-50% silt -0-20% clay (“Growing Zones in New Mexico”, 2023)	(Cortegano, 2021) Siliceous heavy and siliceous loamy (“State of Play Analyses for Alentejo”, 2021)	(Cortegano, 2021)
% of Land Area that is Forested	4.5%-28% forested* Breakdown: >50% pinyon/juniper, Gambel oak, Ponderosa pine (Goeking & Menlove, 2017) *Deforestation may account for differing numbers (Global Forest Watch, 2022)	45% forested Breakdown: 45% cork oak, 27% holm oak, 16% eucalyptus, and 6% stone pine. (Tomé & Fontes, 2019)	Land sharing
Climate and Environment Threats	Desertification and habitat disturbance, wildfires, increasing temperatures, decreasing precipitation, water mismanagement	Desertification and habitat disturbance, wildfires, increasing temperatures, decreasing precipitation	Desertification, wildfires, increasing temperatures, decreasing precipitation
Native Edible Species	“Agave, Amaranth, Beargrass, Beeplant, Bilberry, Bracken Fern, Buffalo Gourd, Cattail, Chickweed, Chokecherry, Cholla, Creeping Hollygrape, Currant, Dayflower, Desert Olive, Devil’s Claw, Flameflower, Gooseberry, Greenthread, Ground Cherry, Heartleaf Bittercress, Hog Potato, Hollygrape, Indian Rice Grass, Jewel Flower, Lambsquarters, Lemonade Berry, Mallow, Manzanita, Marsh Marigold, Mesquite, Monkey Flower, Mountain Parsley,	Black Mustard, Borage, Common Mallow, Dandelion, Fennel, Lamb’s Quarters, Milk Thistle, Mint, Nettles, Purslane, Sorrel, Wild Lettuce, Wild Spinach (Andrews, 2022)	n/a

	Mullein, Nettle, Oak, Panicgrass, Pinyon Pine, Prickly Pear, Purslane, Raspberry, Salsify, Serviceberry, Sheep's Sorrel, Sorrel, Spiderwort, Spotted Bean, Springparsley, Thimbleberry, Thistle, Tuber Starwort, Tule, Tumble Mustard, Watercress, Wild Grape, Wild Onion, Wild Rhubarb, Wild Rose, Wild Strawberry, Wild Sunflower, Wolfberry, Yellowdock, Yucca (Fruit), Yucca (Stalk)" (Botanic, 2019)		
Invasive Species	Cheatgrass, Curlyleaf pondweed, Eurasian watermilfoil, Giant cane, Hydrilla, Jointed goatgrass, Musk thistle, Parrotfeather, Russian knapweed, Russian olive, Saltcedar species, Siberian elm, Tree of heaven (Beck & Wanstall, 2020)	Acacia species, Bermuda buttercup, Black locust, Blue morning glory, Cape dandelion, Hakea, Hottentot-fig, Pittosporum undulatum, Small-leaf spiderwort, Tree of heaven (Invasive plant species in Portugal: An Overview, 2006)	Acacia species and Eucalyptus
Food Insecurity	15.5% (all ages) (Food Insecurity among Overall (all ages) Population in New Mexico, 2021)	7.3% (adults) (Gregório, 2018)	n/a

Table 2: Comparison of New Mexico to Alentejo and Case Study (Agriculture)

	New Mexico	**Alentejo**	**Terra Sintrópica** (Case study of Syntropic Agriculture located in Mértola, municipality of Alentejo)
Acres of Cropland	40.6 million acres ("New Mexico Agriculture", 2021)	5 million acres (Instituto Nacional de Estatística, 2017)	Land sharing

and % of Total Land		42% of land area (Vizinho, n.d.)	4/6 plots
% Irrigated Land, type of irrigation (drip, flood, sprinkler…	76% of all water used in New Mexico for irrigation (3,114,255 acre-feet as of 2015) 749,769 acres irrigated Flood irrigation: 45.4% Sprinkler irrigation: 51.4% Drip irrigation: 3.1% (Stroud, 2020)	75% of all water in Portugal for irritation 741,316 acres irrigated Flood irrigation: 16% Sprinkler irrigation: 35% Drip irrigation: 65%* *some farms use multiple methods of irrigation (Barahona, 2023)	Trees irrigated once a month for one hour During summer, vegetables irrigated 3x/week Otherwise 1x/week Drip irrigation: 100%
Number of Farms	24,721 agricultural holdings (Diemer et al., 2014)	35, 666 agricultural holdings (Instituto Nacional de Estatística, 2017)	6 plots
Average Farm Size	1,624 acres (657 ha) ("New Mexico Agriculture", 2021)	1,455 acres (588 ha) (Instituto Nacional de Estatística, 2017)	6 acres (2.4 ha) Olhos D'Água is the largest Syntropic Agriculture farm with 1,200 acres (486 ha) (Lugar da Terra, 2017)
Common Crops	Livestock, pecans, hay (alfalfa), peppers, corn, wheat, peanuts, cotton, onions (United States Department of Agriculture, 2021)	Cereal crops for grain, tomatoes, rice, maize, olives for olive oil, cork, vines for wine, livestock (Alentejo - Economy, 2003)	n/a
Number of Jobs in Agriculture	27,290 (Las Cruces Bulletin, 2023) which is roughly 2.8% of the labor force (U.S. Bureau of Labor Statistics, 2023)	60,480 people or 10% of the labor force (European Labour Authority, 2023)	2 full time farmers, roughly 18 collaborators, and volunteers
Average Demographic of Farmer	60.5 years (Medlock, 2022)	66 years (Instituto Nacional de Estatística, 2017)	n/a

Discussion of Comparison

As demonstrated in the above tables, the selected regions of New Mexico and Mértola experience similar climate threats of desertification and wildfire intensification, soil conditions, water scarcity, and aging farmer populations as well as average farm size. Due in particular to increasing desertification, agricultural adaptation is essential to both locations. The following describes the feasibility of Syntropic Agriculture as it pertains to soil, climate, rainfall, and farmer populations. The feasibility is also supported through the existence of a traditional and continued history of agroforestry in New Mexico (Allen, 2018).)

Soil Quality

New Mexico's soil is primarily sandy loam and Alentejo has siliceous heavy loam. Loam refers to soil that combines sand, silt and clay, the three sizes of soil particles in descending size. Sandy loam contains higher percentages of sand than the other particle types. Due to the larger size of sand particles, this soil allows more air in but is unable to retain water or nutrients well, an issue improved by the increase of organic material (Lerner, 2000). Siliceous loam is formed from rocks high in silica and has a higher clay composition ("State of Play Analyses for Alentejo", 2021). While different plants prefer different soil compositions, nearly all plants increase productivity in soil with abundant organic matter. The soil of both New Mexico and Mértola tends to be low in organic matter which makes it susceptible to erosion, degradation, and poor water retention. This differs from the soil in plots at Terra Sintrópica. The principles of biodiverse plantations and returning biomaterial as soil cover contribute to Terra Sintrópica's ability to improve soil structure and build organic carbon. Figure 3 shows a typical sample of soil found at Terra Sintrópica. The dark, crumbly nature of the soil is a sign of the rich organic matter.

Figure 3: Soil at Terra Sintrópica (Nathan, 2023)

Climate and Rainfall

One difference between the Sunset Climate Zones of study in New Mexico and Terra Sintrópica's location are the temperature lows which are far lower in New Mexico. Of the zones, Mértola has the most similar temperature highs to Santa Fe in 3A. The conclusion from these differences in climate is that the plants selected for New Mexico would necessarily be different from those grown in the case study. These could include extensive edible native species as well as other crops that are drought tolerant and associated with colder climates. Another strategy to improve plant ability to cope with cold stress is to develop climate-resilient cultivars propagated through methods such as grafting.

At present New Mexico's regions tend to have less annual rainfall than the municipality of Mértola. This precipitation is spread over more days and is in line with predictions for Mértola's rainfall in 2100. Precipitation spread over more days is an advantage to New Mexico because this allows farmers to better manage water intake rather than larger but more infrequent influxes of precipitation. More rain over fewer days in Mértola means that there are higher losses from soil evaporation and percolation. Rainfall is a crucial element to Syntropic Agriculture which aims to most effectively utilize water from precipitation rather than importing large amounts of water through irrigation systems. At Terra Sintrópica, drip irrigation is implemented as a backup method rather than the principal water source. The philosophy behind this is that forests require no irrigation, so it is possible to have a thriving ecosystem (that produces food) without needing to import large amounts of water. As water sources such as the Colorado River and Rio Grande River are less able to provide water (Food & Water Watch, 2023), the ability to efficiently use what precipitation is present will be crucial to the continuation of food production in New Mexico. When irrigation is necessary, agriculture should use the most effective irrigation techniques. For Alentejo's conditions, flood irrigation is the least efficient form of irrigation of the three common systems: flood, sprinkler, and drip. Water is wasted from excess runoff and from water seeping below the roots of the crops making this method only 30% to 70% efficient, thus used in only 16% of irrigation in Alentejo (Barahona, 2023). In contrast it consists of 45.4% of irrigation in New Mexico. Flood irrigation is the oldest method in the state and can be effective when used in certain conditions where ample water is accessible and other forms of irrigation are not feasible (Herrera & Sammis, 2000). It can also be supplemented with dead level contour techniques, an "in-field rainwater harvesting structure" (Gumbo et al., 2021). Sprinkler irrigation is the most common form of irrigation in New Mexico and has efficiencies of 60 to 90%. Efficiency is calculated by the ratio of water absorbed by plants to the total amount of water applied to the land (Barahona, 2023). The most modern and effective form of irrigation is drip or localized irrigation which constitutes only 3.1% of irrigation in New Mexico but is exclusively relied upon at Terra Sintrópica. This system applies low amounts of water over an extended period allowing water to remain in the reach of the roots without percolating. This method is 90%-99% efficient where conditions allow.

Farmer Populations

Another agricultural challenge faced by both Alentejo and New Mexico is the demographic of farmers. In Mértola, abandonment of farms and farmer aging present threats to the agricultural future of the area (Cortegano, 2021). In Alentejo the average age of farmers is 66 and 60.5 in New Mexico. Terra Sintrópica and Syntropic Agriculture have successfully drawn the interest of a younger generation of farmers as demonstrated through the demographic of volunteers and other Syntropic projects implemented in Portugal and across the globe. Terra Sintrópica also provides hands-on afterschool curriculum in five schools in Mértola. Children participate in each stage of food production, learning both the practical skills of Syntropic Agriculture, but also the social application of the syntropic philosophy. The model of how plants can thrive in community can be translated into social lessons about the importance of diversity and cooperation rather than competition. The result is that the youngest generation is prepared with knowledge of where their food comes from as a skill in addressing the ecological crises they will inherit ("Horta-Floresta", 2022).

Existing Agroforestry in New Mexico

Reforestation is a crucial need to counteract ecological crises because forests contribute to sequestering carbon, air quality, animal habitats, biodiversity, and soil quality (Terrapass, 2022). Deforestation in New Mexico is a concern as a result of wildfires, which are expected to increase in the future (United States Environmental Protection Agency, 2016). Agroforestry combines forests with food production and is an example of "land sharing", the idea of promoting biodiversity within an agricultural space rather than conserving or "sparing" land for biodiversity elsewhere. This concept is common in Alentejo with the prevalence of silvopastoralism, a "multipurpose wood-pasture" where livestock are grazed among productive trees (Varela et al., 2022). In Portugal this could be cork, citrus, or olive trees raised in the same pastures with pigs, sheep, and chickens. In New Mexico, orchards are often of pecan trees and the livestock could include goats, cows, and even deer. While the description "silvopastoralism" is not as common in New Mexico, there are other examples of agroforestry such as food forests that are more common especially among gardeners, architect landscapers, and urban farmers.

Likely the closest form of Syntropic Agriculture practiced in New Mexico was by Native Americans prior to Spanish colonization. There is evidence of tree and forest management throughout the American Southwest (Allen, 2018). The Spanish who settled in the southwest brought plants for an agricultural method called "mixta", similar to silvopastoralism, which mixed food producing trees, crops, livestock, and even bees on the same plot of land. While it is far less common on a large scale today, the modern version appears in the form of food forests often with permaculture principles and educational components (Allen, 2018). One prime example is Flowering Tree Permaculture Institute, a food forest in northern New Mexico with over 500 species flourishing (Thompson, 2022). There are other projects in place to support the implementation of agroforestry such as the Santa Ana Native Plant and Tree Nursery which sells 250 species of drought tolerant plants ("Santa Ana Plant and Tree Nursery", 2001).

SWOT Analysis of Syntropic Agriculture in New Mexico

Extrapolated Strategies

With assurance from the success of existing agroforestry projects in New Mexico, it is useful to consider the benefits and disadvantages of attempting agroforestry using the Syntropic model. Table 3 summarizes the main Strengths, Weaknesses, Opportunities, and Threats (SWOT) identified for the implementation of Syntropic Agriculture in New Mexico. The following analyzes particularly notable points in conjunction with others to appropriately assess the viability of Syntropic Agriculture in New Mexico.

Table 3: SWOT Analysis of Syntropic Agriculture in New Mexico

Strengths (internal pro– benefits for farm and farmer) 1. Able to continue producing even as water crisis and climate change alter conditions 2. Improve soil quality rather than reducing 3. Pest and weed solutions –no pesticides or herbicides required 4. Management system and positive utilization of invasive/noxious species 5. Diversification of products – succession economics 6. Benefits of trees at high altitudes	**Weaknesses (internal con – disadvantages for farm and farmer)** 1. Takes time to implement 2. Farmer perception needed to change from conventional practices 3. Needs trial and error to accumulate knowledge of Syntropic Agriculture in the region 4. Large scale implementation is still uncertain
Opportunities (external pro– benefits to the greater environment) 1. A way to combat the desertification of grasslands and forests as ongoing with climate change 2. Increased biodiversity 3. If properly implemented, less vulnerable to pests and diseases 4. Reduced use of agrochemicals → reduce negative effects on human and non-human lives 5. Possible implications for the water cycle (re: higher evapotranspiration may increase precipitation)	**Threats (external con – challenges posed from outside farm)** 1. Comparatively low and sporadic rainfall in New Mexico would require heavier reliance on irrigation than Syntropic Agriculture in other regions 2. Need for agri-food chain restructure (food processors, suppliers, retailers) a. Competing with pecan farmers who have a foothold in the market (re: Southern, Las Cruces area) 3. Restructure of crop insurances and federal/state subsidies

6. Interest from younger generations 7. Compatible with indigenous farming knowledge 8. Wildfire recovery 9. Re-establishing riparian areas– potential for federal grants 10. Support from regenerative agriculture groups	4. Concentration of power in agrochemical companies and industrial agriculture may push against restructure of crop insurances and federal/state subsidies 5. Cost of acquiring land 6. Public misunderstandings of natural processes (ie. leaflitter)

Timing: Building Knowledge

One likely concern for introducing new farms or transitioning existing farms to Syntropic Agriculture is the period of trial and error (W3) that would be required for introducing this method to a new region. One strategy for mitigating the extent of this challenge would be to begin with pilot projects that could serve as educational facilities for farmers eventually interested in implementing Syntropic Agriculture. These educational facilities could be modeled on Terra Sintrópica which provides tours, workshops, and presentations. The pilot projects would be able to practically assess species most compatible with New Mexico's climate and the succession and stratification design of Syntropic Agriculture.

Existing research and experience provides prior knowledge on numerous legumes, seeds, nuts, grains, vegetables, fruits, and herbs. These crops in addition to native tree species could boost biodiversity (O2) ("50 Crops for New Mexico", 2020). One tree species in particular that requires active restoration are cottonwoods which used to form riparian forests along the Rio Grande. Due both to indirect forces such as river flow mismanagement and to active deforestation for farms, river control, and human development projects, these cottonwood forests are significantly diminished (Ellis, n.d.). These forests are crucial to other native plant and animal species making cottonwoods a prime candidate for restoration through syntropic techniques with potential support from federal funds (O9). In the 2023 fiscal year, $16.2 million were allocated by the U.S. Department of Agriculture's Forest Service for "healthy, resilient, climate-adapted forest" restoration (USDA Forest Service, 2023). Of this, 25% went to projects on tribal land.

There is ample potential for collaboration between Syntropic Agriculture and indigenous knowledge (O7) when testing these methods in New Mexico. For centuries, indigenous peoples of New Mexico have practiced similar theories such as soil cover with stone mulch to help the soil retain moisture and extend the growing season by raising soil temperature (Christina, 2019). Another example for integrating traditional knowledge is the "three sisters" crop combination. The three sisters are corn, beans, and squash, a combination traditionally planted by indigenous peoples. They recognize the way that these plants support each other due to the similar logic of Syntropic Agriculture. The three species are typically planted circularly and they each provide a different benefit through their varying heights and interaction with the soil and with each other (Help Desk of the UC Master Gardener Program of Contra Costa County, 2017). The circular layout is being tested in one of the plots at Terra Sintrópica and is predicted to be a successful layout for Syntropic Agriculture. If these theories are tested first in educational pilot projects, they can reduce the trial and error period of future implementations.

Another concern is the intensive time and labor needed for the initial implementation of a syntropic farm (W1). As with most agricultural methods, the most time and labor intensive period is in the initial period, but in Syntropic Agriculture, once plots are designed and planted, they tend to require minimal maintenance. The theory of Syntropic Agriculture is to mimic the design and functionality of forests, ultimately only providing maintenance in the form of pruning, monitoring precipitation or water needs, and harvesting produce. Long term maintenance includes planning the succession of a plot which may lead to another period of more intensive maintenance. The result is that over the long term, Syntropic Agriculture may reduce the amount of labor needed.

Another consideration for implementation time is that it may be longer for existing farms which would require strong farmer buy-in and a perception shift (W2) to the feasibility and benefits of Syntropic Agriculture. For this reason, Syntropic Agriculture may be best suited to the next generation of farmers (O6). Both New Mexico and Alentejo have an aging farmer population and there is an urgent need to inspire and train the next generation. Rather than continue with conventional, industrial farming methods, it is crucial to adapt and teach methods appropriate to the changing world. Another role of pilot projects in the region would be to provide strong education opportunities and exposure to New Mexican youth. Similar to Terra Sintrópica, this could be through extracurricular programs in schools or it could be in the form of internships, volunteer groups, and tours including field trips. In order for the next generation to be able to continue agriculture in New Mexico not only requires education opportunities but also access to affordable land (T5). Funding sources for medium to small scale farms may include government and private foundations. Larger projects could explore the potential of participating in the carbon market through offsets (Walton, 2023).

Scale: Adaptation

At present, Syntropic Agriculture would necessarily be implemented on a small scale as machinery for this method is not readily available (W4). Globally, there are test projects to scale up Syntropic Agriculture such as one experiment to cultivate grain on a large scale without agrochemicals (S3 & O4) (Rebello, 2019). This allows time for New Mexican pilot projects to compile and develop regional knowledge as the global syntropic movement develops techniques for scaling up. Additional changes would also need to be made in the meantime including a restructuring of the agri-food chain (T2) to succession economics (S5). Because of the succession of plants in the process of building soil fertility, products would fluctuate with the evolution of soil. This would require agreements with processors, suppliers, and retailers which could add time to the period of implementation. In succession economics, there is no shortage of abundant produce, but that produce would vary more than in monoculture farming. Pending accommodation by the supply chain, this could be a benefit to farmers who would gain stability from involvement in multiple markets rather than investing heavily in few. The failure of individual crops is a huge risk monocrop farmers take and which has historically led to devastation such as the 1970 corn blight (Watts, 2018). As climate change becomes evermore prevalent, the chance of failure for the world's staple crops is expected to increase (Ruiz, 2022). In addition to environmental threats, studies find farmers may be even more concerned with industry threats such as trade wars, industry consolidation, and decreasing farmgate price (selling value before supply chain costs) (Waldman et al., 2021). Syntropic Agriculture is a system made flexible by a greater diversity of species and therefore products that allow it to adapt to changing climate and industry conditions.

Not only is Syntropic Agriculture an economically responsible strategy for farmers, but it also has economic benefits for the state and national government which fund projects for killing invasive species. These projects often rely on herbicides which are long known to have detrimental effects on human and non-human health (Carson, 2000). Syntopic Agriculture reimagines invasive species as a tool of restoring landscapes rather than solely as a detriment (S4). Especially in areas of degraded soil where it is difficult to coax any species to grow, invasive species that are able to thrive can be understood as a resource. One of the main techniques of Syntropic Agriculture is the reallocation of biomaterial to create soil cover. Terra Sintrópica is piloting innovative strategies of utilizing invasives to evolve degraded soil by treating them as an abundant, available source of biomaterial. This practice is a prime example of how to utilize succession, wherein improving soil conditions slowly makes the land habitable to biodiverse species while naturally phasing out the invasive. Terra Sintrópica is currently implementing this strategy in plots dominated by eucalyptus and acacia trees, the species seen as most invasive to the region. New Mexico too has a number of plants identified as "noxious weeds" including Saltcedar, Tree of Heaven, Siberian elm, and Russian olive. The first two would not be good candidates for this technique because they are both allelopathic, secreting chemicals into soil (or salt in the case of Saltcedars) that are toxic to other species (Tree of Heaven, 2022, Lovich & Hoddle, n.d.). In contrast, the Siberian elm would be an ideal candidate for this technique because it is qualified as a noxious species for its ability to grow quickly in disturbed soil. In other words, it is an abundant, replenishable source of biomaterial that does well in poor soil, but as it aids farmers in changing soil quality, it would likely not thrive in the same way making room for other species to flourish (Old, n.d.). Similarly, the Russian olive is able to survive drought conditions, allowing syntropic farmers to access biomaterial when other plants struggle to grow. In this way, governments can save money, humans and environments are spared the effects of chemical treatments (O4), and farmers can enjoy abundant biomaterial to replenish soils. This is an incentive for state subsidies (T3) though it would likely be opposed by agrochemical companies (T4).

Financial Support

Whether or not government entities want to support the agricultural revolution, the increasingly severe lack of water in New Mexico will mandate adaptation. Syntropic Agriculture effectively requires less imported water than most other forms of agriculture because of its intentional and efficient use of rain. New Mexico has relatively low rain compared to the location of the case study (T1), though the rain is distributed over more days than the case study which is an advantage. A combination of rainwater management as an irrigation strategy and soil restoration has the potential to impact the water cycle (O5). Higher evapotranspiration may increase precipitation thereby combating desertification (O1) (Yang, 2016). Adaption is the only way for farmers to sustainably continue producing in New Mexico into the future (S1).

Potential collaborators for syntropic pilot projects in New Mexico may include Seeding Regenerative Agriculture (SRA) project, NM Healthy Soil Working Group, Quivira Coalition, and Spirit Farms. SRA coordinates field research and technology development among other initiatives to support regenerative agriculture and would therefore be an ideal partner for implementing a pilot project (SRA, 2021). On-field experiments are conducted at the Sustainable Agriculture Science Center at Alcalde where the mission is to test a variety of factors including production techniques to benefit small-scale family farms (NMSU, 2022). SRA is funded by a number of foundations in New Mexico. Additional funding sources for a pilot project may be found through the Healthy Soil Working Group. These include New Mexico Department of Agriculture (NMDA) Healthy Soil Program, NMDA Agricultural Workforce Development (AWD) Program for internship grants, The Brighter Future Fund, and Local Farmer Innovation Enterprise (LIFE) Grants ("Opportunities", 2020). Additional networking support and sharing of knowledge may be accessed through the Quivira Coalition. Finally, a pilot project may benefit from collaborating with a tribal partner such as Spirit Farms to assess the compatibility of Syntropic Agriculture with Indigenous regenerative agriculture ("On the Navajo Nation, One Farm Works to Heal the Land and the People", 2022).

Conclusion

The results of this research suggest that Syntropic Agriculture is an ecologically feasible method to be tested in New Mexico, beginning on a small scale. Some of the benefits of this method to New Mexico's climate and state of agriculture include the possibilities of combating desertification and continuing to produce under water scarcity limitations, reducing or eliminating agrochemicals, and attracting younger generations to the agricultural sector. The primary adjustments to translate this method from a Mediterranean climate to a continental climate would be to assess the ideal plants for the region. At this time, large scale implementation is impractical considering the absence of customized machinery and the need to restructure aspects of food distribution chains and gain government support. Further research is suggested to explore the monetary and social feasibility of applying the proposed strategies. Ideal next steps to test the conclusion of this study would be the implementation of a small-scale, educational pilot project located in one of the Sunset Climate Zones 3A or 10.

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