Agroforestry Management Plan for Three Story Farm, Ithaca, New York, USA

A Thesis

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Master of Professional Studies in Agriculture and Life Sciences

Field of Soil and Crop Sciences, Specializing in Agronomy

by

Robert C. Coville

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ABSTRACT

This document adapts forestry management planning and farm business planning, along with old and new tree crop knowledge, to create a public-domain agroforestry management plan example specifically applied for Three Story Farm (TSF) in Ithaca, NY. TSF was initiated in 2018 on a 25-acre area with a long-term (99 year) lease from Ecovillage at Ithaca, starting with the conversion of a Japanese honeysuckle thicket into a restoration agriculture ecosystem. TSF's restoration agriculture is characterized by swale-berm water management and alleycropping with chestnuts and hazelnuts. This plan supports farm operations and succession through long-term planning. It will also aid in supporter and staff recruitment by offering technical guidance, and it may ease access to funding opportunities by documenting activities for managing agroforestry systems. As there are limited examples of management plans for agroforestry in New York and the Eastern U.S., this document aims to serve the broader temperate-climate agroforestry community.

BIOGRAPHICAL SKETCH

Robert Coville was born in London, England, and raised in Greenvale, NY. In 2013, Robert earned an Associate of Applied Science in Environmental and Natural Resource Conservation from SUNY-ESF Ranger School in Wanakena, NY, and in 2015, Robert completed a Bachelor of Science in Natural Resource Management from SUNY-ESF in Syracuse, NY, where he founded a student chapter of the Society for Ecological Restoration. In 2015 Robert shifted from work in watershed-sensitive forestry toward ecosystem services, beginning work as an Urban Forest Hydrology Specialist and later as a Project Manager with The Davey Tree Expert Company and the USDA Forest Service on i-Tree Tools, free software to quantify tree benefits. Robert began practicing agroforestry in the public forest gardens of Syracuse, volunteering with The Alchemical Nursery Project since 2013 and joining their Board of Directors in 2015 where he continues to serve in a remote support role.

Robert moved to Ithaca, NY, in 2019 to begin a Master of Professional Studies degree in Agronomy at Cornell University under the guidance of Dr. Johannes Lehman. In Ithaca, Robert volunteered with Edible Acres and increased the scale of his hobby tree nursery, growing hundreds of nut trees in semi-portable air prune beds. Robert serves as a property manager of vacant field and forest in Upstate NY, planting hedges and riparian buffers and reforesting from seeds. Moving forward Robert aims to cultivate connection to place and ecological mutualism, engaging community and trees to do so.

ACKNOWLEDGMENTS

I give thanks to my family for enabling, encouraging, and entertaining me in this effort. I work with thoughts and thanks for past ancestors, present family I am fortunate to be with, and future generations. To my dear friends and partner – much thanks.

Learning at Cornell University has been a transformative privilege. Many people at the university and in the local community helped inform and inspire this project. I give thanks to Dr. Johannes Lehmann and everyone at the Lehmann lab for sharing knowledge, feedback, and community as I developed this project. This thoughtful interdisciplinary group welcomed me, my contributions, and this project. The opportunity to work with and exchange ideas with Johannes and this group enabled me to complete this agronomy capstone project with cutting-edge soil science at its foundation.

In Ithaca, connecting with Three Story Farm, Edible Acres, and numerous other regenerative farms greatly enhanced my MPS program. It has been an honor and joy to connect with Bradford, Lisa, and Julia of Three Story Farm for this project. Sean and Sasha of Edible Acres served as wonderful mentors and grew as friends while I interned at their nursery over the Fall 2019 and part of Spring 2020. To them and all stewards I've learned from, thank you for your time and work, may it grow exponentially like a tree. I look forward to engaging trees together, near and at a distance, in mutualism.

I give thanks to my colleagues at The Davey Tree Expert Company and the U.S. Forest Service who I work with on i-Tree Tools. The mentorship, teamwork, flexibility, and support have empowered me over the years and during this degree program.

With thanks I recognize all who share inspiration, knowledge, momentum, and hope toward mass reforestation and ecological mutualism.

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LIST OF ABBREVIATIONS

AMP: Agroforestry Management Plan

CASH: Comprehensive Assessment of Soil Health

EVI: Ecovillage at Ithaca

IPM: Integrated Pest Management

MLS: Master Line System

MWP: Multifunctional Woody Polyculture

RAD: Restoration Agriculture Development

TSF: Three Story Farm

UAV: Unmanned Aerial Vehicle (also known as a ‘drone’)

UMHDI: Upper Midwest Hazelnut Development Initiative

WSS: Web Soil Survey

PREFACE

Agroforestry management planning enables an organized and transferable approach for complex ecological practices. Forestry management plans are widely used, with updates occurring on the scale of 5-year increments and time horizons for management considerations ranging from fifteen years to hundreds of years. Farm business plans serve a similar purpose on a finer time scale, enabling foresight and consistency, monitoring and implementation. Agroforestry management plans (AMPs) tap into both scales, documenting specific annual farm activities along with decades-long tree crop enterprises, with planning horizons that have future generations in mind. This AMP is intended to be a public domain living document, offering procedures and information pertinent to one recently started agroforest farm that can serve as an example for others. This is motivated by the following: succession planning is easier with transferable details about an operation; easements and funding opportunities use management plans as a basis for long-term expectations and common understandings; and documenting an active example of restoration agriculture supports related works.

This plan is, in a sense, a user manual that is intended to evolve over time. This document describes one approach to a diversely practiced style of agriculture, referred to in this case as restoration agriculture, at Three Story Farm (TSF). The restoration agriculture practices of TSF are inspired by Mark Shepard's book by that name, *Restoration Agriculture*. Shepard's consulting company Restoration Agriculture Development (RAD) assisted in starting TSF, as described in this plan's background section. TSF's restoration agriculture is characterized by swale-berm water management earthworks and alleycropping growing primarily chestnuts and hazelnuts, along with a diversity of other desirable perennial plants. This public-domain plan centers on TSF as an applied example, while being tailored for relevance to broader farmer, supply chain, and extension communities interested in restoration agriculture. This plan includes: documentation of actionable and adaptable procedures for tree crop enterprises, especially those practicing restoration agriculture approaches like TSF; a literature review of ecosystem services associated with restoration agriculture practices; and the initial design for a longitudinal field study of restoration agriculture effects on the farm's carbon and hydrology features. Resources providing greater detail about agroforestry techniques and tree crop agronomy are referenced extensively in this summarizing work, while this plan applies or presents that information specifically to TSF. Content includes documentation of existing conditions and efforts of TSF, of TSF's existing plans, and of the results of agronomic investigation on options and development of recommendations relevant for TSF's future goals. Sources of content are generally distinguished by TSF's existing activities noted as current or past-tense, TSF's provided intentions specifically noted as their own plans or strategies, and this document's novel contributions noted as recommendations or otherwise not cited to TSF or other references. This project is based on feedback about needs in the field from Northeast and Midwest agroforesters (including TSF), my own agroforestry efforts and observations, and the notable organization RAD.

BACKGROUND

Plan Method and History

This AMP is developed by TSF owners and local Cornell University student Robert Coville based on mutual benefit. This plan is intended to facilitate long-term management of this temperate-climate farm focused on tree crops and restoration agriculture, while contributing to and cross-pollinating with sources of technical assistance for regenerative tree crop farms. The planning outline and approach used here is guided by prior education, experience, and the *Handbook for Agroforestry Planning and Design* (Gold et al. 2013).

For TSF owners, this project serves to:

- facilitate organization and long-term strategy,
- act as a platform for stakeholder support and recruitment,
- ease access to cost share programs and grants,
- support succession planning and easements, and
- provide an educational resource for regional agroforestry.

For the author, this project serves as the capstone project for a one-year Master of Professional Studies degree in Soil and Crop Sciences specializing in Agronomy. This project accomplishes the goal of contributing to implementation and facilitation of agroforestry and restoration agriculture in Central New York, while advancing the applied field itself through useful documentation and outreach. This plan is an exercise in agricultural consulting and serves as a synthesis of temperate agronomy and agroforestry concepts, resources, and approaches.

This project emerged out of mutual interest identified by Robert Coville and Bradford Smith, with guidance from Mark Shepard and Karen Vanek of RAD who installed (and hosted a workshop about) water management earthworks and alleycrop plantings for TSF in Spring 2018. As there are limited examples of management plans for specific agroforestry enterprises in New York and even in the broader Great Lakes and U.S. East Coast watersheds, we aim for this documentation about TSF's restoration agriculture to facilitate other temperate-climate agroforest enterprises. Notable agroforestry management planning resources include University of Missouri Center for Agroforestry's *Handbook for Agroforestry Planning & Design* (Gold et al. 2013) and *Chapter 2: Planning for Agroforestry* in *Training Manual for Applied Agroforestry Practices* (Gold & Cernusca 2013).

Overall Farm Mission

1. Develop and put into practice farm scale food production that is sustainable, regenerative and economically viable.
2. Encourage the adoption of these practices through demonstration, education, outreach and network building.

Agricultural Approaches

While there are many terms used to describe the agricultural techniques and philosophy of TSF and similar efforts, in this case *restoration agriculture* is the system practiced, *tree crops* are the main farm product, and *multifunctional woody polyculture (MWP)* is the precise scientific term for the agro-ecosystem.

Earthworks and alleycrop planting

TSF's design reflects its core techniques of water management and alleycropping.

1. Design and install resilient water management using the Master Line System (MLS) approach (Shepard 2019).
2. Plant 1000 chestnut trees, 1500 hazelnut bushes, and 300 butternut trees to establish the basis of a resilient food supply in the face of climate change.

Soil health

3. Apply good soil health practices as outlined by the NRCS: keeping soil covered, minimizing soil disturbance, prioritizing plant diversity and planting perennials with extensive root systems, employing no-till weed management, and using holistic Integrated Pest Management (IPM) practices.

Long-term stewardship and propagation

4. TSF is in its Phase 2 of its plan, as of Summer 2020, which consists of:
    a. Maintaining trees from the initial installation,
    b. Building a structure to support future nut harvest and vertical integration,
    c. Adding plantings to increase diversity, trial new species and add more of the primary nut crops (chestnut and hazelnut) and hedges,

d. Establishing new crops (e.g. in 2019 TSF planted 100 honeyberry bushes and dozens of fruit trees),
e. Develop perennial nursery to propagate species for the farm (new plantings & replacement stock) and to offer for sale, and
f. Explore the addition of livestock to the system.

Tree breeding and diversity for climate adaptation

5. During 2020 TSF is working to establish a small grove of pawpaw trees, selected for the desirable hybrid seeds they will produce. Seedlings will be grown in TSF's nursery then planted out in a pawpaw grove for production, with surplus seedlings available for purchase.
6. TSF plans to grow out additional varieties of chestnut trees from seed then plant them on a large scale to discover which are most suitable to our climate and site. Over the long-term TSF plans to do similar work with heartnuts, a Japanese walnut related to native butternut and black walnut trees.

Animals in agroforest ecosystems

7. If Ecovillage at Ithaca (EVI) adopts a change to the Planned Development Zone that permits commercial livestock, TSF plans to trial a small pastured poultry flock in alleys.

Site Maps

Maps are a platform to record information such as management area delineations, spatial crop data (i.e. Normalized Difference Vegetation Index (NDVI)), and measurements of key farm features (such as pond area). Maps for TSF were prepared using ArcGIS software to georeference UAV-derived aerial imagery and to make spatial measurements and using QGIS open-source software for management area delineation and cartography. QGIS has more limitations than ArcGIS but it is freely available for farmers to work with. Information about the mapping process is included below for replicability and clarity, followed by maps referenced throughout this AMP.

Geospatial Information System (GIS) data

Base maps are derived from aerial imagery of 2018 from NYS GIS Clearinghouse, Unmanned Aerial Vehicle (UAV) imagery of 2019 from an EVI resident, a hand-delineated farm outline provided by Bradford Smith, Digital Elevation Models (DEMs) from NYS GIS Clearinghouse (NYS 2020), and a National Weather Service (NWS) shapefile of U.S. States and Territories. The farm boundary, 2019 UAV imagery, and DEMs were georeferenced or reprojected to the following Projected Coordinate System of the 2018 NYS orthoimagery using ArcMap: “EPSG:103118 - NAD_1983_2011_StatePlane_New_York_Central_FIPS_3102_Ft_US – Projected”. The DEM was originally in Coordinate Reference System “EPSG:26918 - NAD83 / UTM zone 18N – Projected”. While the state-provided imagery is projected in units of feet, the federal-provided DEM is projected in units of meters, and the reprojected DEM remains in meters. DEM values were converted from meters to feet using a raster calculator to multiply the DEM values by a factor of 3.28084.

GIS data from this plan is publicly available, as of its first iteration, at: https://drive.google.com/drive/folders/1Xqvw14ulSOA39WZ_Mr1FFBN6tRe7cwy_?usp=sharing

Imagery

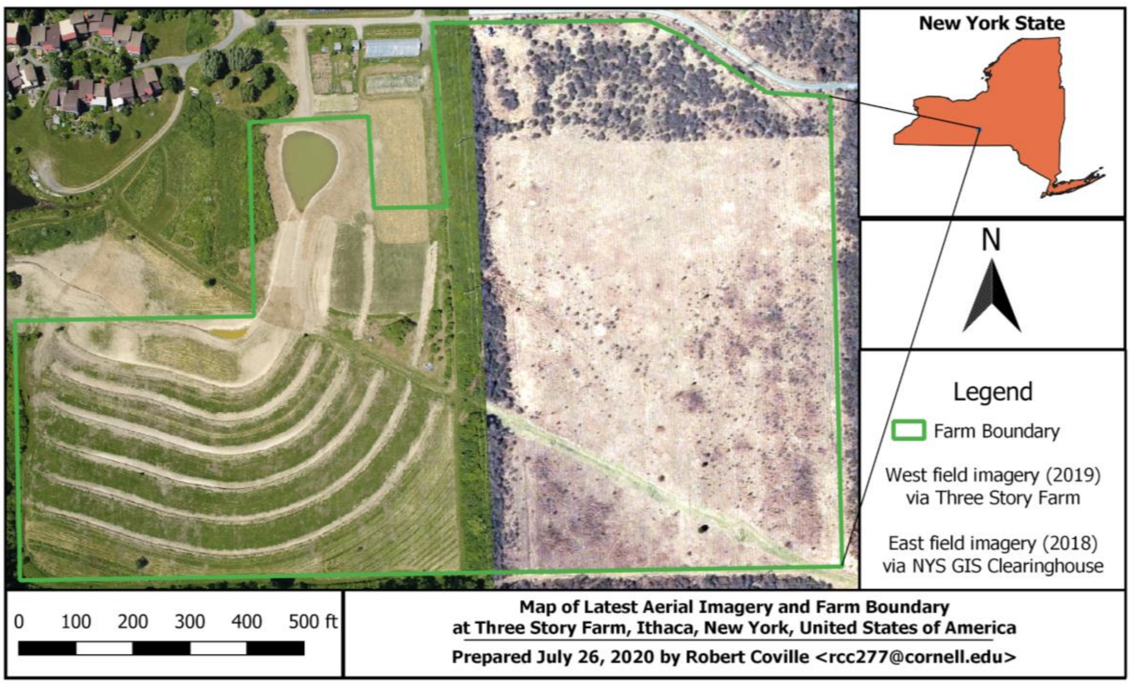

Figure 1. Map of Latest Aerial Imagery and Farm Boundary at Three Story Farm.

Tax parcel

TSF is a part of EVI's tax parcel, leasing 25 acres that are included in EVI's Planned Development Zone in the Town of Ithaca. For this reason, TSF does not have its area delineated as its own tax parcel.

Topography and water features

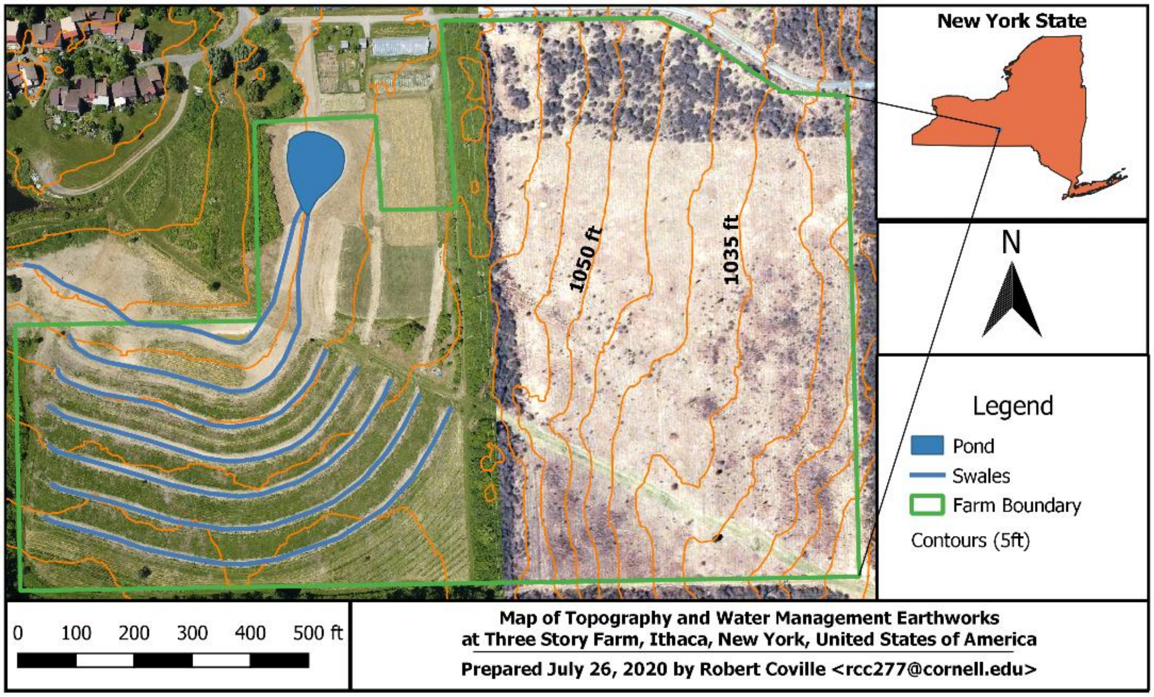

Figure 2. Map of topography and water management earthworks at Three Story Farm.

Note that (2) 275-gallon IBC containers are used as intermediate water storage between the pond and drip lines, with one container located on the northeast corner of the Honeyberry management unit setup with drip irrigation lines into that area and with the other container located at the northern corner of the Alley 1 management unit setup with drip irrigation lines throughout the first five alleys (management units are shown in Figure 3 below). Approximate area of pond is 0.25 acres, and TSF estimates its average depth as 4.5 feet. More specifications about the pond and water management system are available in the [tree crops irrigation section].

Management units

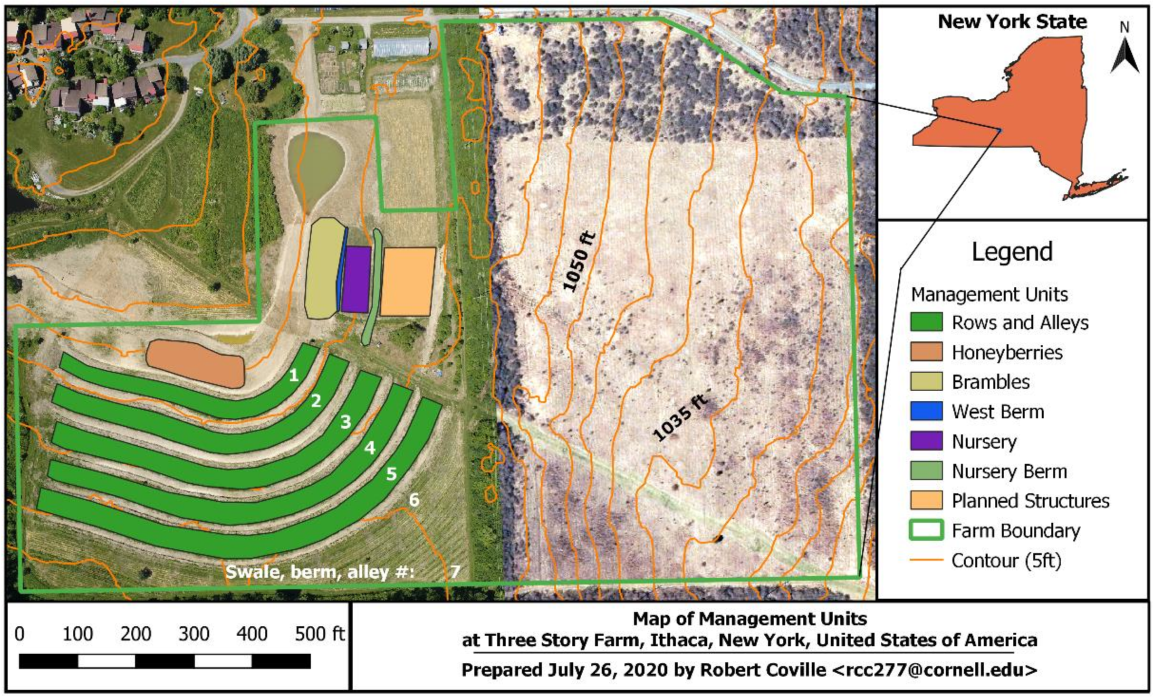

Figure 3. Map of Management Units at Three Story Farm.

Note that alley numbering includes the uphill berm and swale, as in alley 2 includes the swale and berm on the alley's uphill side. Approximate area of arable alleys is 2.5 acres.

Zones of Use

Zone 1 (regular use): Pond, irrigation system, and nursery get frequent attention.

Zone 2 (daily use): No management units are in this zone yet (livestock would).

Zone 3 (weekly use): Berms 2-5, West Berm, and Nursery Berm in weekly rotations.

Zone 4 (occasional use): Experimental crop areas, field perimeter hedges, alleys 6-7.

Zone 5 (infrequent use): East Field.

UAV-based mapping

UAV-based mapping is an appealing tool for farmers wanting contour mapping, up-to-date imagery, and field-scale scouting. There is a range of features and costs for UAVs (also known as ‘drones’), and there are still somewhat limited options in terms of entry level (<$2,000) UAVs, especially if looking for U.S.-manufactured drones. Recommended resources for consideration include:

- Agriculture drone buyer’s guide, which lists the DJI Phantom 4 as an entry-level quad-copter with potential for agricultural scouting (starting at $1,599, priced for basic ag use at $2,000): https://bestdroneforthejob.com/drone-buying-guides/agriculture-drone-buyers-guide/
- DJI Drones are compatible with DroneDeploy contour mapping software https://support.dronedeploy.com/docs/contours-1
- Droners.io, hosted by UAV manufacturer PrecisionHawk, offers a network of commercial drone pilots who can perform custom agricultural UAV services. Registering and posting projects for bids is easy and quick, with many pilots available in the northeast U.S. https://droners.io/dashboard/client/

Site Description

The following sections describes current conditions and context of TSF.

History

TSF was founded in 2018 by Julia Nelson, Lisa Ripperton, and Bradford Smith. TSF’s land tenure is based on a 99-year lease of 25 acres from EVI, where the farm is located. TSF is incorporated as an LLC. Other business models are of interest, such as cooperative ownership, however the scope of this plan does not yet include assessment of alternative business structures. As part of TSF's mission of sustainable, regenerative, and economically viable food production, social and environmental justice in the food system is a priority. It is recommended that TSF seek and respect preferences from Haudenosaunee first peoples and from the rich and growing movement for food sovereignty in the Finger Lakes, including neighboring Groundswell Center and regional Soul Fire Farm. TSF is aiming for productive restoration that enables people to meet basic needs while improving the land which provides that fulfilment, in a reciprocal relationship (as in, the agroecosystem grows better over time and in-turn provides more over time). TSF's efforts and this plan are also intended to reduce the cost of entry and uncertainty for other potential restoration agriculture practitioners. For example, by reducing the annual monetary and labor costs of staple food production by implementing low-input tree-based agro-ecosystems and cultivating them with minimal interference (i.e. the Strategic Total and Utter Neglect method noted in Shepard 2013).

Biophysical context

TSF is in the Eastern Great Lakes lowland forests ecoregion (Bryce et al. 2010). The disturbance regime theorized for these ecoregions includes understory fires occurring within every 30 years, with occasional mixed severity forest fires, and with broad overstory disturbance occurring only once every human generation or two (Menakis et al. 2000). Historic and current forest cover suggests that natural succession is trending toward mixed hardwood forests with intermediary stages of short-lived, faster-growing trees including fruit trees (or in cases of infestation by aggressive non-native species, European buckthorn and Japanese honeysuckle) and with mature stages characterized by dominant species of tree families Betulaceae (i.e. birch), Fagaceae (i.e. oak, beech), Juglandaceae (i.e. walnut, hickory), and Aceraceae (i.e. maple). There is a history of managing these woodlands by indigenous people, wherein anthropogenic disturbances mimicked natural disturbances and promoted long-term sustainability (Kimmerer 2000). Large mammals such as the mastodon have a historic presence in the region, which is an ecological precedence some agroforesters point out in advocating for silvopasture and mimicking disturbance regimes caused by large mammals.

Soil

Soil was first assessed on site by touch, appearance, indicator plants, and Web Soil Survey (WSS). TSF did not conduct a lab analysis of soil health prior to initial earthworks and tree plantings, after having had a pasture consultation and visual site suitability assessment which gave them confidence to move forward with water management improvements and initial tree plantings prior to this plan's development. Initial soil health sampling using laboratory analysis is planned for Fall 2020 with results being incorporated into this plan after its first version's publication. That soil health sampling strategy is detailed in the Citizen Science section.

A preliminary assessment of soil conditions is available using the USDA WSS (Figure 4, NRCS 2020). Data for these WSS maps is collected at a much larger scale than that of TSF's management, as it is part of a nationwide survey of soil qualities, but the WSS offers information for the broader soil context of the farm. This tool can be used to assess soil suitability, moisture, and temperature trends at coarse resolutions, but at the scale of 25 acres its use is limited to estimating soil class and associated textures, slopes, and probable qualities.

Tompkins County, New York (NY109)

Tompkins County, New York (NY109)

Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
BgC	Bath and Valois soils, 5 to 15 percent slopes	9.6	23.1%
Hc	Halsey mucky silt loam	0.1	0.2%
HdC	Howard gravelly loam, 5 to 15 percent simple slopes	19.7	47.3%
LaB	Langford channery silt loam, 2 to 8 percent slopes	4.9	11.7%
PhB	Phelps gravelly silt loam, 3 to 8 percent slopes	7.4	17.7%
Totals for Area of Interest		**41.7**	**100.0%**

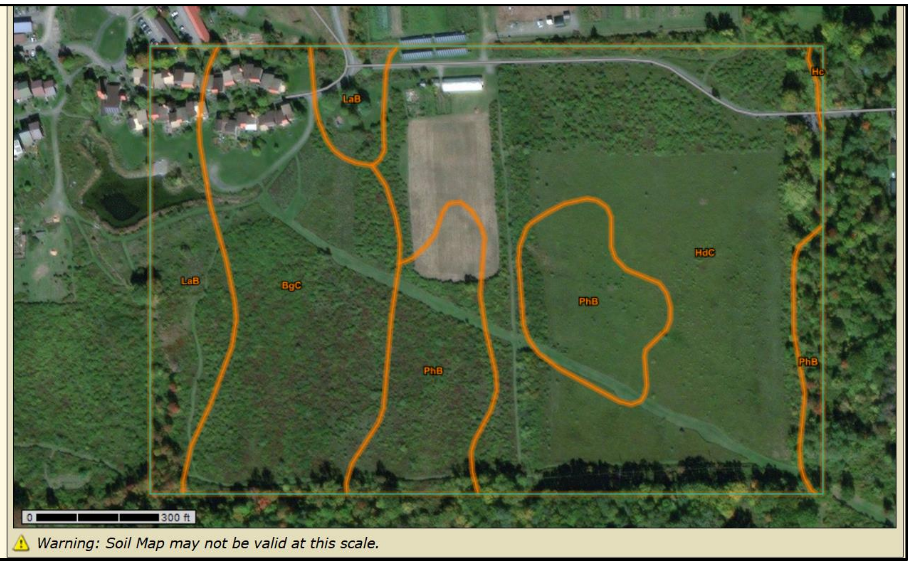

Figure 4. Web Soil Survey results for soil classifications in the broad area of Three Story Farm.

This WSS information is supplemented and refined by field observations which help us build a grounded intuition about the farm's soil. Below are qualities examined and examples of findings in TSF's tree crop alleys.

Physical properties

Soil texture is the foundation of other soil qualities, but this is not sensitive to management. Texture tends to be one of the first things examined when assessing a soil, and this can be done by feel in one's hand (Thien 1979). Testing by hand in the tree alleyways, the soil texture is silty clay loam.

Aggregate stability is a soil physical property recommended for TSF's long-term attention, as it is sensitive to management and is a sign of overall recovery or degradation of soil health. Aggregate stability is indicative of soil porosity, organic matter content, biological activity, nutrient cycling, and erosion vulnerability (NRCS 2011). Laboratory assessment of aggregate stability is described in the Citizen Science section. Farmers can comparatively assess aggregate stability between soils with simpler methods, including slake tests which can be done at home following the method described by SC-NRCS (2018).

Biological activity

Soil biota can be assessed by sampling the abundance of an indicator species (such as counting spiders or earth worms, or qualitatively-scoring for the presence of fine roots) or by sampling the richness of the amount of different species. With low-tech in-field methods, sampling is limited to the scale of visible biota and has other constraints, but a habit of checking soil biota can be an important contribution to one's intuition about a soil's condition. Active carbon is a soil biological property recommended for TSF's long-term attention, as detailed in the Citizen Science section.

Biodiversity

TSF has observed numerous changes and increases in the composition of the plant and wildlife community in and around the farm. Though the observations are anecdotes and not scientific findings, they serve as the basis of farmer intuition about biodiversity in the agro-ecosystem. These observations could be made more empirical by sampling species abundance (relative prevalence of each species observed).

Weather and climate

The Ithaca New York area has meteorological records assessed by the Western Regional Climate Center (WRCC) spanning from 1893 to 2012 (WRCC 2013). Based on that information, the area has an average annual rainfall of 893mm and snowfall of 163mm. Average temperature in winter (December, January, February) is a low of 17.3F and a high of 33.1F, and the average temperature in summer (June, July, August) is a low of 56.3F and a high of 78.6F. The hardiness zone of TSF is 5b (USDA ARS 2012).

Infrastructure, equipment, and resources

This section inventories the features and resources for TSF's operation, organized by function. This is a current inventory and does not include items that TSF plans to integrate into the farm in the future.

Water management: earthworks and infrastructure

The most significant infrastructure at TSF is the ground itself, which has been modified according to the specifications described in the tree crops activity section about earthworks. Discussing TSF's water management features, TSF farmer Bradford Smith shared the following at an EVI meeting in December 2019 (Smith et al. 2019):

> *"It is apparent Three Story Farm is not a traditional farm as soon as you walk out into the fields: the landscape is traversed by berms and swales. We began our project by designing and building a passive water management system to slow and spread the flow of surface water on the site. We now have a pond for irrigation and food production (fish), enhanced resilience to heavy rainfall events and the ability to store water, both in the swales and the soil. As the soil improves and benefits from the additional moisture provided by the passive storage, the amount of organic material will increase, further improving the soil's ability to*

store water. Erosion is well-controlled and ecosystems downhill benefit from the slowing of the surface water flowing offsite as well as the replenishing of the underground aquifer.

These water features add tremendous diversity to the ecosystem. It creates a large amount of new amphibian habitat; ducks frequent the water in the swales and judging by their hoofprints deer enjoy drinking as well. As the number of fish in the pond increases so does the amount of nutrients in the outflow of the pond, which is conducted into the top berm of the field in a technique called "fertigation": it both irrigates and fertilizes at the same time. These benefits to the landscape are in place and will continue to function, for hundreds of years if not longer, without any further need of intervention.

Our water management system has been looked to as a model and possible solution to one of our region's problems: harmful algae blooms (HABs) in the Finger Lakes. The heavy use of fertilizers in traditional agriculture can produce runoff that is damaging to downstream watersheds. The type of agriculture TSF is putting into practice is suitable in a wide variety of locations and soil types. It could be employed on marginal land at the edges of farm fields and on slopes to both control erosion and harmful runoff while at the same time producing valuable food and creating wildlife habitat.

It is useful to observe that these techniques are not "new." Simple earthworks are powerful tools for agriculture and they have been employed since the earliest days of human agriculture (beavers do it too!). USDA publications in the 1940's described and encouraged all of the techniques we are employing here. They have lost favor along with the rise of industrialized agriculture: a hedgerow is lost acreage, a berm is an inconvenience, fields should be drained and flattened to accommodate ever larger machinery. We are exploring these valuable techniques as "solutions we have forgotten": simple, low-input methods to increase our resilience, improve the soil, increase fertility and enhance wildlife habit. All while producing food for the humans who live here and care for the land.

We collaborated with RAD (Restoration Agriculture Development) for our initial installation and education, led by Mark Shepard and Johann Rinkens. They conducted a three-day workshop that taught the techniques and implemented them on the site, including the initial plantings of chestnut, hazelnut and butternut. Future goals include developing the ability to do this type of water management installation with local resources and at a lower cost per acre, to make this type of installation more accessible. Grants may help with the development and training and move us towards broader acceptance and implementation."

Tractor and field crop supplies

In addition to water management infrastructure built into the landscape, equipment and materials to operate on broadacre scale at TSF are inventoried below.

- Kubota M6040 Tractor (65 horsepower) with the following implements:
    - LA1153 loader with front bucket
    - Orchard mower
    - Moldboard plow (1 tine)
    - Access to 3 tong Yeoman's plow (~4ft wide) which can serve as a chisel plow/subsoiler, needed for annual root pruning during orchard establishment

Tree nursery supplies

Nursery-specific materials for tree propagation and sale are listed below.

- Bed materials and growing medium
    - Gravel
    - Sand
    - Mulch
    - Soil mix (50% composted manure, 50% gravel screenings)
- Deer fencing
- Small-scale irrigation equipment: stock tanks, watering carts and cans
- Nursery equipment: sheers, pots, air prune boxes

General farm supplies

Handheld equipment and supplies for finer-scale operations of TSF are listed below.

- Spreader (for broadcasting seed or soil amendments)
- Sprayer (for plant treatments or soil amendments)
- Bushel baskets for hand picking, sorting, etc.

- Signage, printed informative documents for U-Pick members
- Membership roster to track U-Pick membership
- Hedgelaying equipment

Irrigation system supplies

- (2) 275-gallon IBC containers
- 1.5hp sprinkler pump with simple trap to avoid losing pump's prime
- Plumbing to draw water from pond into IBC totes and from those into drip lines

Note that the first alley or two can have low drip line pressure and take longer to water.

Crop & livestock inventory

Living components of TSF currently cultivated are listed below, organized by management unit (which are mapped in Figure 3).

Alley tree crops

A 'live' version of the core tree crop inventory is available at: https://docs.google.com/spreadsheets/d/11bi-oROzkJLX92yG8Ci2VeFTIQSAvFFIqOPuHTMRcXo/edit?usp=sharing

A July 2020 snapshot of that core inventory is included in Table 1 below. These are mostly planted on the western 10 acre half of TSF leased 25 acre area.

Table 1. Tree inventory of Three Story Farm in July 2020.

Current Count	Species	Year Planted	Original Population	Notes
640	Chinese Chestnut	2018	960	Via ForestAg.com
900	Hybrid Hazelnut	2018	1500	Estimated count, select seedlings via ForestAg.com
90	Butternut	2018	150	
7	Heartnut	2020	7	
7	Chinquapin Chestnut	2020	7	
4	Persimmon	2020	5	
10	Asian Pear	2019	10	
92	Honeyberry	2019	100	
15	Serviceberry	2019	17	

Overall species richness

A highlight of species richness at TSF is provided in Table 2, listing desirable species present in the farm's management units.

Table 2. Plantings at Three Story Farm as of November 2019, organized by management units.

Management Unit	Species (and variety)
Alley 1a (on berm)	<unplanted>
Alley 1b (10 feet below berm)	Chinese Chestnuts
Alley 1c (alleyway top 3rd)	Hazelnuts
Alley 1d (alleyway middle 3rd)	Hazelnuts
Alley 1e (alleyway bottom 3rd)	Hazelnuts

Table 2 (Continued)

Alley 2a (on berm)	Asian Pears 'Shinsui', 'Korean Giant', 'Yoinashi'
	Dawes Plum
	Kousa Dogwood
	Mint Root
	Nanking Cherry
	Pyrus betulifolia
	Red Currant
	Rhubarb 'Crimson Red'
	Sea Kale
	Toka Plum
	Underwood Plum
	Western Sandy Cherries
Alley 2b (10 feet below berm)	Chinese Chestnuts
Alley 3a (on berm)	Apples
	Apricot 'Tomcat', 'Puget Gold'
	Asian Pears 'Raja', 'Nijiseiki', 'Shin Li', 'Large Korean', 'Shinseiki', 'Shinko', 'Daisui'
	Cherry 'Surefire Pie', 'Danube'
	Kousa Dogwood
	Mulberry Grafts 'Capsrum', 'Kukosa', 'Carman', 'Italian', 'Illinois Everbearing', 'Ivory'
	Serviceberries 'Northline', 'Smokey', 'Thiessen',
	Nitrogen Fixers:
	Blue False Indigo,
	Honey Locusts,
	Goji Berries,
	Silverberry,
	Seaberries 'Sirola', 'Siberian Splendor', 'Klim's Prize', 'Radiant', 'Star of Altai'
Alley 3b (10 feet below berm)	Chinese Chestnuts
Alley 4a (on berm)	Rhubarb
Alley 4b (10 feet below berm)	Chinese Chestnuts
Alley 5b (10 feet below berm)	Chinese Chestnuts

Table 2 (Continued)

Alley 5c (alleyway top 3rd)	Chinese Chestnuts
Alley 6b (10 feet below berm)	Chinese Chestnuts
Alley 7	Hazelnuts
Honeyberries	Honeyberries ‘Tundra’, ‘Boreal Beauty’, ‘Beast’, ‘Blizzard’, with pollinators ‘Aurora’, ‘Solo’, ‘Maxie’
	Strawberries ‘Jewel’, ‘Wendy A C’
	<u>Herbs</u>
	Candy Lime Mint
	Dotted Mint
	Feverfew
	Garlic Chives
	Lemon Thyme
	Margarita Mint
	Orange Thyme
	Oregano Thyme Mint
	Profusion Chives
	Sage
	Sweet Cicely
	Sweet Pear Mint
	<u>Flowers</u>
	Blue Stocking Bergamot
	Centaurea Montana
	Day Lily ‘Happy Returns’
	Early Meadow Rue
	Mountain Day Lily
	Narrow-Leaved Echinacea
	Rudbeckia
	Yarrow
	<u>Foliage</u>
	Bloody Dock
	Host ‘Blue Cadet’
	Hosta ‘Green and White’
	Lambs’ Ear

Table 2 (Continued)

Nursery	Air Potato
	Alpine Strawberries
	Asparagus 'Jersey Knight'
	Black Currant 'Titan'
	Black Locust
	Bud 118 Apple Rootstock
	Chinquapin Chestnuts
	Chinese Chestnuts
	Chinese Mountain Yam
	Elderberries
	Geranium 'Big Root Hardy'
	Grafted Apples
	Groundnuts 'Clusternut', 'Nutty #3', 'Simon', 'Treasure', 'Virginia'
	Heartnuts
	Hog Peanut 'Crispy Snack'
	Hops 'Willamette'
	Jostaberry
	Mulberries
	Prickly Pear Cactus
	Purple Passionflower
	Red Currant 'Rovada'
	Seaberries
	Senna
	Sunchokes 'Big Bertha', 'Gigant', 'Nora', 'Red Ball', 'Red Rover', 'Supernova', 'Starwhite Cluster', 'Topstar'
	Thicket Bean
	Thimbleberry
	Welsh Onion
	Wild Licorice
Brambles	Black Raspberry 'Bristol' 'Niwot'
	Blackberry 'Triple Crown' 'Prime Ark Freedom'
	Golden Raspberry 'Anne', 'Double Gold'
	Red Raspberry 'Caroline' 'BP 1'

Table 2 (Continued)

West Berm	American Persimmons
	Elderberries ‘Ranch’, ‘Bob Gordon’, ‘Adams’, ‘Wyldewood’
	Horseradish
	Kousa Dogwood
Nursery Berm	Butternuts
	Comfrey
	Pawpaws

Alley field crops

Alleyways are covered with grasses, clovers and other forbs. Swales and wet spots have noticeably reduced herbaceous cover. A cover crop mix of native grasses and varieties of clover was broadcast over site after earthworks in 2018. Primary weeds observed include field bindweed, quackgrass, and in rarer cases cleavers. Alleys have some Japanese honeysuckle returning to it, but repeated mowing for more than 18 months has largely removed Japanese honeysuckle from the plant community. This is because the ecosystem disturbance of mowing returns the mowed areas to earlier stages of succession, dominated by herbaceous annual and perennial plants. As succession proceeds, pioneer trees and woody perennials will begin to establish themselves, and in those cases Japanese honeysuckle would likely return if the space is not occupied by healthy, desirable, and supported working trees.

Animals are not currently integrated into this farm, with the recent exception of a small set of honeybees hives as of Summer 2020. TSF is interested in raising small livestock, rotating through alleyway pastures or larger paddocks on its open east field. This would require fencing and other equipment for rotational grazing of animals on pasture, discussed in the Silvopasture activities section.

Tree nursery

As of this plan's first version, TSF's tree nursery is an emerging enterprise that has not yet been fully inventoried. Species present follow the nursery's management activities and goals, including nut tree crops, higher-value grafts for sale, rubus species, ribes species, and hedgerow trees. Table 2 lists species richness at the nursery's start.

Ecosystem Services of Agroforestry

Ecosystem services are processes and benefits people utilize from the environment, including food, clean water, materials, moderate temperatures, and clean air (i-Tree 2020). Ecosystem services are categorized by the Millennium Ecosystem Assessment (2005) synthesis in four broad categories: *regulating, supporting, provisioning, and cultural* ecosystem services. Each category represents a broad set of benefits that humans experience from the natural functions of ecosystem components. *Regulating ecosystem services* represent the moderation of ecosystem conditions and nutrient cycling, which enable life to exist on Earth (including climate moderation). *Supporting ecosystem services* are the basis of other environmental functions (as in primary production). *Provisioning services* are the most apparent to humanity, as these are the benefits nature provides to our basic needs (as in food, fiber for shelter, fuel for heat energy, and more). *Cultural services* are those social, cultural, and spiritual benefits that humanity derives from our relationship with ecosystems and nature as a whole. Trees provide benefits in each of these categories, including to an even greater extent when 'the right tree is used in the right place for the right reason', as in TSF's agroecosystem. The main ecosystem services prioritized by TSF for enhancement and protection are regulating ecosystem services for carbon, water, biodiversity, and resilience to weather extremes and climate change; provisioning benefits for food; and cultural benefits of restoring forests in our landscape and reducing our costly, fossil fuel-powered resistance to natural succession. A detailed literature review of ecosystem services provided by TSF and similar temperate-climate MWPs is available in Appendix 2, focusing on carbon, water, and cultural benefits provided by agroforestry.

MANAGEMENT ACTIVITIES

Farm activities can be organized in management units, which group activities around common goals and characteristics of management. Grouping management activities this way enables better clarity and organization amid the complexity of restoration agriculture. A map of management units (Figure 3) is available in the Site Maps > Management Units section.

For each management unit, the following aspects are considered in the development of management options and recommendations for TSF.

i. Objectives
ii. Current conditions
iii. Desired future conditions
iv. Management options (and recommendations)

Management units & associated activities are listed below:

- Tree Crops

- Alleyway Field Crops
- Tree Nursery
- Forestry
- Silvopasture
- Education and outreach
- Business and legal activities

Tree Crops

This is the primary enterprise of TSF and accordingly it is the focus of this plan. Many of the activities are informed by references, a community of practitioners, and prior education and experience of both TSF and this plan's original author. Management options and recommendations in this plan and in its references exist along a spectrum as level of management intensity varies. An important context of this plan is TSF's interest in operating with less intervention and lower costs over the long-term, focusing on the (higher up-front cost) establishment of resilient and low-input systems. More details on nut tree cultivation in Central New York are available from Zarnowski & Zarnowski (2020), including annual maintenance schedules for chestnuts (in their Table 8-5) and hazelnuts (in their Table 5-1).

Objectives

TSF's tree crop objective is to develop and put into practice farm scale food production that is sustainable (i.e. usable without 'using it up' and depleting an opportunity), regenerative (i.e. improves over time and offers increasing opportunities for propagation and diversification of food systems), and economically viable (i.e. offers a fulfilling fair share to farmers), contributing to a resilient food supply in the face of climate change and environmental degradation.

Current conditions

Current plantings are focused on showcasing a diversity of perennial crops, with a strong base of chestnut and hazelnut as large producers. Alleys are in meadow, with 2, 4, 5, and 6 mowed monthly and alley 3 left un-mowed.

Desired future conditions

Low-input long-term production of staple nutrients using tree crops (primarily chestnuts for starches and hazelnuts for fats and fiber) and diversity as the basis for a resilient agro-ecosystem, integrated into the regional Central New York food system and the broader community of practice in temperate agroforestry. Over the next five years: cull trees and replant or expand as enabled by the tree nursery, continue mowing and maintaining weed and pest protections (tree tubes, tree cages, weed mats, vole guards) annually; prepare for nut processing necessary to store and distribute early harvests; and begin harvesting early yields of chestnuts and hazelnuts.

Activities

Below is a description of tree crop management activities, including steps already completed or planned by TSF along with options and recommendations introduced through this plan. Maintenance schedules in Gantt-chart format are available from

Zarnowski & Zarnowski 2020 for hazelnuts (in their Table 5-1) and for chestnuts (in their Table 8-5).

Earthworks

The first step to TSF's restoration agriculture implementation was earthworks for water management and site/planting preparation. This sequence follows the Scales of Permanence conceptual framework (Gabriel 2016): topography and water are the first farm features to design and implement, followed by access routes, trees, etc. Each of these land features has a different level of permanence and difficulty to modify, so carefully starting with the longest-lasting feature and designing systems from there is a foundation to site-appropriate land use. For long-term water resilience and watershed benefit, site preparation included the earthworks step of modifying topography. This step was a significant portion of TSF's initial cost and may not be needed in all fields, but it is anticipated that increasingly flashy precipitation regimes in New York will increase the need for (and benefit of) resilient and passive stormwater management.

RAD assisted in the design and implementation of water management earthworks systems, following the MLS approach of Shepard (2019a). TSF's planted field has a slight 1-10% slope, and a bulldozer with a three-way blade was used to carve a series of shallow swales and low berms, spanning approximately 600 feet in the highest elevation alley and approximately 800 feet in the lowest alley, along a 0.5% grade for the pond inlet and on contour for the pond outlet flow paths. Only the first berm has a spillway built in, and TSF has observed that the micro-valleys in berms (from preexisting depressions in the field) become effective spillways during periods of high flow. Based on that, TSF plans to install spillways in most alleys to strategically handle overflows. In later efforts by TSF not involving RAD, a moldboard plow was used to scoop and flip soil in a row, forming a small trench and berm alongside the plow path. These small berms are less consistent and do not have the same scale to hold water as the bulldozed MLS, but they do serve the intended purpose of creating planting mounds with improved drainage compared to surrounding field soils.

Fencing and tree protection

TSF has opted not to use a perimeter fence in the alleycropping system, instead fencing trees on an individual basis (Illustration 1). In higher sensitivity areas such as the tree nursery, a perimeter fence is employed. The higher cost of the perimeter fence makes it less appealing, as does its absolute exclusion of deer and wildlife in general. As livestock are not included in TSF yet, having some wildlife interacting with the system is viewed by TSF as a potentially positive feature in the agro-ecosystem. Individual tree protections are used to help tree crops and wildlife coexist during the sensitive period of tree establishment. Perimeter fencing is desirable in some cases, and more detailed information about fencing chestnut and hazelnut orchards is available in Zarnowski & Zarnowski 2020.

Illustration 1. Five-foot tree tubes, wood stakes, reusable zip-ties, and weed mats protecting 2 year old Chinese Chestnut trees.

With the initial planting, 5-foot-tall tree tubes were used (Illustration 1). TSF farmer Lisa Ripperton noted ‘Tree tubes continue to be used for nut trees and any trees that are intended to grow straight and tall with lower branches naturally pruned. In other cases, such as with fruit trees, welded wire tree cages are used (Illustration 2).’ TSF farmer Bradford Smith commented on an important co-benefit of tree protections: ‘We've found that tubes make the best markers for *where* the plant is. We have put posts next to things but then the mowing gets away from us and even with a stake we have accidentally mowed things down because they got lost in tall grass. The tubes being white make it much more obvious as well as making weed whacking around the plants much easier [though it is safer to leave a thin line of weeds around trees, rather than mow tightly near trees].’

Illustration 2. Welded wire fencing around higher value trees.

TSF also uses a homemade spray to deter deer, which has been found effective as a TSF farmer explained in an online Q&A (TSF 2019): “We have definitely found the egg/oil/dishsoap/water mixture to be effective! The time spent spraying is pretty quick especially by applying with the sprayer meant for liquid pesticides. A few gallon fill on that backpack was enough to spray hundreds of trees. It only took an hour or so and we would spray about once a month [during the first growing season] unless there was a particularly heavy rain storm. I believe that even with the physical work over time it is definitely much less expensive than a deer fence.”

To perform tree fencing activities at the scale of individual trees, simpler tools and less maximum energy is required than when building substantial perimeter deer fences, but both approaches to fencing require significant time, effort, and resources. TSF uses high quality small bolt cutters and weights for efficient hardware cloth unrolling and cutting, forming rings of welded-wire fence (shown in Illustration 2) anchored with stakes around high-value trees and trees that are particularly attractive to deer (such as select nut trees, apples and persimmons). Vole protection is provided primarily by thorough mowing within 4’ of the trees (leaving only a thin strip of vegetation between trees and mowed area) in the fall to eliminate their overwintering habitat. In cases where TSF uses black plastic weed mats, an 8” tall rectangle of ¼” hardware cloth is bent into a cylinder and wrapped around the base of the trunk to protect against voles that may be attracted to living under the weed mats.

Plant sourcing

Most trees at TSF were planted as part of the initial restoration agriculture installation, using hybrid chestnuts and hybrid hazelnuts sourced as bare root trees from Forest Agriculture Enterprises (Viola, WI), the nursery of the consultant RAD who helped implement TSF. TSF sources the many other plants integrated into nut tree rows are sourced from a diversity of nurseries, primarily through online orders to U.S.-based providers of trees useful in agroforestry. TSF gives preference to providers of unique species and varieties that have been recommended for permaculture polycultures, while seeking nurseries with cultures compatible with TSF’s goals and values.

TSF’s own propagation is used to replace and expand plantings while potentially generating revenue from distribution of trees. More information about propagation as a source of nut trees is included in the Tree Nursery management section.

Planting

For larger-scale initial plantings, TSF used a tractor with a tree planter implement in tow. This tractor implement seated two people near the soil with pouches of bare root trees within arm's reach. As the tractor drove along rows 10 feet downhill and parallel from each berm, the tree planter implement would open a planting slot, into which the humans seated in the implement would firmly fit bare root chestnut trees one-by-one at a rate dictated by in-row spacing, with the implement's last piece being a set of tires to firmly close soil around the bare root trees. TSF farmers demonstrate this process in a video posted by TSF's at https://www.facebook.com/watch/?v=266210693967781. TSF farmers noted that planting efficiency vastly increased using the tractor and tree planter, with 3,000 chestnut trees having been added in a year, as compared with 100-300 trees being the reasonable per year limit TSF has identified for planting by hand.

For smaller-scale plantings, a moldboard plow is used to dig a trench and mound as described in the tree crops earthworks section, with bare root trees hand-planted into mounds. A similar approach could be done using a rototiller, auger, or hand digging.

Weed management and orchard floor maintenance

Weed management is handled on TSF primarily using mowing and occultation. Materials used include cardboard and crimped over grass, plastic mats around chestnut trees (Illustration 3), and silage tarps for broader occultation. TSF found that when using wood chips, it is important to first lay cardboard down, as that extends the mulch's functional life up to 2 years as compared with wood chips alone only lasting a few months into the growing season. TSF observes that black agricultural plastic mats with ground staples are controlling weeds and moisture well thus far, with minimal wear-and-tear of mats in the 2nd growing season.

Illustration 3. Tree protections for chestnuts: black plastic weed mat, hardware cloth rodent guard, tree tube and post (TSF 2019).

TSF mows using their orchard tractor and brush hog implement for alleyways and a smaller BCS mower or string trimmer for in-row areas between trees. By mowing within four feet of most tree rows, vole habitat is minimized around the trees and paths for tree inspection are maintained. While trees are not producing, TSF mows 1 to 3 times per year. During production, additional mowing is recommended in late summer before harvest and in late Fall after harvest. A clean orchard floor facilitates harvesting, minimizes waste, and reduces pest and disease pressure. Mowing in tree rows and on berms is a challenging and potentially unnecessary step, but given TSF's public-facing context as part of EVI, TSF finds those efforts for accessibility and aesthetic to be worthwhile. As trees mature, in-row areas will be shaded by canopy and will require less mowing, but cleaning the orchard floor in-rows will continue to be an important task throughout the orchard's operation.

Thinning

TSF planted trees at higher density when using a tractor, and in these cases TSF plans on thinning as necessary to optimize spacing as trees grow and to cull/harvest trees that are less desirable for nut production. It is recommended that thinning be done systematically in a similar fashion as in forestry, with the simple 'silviculture' (forest cutting prescription) as follows: estimate current stand density and growth stage, identify optimal stand density for future growth, then estimate the amount of tree removal that should be done to achieve optimal stand density. With the optimal extent of tree removal in mind, conduct orchard inspections with an eye for poor performing trees, and mark these for removal. For a more rigorous thinning strategy, record information on trees marked for removal and compare that field-based thinning plan with the estimated optimal thinning prescription, adjusting the thinning plan as needed (before making cuts) to better align with optimal stand density. With trees marked for removal, it is recommended that thinning/harvesting be done during winter to minimize disturbance to neighboring trees. Trees can be felled with chainsaw or hand saw, cutting the stump flat and close to the ground. Stump removal can be costly and is often not necessary, but it is recommended to monitor culled trees for problematic regrowth, as both chestnuts and hazelnuts coppice (continue growing new shoots from stumps). Those smaller coppice trees can be useful as fiber and fuel, but this comes with nutrient competition and potential physical interference with neighboring nut-producing trees.

For TSF specifically, most rows are planted with 5-to-10 foot spacing between trees, and the recommended mature density for Chinese Chestnut production is approximately 30 foot spacing in-rows between trees. On that basis it is recommended that one out of every 3-6 trees will need to be thinned out as the orchard matures. Thinning is recommended when neighboring crowns have grown near each other or as trees need to be culled due to disease. Regional nut orchard specialist Z’s Nutty Ridge estimates that chestnut orchards planted with 10 foot in-row spacing will need to be thinned to 20 foot in-row spacing after 10 years of growth and thinned to their mature 30-40 foot spacing after 25 years of growth (Zarnowski & Zarnowski 2020).

Pruning of tree roots and shoots

Root pruning is recommended as an annual early spring activity starting one or two years after trees are planted, once the trees have had time to establish root systems. This activity has been emphasized by RAD as an important step following alley tree plantings. The purpose of root pruning is to limit tree crop competition with alley crops and to encourage deep tree crop rooting. Root pruning is done using a subsoiler tractor implement to cut a trench that severs tree roots from the alleyway root zone, and the process is also known as ‘ripping’ or chisel plowing in conventional agriculture. Root pruning begins in early years to ensure roots do not become established in alleyways, as root pruning can be damaging to the tree or equipment if started too late in tree growth.

Shoot pruning, which is the conventional meaning for the term ‘pruning’, is as important as root pruning and is more ubiquitous in orchard management. Pruning is a nuanced topic covered in greater detail by many public sources. TSF is familiar with pruning and already conducts it.

Replanting

Associated with thinning and tree crop mortality, replanting is eventually necessary in the orchard. TSF’s plan is to hand-plant restocking trees that are sourced from their tree nursery or from high quality varieties from regional nurseries. Hand-planting of these trees is done at lower planting density than the original tree spacing. This is because during replanting, adjacent trees are usually closer to maturity, and planting too close to those more mature neighbors would limit the potential maturity of the replanted tree. For larger hand planting needs, TSF has organized volunteer crews successfully as an education and reforestation workday. Tree propagation and community support are important long-term features for TSF, as replanting highlights.

Harvesting

Harvest is reported to begin in year 5 or 6 for chestnuts (Route 9 Cooperative 2018) and year 3 to 5 for hazelnuts (Zarnowski & Zarnowski 2020). Chestnuts drop out of the husk or in-husk onto the orchard floor when they are ripe, and chestnuts can be rolled out of their husk with one’s boot, then picked up by hand, with a nut scooper, or with machinery. It is important to gather chestnuts within 48 hours, because leaving chestnuts on the ground for more than a few days will greatly increase probability of chestnut weevil infestation or other losses. Hazelnuts ripen on the bushes, and hazelnuts are ready to be gathered when the husks begin to tan or (more reliably) when nuts can be removed from the husk without strain by pushing sideways on them with one’s thumb. Ripe nuts can be left on bushes for their husks to dry, which makes further processing easier, but wildlife gather ripe nuts rapidly, prompting growers to gather ripe nuts as soon as possible even if their husks are still moist and green. It is recommended that ripe nuts are harvested as whole husked clusters to avoid soil borne pathogens from unclean orchard floors or from husks left on trees (Zarnowski & Zarnowski 2020).

Though TSF is designed to be suitable for mechanized harvest, TSF’s current plan is to hand gathering nuts, with the potential to use hand-operated machines such as orchard vacuum harvesters as productions scales up. More details about harvesting chestnuts and hazelnuts at various scales is available in Zarnowski & Zarnowski 2020, and Michigan State University (MSU) compares the cost of gathering chestnuts by hand versus with machinery (MSU 2020). TSF plans for hand gathering of nuts to be done by farmers on their own time or by CSA-members in a U-Pick setting. A few simple tools are recommended to make hand harvesting more ergonomic, efficient, and enjoyable: orchard baskets that distribute a load’s weight, harvest carts that can maneuver around the orchard well to increase gathering efficiency, and nut scoopers that relieves the need to bend one’s back during harvest (such as a Nut Wizard or a Bag-A-Nut tool).

Processing

Processing after harvest includes sanitizing, drying, culling, sizing, and storing nut yields. Processing can be done on the farm, or by nut depots and regional facilities as exemplified by Hammons Black Walnuts enterprise. At least some on-farm processing is needed after harvest, to optimize quality and make the most of these tree products. This section is a summary of processing steps identified for TSF to prepare for as yields come to fruition, and the technical sources referred to throughout this section – Zarnowski & Zarnowski (2020) extensively – are recommended for further review where more detail is desired. TSF is in the planning stages of a tree crop storage and processing facility but otherwise does not have processing specifications yet.

De-husking

Chestnuts are dehusked in the field by mechanical agitation, naturally with wind or by rolling in-husk nut clusters under one's boot using a moderate amount of force.

Hazelnuts require a more systematic approach to dehusking than chestnuts since the nuts are hand-harvested most efficiently as clusters in-husk. Hazelnuts can be husked by hand (nuts coming loose from their husk with gentle sideways pressure is an indicator the nuts are ripe), but for larger amounts of nuts, as in TSF's projected yields, it is economical to use machines to agitate hazelnut clusters and break apart their husks. These machines can be as simple as a primarily a bucket and bungee cords, or as sophisticated as industrial food processing equipment, and examples are both are available from the Upper Midwest Hazelnut Development Initiative (UMHDI) at https://www.midwesthazelnuts.org/processing-101.html Whatever type of machine is used in dehusking, the process is generally more efficient if husks are dryer, and for that reason many farmers will spread and dry freshly-harvested clusters before de-husking (Zarnowski & Zarnowski 2020). After nuts are removed from husks, the mix of broken husks and nuts must be sorted so husks are not including in further processing. Husks can be separated from in-shell nuts using an air aspirator machine, which has a similar range of potential sophistication as de-husking devices: homemade air aspirators can handle small batches and cost as little as a few hundred dollars, or industrial equipment can handle larger loads with costs of thousands or tens of thousands of dollars. To sort husks and nuts by hand, husk debris can be filtered out by agitating the mixture over a screen, making the process more efficient (Zarnowski & Zarnowski 2020).

Sanitizing

Nuts separated from their husks need to be sanitized to remove debris and prevent storage molds and other food safety hazards. Sanitizing involves soaking nuts in a sanitizing solution. Chlorine-based sanitizers are common but leave a residue if not dried properly. Oxygen-based sanitizers (such as peroxide) do not leave residue. Each sanitizer’s dilution rate and exposure time should be followed for safe and effective use.

Chestnuts benefit from an additional sanitizing step – hot water heat treatment – which TSF plans to conduct immediately after harvests. Heat treatment is used to sanitize nuts of chestnut weevils. Weevil sanitizing is recommended by soaking chestnuts at 120 degrees Fahrenheit for 20 minutes. This is an important step as the weevil grubs will otherwise rapidly damage nuts and significantly disgust consumers. Soil amendments can also be used to mitigate chestnut weevils, including the introduction of nematodes and/or fungus that preys on weevils. This information and more about chestnut pest mitigation are available in Zarnowski & Zarnowski (2020).

Culling

Culling nuts is the removal of undesirable nuts from a batch, such as those with insect damage, mold, cracks, husk remnants, or other defects that are out of character with the batch's quality (Zarnowski & Zarnowski 2020). Culling tends to be done after drying, during the packing stage for storing or sale. Culling is an eyes-on process and is therefore more efficient when integrated into the nut processing workflow where viewing and handling of de-husked nuts is required. This sorting and removal can be aided by inspection equipment for larger operations, but for most growers this is a human powered step. Quality standards for hazelnuts are available from USDA, designed for the larger hazelnut industry of Oregon and Washington (USDA 2016).

Drying

Drying is a high priority after harvest for hazelnuts and many tree nuts, but for chestnuts, while drying is an option, optimal freshness is achieved by maintaining humidity and low temperature. With hazelnuts, drying to 6% moisture is a standard for avoiding mold (Zarnowski & Zarnowski 2020). This can be done using wooden frames with metal screens or tarps to spread nuts out and fans to circulate air, serving as solar dryers (as in Illustration 4, Mayer 2019) which require rodent guards, height off the ground, and covering at night. Other strategies for nut drying are shown in Table 3 which lists pistachio drying methods and trade-offs, many of which are relevant for hazelnuts.

Illustration 4. Solar drying table used by acorn processor Marcie Mayer in Greece (Mayer 2019).

Table 3. Drying method pros and cons for Pistachios in Malaysia (Shakerardekani et al. 2010).

Drying method	Advantage	Disadvantage
Sun drying	Good final product quality High product uniformity Increase nut splitting	Negative climate condition Risk of contamination
Solar drying[a]	Good final product quality	Expensive solar radiation equipment
Bin drying[b]	Good final product quality	Low capacity High damage of product
Vertical continuous drying[c]	Less energy required for operation	Negative effect on nut splitting
Vertical cylindrical drying[c]		Low product uniformity
Funnel cylindrical drying[b]	Ability to control movement and holding time	Usage of higher temperature
Continuous mobile and steady tray dryer	Ability to use different drying temperature High product uniformity	Usage of high amount of fuel
Batch drum dryer	High product uniformity	Low capacity
Continuous belt conveyor dryer	Ability to use different drying temperature	Usage of high amount of fuel

[a] Middilli, 2001
[b] Kashaninejad, 2003
[c] Rostami & Mirdamadiha, 2004

Sizing

The greatest value for nut yields is achieved by selling them sorted by size. Size-sorted nuts enable larger classes to go for direct consumption, and consistently-sized nuts facilitate bulk nut cracking for added value processing. Hazelnut size classes are established by Table I of the U.S. Standards for Grades of Filberts in the Shell (USDA 2016). Batches of nuts can be sized by tumbling them through a perforated table or cylinder, with holes increasing in size as nuts travel through the system. Zarnowski & Zarnowski 2020 details specifications for homemade nut sizing devices.

Storing

Nuts store well in bags that allow air flow, such as in onion sacks. Fresh chestnuts are recommended to be stored in a humid refrigerator and have the best taste 1 to 3 weeks after falling from the tree (Route 9 Cooperative 2018). Hazelnuts need to be dried for storage (Zarnowski & Zarnowski 2020) and keep well in root cellar settings.

Adding value

TSF plans on vertical integration and collaboration to increase opportunities for adding value to nut crops. Processing beyond the minimal steps described above can increase convenience and appeal for potential consumers. For chestnuts this includes peeling and preserving them through freezing, canning, vacuum-packing, or dehydrating, resulting in a ready-to-eat snack or versatile ingredient. The New Zealand Chestnut Council (2000) lists a variety of processed chestnut products designed for supermarket shelves and everyday consumption: "…sugared confectionery, purees, ice-cream, baby foods, chips, yoghurts…flour for bread and biscuits, etc." Hazelnuts have a similar breadth of opportunities for added value. NYTCA, a newly formed and nearby nut growers' cooperative, purchased a small industrial-scale oil press which can produce hazelnut oil and residual cakes that can be further processed into flour (Walsh 2019). TSF is interested in collaborating with NYTCA, in addition to exploring other value adding processes that fit TSF’s strengths, interests, and infrastructure plans. TSF’s infrastructure plans include constructing a barn for drying, storing, and processing nuts, with the potential to house vertical integration utilities such as a freezer, a cooler, and a commercial kitchen.

Marketing and distribution

TSF is in the early phases of marketing and distribution planning and is soliciting input on the subject. Markets of interest are explored below.

NYTCA

An exciting market of interest is the New York Tree Crop Alliance (NYTCA) which began in 2019 (Walsh 2019), a year after TSF began. NYTCA aims “to produce high quality nuts and nut products, and to promote the cultivation and consumption of tree crops. We make our products available through retail and wholesale, domestic and international by combining the resources of multiple growers in NYS and the surrounding areas. We are primarily focused on the production of chestnuts, hazelnuts, and their products. Because of the significant costs of the equipment used to process nuts, one grower can only take things so far. Shared processing equipment and facilities allow us to get nuts into the hands of consumers.” In October 2019, NYTCA announced its successful crowdfunding and purchase of a Kernkraft oil press which can squeeze gourmet cooking oils from in-shell hazelnuts and hickory nuts that growers contribute to the co-op. NYTCA aims to offer additional value-added nut processing and sale opportunities, first to a 100-mile radius around Central New York and potentially in broader regions of New York and the Mid-Atlantic.

U-Pick orchard

TSF plans for a U-Pick orchard enterprise to be integrated into the whole farm, tapping into its multi-textured structure filled with a diversity of useful crops throughout alleys, tree rows, hedges, and pond edges. The U-Pick orchard concept is planned as a form of Community Supported Agriculture (CSA) that gives supporting patrons access to the farm's variety and abundance, with TSF planning to have set days for members to pick nuts and fruits and forage TSF's broad pallet of plants. Because this kind of agro-ecosystem is 'knowledge-intensive' rather than 'capital-intensive' in nature, TSF plans to provide education and signage to help patrons engage and enjoy this environment, reducing cost for consumer and producer. The U-Pick orchard is intended to offer an experience, fitness, education, and ecologically mutualistic food, goods, and other co-benefits. In the bigger picture, TSF's aim for the U-Pick orchard is a form of biocultural restoration, (re)connecting patrons with foods and plants that have a longer history with humanity than small grains. The U-Pick orchard is also enhanced through TSF's connections and collaborations with the EVI community. For example, there is potential for a neighboring berry farm to collaborate with TSF to add TSF's tree fruits & nuts to that farm's existing U-Pick CSA's 'menu'.

Management of the U-Pick orchard is largely covered by specific enterprises, and wild ecology and succession on site. Tasks most specific to the U-Pick orchard are:

a. Maintain public access
    i. Mow alleys for walkability
    ii. Maintain signage for orientation

As the U-Pick orchard opens to membership, specific guidelines and prices for patrons will need to be shared in marketing material, and member management will grow as an additional activity for TSF.

Direct-to-consumer

Relevant farmers’ market opportunities and local food hubs (aggregation and distribution points) can connect the surrounding community with TSF’s offerings. TSF farmers are not interested in working at farmers’ markets themselves, but this is an area where TSF is interested in hiring an employee who has sales skills and a desire to work farmers’ markets. Food hubs require less direct marketing and are of greater interest before production has scaled up sufficiently to support staff for farmers’ markets.

Local food hubs of interest include:

- Headwater Food Hub (https://www.headwaterfoodhub.com/)
- Pressbay Alley Food Hub (local direct-to-consumer COVID19 relief effort)

Fence maintenance

Fence maintenance is a year-round activity (Zarnowski & Zarnowski 2020). Higher quality fence materials and installation will result in less wear-and-tear and failure of the fence over time. Following this reasoning and TSF’s philosophy of greater initial input (as in ecosystem disturbance events) followed by lower-input management, TSF has taken care in the quality of individual tree protections setup to begin with. TSF’s routine tree inspections include checking that tree tubes and cages are in-tact and well-staked, that the area protected is clear for tree growth, and that weed mats and vole guards (where used) are in-tact and are not too wet or dry underneath.

Crop maintenance: pest and disease control

Scouting, pruning, and other steps to understand and mitigate pests and diseases are critical to maintain a healthy orchard and yields. This is a substantial and evolving topic and only TSF's specific activities are included here. Local cooperative extension agencies are a reasonable starting point for further support in identifying and mitigating pests and diseases. Zarnowski & Zarnowski (2020) also list and describe common pests and diseases of hazelnuts and chestnuts.

For hazelnuts, little has been implemented by TSF specifically for pest and disease control thus far, aside from sourcing hazelnuts as European x American hybrids to mitigate Eastern Filbert Blight which plagues the otherwise-better-yielding European hazelnut varieties. Most hazelnuts at TSF are managed minimally to identify the most resilient specimen, and some IPM strategies – including TSF's overall diversity and cultivation of food chains that support the predators of pests – are used. It is recommended that pheromone traps are used outside of the orchard for Japanese beetles (a significant hazelnut pest) which are present at TSF.

For chestnuts, weevils are a significant pest which are addressed in the tree crop sanitizing section. Animal pests are also a challenge for orchard establishment, and mitigating these pressures is covered in the fencing and tree protection section. Chestnut blight is the most significant disease facing chestnuts. To mitigate the blight, trees used have been bred for disease resistance, and scouting and culling are the primary techniques TSF plans to use to mitigate chestnut blight.

Irrigation

Water tends to be the most limiting nutrient for plant growth and crop yields, and accordingly, irrigation is a major focus of TSF's design and water management is a large portion of initial farm setup cost (as discussed in the tree crop activities section on earthworks). These two water features are related, as earthworks included the creation of a pond which feeds TSF's irrigation needs.

To assess irrigation capacity, a simple water budget model was developed by TSF accounting for estimates of pond capacity (volume as a function of average depth and pond area), evaporation, normal irrigation water use, and maximum irrigation water use. That model's premises and findings are described below and shown in Figure 4. In Figure 4, a scenario is assessed where the pond starts 0.5 feet below max depth (thus starting with an estimated 325,851 gallons available) and receives no inflow or precipitation, while losing to evaporation 2 inches per week and withdrawing the maximum observed irrigation rate of 495 gallons (two 275-galon IBC totes) per day. With these conservative inputs that err on the side of underestimating available water, this model predicts that TSF's pond can provide for the farm's current water needs for a four-month period with no precipitation.

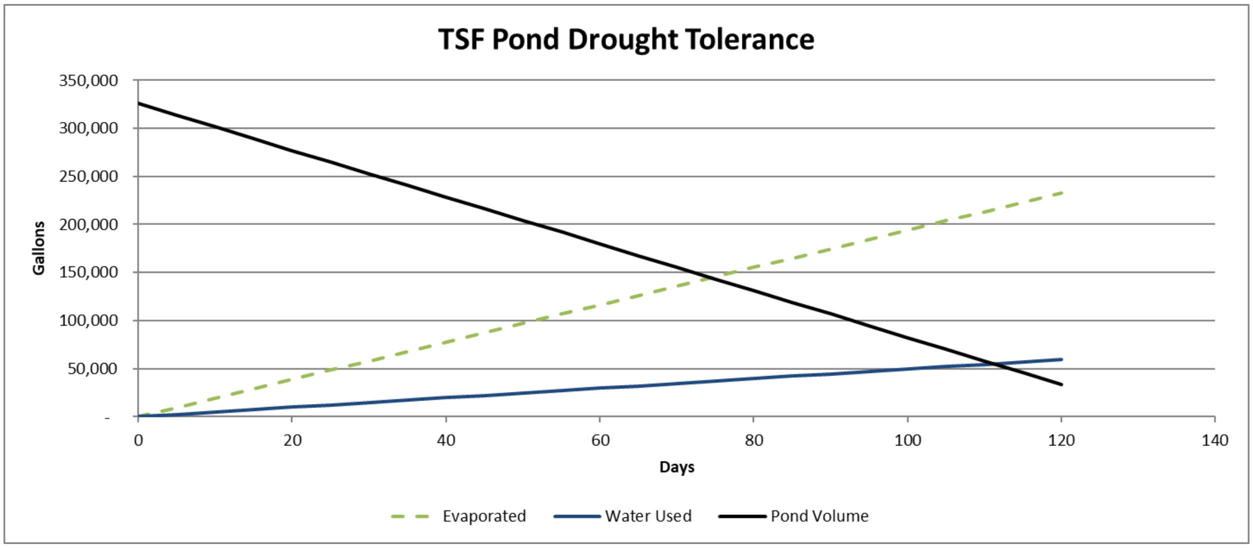

Figure 4. Graph of pond water budget for TSF's conservative scenario of water availability.

Pond capacity was estimated at 366,582 U.S. liquid gallons based on TSF's estimated average pond depth of 4.5 feet and a GIS-based pond area estimate of 0.25 acres which this plan introduces (Figure 2). Multiplying that area and depth and then converting the volume of acre-feet to gallons (using a factor of 325,851 U.S. gallons per acre-foot) results in the pond capacity estimate.

Evaporation is a difficult but significant rate to estimate for small farm water budgets. In TSF's pond water budget, evaporation was estimated as 2 inches per week based on TSF farmer Bradford Smith's literature review and preference for a conservative estimate. For this plan the evaporation value was checked against National Weather Service (1982) records, which shows that for Aurora Research Farm (the nearest station to TSF that has 10 years or more of records) the mean pan evaporation for May through October is 31.21 inches as observed between May 1957 and May 1978. That converts to a 5.2 inch per month mean pan evaporation rate, which, divided by 30, results in an approximate 0.17 inch per day or 1.2 inch per week mean evaporation rate over the growing season. TSF's estimate of 2 inches per week is used in the model to ensure a conservative estimate, erring on the side of finding more water available than predicted by this water budget.

The maximum and normal irrigation rates are based on TSF's historic experience. TSF observes their irrigation rate based on how many times the intermediate IBC totes are filled and depleted during irrigation in a given period. The maximum rate observed was 2 totes per day with slightly-less than complete turnover of water in totes during that period (which was during chestnut and hazelnut seedling establishment in 2018), resulting in an estimated 1.8 totes per day or 12.6 totes per week maximum irrigation rate. The normal irrigation rate over the 2018-2020 growing seasons observed by TSF is 2.5 totes per week, of which TSF notes a substantial portion (1 to 2 totes per week) is used by the tree nursery. While new plantings create demand for irrigation, established trees are more resilient to dry conditions and require less irrigation, resulting in TSF's estimate that this normal rate will be consistent with a consistent tree establishment rate and will decrease when planting rate is reduced.

To aid in understanding the normal and maximum irrigation rates and as a demonstration for others, TSF farmer Bradford Smith provided the description below about the system's layout, use, and history:

> *"A 1.5 HP sprinkler pump feeds a series of two 275 gallon IBC totes through a 1" polypipe [Illustration 5]. These totes are situated at the top of field to provide as much pressure for the gravity feed; one tote is on a short (2' high) platform. Water from the totes flows out through a 3/4" polypipe header to supply either low-pressure driptape lines, or directly into a stock tank with float valve shutoff. Simple full-flow PVC ball valves allow us to select which headers are active and individual drip tape lines have valves where they join the header.*
>
> *The summer of 2018 was very dry in Ithaca [NRCC 2020] and we had over 2500 new seedlings planted. We ran over 8,000 linear feet of drip tape, setup in*

lines as long as 800'. The longer lines are further down the hill providing them with better pressure, allowing us to run the entire 8 acres from two totes and keep everything watered. We had no appreciable losses due to water stress in the areas with drip tape.

The 2019 season had good rainfall and required no supplemental watering. 2020 is much drier in general and we are again setting up headers and drip tape. Basic good practices are recommended when laying out the irrigation: pipes in areas that will be mowed or driven across should be buried. Buried lines should be marked either above ground or with a surveyor flag laid flat and buried along with the pipe, to be found later with a metal detector. Drip tape complicates weed management, so planning in advance is helpful. We did not build out the irrigation system along with planting and ended up scrambling to get it in place. We are continually learning as we go and now we include irrigation planning as an essential part of new plantings."

Illustration 5. One of two 275-gallon IBC totes filled by pond and feeding drip tape for irrigation.

Soil amendments

Soil amendments should be made using soil health assessment and leaf analysis results to inform limiting nutrient needs. An important concept in applying amendments is considering Liebig's Law of the Minimum: growth is governed by the most limited resource (which tends to be water), not by the total resources available. For this reason and for ecosystem service protection and economic efficiency, amendments should be used sparingly and based on scientific analysis and best practices such as the 'Four Rs of Fertilizer Management (Hochmuth 2014): Right Source of nutrient, applied with the Right Timing, using the Right Rate of application, in the Right Placement, for optimal uptake and minimal loss and negative externalities.

Relevant analysis of farm nutrients to guide amendments include soil health testing to understand what deficiencies are present in soil conditions and can be addressed with management, and leaf analysis to assess micronutrients and overall plant uptake of soil fertility. Neither of these analyses have been conducted yet at TSF, and it is recommended that both are: soil health analysis will be conducted as part of TSF's citizen science efforts with Cornell University's Soil Health Lab or Dairy One recommended for their testing services, and leaf analysis can be conducted using Dairy One's plant tissue analysis for tree fruit. With leaf analysis, boron and zinc are important nutrients for nut development, and Zarnowski & Zarnowski (2020) identify Olsen (2013) as a publicly available source of leaf analysis results to aim for with management. (A common challenge in applying leaf analysis results is interpreting results and comparing to a reasonable standard for the crop, cultivar, and soil conditions of interest.) Rules of thumb for orchard fertilization include no fertilization before trees' second year of growth (as earlier fertilization can increase mortality) and no fertilization after July 4 (which can delay tree dormancy leading to frost damage) (Zarnowski & Zarnowski 2020).

Alleyway Field Crops

This section explores management options for TSF's tree crop alleyways based on local agronomic research and TSF's goals and current conditions. In 2020, most of TSF's alleys follow the 'minimally-mowed meadow' management scenario noted below.

Alleys between rows of nut trees offer farming opportunities with faster-paced crop rotations and cash flows than most tree crops, complementing and facilitating diverse orchard production. Selecting field crops for production or environmental benefit goals should include consideration of soil type, precipitation regime, hardiness zone, field ecosystem features, available equipment, supplies, and markets. In the context of agroforestry, the field's ecosystem features are more complex and of even greater focus for field crop suitability, given the agro-ecological approach to farm management. Succession planning is of central importance, adjusting tree crop and field crop management for both to grow compatibly and even complementarily with one another. As trees are young, alleyways can support full-sun crops, including commonly grown field crops. As canopy begins shading alleys, alleyway field crops can transition toward partial-sun agro-ecosystems including pasture, forages, and meadow. As codominant-canopy tree crops mature, alleys become mostly or fully shaded depending on alley width, and these later and longer stages of succession are suitable for shade-tolerant crops such as forage, asparagus, elderberries, pasture, and potentially for forest crops such as mushrooms, ramps, and ginseng.

Spectrum of management

The spectrum of management intensity can potentially vary between alleys, supporting diverse enterprises all existing in an agroforest setting that is more resilient against droughts, floods, pests, and diseases overall compared with non-forested agro-ecosystems. The sub-sections below highlight a range of management options, from doing nothing on one end to intensive annual field crop production on the other. Options are listed in ascending order of management intensity.

‘Do-nothing’ scenario

Completely inactive alleyway management is incompatible with a healthy and productive nut orchard, but considering this scenario is an exercise to identify why and what management intervention is necessary. A lack of mowing or meadow maintenance would have downsides of increased vole habitat, limited access for potential U-Pick customers, difficulty harvesting and inspecting trees and in-turn an orchard prone to pests and diseases. There are other problems that could emerge with no management of the meadows, such as it returning to later successional stages with Japanese honeysuckle thus suppressing biodiversity and further succession or losing community support due to aesthetic impacts on the adjacent neighborhoods’ viewsheds.

Minimally-mowed meadow

This scenario reflects TSF’s current mowing strategy, as described in the tree crops weed management section. To prevent woody succession in alleys – thus maintaining those areas as arable (suitable for tillage and annual crop cultivation) – mowing is needed once every other year or every year depending on mower capability.

Basic cover crops

This scenario builds on the previous scenario and adds broadcasting cover crop mixtures intended for ecosystem service goals of building organic matter, reducing pest and disease pressure in the orchard, and reducing weed pressure in alleyways. This kind of cover crop broadcast was completed by TSF after the initial removal Japanese honeysuckle in 2017 (at which point winter rye was spread) and after initial earthworks in 2018 (at which point a mix of oats, clover varieties, and grasses was spread). TSF prefers cover crop mixtures to have provisional potential, which in this low-intervention scenario would be as forage for livestock or as wild-simulated human forage of foods and medicines. Mix examples include hairy vetch, pennycress, and red clover; or oat and pea. By mixing two or three cover crops, functional niches are better filled in the agro-ecosystem the cover is spread in, thus getting more functionality out of the cover crops and increasing the chance of establishing desirable ground cover.

When selecting cover crops, consider functional goals for a mix. The following list is an expansion of suggestions on Cornell University's CoverCrop.org web tool, which offers examples of cover crop goals and other technical assistance in selecting and implementing cover crops. This list highlights TSF's cover crop priorities in bold and in descending order of interest.

1. **Actively adding organic matter to soil**

2. **Suppressing weeds:** This will be a perennial issue in alleys as nearby meadow, Japanese honeysuckle, and fallow alleys contribute weedy plants to the seed bank.
3. **Suppressing soil diseases and pests**: While this is less critical given the diversity on site, additional IPM is desirable to help minimize any need for biocides.
4. Breaking hardpan: While earthworks can cause compaction, farmers found that earthworks and field preparation at TSF did not result in noticeable compaction in most areas. Building active organic matter is a higher priority, along with minimizing the need for tillage which can result in hardpan and other long-term negative soil health effects.
5. Biologically fixing nitrogen
6. Scavenging soil nitrogen
7. Protecting soil from rain or runoff
8. Improving soil aggregate stability
9. Reducing surface crusting

Yield-oriented cover crops

Building on the previous scenario and including a higher portion of leguminous or small grain cover crops with potential as human food or hay for animals, to be harvested on small scales or terminated more efficiently with a tractor as needed. See Cornell University's CoverCrop.org or Appendix 1 for an index of cover crop features & suitability. From these options, TSF can select crops with fodder or forage potential.

TSF shared their positive experience with GreenCoverSeeds.com for mixes and guidance which they may return to as a source for cover crop seeds in the future.

Minimal-till horticultural crops

Using minimal tillage to grow crops that have high value, high stress tolerance, and high storability compared with most horticultural crops. For example, an alley could be brought into this level of management as a collaborative enterprise with entry-level farmers (Shepard 2013). The steps to begin this level of management include mowing; reducing weed pressure through solarization, occultation, or advanced use of weed suppressing cover crops; field preparation using secondary tillage (e.g. a disk harrow) or direct planting. Crops with potential in this setting include winter squashes like butternut and acorn, garlic, peppers, or perennials such as asparagus, elderberry, hazelnuts, currants, or honeyberries. This management approach, along with silvopasture, fills most alleys of New Forest Farm, the applied example of *Restoration Agriculture* (Shepard 2013).

Row crop production

Row crop production is a less appealing option for TSF but given the importance of row crops as a staple food source, this is an area TSF wants to investigate alongside tree crops. Example row crops include corn, soybeans, canola, and sugar beets, with a key distinction of row crops being the broad-scale drilling of seeds into ground rather than broadcasting seeds as done with some small grains and with many cover crops. TSF is unlikely to cultivate row crops in their own alleys because of the costly equipment required and the small alleyway acreage currently available (approximately 2.5 acres as the cumulative area of the first five alleys, see Figure 3), along with trade-offs presented by row crop production versus ecosystem service enhancement goals, diversity versus management efficiency, and row crops' need for tillage or herbicides to mitigate weeds. Row crops in alleyways are more suitable for larger scale operations and/or farms already operating with row crops and the necessary equipment. Growing row crops within alleys presents significant benefits compared with monocropping of the same plants, given the tree-based diversity in an alleycropping system. The Savanna Institute provides support and resources for the cultivation of field crops in agroforest systems.

To implement row crop production in TSF's restoration agriculture system, alleys would be largely treated as any field cropping area would be, except for a few important differences: alley widths and tractor tool widths must be compatible, alleycropping system needs sufficient spacing for tractor turnaround between rows, and tree crops require root pruning to prevent tree and field crop interference. For row crops, primary tillage is recommended to prepare for the first year of production and tillage can be minimized with secondary tillage after that, transitioning toward a no-till relay cropping system using cover crops to mitigate weeds and protect soil health. Profit margins are notoriously tight for many row crops, which emphasizes the need for a specific business plan and appropriate scale of production with row crops.

Crop selection should be based on field suitability (which initial soil health results will be useful for), on local farmers' successes, and on available markets. Near TSF, Oechsner Farms is an exemplary organic grain producer and they list notable crop varieties at https://www.oechsnerfarms.com/crops-1. Notable markets include emerging markets for high quality barley used in malting and the Farmer Ground Flour cooperative which buys and sells local organic small grains.

Specific tools for row crops depend on what crops are grown, how they will be stored, and what markets they are intended for. In TSF's case, to grow grains common in our area such as rye, soy, corn, or barley, the following equipment would likely be needed in addition to existing tractor implements. TSF's tractor may also need to be upgraded (to at least 100hp) to handle management activities needed for row crops.

- Cultivator (for primary tillage, if not using plow)
- Disk harrow (for secondary tillage)
- Grain drill, corn planter, and/or cultipacker (for direct sowing)
- Combine (harvest, thresh, winnow)
- Baler (for hay or straw)
- Grain storage (and possibly drying) bins

Tree Nursery

As noted in the agricultural approaches section of this plan, TSF has developed a perennial nursery to propagate species for the farm (new plantings & replacement stock) and to offer for sale. That includes breeding efforts to form and propagate improved trees from a pawpaw grove; growing out additional varieties of chestnut trees and testing their suitability throughout the site; and improving heartnuts and black walnuts. The nursery grew organically out of having a tree crop farm which presents the need and opportunity for propagation.

For this tree nursery to operate, TSF recognizes the following activities as essential: fencing (e.g. Illustration 6), nursery materials sourcing and preparation, nursery stock sourcing, propagation activities (germinating and rooting, seedling up-planting, field planting, grafting), and marketing and sales.

Illustration 6. Nursery perimeter fence in background with rabbit fence for bed in foreground.

TSF plans for tree nursery products to be marketed and sold through word-of-mouth and online ordering, arranging for direct pickup. Mail-order sales are a recognized opportunity to scale-up nursery sales, but this increased scale is not necessarily desirable given the increased labor and logistics to ship bare root plants. There is high demand for nut trees, fruit trees, and conservation perennials in the area.

This tree nursery emerged out of an organic need for it at TSF. Since its origin, the nursery is increasingly recognized by TSF as a core farm component and potentially one of the most profitable parts of this agroforestry enterprise. This plan's first iteration does not elaborate on nursery business management however, as the initial scope is focused on the alleycropping system which is less well documented in literature.

Forestry

There are no timber stands in TSF to be managed for forestry yet. TSF is establishing diverse hedges and a coppice of hazelnut, willow, and other species using the tree nursery for stock. These woody polycultures will offer multiple functions including mother trees for further propagation, a low-input source of provisions including food and fiber, wildlife habitat, viewshed enhancement, and biocultural restoration. Fiber, food, and biodiversity are major products of interest in TSF's hedge and coppice efforts. In *Restoration Agriculture*, Shepard (2013) emphasizes the value of biomass and would-be 'waste wood', which is often a cost (rather than a source of value) and a negative externality for large-scale monoculture orchards: "Coppice wood and prunings represent a significant yield in a restoration agriculture system." Shepard goes on to describe various uses of biomass from a similar alleycropping system as TSF's: "One of the benefits of gasifying hazelnut shells, coppice underwood, and prunings is the production of biochar that can be used as a soil amendment." Focusing on simpler uses, Shepard shares his main ones for this fiber: home heating fuel and growing mushrooms (wherein even forest fiber can become forest food). TSF looks forward to collaborating with members of the Hedgelaying in the Ontario Landscape team, who in 2019 presented at a Cornell Cooperative Extension (CCE) event in Ithaca and led a workshop at local Wellspring Forest Farm. See https://www.ontarioruralskillsnetwork.com/hedgelaying-inthe-ontario-landscape for more information on the upcoming "North American Hedgerow Society" which TSF intends to participate in and potentially host hedgelaying conferences for.

Silvopasture

Silvopasture is an agroforestry technique with great potential to utilize tree crops and reduce the need for human intervention in agro-ecosystems (Gabriel 2018). TSF is focusing first on tree crop establishment and will explore small-scale silvopasture (e.g. with chickens, rabbits, or sheep) in more depth once more established. Bees have begun to be integrated into TSF in collaboration with a local farmer mentoring one of the TSF farmers on beekeeping. The social context of TSF is important in the case of silvopasture, as EVI community members may have mixed and strong feelings about the inclusion of livestock on a neighboring farm, but certain animals are more culturally acceptable in the landscape including bees and chickens.

To aid in considering silvopasture, the Association For Temperate Agroforestry offers a useful introduction at https://www.aftaweb.org/about/what-is-agroforestry/silvopasture.html, and the following list is a recommended starting point for TSF's silvopasture enterprises.

Outline for converting meadow to silvopasture:

1. Mow to return to an early stage of succession with less herbaceous pressure
2. Plant tree rows using tractor-drawn DNR-type tree planter
3. Broadcast to establish grass and forb mix if pasture composition is poor
4. Install fencing: This can be the same fencing used to close tree crop areas off from deer as when a perimeter fence is implemented. Portable electric fencing is helpful for more temporary paddocks, setup at appropriate wire heights (e.g. low

for pigs, high for cows), quantities (i.e. paddock numbers and sizes), and charges for the livestock to be grazed. Expect fences to have a buffer of 5 to 6 feet on either side not well grazed.

5. Livestock sourcing
6. Rotation design (for technical guidance on this topic, visit resources below)
   a. https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1167344.pd
   b. https://smallfarms.cornell.edu/2010/07/how-to-get-started-with-sheep/
7. Herd and flock support
   a. Irrigation
   b. Supplemental feed
   c. Hygiene, medicine
8. Harvesting, butchering, transportation
9. Marketing and sales

Education and outreach

Research

TSF is interested in conducting longitudinal studies as citizen science in support of agroforestry-related science, recognizing that there are few long-term study sites for alleycropping in the northeast U.S. This document includes experimental design to set the stage for citizen science research that TSF intends to conduct as part of its education and outreach efforts. The study description and activities are documented in the Citizen Science section. In addition to longitudinal study efforts, TSF experiments with different best practices for agroforestry to improve the state-of-the-art through documentation in text (including this plan), images, videos, and public engagement. This includes their investigation of lower-level questions such as “What establishment techniques are preferable for chestnut orchards, how did the establishment methods go that were used on this site?” and higher-level questions such as “How does soil moisture fluctuate in, above, and below the swale-berm-tree rows that line alleyways, as compared to one or more control sites?” An inspiration and example for TSF’s applied agroforestry research and development is the Balkan Ecology Project (balkep.org).

Events hosting

To share the unique physical setting of TSF and cultivate connections with the broader food systems community, TSF is interested in hosting a variety of potential events (when physical-distancing does not constrain this possibility). Ideas include:

- Collaboration with Thrive EcoVillage Education Center for public outreach events
- EVI community members in volunteer days and workshops,
- Tree crop galas
- Hedgelaying conferences in collaboration with Jim Jones and others from the Hedgelaying in the Ontario Landscape team (see this plan’s Forestry section for more information).

Public engagement

To cultivate patronage and public interest in agroforestry, while networking with the broader community of practice, public engagement is part of TSF's ongoing efforts. Broadly accessible forms of public engagement which TSF plans to practice include:

1. Activity on social media, posting photos, videos, and Q&A responses
2. Setup website if online direct sales are desired
3. Post notices (events, findings, products, promotions) on social media and to local listservs such as SALT-CNY, the Northeast Permaculture Listserv, and the Finger Lakes Permaculture network

Business and legal activities

Legal requirements to operate this enterprise commercially have fees, in addition to the labor it takes to investigate and complete required steps and setup necessary systems to do business. To incorporate an LLC in NY, an application must be submitted with a $200 one-time fee (which can be filed online at https://appext20.dos.ny.gov/ecorp_public/f?p=201:17). An LLC can receive an Employer Identification Number (EIN) from the IRS for free, which can serve as a replacement for a person's Social Security Number when registering for enterprise licensing or other needs (online EIN application is available at https://www.irs.gov/businesses/small-businesses-self-employed/apply-for-an-employer-identification-number-ein-online). Tree nursery licensing requires a $100 fee for a two-year registration period (Nursery Grower Application, NY form PI-69, available at https://agriculture.ny.gov/plant-industry/licensing-and-plant-inspections). A website for doing business can cost as low as $100 per year but requires skilled labor to setup and maintain.

Each year, farm taxes must be filed using a Schedule F tax form (https://www.irs.gov/pub/irs-pdf/f1040sf.pdf). To be eligible for financial support and agricultural tax exemptions, it is recommended to begin filing the Schedule F tax form early in farm operation, even if it will take years before the business is fully operational (as with nut orchards taking 5 or more years to reach full production and cash flow). It is also recommended to have a dedicated bookkeeper (either as the role of a farm manager, or as a part-time specialized role) who can interface with the business's legal requirements and with an accountant familiar with agriculture as needed.

FINANCES

Financial statements and projections

This section does not include actual finances for TSF because financial data for TSF or RAD are not available in the public-domain. In lieu of that, recent and relevant financial decision support tools are highlighted which can be used as guides and templates for cash flow projections and business planning. These resources are provided by experts on the cutting-edge of chestnut and hazelnut agronomy and supply chain advancement.

- University of Missouri Center for Agroforestry's Chestnut Decision Support Tool, available from http://www.centerforagroforestry.org/profit/

- UMHDI’s Hazelnut Enterprise Budget Tool, available from https://www.midwesthazelnuts.org/publications.html
- Zarnowski & Zarnowski (2020)’s Tables 7-1 and 7-2, estimating costs of establishment for both hazelnut and chestnut orchards, specific to conditions in New York.

Business structure and strategy

TSF is incorporated as an LLC and is funded primarily by its founders, who both have off-farm income and are operating as part-time farmers. Collaboration with neighboring organizations at EVI is an important part of TSF’s business strategy, including working with West Haven Farm, Kestrel Farm, Thrive EcoVillage Education Center, and nearby volunteer groups.

Nut crop processing, aggregation, and distribution is also an area TSF hopes to work collaboratively on, both on-farm in their own efforts to support other farmers and with regional efforts such as the New York Tree Crop Alliance (NYTCA) nut grower cooperative. In the Midwest where chestnut production in the U.S. is centered, the Route 9 Cooperative of chestnut growers notes that “To economically justify cleaning, sizing, and sorting equipment, as well as cold storage and marketing, it is necessary to have at least 50 acres in production, preferably more. Combining production from several or more growers in the form of a marketing cooperative is a viable way to achieve the necessary economies of scale.” (Route 9 Cooperative 2018) Given TSF’s less-than 50 acre scale, it is recommended and intended by TSF to collaborate with regional nut processing and distribution enterprises.

Succession planning

Enterprises on TSF and farms in general have key roles to fulfil which can transfer over generations of farmers (Sylvanaqua Farms 2020): field hands and field operations management, business operations management to handle financial and legal needs, value added management to optimize the benefit of crops to farmers and patrons, and marketing and sales management to engage patrons and deliver goods. This plan is intended to facilitate the transfer of responsibilities between people and the recruitment of agroforest enterprise operators, during the potentially centuries-long life of this restoration agriculture farm. This is accomplished through documentation of these key components of TSF – field management, business management, processing management, and marketing management – throughout this plan's various sections.

Support programs

Conservation easements and programs can support farm succession and viability, but there are few conservation easements tailored for agroforest farms (Shepard, personal communication, August 4, 2019). This plan and the technical resources found in its references can serve as documentation in support of conservation easements for agroforestry. Avenues of support sought by farms in Central New York include tax exemptions for agricultural or forestry production (e.g. Agricultural Assessments to reduce property tax, https://www.tax.ny.gov/research/property/assess/valuation/agindex.htm; or 480-a Forest Tax Law to shift property tax to timber harvest tax with potential savings, https://www.dec.ny.gov/lands/5236.html), and grants related to research and development in sustainable agriculture (e.g. Northeast SARE Farmer Grant Program, https://www.northeastsare.org/Grants/Get-a-Grant). Agencies providing financial support for farms include FSA for loans and NRCS EQIP conservation programs, for which there are plain language guides to applying provided by SARE at https://www.sare.org/Learning-Center/SARE-Project-Products/Northeast-SARE-Project-Products/Plain-Language-Guides-for-New-and-Under-Served-Producers/Financing-the-Farm-Applying-for-an-FSA-Loan.

CITIZEN SCIENCE

TSF seeks to study the effects of restoration agriculture on TSF's soil carbon and ecohydrology, and to achieve this, a longitudinal field study will be conducting using a citizen science approach guided by this Cornell University capstone project. This section documents procedures to be carried out each Fall by TSF to conduct the longitudinal study. There are few temperate study sites where alleycropping and other agroforestry applications are investigated rigorously over the long-term, and TSF aims to include experimentation and field research as part of their education efforts.

Soil organic matter (SOM) is the primary interest of TSF farmers, understanding the many regulating ecosystem services it provides. SOM and the related soil component of soil carbon are valuable both globally and directly to long-term farm success. This study is primarily intended to estimate how management activities in TSF's restoration agriculture system affect soil carbon, and to a lesser extent how soil carbon correlates with better crop outcomes. An initial research question is: To what extent does TSF’s water management, tree cropping, and cover cropping systems increase soil active carbon in cropping alleyways over time? It is theorized that soil active carbon in areas managed for tree crops in restoration agriculture settings will improve from a soil health indexing perspective, compared with unmanaged adjacent areas serving as controls, because of the increased surrounding tree cover, water management (slowing and spreading), and prioritization of plant diversity and minimal soil disturbance over time. TSF intends to introduce and collaborate with others on additional research questions over time as this long-term field study and related sciences progress, and for that reason, a broader set of parameters than only active carbon is recommended for longitudinal observation to inform a variety of science questions that may emerge.

To address TSF’s long-term study interests, it is recommended that the following farm properties be observed annually (at least beginning the series with that frequency):

- **For carbon**: Consistently analyze and record results for active carbon, total carbon, wet aggregate stability, and soil temperature and moisture (averaged over sub-sample sites within ‘treatment’ and ‘control’ sample areas of interest).
- **For hydrology**: Qualitatively-rank indicator plants such as sunflower (that are very responsive to soil moisture based on their turgidity) to assess water availability differences, establishing annual or perennial plantings in management areas of interest and comparable areas.
- **For modeling** (in case carbon credit systems trend toward the use of computer modeling approaches): Maintain (actual or estimated) record of carbon inputs (compost, cover crops, crop residues), carbon outputs (firewood, crop yields,

residues or straw removed), and biomass stocks and growth (trees per acre, diameter, % loss).

The recommended priority for long-term study by TSF is beginning the data series for active carbon and other soil carbon variables of interest noted above. During this plan's creation, COVID19 disrupted soil analysis opportunities during the Spring 2019 period that was most suitable for soil sampling (around May after ground has thawed, before it dries significantly over Summer). Adapting to this, during Summer 2020 TSF decided to begin the long-term study data series in Fall 2020, because Cornell University's Soil Health Lab reopened to process samples mid-Summer and because Fall is one of the desirable times for farmers to assess soil health. Fall soil health assessment provides a snapshot of end-of-season growing conditions and gives farmers the Winter to consider and prepare soil amendments for Spring plantings.

The following procedure for soil sampling and analysis serve as guidance to begin the soil carbon longitudinal study data series:

Soil sampling procedure

Soil samples can be sent to Cornell University's Soil Health Lab for their Comprehensive Assessment of Soil Health (CASH). For each area sampled, soil can simply be analyzed in CASH's Basic Package ($70/sample). A slightly cheaper analysis option, which limits its scope to the variables recommended for longitudinal study of management's effects on soil carbon and overall soil health, is to use CASH's Ala Carte analysis of Active Carbon ($20/sample) and Total Carbon and Total Nitrogen ($20/sample) to assess soil carbon and additionally Wet Aggregate Stability ($20) as a broad biological indicator of soil health that is sensitive to management. (For more information on analyses available, please visit: https://soilhealth.cals.cornell.edu/testing-services/.) With each sample, soil temperature and moisture may also be useful to measure, because these parameters enable a broader set of science questions to be investigated using this longitudinal study data series.

Cornell University's Soil Sampling Protocol (Moebius-Clune et al. 2016) details tools and procedures for preparing samples to be sent to the Soil Health Lab for analysis. These are reiterated here for TSF's needs. Soil Samples will require three cups of soil to process in CASH's Basic Package, and that sample should be composed of five to ten sub-samples obtained throughout the sample's area of interest (with seven sub-samples recommended for TSF's samples, since the samples represent areas larger than home gardens but smaller than most row crop fields). After selecting areas to sample, gather tools and plot out a zig-zag course through the sample area to take seven representative bulk soil sub-samples at least fifteen feet apart from each other. For each sample the following materials are needed: one clean 5 gallon bucket, one sturdy 1-gallon re-closable zip-lock freezer storage bag, a submission form and ability to write on it, a marker for labeling the sample bag; a cooler to store samples in, and a straight shovel (such as a nursery or trenching spade). Sampling should be done when soils are at field capacity, meaning when excess water has drained and downward movement of water has slowed but there is not excessive drying. Irregular, non-representative areas such as an unusually low spot should be avoided to help ensure results best represent the sample area overall. For each sub-sample: remove surface debris; dig a hole 8" deep and two or three spade-widths across; cut a vertical, rectangular slice of soil from the pit's wall, removing excess soil to have get an even 6" long by 2" thick sample, being careful to capture an even amount of soil from each depth so to avoid over-representing conditions from a certain depth in the overall sample results; add the sub-sample's soil to the bucket, mixing it in thoroughly with other bulk soil samples from the sample area; and fill in the sampling hole. After completing all sub-samples, bag at least 4 cups of mixed soil from the bucket and label the bag with the sample area, date, and farm name. Keep samples cool and out of direct sunlight, shipping as soon as possible according to the latest lab guidelines.

For TSF's long-term study, the main areas of interest to sample are the managed alleyway and an unmanaged control. The alleyway is of greater interest than the tree rows or earthworks itself, as the alleyways are where arable (tillable, plantable) land is maintained in this restoration agriculture system. To test the theory that restoration agriculture management overall will improve growing conditions in these alleyway areas, sampling alleys serves as the independent variable for future scientific studies. Optionally, tree rows and their rooting areas could serve as alternative sample sites representing another independent variable (tree crops themselves) to investigate. This would shed light on how soil carbon changes within the long-term component of this restoration agriculture system, but its results would be less pertinent for field crop production and less novel considering forest effects on soil carbon are better studied.

In addition to one or two areas sampled in the managed system (for example, a sample representing alley 3 and a sample representing another alley with unique management), one or two areas will be sampled as controls: the lower field which is east of TSF's existing earthworks and has similar characteristics as the managed area but receives its runoff and has had less Japanese honeysuckle present, and a Japanese honeysuckle thicket near Song neighborhood in EVI which has very similar characteristics as TSF prior to its transition to restoration agriculture.

For information about less rigorous soil assessment that does not require laboratory analysis, see the approaches noted in the site description, soils section. This includes soil texture assessment by touch (Thien 1979) and soil biota assessment by sampling for aggregate stability or the abundance of indicator species.

CONCLUSION

This AMP documents TSF's current and planned practices, along with novel recommendations for TSF specifically, and it is intended to serve the broader tree crop farming, supply chain, extension, and enthusiast community of practitioners. Many of the subjects touched on in this AMP have entire texts dedicated to covering them in-depth, and references from this plan are threads that readers can follow for more detail as needed. While those resources detail each complex topic, this plan synthesizes those topics into a user manual for a specific, applied example. Documenting the breadth of techniques and their applications on agroforestry-centered farms is a niche in the literature identified as lacking. More public-domain documentation of specific examples can complement the growing wealth of technical resources on these various subjects, including silvopasture, multi-story plantings, relay cropping, alleycropping, soil carbon cultivation and benefits, earthworks for passive water management, tree crop processing and economics, tree crop varieties and their specific pests and diseases, and more. Our agriculture landscapes and our culinary lifestyles can transform toward ecological mutualism as more applied examples come into operation and as people engage these potentially resilient supply chains for staple foods. With that aim in mind, this plan closes with thanks to all past practitioners, from first peoples to recent agroforestry innovators, and with thanks and encouragement to readers. Please contact TSF <threestoryfarm@gmail.com> and/or the plan's original author <rcc277@cornell.edu> for more information, proposals to collaborate, questions, comments, or suggestions.

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APPENDIX 1. COVER CROPS INDEX

By Robert Coville for *Soil and Crop Management* (PSLCS 3210)

Master of Professional Studies in Agronomy, Cornell University

School of Integrative Plant Science, Soil and Crop Sciences section

1. Fagopyrum esculentum

a. Common name: **Buckwheat**

b. Plant family: Fagopyrum

c. Life cycle: Annual, warm short season crop June July planting

d. Timing of planting: Spring or Fall

e. Winter hardy in NYS: not winter hardy, hardiness zones 3-7

f. Root description: Deep tap root with shallower branching roots

g. Benefits: Green manure, erosion control, crop, pollinators

Kills easily, can mow buckwheat and plant another (cover) crop following it

2. Raphanus sativus

a. Common name: **Radish**

b. Plant family: Brassicaceae

c. Life cycle: Winter Annual

d. Timing of planting: Fall (before Sept 1) terminating in winter ready for spring

e. Winter hardy in NYS: Yes, hardy zones 2-10

f. Root description: Deep roots

g. Benefits: Reduced compaction, biofumigant, nutrient cycling deep N

3. Avena sativa

Good compliment to cereal rye (springtime cover)

a. Common name: Oats

b. Plant family: Poaceae

c. Life cycle: Annual

d. Timing of planting: Fall

e. Winter hardy in NYS: No

f. Root description: Deep fibrous roots

g. Benefits: Scavenge N, good forage

4. Lolium multiflorum

a. Common name: **Italian rye grass**

b. Plant family: Poaceae

c. Life cycle: Annual

d. Timing of planting: Mainly Spring, between March and May, or August

e. Winter hardy in NYS: Yes (can become weedy)

f. Root description: Highly branched fibrous root system

g. Benefits: Erosion prevention, scavenge nutrients & root building aggregates, mows well, fodder

5. Secale cereal

Major cereal grass, can be planted later than many winter annuals

a. Common name: **Cereal Rye**

b. Plant family: Poaceae

c. Life cycle: Annual

d. Timing of planting: Late summer, early Fall

e. Winter hardy in NYS: Yes

f. Root description: Deep roots

g. Benefits: Suppress weeds, scavenge N, prevent erosion

6. Trifolium pratense

a. Common name: **Red clover**

b. Plant family: Fabaceae, Legume

c. Life cycle: Short-lived perennial, biennial, winter annual

d. Timing of planting: Depends where, early Spring common or frost seeding

e. Winter hardy in NYS: Yes

f. Root description: Thick roots but not very extensive

g. Benefits: Versatile and low cost

7. Trifolium repens

a. Common name: **White clover**

b. Plant family: Legume

c. Life cycle: Short-lived perennial through hardiness zone 4

d. Timing of planting: Late Spring

e. Winter hardy in NYS: Yes

f. Root description: Shallow, not drought tolerant

g. Benefits: N fixing, out-competing weeds, green manure

8. Trifolium incarnatum

a. Common name: **Crimson Clover**

b. Plant family: Fabaceae

c. Life cycle: Annual, upright spreading, faster than Red Clover

d. Timing of planting: Spring or especially Fall (before Sept 1)

e. Winter hardy in NYS: Yes (partially, for zones 6-9)

f. Root description: Deep, nitrogen fixing

g. Benefits: Nutrient cycling, nitrogen fixing, weed suppressant

9. Medicago sativa

a. Common name: **Alfalfa**

b. Plant family: Fabaceae, Legume

c. Life cycle: Short-lived perennial

d. Timing of planting: Late summer, early Spring

e. Winter hardy in NYS: Yes

f. Root description: Deep to reach groundwater, prefers well-drained

g. Benefits: Erosion control, N cycling, forage, green manure

10. Melilotus officinalis

a. Common name: **Yellow Sweet Clover**

b. Plant family: Legume

c. Life cycle: Biennial or short-lived perennial

d. Timing of planting: Planted Fall or Winter, germinates in Spring

e. Winter hardy in NYS: Yes

f. Root description: Large tap root or small group of tap roots

g. Benefits: Grows in hot dry conditions, forage & OM, breaks compaction

11. Vicia villosa

a. Common name: **Hairy vetch**

b. Plant family: Legume

c. Life cycle: Winter annual, can become weedy if before wheat

d. Timing of planting: Fall July - Sept 1, or early Spring

e. Winter hardy in NYS: Yes zones 3-4

f. Root description: Fibrous

g. Benefits: Great N fixing, increasing macropores & reduces erosion

12. Sorghum sudanense

a. Common name: **Sorghum sudangrass**

b. Plant family: Poaceae

c. Life cycle: Annual, summer grass

d. Timing of planting: Warm Late Spring or Summer

e. Winter hardy in NYS: Yes

f. Root description: Deep, fibrous, orange!

g. Benefits: Smothers weeds, lots of OM for cost

13. Sinapsis alba

a. Common name: **Yellow mustard**

b. Plant family: Brassica

c. Life cycle: Annual

d. Timing of planting: Spring, or winter cover crop

e. Winter hardy in NYS: Yes

f. Root description: Fibrous fine roots, building aggregates

g. Benefits: Break compaction, biofumigant

14. Crotalaria juncea

a. Common name: **Sunn Hemp**

b. Plant family: Fabaceae

c. Life cycle: Summer annual

d. Timing of planting: Late May or June, even later like mid-July

e. Winter hardy in NYS: No

f. Root description: Taproot, big nodules

g. Benefits: N fixation

15. Vigna unguiculata

a. Common name: **Cow pea**

b. Plant family: Legume

c. Life cycle: Adapted to moist hot zones

d. Timing of planting: Late Spring or Summer, warm soil

e. Winter hardy in NYS: No

f. Root description: Taproot with nodules for N fixing

g. Benefits: Withstands drought & low-quality soil, smothers weeds, forage

APPENDIX 2. A REVIEW OF CARBON, WATER, AND CULTURAL BENEFITS FROM TEMPERATE AGROFORESTRY IN CENTRAL NEW YORK, USA

By Robert Coville for *Ecology of Agricultural Systems* (PLHRT 4730)

Master of Professional Studies in Agronomy, Cornell University

School of Integrative Plant Science, Soil and Crop Sciences section

Introduction

Trees integrated into agricultural landscapes support mitigation of, and adaptation to, worsening climate change and environmental degradation. This mitigation and adaptation occurs on two fronts: global nutrient cycles overall (i.e. the carbon cycle) and in local agricultural landscapes specifically. While carbon is central to life on Earth, its increased atmospheric concentration is a key factor in anthropogenic climate change. Simple and intensively managed agricultural landscapes have a high amount of embodied carbon emissions in their inputs, while also leaking carbon out of the terrestrial system and suffering the negative effects associated with depleting carbon reservoirs (Drinkwater et al. 2017). Reforestation contributes to restoration of the carbon cycle (Cunningham 2015), tightening carbon flows geographically and enhancing carbon reservoirs over time. Carbon sequestration is an increasingly pertinent issue in New York, USA, as the state is advancing a carbon farming act through its senate (S8256 2018) to address this global issue and New York's relatively high contributions to it (Ritchie et al. 2017). Agroforestry as a tool for carbon sequestration has the added benefit of providing that ecosystem service while continuing agricultural production

(Schoeneberger 2008) and providing a range of other benefits to Central New York and beyond, including: air temperature moderation (Rahman & Ennos 2016) which supports health of crops (Hatfield & Prueger 2015) and humans (Sheridan & Allen 2015), stormwater mitigation (Coville et al. 2020)., and cultural benefits.

This review will assess scientific literature to identify empirical effects of specific agroforestry techniques on select ecosystem services that are pertinent for Central New York, USA: carbon storage and sequestration, hydrologic regulating ecosystem services, and cultural ecosystem services. Agroforestry techniques that this review focuses on are those most-closely mimicking the natural history of Central New York and serving as "multifunctional woody polycultures" (MWPs), which have a much greater capacity for biodiversity and ecological functions than their monocultural counterparts (Cunningham 2015). Specific MWPs considered include forest farming, silvopasture, riparian buffers, windbreaks, alleycropping, and forest gardening, which are described as practices for the Northeast by Roberts (2017). The complexity of these integrated systems makes the "MWP" umbrella-term (demonstrated in Figure 2.1c) useful in discussing the environmental effects of these collective practices.

FIGURE 1 (a) The existing land management paradigm in most temperate regions: a landscape dominated by annual row crops and distinctly separated from the small patches of remaining natural areas. (b) Mature, traditional alley cropping (AC) in France, with hardwood tree rows and an alley crop of small grains. (c) AC augmented with tree crops and woody polyculture, using both nut trees and grape vines within tree rows

Figure 2.1 Spectrum of agricultural landscape complexity (Wolz et al. 2018)

Looking at unmanaged ecosystems in temperate climates such as Central New York, nature tends toward perennial grasses and woody perennials (Olson et al. 2000) which have soil carbon-building benefits (Nave et al. 2013). Agroforestry polycultures can tap into the momentum of that natural tendency, known as ecological succession: to reforest, to restore and enhance carbon reservoirs of meadows and forests, and to benefit from healthier nutrient cycles (Wolz et al. 2018). Findings from relevant articles, derived from the methods described below, are considered together to inform this review of the state-of-the-art science about agroforestry's carbon, water, and cultural benefits to the region.

Methods

To work with the latest information about my overarching interest in temperate climate tree crops, I began a literature review by searching the following keywords on Google Scholar: *agroforestry agroecology temperate climate tree crops hazelnuts chestnuts*. Of the first 150 search results, I opened all articles relevant to agroecological functions and interactions in temperate climate tree cropping systems. I sorted those by relevance and scope based on keywords and abstracts, then took a more careful read of select articles to develop a bibliography that covered key topics, extents, and contexts. That is, articles which examine ecosystem services in temperate agroforestry systems and articles which examine biophysical processes in the context of agroforestry agronomy. Iterating through this process with improved keywords and narrower review scope helped me isolate the present research question around an area of interest to me and with enough research published.

Improved iterations of literature review proceeded to inform this review’s outline on carbon, water, and cultural benefits of temperate MWPs. Major searches were conducted using the following queries: *(reforestation or agroforestry) carbon mitigation*; *forest soils and carbon sequestration* also including *temperate agroforestry*; *decomposition carbon cycle temperate agroforestry*; *“temperate agroforestry” deforestation new lands agriculture*; *"carbon sequestration" forest succession agroforestry* (and same search with “temperate agroforestry” in place of agroforestry); *temperate "forest succession" "carbon sequestration"*; *drought mitigation "temperate agroforestry"*; *"temperate agroforestry" buffer eutrophication*; *crop flood stress "temperate agroforestry"*; *cultural ecosystem services "temperate agroforestry"*; *"temperate agroforestry" placemaking*; *agroforestry placemaking.* To parse results from these queries, articles were sorted by relevance, and the number of citations was used as a measure for the information’s utility to the scientific community focusing on the article’s topic. For specific topics, an individual Google Scholar search was conducted, and the top relevance articles were assessed, e.g. for forest bathing. In some cases, relevant articles were known in advance and cited as part of the basis and motive for this more in-depth review, as in the referenced works by Lovell (e.g. Wolz et al. 2018) and Coville (e.g. Coville et al. 2020).

Review

The structure of an ecosystem affects its ecological functions, which can provide benefits to humanity and be valuable for that reason and other reasons to be discussed. These benefits we experience with our environment are referred to as ecosystem services. Ecosystem services are categorized by the Millennium Ecosystem Assessment (2005) synthesis in four broad categories: *regulating, supporting, provisioning, and cultural* ecosystem services. Each category represents a broad set of benefits that humans experience from the natural functions of ecosystem components. *Regulating ecosystem services* represent the moderation of ecosystem conditions and nutrient cycling, which enable life to exist on Earth (including climate moderation). *Supporting ecosystem services* are the basis of other environmental functions (as in primary production). *Provisioning services* are the most apparent to humanity, as these are the yields nature provides satisfying our basic needs (as in food, fiber for shelter, fuel for heat energy, and more). *Cultural services* are those social, cultural, and spiritual benefits that humanity derives from our relationship with ecosystems and nature as a whole. Trees provide benefits in each of these categories. As described in the introduction, this review will focus on how MWPs affect select ecosystem services of high importance to Central New York: carbon storage and sequestration (regulating services), hydrologic regulating ecosystem services, and cultural ecosystem services.

Carbon: Storage and Sequestration

Regulating ecosystem services moderate the conditions of ecosystems so to enable their continuation. One of the major regulating ecosystem services is of the carbon cycle. Closely related to regulation of the carbon cycle is regulating climate cycles, an especially important issue at this time as anthropogenic factors disrupt climate stability (Millennium Ecosystem Assessment 2005). Carbon dioxide concentrations in the atmosphere have increased over 30% since the Industrial

Revolution, caused primarily by fossil fuel use and land cover change (Millennium Ecosystem Assessment 2005). Forest land cover has historically been a carbon sink, but due to land-use change, previously-forested lands have become sources of carbon emissions and/or degraded carbon sinks. Reforestation, afforestation, and profestation (Moomaw et al. 2019) have the potential to reduce and reverse those emissions as well as restore the storage and sequestration capacity (Nowak & Crane 2002) that once-forested lands once offered (Foote & Grogan 2010). These benefits come directly and indirectly: direct benefits come in the form of plant biomass, and indirect benefits include the reduced use of nonrenewable fuel sources and the use and preservation of renewable fibers. Forests are also involved in the carbon cycle in other ways, including building soil and by supporting trophic chains and thus nutrient and carbon cycling overall (Smith et al. 2012). Carbon cycle functions of temperate forests are examined in this section, with a specific focus on how MWP practices affect carbon storage and sequestration.

Carbon storage by trees is of global significance, with all atmospheric carbon cycling through terrestrial systems in approximately 7-year cycles and 70% of that cycling occurring through forest systems (Waring and Schlesinger 1985). Much of the capacity of forests to store carbon has been degraded, with over 1 billion hectares of forests degraded in the tropics alone and with 1 billion tons of carbon released to the atmosphere each year due to deforestation on a global scale (Schroeder 1994). This deforestation is largely due to unsustainable logging and land-use change toward agriculture (field crops and pasture) or urbanization. Agroforestry is a land use that, especially with diversity in space (polycultures) and time (shifting in succession and rotations), can potentially: serve as a sustainable (even "permanent" as in "permaculture") agricultural system (Smith 1929); reforest lands (as in "Restoration Agriculture" (Shepard 2013)); stave off the need for further deforestation (as in "productive conservation", e.g. by building soil fertility) (Smith et al. 2012; Angelsen & Kaimowitz 2004; Schroeder 1994); and increase carbon stored in currently degraded lands (as with forest restoration and carbon sequestration) (Schroeder 1994). While some cases of agroforestry can contribute to deforestation due to maligned incentive schemes promoting monocultures of woody cash crops, as described by Angelsen & Kaimowitz (2004), focusing on MWPs with spatial and temporal diversity ensures agroforestry approaches will effectively reduce deforestation and increase carbon storage and other forest benefits. Angelsen & Kaimowitz (2004) focus on a tropical context but examine phenomenon that apply in Central New York as well, where ecosystem service conservation approaches tend to be in competition with land productivity. In that context, it is important to note that Angelsen & Kaimowitz (2004) find MWP approaches to agroforestry can provide ecological benefits alongside sufficient productivity so to prevent the need for conversion to more ecologically-degrading land-use alternatives (e.g. input-intensive monocropping of annuals with low diversity). Forestry offers well-established examples of 'productive conservation' in the Northeast, as in New York City's water supply benefiting from water-sensitive 'working forests' to maintain both the viability and benefits of forested land cover (Watershed Agricultural Council 2015). There are similar examples of productive conservation taking place with temperate agroforestry overall (Smith et al. 2012) and more specifically in Central New York with MWPs including forest farms (Mudge & Gabriel 2014), silvopastures (Gabriel

2018; Chedzoy and Smallidge 2011; Orefice and Carroll 2016), and extensive forest gardens (Silver 2019). These MWPs provide diverse forms of implementation and productivity to meet land manager needs while maintaining ecologically beneficial landscapes that offer carbon storage and sequestration in addition to other ecosystem services.

Carbon storage serves as a nutrient pool for terrestrial carbon, and carbon sequestration serves as the flux to reduce atmospheric carbon by drawing it into terrestrial pools. This flux in carbon from the atmosphere to lithosphere and rhizosphere is catalyzed by the woody, fungal, and other living communities involved in forest succession (Waring and Schlesinger 1985; Clemmensen et al. 2014). Wood product utilization, as in fiber for construction, can also sequester carbon (Johnston & Radeloff 2019). While the similarity between agroforests' and natural forests' carbon sequestration functions requires additional study and clarification (Ramachandran Nair et al. 2009), studies have found that temperate agroforestry can restore many ecosystem services that industrialized agriculture lacks while mitigating negative impacts of agriculture (Smith et al. 2012). The agroforestry techniques grouped under the umbrella of MWPs – including riparian buffers, silvopasture, forest farming, and forest gardening – incorporate both spatial and temporal diversity, mimicking ecological succession and local natural history (Lefroy 2009). Accordingly, these MWPs have the potential to restore diversity and functional niches in degraded agricultural systems over time, enhancing carbon sequestration as these systems progress from early successional stages to later, more diverse successional stages (Foote and Grogan 2010). Agroforestry provides these conservation benefits while serving as a 'working forests' that generate carbon-sequestering fiber products and other goods and services. In this way, MWPs can be a source of productive conservation for Central New York and beyond, restoring regulating ecosystem services for the carbon cycle while providing other pertinent ecosystem services.

Water: Flood, Erosion, Eutrophication, and Drought Moderation

Water resource storages, flows, and quality are affected primarily by land cover. Even precipitation itself can be affected by changes in land cover and specifically tree cover, as is the case in tropical deforestation and desertification causing reduced rainfall (Millennium Ecosystem Assessment 2005). Trees tend to have a moderating effect on hydrology by: facilitating drainage and buffering flows to reduce flooding and associated erosion and eutrophication (Smith et al. 2012); and enabling greater water access and retention to increase water availability during droughts (Schoeneberger et al. 2012). Alongside these water quantity moderating benefits, forests are a key solution to nutrient load buffering (Jose et al. 2012) and thus mitigating eutrophication. These water resource issues – flooding, erosion, eutrophication, and drought – are all of high importance for New York State (Negro & Porter 2009). This section explores the role of forests and MWPs in mitigating and adapting to each of these issues.

Stormwater runoff and flooding are worsened significantly by urbanization and the increase in 'directly connected impervious area' associated with it (Schueler 1994). Urban stormwater issues are pertinent for Central New York and much of the wet temperate and urban world, where flooding can be costly and prevalent (CNT 2014). Stormwater runoff and water quality are mostly sensitive to changes in impervious cover and to a lesser extent to changes in tree cover (Coville et al. 2020). While urbanization contributes to deforestation to varying extents (Clement et al. 2015), trees and impervious cover are not mutually exclusive as is demonstrated by urban forestry and other MWP forms of productive conservation. The dynamic of trees integrating into urban land-uses highlights how trees can be multifunctional while guiding other landscape elements: in addition to stormwater and other co-benefits (Kuehler et al. 2016), the integration of trees into urban areas is a platform for the disconnection of otherwise-continuous impervious surfaces (Lefrançois 2015). Decreasing that impervious connectivity is a critical improvement as stormwater extremes are primarily sensitive to the connectivity of impervious cover (Coville et al. 2020), and trees can facilitate that improvement while offering co-benefits. As urban trees can mitigate stormwater problems (CWP 2017), MWPs can enhance this benefit by stacking functions of conservation with productivity. Forest gardening is a MWP approach which exemplifies this, being well suited for urban environments and nature-based stormwater solutions. While the practice of forest gardening is scarcely studied scientifically, there are some living examples with early assessments done on their stormwater mitigation benefits: In Syracuse, New York, the Rahma Edible Forest Snack Garden was assessed for its hydrologic and other environmental benefits provided by trees. This assessment was conducted as a citizen science effort led by the non-profit Alchemical Nursery which manages that garden. The 1/3rd-acre forest garden's land cover at its 10th year of growth was compared with two scenarios using the USDA Forest Service public-domain scientific model i-Tree Hydro. The first scenario removed all tree and shrub cover, and the second scenario did the same and expanded an existing parking lot, mimicking a land-use alternative that had been considered prior to the forest garden's emergence. Preliminary model results found the first (no-tree) scenario led to a 2% increase in total surface runoff from the site, while the second (parking expansion) scenario resulted in a 45% increase in total surface runoff from the site (Alchemical Nursery 2019). This first-order assessment highlights the importance of MWPs *productive* aspect in conjunction with its *conservation* aspect: if not for this forest garden's productive roles desirable to the landowner, the area might instead be a parking lot with a worsening effect on flooding.

Flooding poses threats in both rural and urban areas, as high rates and amounts of rainfall can stress crops, lead to erosion, and worsen Non-Point Source (NPS) pollution which contributes to eutrophication and Harmful Algal Blooms (HABs). While trees are not a panacea for the problems of heavy rainfall and high flows, they are a critical part of a comprehensive water resource management strategy (CWP 2017; Cotrone 2015), and trees can help mitigate flood impacts on crop stress, erosion, and NPS pollution (Jose 2009). The effects of trees on crop stress due to flooding is not well documented, but some research does indicate tree effects on soil increase crop resilience to both flood and drought water stresses (Rivest et al. 2013). Evidence also shows that forests reduce flooding downstream (Kays 1980). MWPs – such as urban trees in forest gardens – can have the features of rural forests which mitigate flooding: rainfall interception; improving soil infiltration; and reducing saturation through evapotranspiration (CWP 2017). In addition to direct tree hydrology benefits, MWPs tend to be integrative systems which include distinct water management practices beyond only growing trees. Alleycropping in temperate agroforestry systems often include the development of swale-and-berm systems at large- (Shepard 2019) and small-scales (Edible Acres 2019) or mimicking natural pit-and-mound forest topography in tree crop systems (Silver 2019; Dacha Project 2019). These are complex landscape alterations which can mitigate negative impacts from excess water in crop production (Altieri et al. 2015). These practices are in place on farms around Ithaca, New York: large-scale swale-and-berm systems at Three Story Farm in Ithaca, NY; and medium- and small-scale swale-and-berm and pit-and-mound systems at Twisted Tree Farm in Spencer, NY, and at Edible Acres in Trumansburg, NY; along with many other examples not listed here. Though scientific literature has not documented these practices well, these examples documented by practitioners in their educational outreach show the integrative role of alleycropping with complex water management systems that offer hydrology-moderating benefits.

Heavy rainfall associated with flooding is also a driving factor of erosion and NPS pollution. Erosion is a significant problem for agriculture around the world, including throughout the rolling hills of the Northeast USA where urbanization increases and rainfall regimes become flashier (Barron 2000). Tree-based mitigation of flood impacts as described above also serve as erosion mitigation strategies, especially by reducing raindrop impacts and stabilizing soil (CWP 2017). Trees are used as an erosion control method throughout the world, reducing both hydrology-driven erosion and wind-driven erosion (Jose et al. 2012). MWPs with greater canopy cover – such as forest farming, riparian buffers, and other practices that maintain nearly- or fully-closed canopy cover – can reduce the extent of erosion while being an economically productive, viable agricultural land use (Wilson & Lovell 2016; Shepard 2013). Examples of this in Central

New York include the integration of trees on livestock grazing operations at Wellspring Forest Farm (Gabriel 2018) and at Angus Glen Farm in Watkins Glen, NY. At both sites MWPs (silvopasture, riparian buffers, windbreaks, and more) provide both economic and water resource conservation benefits.

Water quality is a complex condition made up of biological, chemical, and physical characteristics that depend on many drivers. A specific water quality issue pertinent for the Northeast USA is nutrient loading from NPS pollution which contributes to eutrophication and HABs. The effective use of forest buffers to mitigate nutrient loading, especially from agricultural runoff, is well documented (e.g. Udawatta et al. 2010; Udawatta et al. 2011). These buffers can be MWPs – whether multifunctional and diverse riparian buffers, or other diverse woody cropping systems integrated in agroecosystems – that offer economic benefits in addition to effective water quality conservation. Trees improve soil health and nutrient cycling which reduces nutrient loading in runoff by the reduced need for agricultural nutrient inputs and by the improved ability of the agroecosystem to uptake and buffer nutrient loads (Wilson & Lovell 2016). These beneficial soil and nutrient cycle effects of trees are of critical value to Central New York and downstream waters, as they offer an economically productive land use that mitigates common causes of costly HABs from similar (agricultural) land uses, while providing co-benefits and a resilient agriculture.

Drought is an opposite but related extreme to the flooding issues discussed above. Where urbanization increases flooding by reducing an area's capacity for infiltration and percolation, it also exacerbates the severity of droughts since what water was in the landscape will drain faster due to increased channelization and imperviousness in the watershed (CNT 2014). Outside of urban areas, in agricultural and rural landscapes, drought can have severe effects on critical water supplies even in water-rich regions as Central New York (Wilson 2016). Integrating MWPs into agroecosystems can mitigate drought stress in complementary ways to how trees moderate flooding stress. Deeper roots and evapotranspiration from trees facilitate access to water for the rest of the rhizosphere and lithosphere, while those same roots improve soil biogeophysical capacity for water infiltration and retention (Verchot et al. 2007) and resilience to moisture extremes for both the trees themselves and adjacent crops (Rivest et al. 2013). Beyond mitigating of deleterious effects of drought, MWPs offer agricultural resilience in the diversity they add to agroecosystems: spatial diversity in horizontal and vertical forms throughout farms with integrated trees; temporal diversity of yields over different time-scales and times of year; and species diversity from intercropping various woody perennials together alongside other crops as done in alleycropping, forest farming, and other MWP systems. This resilience can help sustain food systems and livelihoods undergoing drought and flood stresses (Verchot et al. 2007).

Culture: Basic and Higher Needs for Individuals, Communities, and the World

Cultural ecosystem services tend to be the most difficult to define and quantify (Fagerholm et al. 2016). This class of services are no less important though and require greater attention. The uptake of temperate agroforestry practices depends on a combination of its ecological, economic, and socio-cultural viability, as found in a study of modern and traditional tree-based intercropping uptake in Europe by Herzog (1998). Even where cultural services are known to have benefit, these benefits may not be consciously recognized by the public (Fagerholm et al. 2016). Cultural ecosystem services range from individual spiritual value derived from trees, to landscape aesthetics and a sense of cultural identity and heritage (Millennium Ecosystem Assessment 2005). In this review, two interrelated tiers of cultural ecosystem services are briefly discussed in the context of MWPs in Central New York: individual wellbeing; and community wellbeing. As described below, community wellbeing also pertains to the broader global context within which Central New York communities interact through global trade and multinational food systems.

Individual relationships with trees and forests vary widely, yet studies thus far indicate a universal benefit for humans practicing ‘forest bathing’ to reduce stress and thus improve overall health (Hansen et al. 2017). The individual benefits we derive from forests can be primarily biophysical, as in the effects of beneficial Volatile Organic Compounds (VOCs) that boost human immune functions during forest bathing trips (Li 2010). Benefits we experience as individuals can also tie into our community identity, as with the favorable aesthetics and sense of heritage associated with hedgerows and other traditional forms of agroforestry in Europe (Herzog 1998).

Where individual and community benefits intersect is in one’s connection to place, that is, the quality of public spaces and the landscape overall to promote wellbeing and a sense of self identification with place. Placemaking is a substantial topic in the field of planning but is largely beyond the scope of this review. The importance of placemaking as a cultural ecosystem service provided by MWPs is in the wellbeing and sense of community it can facilitate (Ciftcioglu 2017). MWPs – being knowledge-intensive, holistic, multi-faceted, and long-term agroecosystems – are suggested to contribute to placemaking in Europe (Herzog 1998). In Central New York, the ecological and economic scale of agricultural MWPs fosters a community of local food producers and consumers, highlighted in an annual celebration of tree crops called the Nut Bonanza hosted by Twisted Tree Farm in Spencer, NY, occasionally in collaboration with Cornell Cooperative Extension. As MWPs in this region tend to be of smaller-scale and catering toward local and regional agricultural markets, there is a greater connection between producer and consumer than there is in larger farms targeting national and global commodity markets.

The localized scale of MWPs in Central New York does not mean these agroecosystems lack the capacity to produce staple commodities. A benefit of MWPs which extends beyond one region and into the global context is the potential to shift away from reliance on ecologically-degrading multinational food systems for basic needs, instead relying more on regional tree-based 'productive conservation' for staple goods (Shepard 2013). Historically, trees have provided many of society's basic needs (Smith 1929), and practitioners implementing MWPs recognize this capacity through the 'Seven F's of Forestry' yields: fiber, fuel, food, fodder, fertilizer, "farmaceuticals", and fun (Toensmeier & Jacke 2005). As we turn tangibly toward connection to place for basic needs, we also reduce our exportation of negative externalities that come with the importation of our subsistence from other parts of the world (Marsden 2012). Fossil fuels offer the starkest example of this, where heating can come from local sources with negative externalities that have a limited geographic range and reduced magnitude, as compared with the range and magnitude of negative externalities involved in the supply chain for fossil fuel use in the Northeast. While the extent of high-efficiency residential wood heating and municipal biofuel use to replace fossil fuels is still limited, this potential does exist (Volk et al. 2016). MWPs facilitate that tangible potential while providing the more subtle benefits of placemaking and individual wellness, which all contribute to a culture of greater ecological mutualism globally.

Conclusion

Tree-based cropping systems featuring diversity and appropriate scale can serve important roles in mitigation and adaptation to environmental issues related to carbon, water, and culture in Central New York. The functions and benefits of MWPs are becoming better documented in scientific literature over time, but many aspects have limited research coverage at this point. That limitation is especially true for qualitative benefits such as cultural services and for complex systemic aspects like the relationship between local small-scale sourcing and multinational industrial-scale sourcing of staple goods. The latter area of research has broader agroecological implications at many scales. As ecological and economic challenges lead regional and global systems to change, this aspect of temperate agroforestry may increase in importance for research and application. As an example of what that complex research could explore: how would regional sourcing of staple carbohydrates predominantly from low-input chestnut cultivation change regional and global ecological footprints, as compared to the same region sourcing carbohydrates from industrial annual monocultures in multinational food systems?

With the current scientific understanding of MWP benefits, along with reasonable inferences about less-documented co-benefits of MWPs and practitioner reports, there is encouraging potential for MWPs to provide critical ecosystem services for Central New York. It is also encouraging that research in this area is advancing (as in the Savanna Institute's 2019 publishing of *Overcoming Bottlenecks in the Midwest Hazelnut Industry* which has analogous implications for Central New York) and scaling up (as in University of Missouri's Center for Agroforestry 2019 opening of the Land of the Osages Research Center in collaboration with indigenous Osage Nation for long-term demonstration and research of MWPs). This review has been a helpful means for me to familiarize myself with, and summarize broadly, the latest scientific research and documentation on MWPs and their carbon, hydrology, and cultural benefits in Central New York. That familiarization and summary can serve as a useful resource moving forward with agroecological research and applications in the future.

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