



Forever Green Initiative

Developing New Crops for

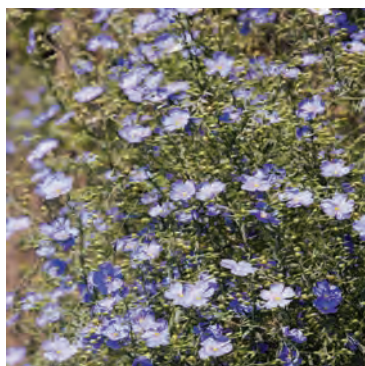
- High efficiency agricultural systems
- Improved soil and water quality
- New economic opportunities for farmers, industry, and rural Minnesotans

The challenge is clear:

For the state of Minnesota, to meet proposed water quality goals, we must incorporate winter annual and perennial crops into agricultural landscapes. The Forever Green Initiative at the University of Minnesota is positioned to realize this goal and more. The Forever Green Initiative is focused on developing new crops to ensure agricultural production to strengthen economies while protecting water and other natural resources.

By coupling innovations in crop breeding, agricultural production methods, food science, and utilization technologies, we can add to the productivity and profitability of current agricultural systems and enable major improvements in water quality.

Forever Green innovations are based on perennial and winter-tolerant crops that will create new economic opportunities and environmental benefits for crop production in northern climates. The array of perennials and short season winter annuals can be used within traditional crop rotations, including corn and soybean rotation, while adding new crop rotation options.



Perennial Flax



Pennycress



Hazelnut



Intermediate Wheatgrass

Forever Green researchers are using new breeding technologies to make rapid improvements in new crop species and are developing new high efficiency production systems. Researchers are utilizing Forever Green crops as feedstocks for new products and minimizing risk for potential investments in these crops and technologies for entrepreneurs and investors.

PERENNIAL CROPS

Alfalfa—cover crop, new proteins, food products

Intermediate wheatgrass—wheat-like grain, forage, biomass

Kura clover—nitrogen-fixing cover crop

Native polyculture grassland mixtures—biomass, forage, natural products

Perennial flax—edible oil, floriculture, fiber

Perennial sunflower—edible seeds, oil

Silphium—edible oil

WINTER ANNUAL CROPS

Hairy vetch—cover crop, nitrogen-fixation

Pennycress—oil, biofuel, cover crop

Winter barley—food, malting barley

Winter camelina—new proteins, edible oil, bioplastics, cover crop

Winter pea—new proteins, nitrogen-fixing, cover crop

NATIVE WOODY CROPS

Agroforestry—woody and herbaceous crop mixtures for feed, food and fuel

Elderberries—antioxidant-rich fruit

Hazelnut—nuts, edible oil

Shrub willow—biomass

PROBLEM Farmers cannot easily increase productivity and profitability and simultaneously enhance water quality and soil health.

GOAL Develop and enhance agricultural systems to improve natural resources and provide economic opportunities.

ASSUMPTIONS

Farmers want to diversify their cropping systems. Farmers want to improve water and soil quality. Forever Green crops can be profitable for MN farmers. There is market demand for Forever Green products. Forever Green seeds and plants will be available in quantities needed.

ECONOMIC INCENTIVES

Minnesota industry-driven interest in new ingredient sourcing and improved supply chain sustainability metrics. Farmer interest in trialing new cropping systems to diversify economic opportunities. Increasing consumer demand for Minnesota-produced food products with positive environmental, social, and economic impacts.

SITUATION

CURRENT STATUS

Forever Green crops have been shown to enhance water and soil quality
New crop species have been identified but need to be improved
Studies are required to integrate Forever Green crops into current cropping systems
Farmers need information to produce and market the Forever Green crops
New products need to be developed to meet the market demand
Forever Green Initiative continues to develop scientific talent

INPUTS

WHAT WE INVEST IN

Faculty
Staff
Postdoctoral associates
Graduate students
Undergraduate students

Outreach and Communication
Volunteers
Time
Expertise
UMN laboratory and field research space

Tools, materials, and equipment
Networking with MN industry and small business
Space on existing website for hosting educational resources related to the project

ACTIVITIES

WHAT WE DO

Improve crops using new breeding tools
Work closely with farmers to establish Forever Green cropping systems
Develop food, feed, energy, and bio-based products

Strategically position Forever Green production systems to enhance soil and water quality
Educate students and community

WE REACH

Farmers and farming organizations
Extension educators
Students
Research community
Minnesotans
Supply chain partners

OUTPUTS

Products, services, and events intended to lead to the project's outcomes:

FOR FARMERS

Seed for new crop cultivars
On-farm field days
Agricultural management resources

FOR THE RESEARCH COMMUNITY

Scholarly research publications

FOR MINNESOTANS

Information on Forever Green via TV, radio, newspaper, blogs

OUTCOMES

CHANGES IN KNOWLEDGE

Increased awareness and use of UMN educational resources
Increased knowledge about contribution of Forever Green crops to ecosystem services
Increased farmer knowledge of Forever Green crop production systems and economic potential
Increased public awareness of locally produced crops and products

CHANGES IN BEHAVIOR

Farmers use UMN educational resources to learn how to produce Forever Green crops
Farmers value ecosystem services provided by Forever Green crops
Farmers plant Forever Green crops in buffer and wellhead protection zones
Consumers purchase more locally produced Forever Green products

IMPROVED SOCIETAL CONDITIONS

Water and soil quality are enhanced
Diversity of crops grown in Minnesota increases
Farmer profits increase by growing higher-value crops
Availability of locally-produced Forever Green products increases
High-quality scientific talent is attracted to UMN to meet future MN workforce needs

LOGIC MODEL Forever Green



A solution is clear

In Minnesota, a Forever Green bioeconomy will...

- Build on current agricultural strengths
- Tolerate changing weather patterns and new pest and disease pressures
- Sequester soil carbon
- Improve soil health

- Provide sources for a wide range of new food, energy, and bio-based products
- Attract high quality talent to the University of Minnesota to meet the future workforce needs



- Support clean water
- Expand pollinator forage and habitat
- Diminish nutrient runoff into ground and surface water



- Create new businesses and employment opportunities for rural communities including food, health, fuels, and other industries



- Has the potential to create some 12,000 permanent jobs in rural Minnesota. Market opportunities exist for Minnesota companies of all sizes and market channels—from Fortune 500 and regionally-based grower co-ops to locally-owned business and start-up ventures.
- Can become a permanent part of the path to enhanced water quality, improved natural resources, and high efficiency agricultural production.

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CROP OVERVIEWS

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Alfalfa

A PERENNIAL PROTEIN CROP FOR PROTECTING THE ENVIRONMENT

Overview

Alfalfa is the third most widely grown crop in the U.S. with a direct annual value of over \$9 billion. It is the main forage crop for meat and milk production systems worldwide grown on about 80 million acres and generating approximately \$30 billion annually. Alfalfa is oftentimes referred to as the 'Queen of the Forages' due to its wide adaptation, nutritional content, and perennial nature. As a result of these important attributes, alfalfa can be an important crop in a growers rotation that aids in the protection of water and soil resources, enhances soil fertility, and sequesters soil carbon.

What may be surprising to some is that alfalfa produces more total protein per acre than any other crop while requiring no synthetic nitrogen input. This is important for many reasons, including reducing input requirements for growers and the strong market demand for novel plant proteins for new consumer food and animal feed products. UMN Forever Green crop and food science researchers believe alfalfa has great potential to provide another source of protein for human consumption and feed for non-ruminant animals such as fish and crustaceans.

Researchers are developing new crop breeding technologies, including genomic prediction, gene editing, computer vision, and artificial intelligence to develop alfalfa varieties that produce more from each acre planted (especially in low fertility soils); deliver more energy to animals, reduce waste and potential water pollution; and increase longevity of soil cover in winter and spring by improving cold tolerance. Optimized cropping systems, including alfalfa in rotation with annual crops, can significantly reduce soil erosion and increase carbon storage, thus protecting water quality, improving soil quality, fertility and lengthening the period of continuous living soil cover.

Research Status and Goals

Investments made in faculty, post-doctoral researchers, graduate students, technicians, undergraduate employees, and site support:

ARTIFICIAL INTELLIGENCE, BREEDING AND AGRONOMICS

Activities: UMN researchers will be prioritizing the identification of germplasm to breed for improved and/or optimized traits, including enhanced protein and oil concentration and quality for conventional and alternative uses; extreme-cold tolerance/winter survival/frost tolerance to increase winter and spring soil coverage and more reliable yields; higher biomass yield, improved nitrogen fixation, wet soil tolerance, and cultivation with grasses. as well as develop germplasm for low phosphorus (P) fertility and to reclaim P from manured soils.

The agronomic team will focus on working with growers through research and on-farm trials that research optimal cropping systems that include alfalfa. These systems will be evaluated for their ability to minimize greenhouse gas emissions, increasing soil carbon sequestration and maximizing farmers profitability. Additionally, the research teams will provide best management practice recommendations to spur farmer adoption and increase alfalfa acreage in Minnesota.

Outcomes: Novel germplasm and new alfalfa varieties with optimized cropping systems will enable growers to achieve better benefits and higher profitability in conventional and new cropping systems. Products will include improved varieties, guidelines for production, and scientific reports on cultivars and agronomic strategies.

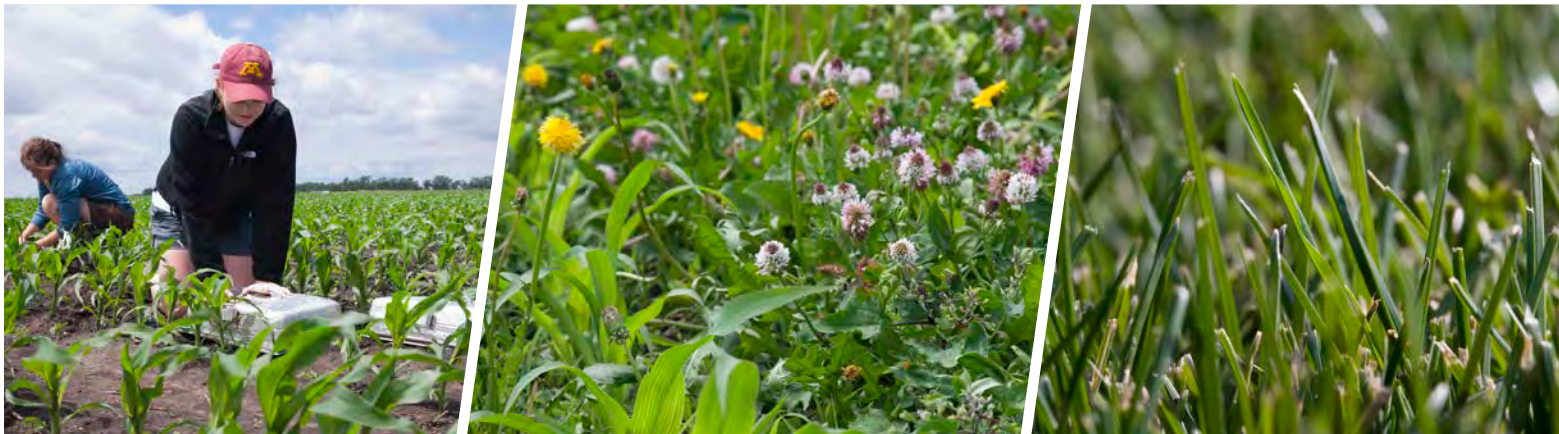
COMMERCIALIZATION PLAN

Develop new breeding methods and improved germplasm for the alfalfa industry, optimize cropping systems, and empower the creation of new value-added products that increase profits for producers and improve environmental conservation through use of perennials on the landscape. As a next generation protein crop, UMN researchers will be identifying end-users in various market channels, including human food, animal feed and plant based protein sectors to engage in early stage pilot projects and product research and development.



Ongoing Studies

1. Root type selection developed stable lines with highly-branched roots and stress tolerant taproots that will be combined with nitrogen fixation and nitrate uptake traits for specific applications on the landscape.
2. Selection for stem cell wall digestibility resulted in lines with improved digestion by ruminants. Comparisons of digestibility between genetically modified lines and selected lines are underway. Stacking of the selected lines with genetically modified lines will be explored to increase digestible biomass yield and animal performance.
3. New breeding methods using computer vision and the Microsoft FarmBeats artificial intelligence (AI) platform are being testing for accurate real-time live phenotyping for cold-tolerance, canopy structure, disease resistance, winter and spring soil coverage, and to increase yield.
4. Testing of wet processing and leaf-stem separations of nonlodging alfalfa for high protein feed and food products.
5. Genomic markers for disease resistance to increase stand life and forage yield.
6. Evaluation of agronomic, economic, and environmental aspects of novel perennial cropping systems with alfalfa.



Cover Crops, Forage Grasses and Legumes

FOR GRAZING, FORAGE, BIOMASS AND DUAL-USE SYSTEMS

Overview

Winter-hardy cover crops, perennial grasses, and legumes are options for diversification of summer-annual cropping systems by providing year-round ground cover. Cover crops provide soil coverage during seasons when a summer annual crop—such as corn and soybean—is not actively growing. Cover crops are useful management tools for enhancing the sustainability of agroecosystems and reducing negative environmental impacts in a summer-annual system, by lengthening the “green phase” of the system by growing in the months between harvesting and planting. Cover crops can decrease soil erosion, improve soil organic matter, and water quality. They support summer annual crop production by suppressing weeds, and disrupting pest and disease cycles. Cover crops can improve soil nitrogen management and water quality by utilizing nutrients in late fall and in early spring when they are typically lost in a field with only summer annual crops. Perennial grasses and legumes provide year-around ground cover and forage for many livestock species, and are key to a rapidly growing organic dairy industry. These crops greatly reduce soil erosion and store significant quantities of carbon belowground; in rotation, these crops can greatly improve soil quality and fertility.

Dual-use systems provide an important pathway for integrating cover crops and perennial grasses into current farming systems. Biomass from cover crops and perennial crops can be marketed for bioproducts and/or animal feed. If complemented with cover crops and perennial grasses, corn-soybean farms can sustainably produce large amounts of corn residue biomass, as well as additional biomass from cover crops and perennial grasses, increasing total production and profit while also improving soil and water quality. Sustainably-produced biomass is increasingly demanded for liquid fuels, high-value animal feeds, and other bioproducts. Another promising dual-use system is grazing of cover crops to enhance sustainable livestock systems.

Research Status and Goals

Investments made in faculty, post-doctoral researchers, graduate students, technicians, undergraduate employees, and site support:

BREEDING, GENETICS, AND AGRONOMICS

Improve the genetic quality of cover crops including hairy vetch and Kura clover, and forage grasses such as perennial ryegrass.

Activities:

1. Hairy vetch breeding to improve winter hardiness and earlier spring maturity.
2. Testing a new method to establish Kura clover by interseeding it into an existing alfalfa stand, allowing development of a kura stand as the alfalfa eventually thins, while continuing to harvest forage.
3. Working with tillage equipment manufacturers to develop new methods for seedbed preparation when planting corn into kura clover living mulch.
4. Perennial ryegrass breeding to improve winter hardiness and introduce a spreading trait into forage-type ryegrass breeding populations.
5. Dual-use system research to improve biomass from corn residue (stover) and other crops, and develop decision-support tools for advanced crop/soil management methods.
6. Cropping systems research to improve legume potential to enhance nutrient cycling and soil health.

Outcomes:

New varieties of cover crops and perennial forage crops will enable profitable seed production, provide adequate and affordable seed stocks for these crops, and enable growers to better achieve benefits from using these crops in cropping systems. Products will include improved varieties, guidelines for production, and scientific reports on varieties and agronomy strategies.

TIMELINE

2020–25 AND BEYOND

- Improved varieties and agronomic systems
- Key pilot and commercialization activities

Pilot Studies

Selection nurseries are variously located at Becker, Rosemount, Roseau and St. Paul. Focal traits include: vetch—emergence and vigor in late fall, winter survival, flowering date, seed production potential and biomass yield in spring and fall; and perennial ryegrass—improved performance under grazing, forage yield, fast regrowth potential, winter survival, and spreading growth habit; Kura clover—increased seed production potential and harvest efficiency.

Pilot studies on dual-use systems are advancing integration of diversified biomass production in corn-soybean systems within several watersheds in south central Minnesota. Key pilot activities will include: on-farm and experiment station research and demonstration work to improve crop and soil management for more sustainable biomass production; multi-level collaborative planning and coordination for extensive diversified biomass production; and providing and improving model-based decision support for diversified biomass production.

Commercialization Plan

Minnesota has a vibrant grass and legume seed production industry centered in Roseau and Lake of the Woods counties in northwestern Minnesota. The University has a long-standing relationship with the seed growers dating back over 60 years when funding to initiate a research program in seed production was received. Our goal is to enable profitable, large-scale production of our improved hairy vetch, Kura clover, and perennial ryegrass varieties by northern Minnesota seed growers. Dual-use system commercialization will leverage the broad appeal of diversified biomass production systems, which can substantially improve production, profit, and conservation, offering a strong value proposition to many commercialization partners. Biomass end users, such as POET LLC, are keen to diversify biomass sources for their biorefineries to manage risks associated with fluctuating supplies of corn biomass. Commercialization will be advanced by collaboration with a wide range of leading firms and organizations working on issues related to production, processing and marketing. These firms, organizations, and agencies include providers of biomass harvest systems (Pacific Ag) and services (FDC Enterprises), sub-field diversification strategies for producers (AgSolver), policy innovation (Delta Institute), and a range of non-profit groups (including the Nature Conservancy, Minnesota Corn Growers), and governmental agencies (Minnesota Region 9 Economic Development). Initially, we will focus on establishing pilot-scale diversified biomass production in a watershed that has provided formative stakeholder input to the commercialization project already near to an existing grain ethanol facility.



Hybrid Hazelnuts

A POTENTIAL PERENNIAL FOOD CROP FOR MINNESOTA

Overview

American hazelnuts (*Corylus americana* Marshall) are native to the Upper Midwest and are often found growing in the understory of woods and along trails. These hardy nuts are resistant to the hazelnut disease Eastern Filbert Blight (EFB) and have the cold-hardiness necessary to survive the harsh winters of Northern Minnesota. For the past two decades, Upper Midwest growers and researchers have been actively crossing native hazelnuts with the larger-fruited, thinner-shelled European hazelnut (*C. avellana*) in an effort to combine the best traits of the two species. Recent breakthroughs in identifying the best plants for production and accelerating the propagation of these selections is putting hybrid hazelnuts on an exciting track to become the Upper Midwest's first agricultural nut crop.

Hybrid hazelnut production as an agricultural crop provides both a delicious new protein and oilseed crop as well as significant environmental benefits. Hazelnut production in the Upper Midwest will be grown in hedgerows, with the potential for a third crop, grasses and/or legumes in the alleys between the rows. This system prevents soil erosion, protects water quality and, because hazelnuts have deep fibrous roots, sequesters carbon in the soil. Their long life-span and bushy growth form also make them especially valuable in windbreaks, shelterbelts and living snow fences, where they provide habitat for shrubland bird species while adding economic value.

Global market demand for hazelnuts far exceeds supply. Consumers enjoy hazelnuts eaten as a snack, sprinkled on salads or ice cream, baked into cookies or granola, and slathered in chocolate. Companies crush hazelnuts into spreadable nut butter or soak and process the nuts into a dairy-free milk. The oil has a high-flash point and nutritional and culinary qualities similar to olive oil.

The two big challenges for hybrid hazelnuts and Upper Midwest growers is the variability in the genetic plant material, or germplasm, of hybrid hazelnuts and high processing costs. Forever Green researchers partner closely with growers and researchers across the Midwest to address these challenges under the auspices of a formal collaboration called the Upper Midwest Hazelnut Development Initiative (UMHDI). Interested readers can access grower guides, research findings and learn more about hybrid hazelnut progress at midwesthazelnuts.org.

Research Status and Goals

Investments made in faculty, post-doctoral researchers, graduate and undergraduate students, technicians, land, field and lab supplies, and transportation support:

AGROECOLOGY

Activities: American and hybrid hazelnuts differ from domesticated European hazelnuts in that they grow as bushes and not as trees. Their bush form is especially well suited for integrated agroecological systems which maximize ecological benefits. But it also means that we need to develop entirely new production systems for them. University hazelnut breeders are collaborating with agricultural engineers in Wisconsin to match shrub architecture with new harvesting equipment, and to match shell characteristics with new shelling and cleaning equipment. We are also developing recommendations for weed control, fertilization, pruning, sucker control, and insect management specific to our unique germplasm, soils, and climate. Literature for other woody crops supports our claims of ecosystem benefits from growing hazelnuts, but we will need to validate them in our production systems once these systems have been refined.

Outcomes: Extension bulletins describing best management practices for hazelnut weed control, fertilization, plant size management, and insect management; and new equipment designed specifically for our production systems and our germplasm.

BREEDING AND GENETICS

Activities: We evaluated hybrid hazelnut germplasm for nut quality and yield potential in five replicated hybrid hazelnut germplasm trials and are now propagating the best selections from these trials for replicated on-farm pilot plantings which we will establish in spring 2021. These will be the first in a pipeline of continuously improving genetics, as we are starting to identify even better germplasm from the thousands of progeny from new crosses between our best material and advanced selections of European hazelnuts. All of this is contingent on success in developing commercially viable methods of vegetative propagation of hybrid and American hazelnuts, lack of which is the main bottleneck to dissemination of these advanced selections.

Outcomes: Improved economically viable germplasm to be disseminated to growers; improved methods by which to propagate this germplasm to be shared with nurseries; scientific papers about the hormonal control of rooting of recalcitrant woody species such as hazelnuts; a reliable protocol for hazelnut propagation and a protocol for rapid screening for durable EFB tolerance.

FOOD SCIENCE

Activities: We are developing recommendations for maintaining quality in hazelnut kernels after harvest and processing, and during storage. Ensuring that only the highest quality nuts reach end-users is crucial for maintaining consumer acceptability. We are developing protocols to preserve desirable flavor, ensure microbial and chemical safety, and prevent rancidity, which may be a problem after shelling and grinding due to the high lipid content of hazelnuts. We are evaluating the effect of roasting, which is used to destroy pathogenic microorganisms, on kernel flavor and assessing routes of potential mycotoxin contamination. We are also identifying the compounds responsible for the bitterness found in some hazelnut germplasm, with the objective of developing a rapid screening method for culling out bitter genotypes early in the breeding process.

Outcomes: Recommendations for post-harvest handling to ensure food safety and quality and a rapid screening method for eliminating germplasm with bitter flavor.



COMMERCIALIZATION

With demand already greatly exceeding supply, not much market development is currently needed. General Mills and PepsiCo are interested in large quantities for baked products and snack foods, and current growers doing direct marketing cannot keep up with demand. The biggest need is for processing infrastructure. Work is underway to develop small grower-owned production and processing clusters around regional production hubs in the ecologically sensitive areas. New and more efficient processing equipment combined with better quality germplasm and better agronomic recommendations will make hazelnuts more profitable than is currently possible.

TIMELINE

2020—First selections released to on-farm pilot plantings

2020—Recommendations for post-harvest handling, storage and processing to maintain food quality

2021—Basic improvements in propagation methods available

2023—Reliable improvements in propagation available

2024—More definitive weed control, fertilization, and pruning recommendations

2025—First selections released to general public; rapid screening method for culling bitter genotypes available



Intermediate Wheatgrass

A PERENNIAL, MULTIFUNCTIONAL FOOD, FEED AND ECO-FRIENDLY CROP

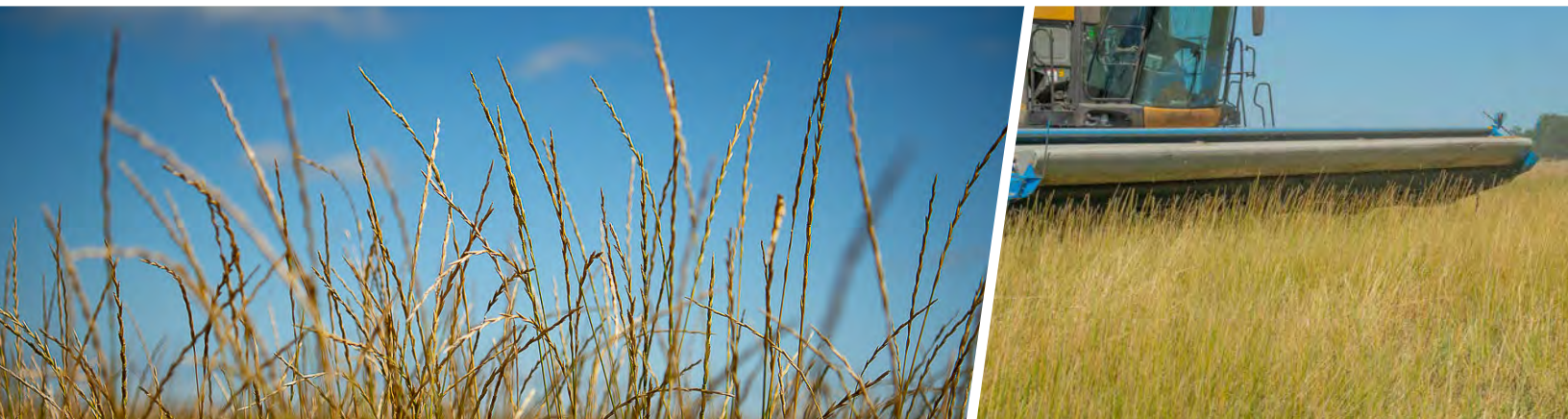
Overview

As the first commercially available perennial grain crop in the United States, intermediate wheatgrass will change agricultural landscapes by providing valuable ecosystem services. The Forever Green Initiative is striving to advance intermediate wheatgrass production and end-use opportunities to commercialize this crop while providing new economic opportunities to Minnesota farmers, protect the environment, and supply the nation with a new, healthy grain.

Intermediate wheatgrass (*Thinopyrum intermedium*, IWG) provides year-round soil coverage and uniquely large belowground carbon inputs from roots. Farmers growing this crop will likely sequester more carbon and reduce greenhouse gas emissions. Research is showing IWG reduces nitrogen and phosphorus contamination of freshwater and marine ecosystems, and reduces weed competition which minimizes the need for tillage or herbicide applications. With continuous soil cover, farmers will also greatly reduce soil erosion, potentially turning agriculture into a soil-forming ecosystem, much like the natural ecosystems it replaced.

The IWG breeding project at the University of Minnesota has made great strides in targeted trait improvement, resulting in increased seed size and seed yields significantly larger than those of original populations. This has led to production and sales of this crop under the trade name Kernza® (trade name is property of The Land Institute, a nonprofit organization that has led development of the crop since 2003). UMN released its first commercial variety of Kernza Intermediate Wheatgrass in 2019. They named their variety MN-Clearwater, as a nod to the many lakes in our state and importance of clean, safe water throughout Minnesota.

The UMN food science team and commercialization team is working with a range of interested commercial partners to determine how IWG can be incorporated into their food products as a green and earth-friendly crop. Food companies, restaurants and businesses have especially been interested in incorporating IWG into their product lines and on their menus in order to attain sustainability goals and gain valuable marketing advantage by reducing their greenhouse gas footprint.



Research Status and Goals

Investments made in faculty, post-doctoral researchers, graduate students, technicians, and undergraduate employees support:

AGROECOLOGY

Increase intermediate wheatgrass yields and measure the environmental benefits possible from this new crop.

Activities: Field experiments are addressing crop rotations, optimum nitrogen fertilizer rates and row spacing for maximized grain yields, incorporating legumes into intermediate wheatgrass stands to reduce nitrogen fertilizer needs, harvesting or grazing forage to complement grain yields, and improving grain harvest efficiency methods. Projects address agronomic development, reductions in nitrate leaching to groundwater, reductions in soil erosion, and better understanding Kernza's potential for sequestering carbon in roots and soil.

Outcomes: Best management guidelines for intermediate wheatgrass productions, Extension education documents for farmers and producers, and scientific reports describing intermediate wheatgrass merits.

BREEDING AND GENETICS

Improving intermediate wheatgrass for profitable production in the Midwest.

Activities: Projects are focused on domestication traits such as reduced seed shattering, improved free grain threshing, and seed size. There is plentiful genetic variation for these traits in our breeding germplasm and rapid gains have been made with seed size increasing at a rate of about 5 percent per breeding cycle. The first five IWG variety candidates entered statewide yield tests in 2016 and the first commercial release was in 2019. A dozen more candidates are currently being evaluated. To increase the efficiency of selection and accelerate its improvement, we have optimized and established genomics tools based on DNA fingerprinting. These genomics tools can shorten the breeding cycle from three to five years to less than one year and allow us to evaluate more plants than is possible with field-based selection alone.

Outcomes: Continuously improved IWG germplasm, including new variety releases with increased grain yield and grain harvestability.



FOOD SCIENCE

Quality traits characterization and viable methods to store, process, and utilize intermediate wheatgrass in commercial foods.

Activities: Continue to characterize intermediate wheatgrass quality traits (starch composition, gluten protein profiling, dietary fiber content, antioxidants, and problematic enzymes), evaluate its use for various food applications (e.g. flour blends, cereal-based products, baked goods), improve storage and shelf life, and measure the effect of refinement and processing methods on quality characteristics. Tempering, a critical pre-treatment step before milling, is commonly used for hard red wheat to optimize its flour production. Recent research has shown that tempering conditions when optimized for intermediate wheatgrass have positive impacts on the physio-chemical and functional properties of intermediate wheatgrass flour. Improving the functionality of intermediate wheatgrass as a flour ingredient will expand the applications of the grain in baking and product applications and result in breads and baked goods that better match consumer expectations.

The food science team is also working closely with brewers and maltsters to optimize intermediate wheatgrass for malting, brewing and distilling applications. The craft brewing industry has seen dramatic growth across the country, which has resulted in a high demand for new ingredients to meet the expanding consumer interest. Additionally, many brewers are committed to sourcing ingredients grown in Minnesota, and seek ingredients that promote ecological and social benefits. As a result, intermediate wheatgrass has garnered considerable interest from brewers across the state, country and even globally.

Outcomes: Guidelines for directing end-use products development using intermediate wheatgrass, evaluation of new varieties for guiding breeding efforts toward achieving grain quality objectives, and scientific papers documenting strategies used to characterize and improve intermediate wheatgrass.



PHOTO: METTE NIELSEN

Clusters of Production: Piloting Sustainable Supply Chains

Intermediate wheatgrass, with its extensive root system, has proven to be effective at mitigating nitrate leaching into groundwater resources. This has caught the attention of rural water associations and city utilities that recognize the opportunity to mitigate serious and costly drinking water issues by planting IWG to protect source water. As a result, “clusters” of production have started to develop across Minnesota in areas where local leadership and associations have partnered with growers to strategically plant, harvest, store and process the IWG in vulnerable wellhead areas. Restaurants, bakers, brewers and retail businesses in the regions are working with the grain, adding to their product offerings, menus and store shelves. Lastly, the Minnesota legislature, the Clean Water Legacy Council and Department of Agriculture also recognize the economic and ecological benefit of this work and have spurred cluster production and supply chain development through funding support.

COMMERCIALIZATION PLAN

Increased production and acreage of MN-Clearwater is currently underway, with an estimated 700 new acres planted in 2020. Incremental scaling of seed supply and food production acreage is on track and will continue to align with the source water protection strategy as a high priority.

Recent additions of two new Minnesota-based seed cleaners—one for seed and one for food grade production—has allowed for the incremental expansion of market development. The seed company has worked closely with the UMN to manage the cleaning and distribution of IWG seed to Minnesota growers. Additional Minnesota seed companies have expressed interest in commercial seed distribution and efforts are underway to strategically expand seed cleaning, production and distribution. A food grade grain company is working with Minnesota growers to source food-grade Kernza and now offers wholesale and direct-to-consumer distribution of Kernza grain and flour. Businesses interested in sourcing Kernza for menus or product development can now procure a safe, consistent and reliable supply of Kernza.

Market testing and product development is currently underway by a range of commercial partners. General Mills recently tested a small run of a breakfast cereal; Perennial Foods, a start-up company in Minnesota, is now selling Kernza grain and flour for home use; a cracker company in Pennsylvania is sourcing MN-Clearwater for its sprouted grain Kernza cracker and restaurants, brewers, distillers and bakers across the country have been incorporating it into their menus. Grain and flour samples for product research and development have been and will continue to be shipped to interested companies of all sizes. Shipments have been sent across the state, country and even overseas.

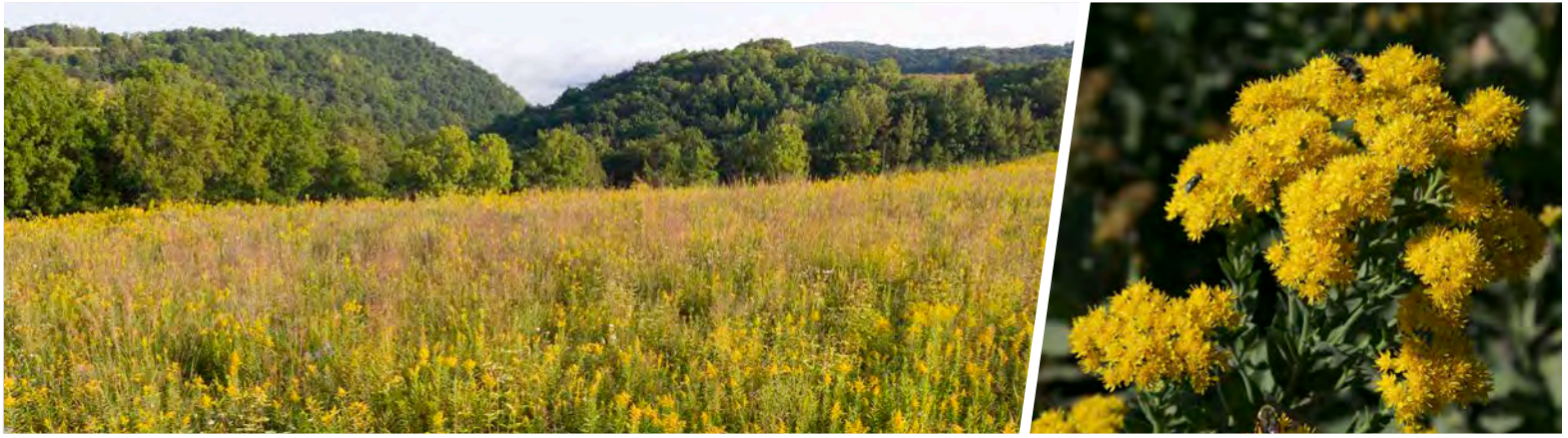
Markets are poised to grow as grain becomes more available and the supply chains improve. Notably, Kernza growers are in the process of formulating a market structure, such as a co-op, that will provide economic, technical and research support for farmers currently or considering growing Kernza.



TIMELINE

2020–25 AND BEYOND

- Agroecology research to continuously improve agronomic production practices and track long-term impacts of this new crop on the environment.
- Breeding work to expedite IWG's domestication timeline using cutting-edge genomic tools that will lead to development of new varieties with improved grain yield.
- Food science research to analyze food quality applications, characteristics and benefits.
- Work with growers and communities to strategically site new acres of IWG in vulnerable source water and drinking water areas to protect water.
- Engage with food and beverage companies to foster product research and development and spur demand for IWG produced by Minnesota farmers.



Native Perennial Grassland

MANAGING FOR BIOMASS AND ENVIRONMENTAL SERVICES ON UNDERUTILIZED FARMLAND

Overview

Biomass from mixtures of native perennial grassland plants can be harvested annually as a source for bioenergy production—a new source of potential income for rural Minnesota. Native perennial grasses, forbs, and legumes grown together in grasslands can be produced on underutilized farmland, land that is not suitable or economical to grow commodity crops. Biomass harvested from these plants can serve as a source of revenue for farmers on land that has been considered marginal. Reestablished native grasslands provide a number of environmental services besides biomass for renewable energy. Grasslands stabilize soil and prevent wind and water erosion, protect natural waters by intercepting nutrients from runoff, provide habitat for wildlife, provide resources for pollinators and enemies of crop pests, and sequester carbon deep beneath the soil surface.

Grassland biomass systems can serve the functions of land in the Conservation Reserve Program (CRP), plus provide additional benefits to producers and the environment. With uncertainty about the continuation of the CRP, now is a good time to plan for a market-based approach to fund state and federal goals of protecting soil and water, and providing habitat with perennial cover. A self-sustained grassland bioenergy system can provide an additional revenue source for producers while providing ecosystem benefits.

Many states have renewable energy production goals, including Minnesota's goal of 25 percent electricity generation from renewables by 2025. As the deadlines for these statewide goals approach, demand for biomass could increase. Many technologies are ready to convert biomass into renewable energy, including enzymes for converting cellulose to ethanol, systems for anaerobically digesting mixtures of manure and biomass to produce natural gas, and methods for mixing shredded biomass for burning with fossil fuels to generate electricity with reduced net carbon emissions. As these technologies improve, the cost of bioenergy should decrease and improve the economic potential for farmers to grow biomass crops on marginal lands.

Research Status and Goals

Investments made in faculty, post-doctoral researchers, graduate students, technicians, and undergraduate employees support the research and development of grassland biomass research on underutilized farmland.

Activities: The Forever Green Initiative (FGI) has led numerous research projects relating to the agronomics and ecosystem services of grassland biomass. For example, we evaluated the productivity and soil health benefits of switchgrass monocultures compared to native grass and legume mixtures in six agricultural regions of Minnesota. We have also monitored changes in mixture composition over time. Future studies will focus on how grassland biomass can address specific environmental needs of Minnesota. We plan to test the effectiveness of managing grassland biomass on wellhead protection areas to provide an economically viable method for reducing nitrate leaching to groundwater. A comprehensive study is needed to measure hydrology and nitrogen dynamics beneath grassland biomass production systems. A second major objective is to measure profitability and water quality benefits of growing grassland biomass crops in buffer zones adjacent to rivers, streams, lakes, and drainage ditches. The continuous living cover provided by grassland biomass crops is expected to reduce subsurface nitrate transport, surface runoff of nutrients like phosphorus, and soil loss to ground and surface waters. We propose a long-term project that would quantify the water quality improvements by replacing annual crops with perennial grassland bioenergy crops along waterways requiring a buffer.

Studies will be continued to determine appropriate fertilizer rates for switchgrass and grassland mixtures, harvest timing for conserving valuable nutrients, and methods to improve establishment success of native grassland species. We will continue to measure bioenergy yields across various grassland types and regions of Minnesota.

Outcomes: Outcomes of future projects will focus on providing detailed information and guidelines on the impact of native grasslands on water quality and carbon sequestration by native grasslands when planted over wellhead protection areas and in buffer strips along waterways. The University of Minnesota Morris campus has a biomass gasification facility (left) to convert biomass into renewable energy. This could be the site of a farm-to-fuel demonstration. The Morris campus has a substantial existing research facility for processing biomass, converting it to bioenergy, and measuring biological and economic implications of the conversion.



COMMERCIALIZATION PLAN

Some of the prior pilot projects harvested native grassland biomass on approximately 1,000 acres of Minnesota, typically on land that was marginal for other agricultural crops. Those projects showed that such harvesting was sustainable and provided healthy habitat for Minnesota wildlife that would not be available with other uses of the land. Economic evaluations in those projects suggested that scaling up by a factor merely of ten would make this kind of renewable bioenergy economically viable, providing an increment in income to local rural landowners and a profitable return to power companies. Therefore, a proposed next step is to establish a collection of land at this enlarged scale, work with property owners to arrange care and harvesting of biomass on the land, and work with select power generation companies to profitably convert the biomass into renewable energy. The Morris research site can contribute methods and measurements to this effort. The ultimate potential is substantial. Previous estimates from the pilot projects showed that the idle and degraded land in Minnesota, converted to grassland biomass, could provide enough renewable energy to obviate the need for several large new fossil fuel or nuclear power plants.

TIMELINE

2020–25 AND BEYOND

- Research and development of native grassland biomass systems for underutilized agricultural land
- Long-term experiments to determine how these perennial systems change through time and how changes affect the ecosystem services





Natural Products

HIGH VALUE PERSONAL CARE PRODUCTS AND ENVIRONMENTAL BENEFITS FROM NATIVE MINNESOTA PLANTS

Overview

Strategic placement of native perennial plants on Minnesota's landscape has been identified as a way to improve our environment. Native perennials grown in mixed plantings or polycultures can sequester carbon and nitrate, prevent soil erosion, increase water filtration, and provide wildlife and pollinator habitat. They have great potential for inclusion in well head protection and water buffering areas. The cultivation of native plant polycultures has garnered attention throughout the Midwest as a source of revenue in the form of bioenergy while providing ecosystem services in agricultural areas.

However, revenues from the bioenergy market alone have been insufficient to sustain cultivation of this system. High-value end uses of native plant products are being investigated to further incentivize restoration of native polycultures across the Minnesota landscape.

Plants produce a wide variety of specialized metabolites, many of which have been identified as containing properties useful for human products like pharmaceutical drugs, pigments, and fragrances. Consumer demand for natural products in personal care items has contributed to rapidly increasing demand for organic personal care products that contain plant-based ingredients. University researchers are working to identify high-value antimicrobial compounds that have cosmetic applications from several dozen native Minnesotan plants in wild areas. The strategic inclusion of these plants into polycultures could increase the value of restoring native perennial plant systems for Minnesota growers, resulting in benefits for the environment and creating a local economy around natural compound production for the Minnesota cosmetics industry.

Current Status and Goals

Investments made in faculty, graduate and undergraduate students, and community collaborators support conducting plant collection, field research, and identification of plant metabolites.

Activities:

Previous work at the University under the Forever Green Initiative evaluated the antimicrobial and antioxidant activity of compounds from 336 native and naturalized plants of interest, and identified several dozen plant species as promising candidates for large-scale production and commercialization of the natural compounds they produce.

For example, two antimicrobial compounds of commercial interest that showed significant antimicrobial activity against *Staphylococcus aureus* and *Pseudomonas aeruginosa* were identified in the native forbs sweet fern (*Comptonia peregrina*) and wild licorice (*Glycyrrhiza lepidota*). In addition, the common native prairie forbs purple coneflower (*Echinacea purpurea*), showy tick trefoil (*Desmodium canadense*), and Canada milk vetch (*Astragalus canadensis*) were identified as promising candidates for production of natural compounds for the cosmetics industry.

Outcomes:

- Continue large-scale screening of native and naturalized plants for potentially important compounds, and optimize chemical methods for extraction and isolation of natural plant compounds of interest.
- Identify particular ecotypes within species that produce the greatest quantity of the plant compounds of interest, as well as identifying agronomic management methods to optimize production of natural plant compounds in the herbage, roots, and flowers of native forbs.
- Quantify and compare ecosystem services for native pollinators between agroecosystem types (monoculture, low-diversity polyculture, and high-diversity polyculture plantings).
- Promote integration of native perennial plants onto existing agricultural lands, marginal lands, and riparian buffer areas.
- Connect Minnesota farmers with existing industries and support the creation of a new industry around natural plant products and native plant polycultures in Minnesota agroecosystems.

Pilot Studies

The native perennials and natural products team at the University is currently cultivating purple coneflower, showy tick trefoil, and Canada milk vetch at the University of Minnesota Research and Outreach Centers in Becker and Rosemount.

Herbage, roots, and flowers have been harvested from these native forbs, and the effects of the plant community structure on production of the active chemicals are being evaluated between monoculture and polyculture plantings of these three forbs. Monocultures of each forb species and two polycultures were established. Ecosystem services, including habitat provision, are being evaluated by measuring pollinator visitations, floral density, pollen availability, and nectar quantity and quality in all planting types. Untargeted metabolomics analyses and comprehensive informatics approaches will be conducted to investigate the effects of planting density and community composition on the production of chemical compounds of interest within the three forb species.

COMMERCIALIZATION PLAN

The organic and natural personal care market has shown continual growth and demand is expected to increase in the future, thus we will continue to pursue agricultural production of natural plant products for this industry. We will continue to develop and optimize methods for the isolation, characterization, and utilization of natural products from native plants. We will seek out opportunities where we can use the research and development model to collaborate with local companies involved in the production of personal care products, and form partnerships between these companies and Minnesota growers.

TIMELINE

Ongoing research will continue until we have been able to test all potential native plants with potential to yield natural products. We are designing high-throughput methods for rapid analysis of biologically-active natural products of commercial interest.



Additionally, germplasm of eight native plants of commercial interest was collected from three dozen ecoregions across the state of Minnesota and established in a common garden on the St. Paul campus for evaluation of compound production among plant ecotypes. As some ecotypes within plant species produce greater quantities of certain compounds than others, evaluation of different ecotypes will contribute to maximization of yield of the plant compounds of interest.



Pennycress

A POTENTIAL NEW SHORT SEASON WINTER ANNUAL OIL SEED CROP FOR USE IN MINNESOTA CROPPING SYSTEMS

Overview

The University of Minnesota is a leader worldwide in developing winter hardy cash cover crops as new agricultural opportunities. Field pennycress (*Thlaspi arvense*) is a winter annual oilseed showing great promise as a new crop for growers to adopt that will keep the soil in continuous living cover, protect water quality and increase profitability.

The seeds of field pennycress are oil-rich (>30%) and contain specific fatty acids that can be used for select purposes. Rapid advances have been made in identifying different genetic lines (non-GMO) in pennycress, allowing researchers to earmark the traits for healthy edible oils, novel plant proteins, biodegradable (plastic) packaging materials, lubricants, and biofuels. The seed meal that remains after oil processing also has important uses as highly nutritional food and animal feed (rich in protein, essential fatty acids, and fiber), and soil amendments (organic nitrogen fertilizers). All of these products and

uses equate to additional economic returns for Midwest farmers.

Pennycress can be sown after harvesting crops like spring wheat or silage corn, or interseeded during summer in growing field corn, soybean, or sunflower. The emerged seedlings form rosettes in the autumn and cover the soil surface prior to entering winter dormancy. As rosettes they protect the soil surface from erosion caused by high winds, intense rains, or snow melt. Additionally, the rosettes absorb soil nutrients, like nitrates, in autumn and spring, thereby almost completely eliminating nitrate and phosphorus contamination of ground and surface waters. This keeps well water safe for drinking and improves the quality of water in our wetlands, streams, rivers, and lakes. Furthermore, the pennycress rosettes compete effectively with autumn- and spring-emerging weeds, which lessens the need for herbicides.

In spring as the rosettes bolt (elongate) to form flowering stems, summer crops like soybean can be

interseeded into the pennycress crop. The pennycress plants continue to mature and flower as the soybean germinates and emerges. Pennycress flowers throughout the month of May in Minnesota, thereby providing large quantities of nectar and pollen to hungry pollinators. Seeds are harvested in June while the understory soybean plants are still short enough not to be damaged by the cutting bar of the combine harvesting the pennycress seeds. The soybean continues growth after pennycress harvest and matures at the normal time in September.

Successful development of adapted pennycress varieties and planting of those varieties in millions of acres across Minnesota and surrounding states has enormous potential to generate significant economic rewards for farmers while simultaneously alleviating water contamination. It also will showcase the University of Minnesota as one of the leading institutions committed to promoting agriculture as a force for protecting and enhancing our soil, water and natural resources.

Research Status and Goals

Investing in people, tools and research drives the mission of the Forever Green Initiative forward.

AGROECOLOGY

Deploy pennycress production to the Minnesota landscape and measure the environmental benefits possible from this new crop.

Activities: More than ten experiments currently underway address pennycress agronomic needs and include method and timing of pennycress planting, in season management, and harvest; the effect of pennycress on following crops, water quality, weeds, and other pests; and economic and environmental benefits. More years, environments, and experiments are needed to determine best practice guidelines for integrating pennycress into cropping systems in Minnesota and throughout the Midwest.

Outcomes: Best management guidelines for pennycress production and integration into Minnesota cropping systems; Extension documents and workshops to address pennycress production; scientific reports identifying the ecosystem services provided by pennycress; and the knowledge necessary for farmers to improve their land and increase profit margins.

BREEDING AND GENETICS

Activities: Initial efforts have focused on domestication traits such as reduced seed shatter, early maturity and edible oil. In addition to these traits, we are also breeding for higher oil content, reduced glucosinolate content, and larger seeds which will improve the marketability of pennycress. Thousands of lines have been screened for these valuable traits with the most promising lines undergoing further testing. The UMN pennycress genetics program has successfully sequenced the pennycress genome which has been key to developing domesticated pennycress using non-GMO techniques. These new lines are being tested in several locations in Minnesota and represent the first generation of domesticated pennycress breeding lines. With further investment in research sites with diverse soils and environments, we can identify the top performing lines to maximize oil and seed yield for Minnesota producers.

Outcomes: New and improved pennycress germplasm and variety releases within five years. Trait development will be an on-going activity.

Pilot Studies

A number of plot-scale pennycress research projects are distributed throughout central and southern Minnesota. These research projects include optimization of pennycress planting and harvesting methods and improvement of relay cropping system performance.

Plans are underway to expand this research throughout Minnesota and the Upper Midwest. Research trials to determine the environmental and economic impacts of pennycress are underway.

COMMERCIALIZATION PLAN

Industry has expressed interest in pennycress oil as a feedstock for biofuels, biopolymers for bioplastics and novel plant proteins for food production, and a healthy and sustainable food grade oil. Pennycress meal is also being tested as a feed source in aquaculture and other sectors.

A significant, federally-funded partnership known as IPREFER (Integrated Pennycress Research Enabling Farm and Energy Resilience) between the Forever Green Initiative and a handful of industry and university partners in the Upper Midwest has been launched with a mission to optimize and launch pennycress production as a cash cover crop. Agricultural Utilization Research Institute (AURI) is an important partner in seed processing, product testing and industry partnership development. Small samples of oil and meal have been provided to bioplastic, food and biofuel companies to conduct product R&D at lab bench and pilot run scales.

The release of selected lines will be managed by UMN and MN Crop Improvement Association. Improved pennycress traits are yet to be licensed in the Upper Midwest. Commercializing pennycress at scale will require investment and partnership with growers and industry. Preferred partners are those that can achieve landscape-scale change while delivering integrated economic, environmental, and social benefits to Minnesota.

UMN is also working with state agencies and conservation organizations to prototype policy solutions that will help growers manage risk, maximize and compensate growers for ecosystem services, and support commercialization.

TIMELINE

2020–25 AND BEYOND

- Agroecology research to improve agronomics and track long-term environmental impacts
- Breed for early maturity, low seed shattering, improved seed yield and oil quality traits resulting in new varieties for release to farmers
- Develop lead partnerships with grower and industry groups, spurring investment
- Cultivate industry partnerships to spur collaborative product development and innovation
- De-risk crop adoption for growers, support investments for ecosystem services
- Secure GRAS (Generally Recognized as Safe) status for pennycress food grade oil



Perennial Berries

A FLAVORFUL SOLUTION TO ECOSYSTEM AND FINANCIAL CHALLENGES

Overview

Perennial fruits planted in buffer strips offer a potential solution to both nitrate losses in the ecosystem and financial losses in farming systems. Berry production can be incorporated into buffer plantings. Additionally, perennial fruits planted elsewhere offer opportunities for reducing fertilizer loss across the landscape. Demand for fruit is still increasing due to its health benefits. In addition, the majority of fruit production occurs in the western U.S., conflicting with an increasing desire for locally produced fruit. Increased local fruit production can potentially be achieved by planting perennial fruits in agricultural watersheds, helping to meet market demand while simultaneously enhancing water quality and soil health.

Berry crops grow in a wide range of habitats, covering the diverse environmental conditions in agricultural watersheds throughout the state. For instance, elderberry (*Sambucus canadensis*) and raspberry plants can grow in diverse habitats, including those found in buffer strips. Many berry crops feature widely spreading, shallow root systems which provide erosion control. These plants provide ecosystem services, such as food and habitat for wildlife and native pollinators, and reducing soil erosion while enhancing water and soil quality. These crops improve biodiversity on farms, diversify farmer profits, and increase availability of locally-produced berries.

Research Status and Goals

Investments made in faculty, post-doctoral researchers, graduate students, technicians, farmers, and sites support plant breeding, production research, and outreach on fresh market berry crops.

The overall goal of the fruit breeding program is to combine winter hardiness for northern zones with high fruit quality. This program has historically worked on a number of different species including strawberry, raspberry, blueberry, and currants. To date, the program has released eight blueberry cultivars, most recently “Pink Popcorn.” The strawberry and raspberry breeding efforts are smaller with three strawberry and two raspberry cultivars released over the last 30 years. Two black currant cultivars were released in collaboration with the Scottish Crop Research Institute in 2013.

Production research has focused on management practices to reduce weed, insect, and disease pressure, in addition to season extension strategies. The project on weed control has been ongoing for more than 15 years with a collaborative project among researchers on the University’s St. Paul campus, West Central Research and Outreach Center, and farmers interested in growing berries. This work is detailed in the ebook “Cold Climate Strawberry Farming,” a project funded in part by the Walmart Foundation. Weed control research has also been funded through USDA-SCRI, the Minnesota Department of Agriculture, and grower organizations. Insect control continues to be a challenge for berry growers. The latest insect to infest berry crops across the U.S. is spotted wing drosophila. Work on understanding the life cycle and control options at the University has been funded through USDA-OREI, USDA-NIFA, and grower organizations.

Pilot Studies

Pilot studies will focus on establishment strategies for perennial berry crops for use in the fresh and processed markets. For fresh market berries, we will identify farms representing diverse soil types around the state for demonstration plantings and to host field events for farmers in the area. We will work with these farmer collaborators to develop commercialization strategies for these fresh berries. For processing berries, we will identify collaborators with newly established buffer strips. We will establish perennial berries on each site, inter-planted with non-competitive, flowering cover crops. Treatments will consist of varying intensities of maintenance related to weed management, irrigation, and fertility. During establishment years, we will collect data on plant vigor, survival, and early production.

As plantings age, we will measure ecosystem services at each site. These results can be compared to buffer strips at similar sites that are planted in native grass or other control standards.

Commercialization Plan

Berry crops are primarily direct-marketed to consumers. With demand for locally produced berries increasing, there has not been an increase in market outlets or production. For example, in 2013 the annual per-person consumption of fresh strawberries in the U.S. was 7.9 pounds; Minnesotans only eat 0.72 pounds of strawberries from local sources on average each year.

With this demand, there is a market for berries in Minnesota. Currently, only 790 acres of farmland are dedicated to berry crops in the state, and an estimated 100,000 acres of farmland will be dedicated to buffer strips with the new Buffer Law signed in April 2016. If even one percent of that acreage is dedicated to berry crops, it would more than double the amount of local fruit available to consumers. We will continue to work with our partners to bolster berry marketing strategies for Minnesota farmers and increase awareness of locally produced berries among consumers.

Recent market studies in the U.S. have shown potential for specialty berries used in juices. However, U.S. production of these berries is low. An estimate of elderberry production in the U.S. is less than 1,000 tons, and in 2013 more than 95 percent of elderberry used in the U.S. was imported from Europe. To develop this type of market in Minnesota, equipment for juicing is needed. Established Minnesota wineries own juicing equipment and have expressed interest in using that equipment for other berry crops.



TIMELINE

2020 THROUGH 2024 AND BEYOND

In addition to ongoing plant breeding, production research, and outreach on fresh market berry crops, we will analyze costs and benefits of processing. Such an analysis will also allow farmers and processors to plan future decisions about value added juices. Significant long-run opportunities exist for processing berry harvests as dried, powdered and frozen ingredients for the functional beverage, alcoholic beverage and natural colorant categories, both domestically and for export.



Perennial Flax

A NEW PERENNIAL OILSEED FOR FOOD, FIBER AND HORTICULTURAL USES

Overview

Golden flax, a summer annual crop, has a long agricultural history in Minnesota. The University of Minnesota was active in flax breeding and research throughout much of the early to mid 20th century. The crop was in high demand and used to produce industrial products such as linen, linoleum, paints and protective coatings. By the 1980s, commercial interest in flax faded with the advent of petroleum-based or synthetic alternatives to flax products.

However, today we are seeing a growing interest in flax (*Linum usitatissimum*) primarily due to the health benefits of oils high in omega-3 fatty acids. Flax has the highest concentration of omega-3 in the seed oil of any cultivated plant (~50% of total oil is linolenic acid), and clinical studies in humans have shown that diets rich in flax seed oil result in improved cardiac health. The food industry uses golden flax as an ingredient in whole grain foods, breads, cereals, snack bars, and crackers.

Forever Green has been active in researching and breeding perennial flax species (*Linum spp.*) that provide a similar nutritional profile as golden flax, but also provide important ecosystem services as a perennial crop. Under agricultural management in Minnesota, some perennial flax accessions could be harvested twice a year (June, September), providing forage for pollinators at times when annual flax and other bee-pollinated crops are not flowering. Flax would work very well in buffer zones on Minnesota farms while also producing a high-value grain for sale. This combination of ecosystem services and a high-value grain product would make perennial flax a useful addition to Minnesota cropping systems. Perennial flax is unique because of its ability to also be an ornamental bedding plant and a cut flower crop. Vase life experiments have shown that several perennial flax species have an average vase life greater than 9.2 days, exceeding the minimum number of postharvest days for a cut flower. Many species of perennial flax are cold hardy and retain green vegetation late into the fall and begin regrowth early in the spring, retaining soil-water and stabilizing soils. Perennial flax has a long flowering period which often continues well after the first frost, making it a useful late-season food source for pollinators.

This project will enhance yield and quality for multiple end uses in Minnesota by working with our food industry and horticultural partners to realize the long-term potential of perennial flax and its derived products.



Research Status and Goals

We will study agroecology of perennial flax production and food and end use quality traits of perennial flax.

AGROECOLOGY

Activities: We are working with collaborating agronomists at North Dakota State University to determine appropriate production practices (especially weed control) for perennial flax that maximize value to consumers and producers, while optimizing environmental benefits. Two experiments were conducted in 2020 at field sites across Minnesota and North Dakota to determine optimal weed control for perennial flax. The first experiment compared several continuous living cover systems (organic), while the second evaluated herbicides (conventional). Food science research, in collaboration with food industry partners, seeks to find suitable grain and fiber characteristics for commercialization.

Outcomes: Develop best management practices for Minnesota producers to maximize yield and production of specialty food traits that are important for end markets and consumers.

BREEDING AND GENETICS

In Fall 2018, we added a full-time graduate student to conduct breeding research on perennial flax. Another graduate student began genomics research in 2020, along with a full-time research technician. They are supported by two faculty and one scientist.

Activities: The University has been conducting breeding activities for more than a decade on perennial flax species. Breeding efforts with these populations have produced lines that yield nearly 100 lb/acre more than the existing perennial flax ‘Appar’ (382 vs. 298 lb/acre) in one harvest, which is also about one-third of the annual flax yield in the region. With the addition of full-time graduate students, this program has been expanded to include promising lineages of perennial flax obtained from local collections, germplasm repositories, and our collaborators. We hope to: 1) further the improvement of yield and quality traits using recurrent selection of existing breeding populations of wild perennial flax from Eurasia and North America, 2) further the improvement of native Lewis flax (*L. lewisii*) using similar techniques to produce a cultivar with North American origins, high yield, and acceptable quality, and 3) develop ornamental cultivars of perennial flax suitable for the garden or cut flower market.

Outcomes: Provide superior germplasm to our agroecology, horticultural and food science partners to further our understanding of this new crop. Use these resources to help Minnesota producers integrate perennial flax into existing cropping systems.

COMMERCIALIZATION

By 2021, we plan to provide seed of a breeding line in large enough quantities to begin on-farm trials of perennial flax. No new equipment will be needed for many farmers, because standard windrowers and combines will be used for harvest. General Mills is already interested in evaluating selected germplasm for suitability in their natural foods product line. Particularly for southern Minnesota, developing a market such as this through the food industry in the Twin Cities appears to be the most promising route for commercialization. In the case of northwestern Minnesota, standard supply and value chains already exist for flax. Companies are already buying and marketing flax products from northern Minnesota. These producers can also access established networks in North Dakota and western Canada.

TIMELINE

2020–25 AND BEYOND

- Agroecology and food science research to prepare crop for large-scale production
- Breeding and genetics to improve yield, horticultural, and agronomic fitness while releasing new varieties
- Conservation of flax genetic resources in collaboration with USDA’s Germplasm Resources Information Network



Perennial Sunflower

A NEW POTENTIAL PERENNIAL OILSEED AND FOOD CROP

Overview

Annual sunflower (*Helianthus annuus* L.) is a valuable oilseed crop grown for food (oil), confectionery seeds and ornamental purposes. Forever Green researchers are breeding and developing a perennial sunflower for agricultural production that has the potential to provide similar end-use applications as annual sunflower, as well as new options for farmers to diversify their operations while improving profits and providing environmental benefits.

Helianthus tuberosus L., a tuber-bearing perennial sunflower species, is a prime candidate for the introduction of perennality into domestic sunflower. The overwintering tubers of the perennial sunflower are the key to its perennality and breeders are finding they can identify and select plants for good plant vigor, single stalk habit, and large head and seed traits with high oil and protein content. *Helianthus tuberosus* L. has been used to introgress, or transfer genes through hybridization and backcrossing, traits into *H. annuus* for nearly a century and has been grown as a specialty food tuber crop for many years.

Compared to annuals, perennial crops provide living ground cover for longer periods during the year as plants grow into the fall and emerge from dormancy early in the spring. Additionally, perennials do not require fall tillage and due to their extended growing season they take up more soil moisture, which decreases drainage and nutrient losses. For all of these reasons, perennial crops such as a perennial sunflower play an important role in protecting our soil and improving water use and quality.

The Forever Green breeding program is using two breeding approaches to create perennial grain sunflower; direct domestication of a perennial sunflower species (Rough sunflower, *H. divaricatus*), and genetic introgression of perennial habit from wild relatives into domesticated annual sunflower. Our team is combining traditional plant breeding with modern genomic tools to develop a perennial sunflower that is as productive as current commercial varieties but offers superior profit potential and ecosystem services for Minnesota farmers.

We envision working with sunflower growers and processors to further expand perennial sunflower production in Minnesota. As most of Minnesota's sunflower production is in the northwestern part of the state, we have developed close collaborations with the Sunflower and Plant Biology Research Unit of the USDA in Fargo, North Dakota. We believe that buffer zones around rivers, ditches, and well head protection regions provide an excellent opportunity for us to introduce this new perennial crop to landowners and provide new options for growers to protect their soil and water.

Research Status and Goals

Investments made in faculty, post-doctoral researchers, graduate students, technicians, and undergraduate employees support:

AGROECOLOGY

Best practices for growing, maintaining, and harvesting perennial sunflowers.

Activities: We will develop experiments to identify 1) optimum nitrogen fertilizer rates and row spacing for maximized grain yields, 2) how to best control the spread of clonal plants by belowground tissue, 3) optimal planting times for seed or rhizomes/tubers, 4) the number of years a stand should be maintained before it is replanted, and 5) the appropriate scale of genetic diversity (i.e. the number of clonal genotypes) to plant in given field. Following initial evaluations and the release of material, we will work with farmers to determine the environmental impacts of perennial sunflower, focusing on soil erosion and chemical leaching to groundwater.

Outcomes: Best management guidelines for perennial sunflower production, extension documents for addressing specific agronomic challenges, and scientific reports highlighting the environmental effects.

BREEDING AND GENETICS

Activities: The goal of the perennial sunflower program is to develop a high-yielding perennial sunflower with fertile seeds. Plants have been developed that are winter hardy, have single heads, but have limited seed set because of sterility issues. This limitation will be the focus of the breeding program in the near future. Toward this aim, researchers at the UMN have hybridized the annual sunflower, *H. annuus*, with cold hardy perennial species Jerusalem artichoke (*H. tuberosus*). Hybridizations are well underway and have demonstrated impressive gains in flower head size and seed size over five generations of breeding. We have identified a relatively simple genetic control for perenniality and aim to identify the genetic basis of other domestication traits, such as flower head size and seed viability, to increase the efficiency of selection and accelerate improvement. Current efforts focus on maintaining perenniality while increasing head size, and head filling and enhancing fertility and seed set.

Outcomes: Products from this research will include a perennial sunflower germplasm and ultimately a public release of perennial sunflower.

FOOD SCIENCE

Investments in technicians and materials will support our evaluation of the chemical profile of perennial sunflower seeds.

Activities: We ultimately aim to develop a perennial sunflower whose oil can be blended with, or used in place of, high oleic sunflower oil. Towards this goal, we will measure the seed oil profile of our perennial sunflower and compare it to commercially sold high oleic sunflower.

Outcomes: Evidence that perennial sunflower oil is comparable to high oleic sunflower oil, making this product an easy sell to vegetable oil companies and consumers. To the extent that perennial sunflower oil initially deviates from traditional sunflower oil, we will continue to select for oil composition that resembles that of annual sunflower.

Pilot Studies

Most of our work will be conducted at the University of Minnesota greenhouses and on the Minnesota Agriculture Experiment Station (MAES). As most of Minnesota's sunflower production is in the northwestern part of the state, we have developed close collaborations with the Sunflower and Plant Biology Research Unit of the USDA in Fargo, North Dakota and plan on testing experimental material in the Fargo/Moorhead area. We believe that state-mandated buffer zones around rivers, ditches, and well heads provide an excellent opportunity for us to introduce this new perennial crop to landowners. Depending on the success of the buffer zone plantings, we hope to work with sunflower growers to further expand perennial sunflower fields in Minnesota.

COMMERCIALIZATION PLAN

Market opportunities currently exist within the annual sunflower oil and birdseed market. As we further develop our material, we will contact sunflower oil companies and explore two options towards commercialization: 1) Blending perennial and annual sunflowers for a consistent oil, and 2) Branding perennial sunflower as a green, sustainable product for a specialty oil.

TIMELINE

We are currently advancing breeding material to achieve the outcomes outlined above. We plan to generate enough seed for larger trials in 2022, when we will also begin agroecology and seed oil experiments. By 2024, we plan to have material available for use as a trap crop to reduce bird predation in nearby commercial annual sunflower fields. We aim to stabilize the genome of this hybrid by 2022 and at that time deploy plants in buffer zones. This should allow for an initial set of experimental plants on farms by 2029.



Silphium, or Silflower

A PERENNIAL OILSEED CROP TO PROTECT WATER AND SOIL RESOURCES

Overview

Silphium integrifolium—also commonly referred to as silflower or rosinweed—is in the early stages of domestication to become part of a diverse, sustainable, and productive cropping system that will protect Minnesota soil and water resources by providing continual cover of the landscape and deep-rooted exploration of the soil. Silflower is a relative of annual sunflower and is a native forb in the tallgrass prairie region of the U.S. Prior work by our collaborators at The Land Institute (landinstitute.org) has demonstrated the potential of silphium as a new crop. Attractive features of the plant include relatively large seeds, a favorable nutritional profile as an oilseed, an upright plant architecture, and a robust root system. This root system can tap water and nitrogen deep in the soil, which enables these plants to tolerate drought and intercept leached fertilizer that would otherwise be wasted. Silflower also serves as a source of pollen and nectar to native pollinators and other beneficial insects.

To help this plant achieve its potential, we are using modern genome-empowered breeding methods to rapidly domesticate silphium to serve as a sustainable, perennial oilseed crop for the American prairie. As we improve this plant through breeding, we will identify best practices for growing and harvesting silphium and develop seed processing methods for commercial use.

Crop production research will be conducted on soils in diverse ecoregions of the state. Because silphium is especially well adapted to soils with drought potential, sites will include soils in the Anoka Sand Plain, where leaching of nutrients to groundwater is a problem. Additionally, silflower is being evaluated in the drier climate of northwest Minnesota, where most of the state's sunflower is produced. Research into commercial end-uses for silphium is in the early stages, but we anticipate a multi-purpose crop that can provide two or more of the following: food grade vegetable oil, sheep or cattle forage, honey bee forage, silage, or bioenergy. Because we are early in the breeding of this crop, we are keeping our eyes open to a wide range of plant traits and production systems that would contribute ecological, agricultural, and nutritional value to our food system.

TIMELINE

2020 AND BEYOND

- On-farm trial evaluations of improved populations and varieties
- Development of management guidelines for growers
- Integrate modern genomics/phenomics with current breeding program to accelerate the release of new varieties to farmers
- Optimize a protocol to accelerate breeding cycles and for rapid commercialization of elite selections
- Determine if yields decline or improve in monoculture stands after three years of perennial growth and what fertility or plant density management regimes may be required to sustain yield
- Analyze protein and oil quality profile and pilot small-scale production to increase supply of material for product research and development

Research Status and Goals

Investments made in faculty, post-doctoral researchers, graduate students, technicians, and undergraduate employees support:

AGROECOLOGY

We have investigated several important dimensions of agronomic practices for silphium including defining the optimal seeding date, level of nitrogen fertilizer application, and seeding density. Currently, we are looking into the potential for silphium as a dual-use crop, with livestock forage being an additional use.

Activities: Research is focused on the ecosystem services provided by silphium, and sustainable production of the plant. Research examining these ecosystem services provided by silphium include determining the plant's nitrogen uptake and the pollinator resources that silphium provides. To understand these services, we will quantify the nitrogen use efficiency of silphium and its ability to prevent nitrogen leaching into water systems, as well as measure the pollen and nectar produced by silphium flowers. Our goal is to develop management guidelines to maximize the plant's economic potential for growers while benefiting environmental health.

Outcomes: On-farm test plots with improved silphium varieties, a management and production guide for Minnesota growers, on-farm testing of silphium in cropping systems (monocultures and polycultures with native grasses), and management and economic recommendations for carbon credits/wildlife habitat.

BREEDING AND GENETICS

Survey the variation for agronomic traits and study their underlying genetics with the ultimate goal of developing an improved silphium variety adapted to Minnesota's climate and soil conditions.

Activities: We developed a diversity panel of more than 400 silphium genotypes, an organism's set of heritable genes that can be passed down from parents to offspring, planted in several environments. As we collect trait data and genotype the panel with genetic markers, we will identify traits important for breeding and develop models to predict traits to accelerate breeding. We have also assessed the effects of inbreeding to help us better plan how we make crosses. In parallel with developing our genetics toolbox, we are developing procedures to shorten the breeding cycle time by modifying the vernalization requirement and developing a micropropagation protocol to facilitate rapid generation of genetically identical individuals for trait evaluation and large scale seed production. These tools will be used to accelerate the breeding of silphium that will maximize its value in agricultural cropping systems. Lastly, our group is actively selecting improve silflower populations for variety or on-farm trials with growers. The ultimate goal is to produce silphium populations that will be released as cultivars for production in Minnesota.

Outcomes: Comprehensive genetic map, identification of genes/quantitative trait locus controlling important traits, and development and release of the first improved varieties.



COMMERCIALIZATION PLAN

In the short term, we will explore using silphium oil as a gourmet or specialty oil in select markets. We anticipate the production and sale of silphium oil for use as a salad oil or gourmet cooking oil, where it would complement olive, sesame, walnut, coconut, avocado and other specialty oils. There is precedence for a number of oils finding niche uses in these ways, where novelty and sustainability add value to the product.

In the long term, the major commodity goal for silphium domestication is food-grade vegetable oil to complement vegetable oils produced by annual crops such as soybean, canola, safflower and sunflower. The flavor of silphium seeds is very similar to sunflower seeds and the oil has a very similar fatty acid profile. As silphium seeds are protein rich, the byproduct of oil production, press cake, should be a valuable component in livestock feed rations. Whole seed is favored by wild birds and could be produced and sold in the organic/sustainable birdseed or poultry feed markets. Press cake will be marketed to organic dairy and hog producers.

FOOD SCIENCE

Optimize procedures for the extraction of oil and protein from silphium seed and compare the oil produced by silphium to other edible oils for various food applications.

Activities: Several protein and oil extraction methods will be evaluated for maximum yield and quality. Protein quality (amino acid composition and digestibility) and functionality will be assessed to determine potential usage in various food products. Additionally, dietary fiber and antioxidants in the defatted meal will be evaluated. Dietary fiber and antioxidants are desirable traits in the marketplace that promote the health benefits of this crop. These research efforts will provide valuable feedback to facilitate the development of new varieties and identify growing conditions to optimize seed quality.

Outcomes: Pilot-scale oil processing, first silphium oil served in a Minnesota restaurant, first bottled silphium oil for sale, guidelines for use of high protein meal, and commercial scale vegetable oil production.



Summer Annual Grains for Double Cropping

ANCIENT GRAINS FOR NEW MARKETS

Overview

Forever Green Initiative (FGI) researchers are investigating how summer annual grain crops can be integrated into Minnesota environments and crop rotations. These grains include sorghum, teff, buckwheat, pearl millet, Japanese millet, foxtail millet, and proso millet. One of the major challenges facing FGI is how to fit cover crops and winter annual crops into Minnesota's short growing seasons around corn and soybeans, both bred to be early-planted and late-harvested. Summer-planted grains can increase the FGI's scope for winter annual and cover crop development by providing a cash crop whose growing period complements that of the winter crops, allowing them more time to develop spring biomass or mature grain. This opens the door to double cropping, in which a winter grain—including the traditional winter wheat as well as newly developed pennycress, camelina, or winter barley cultivars—can be followed by a summer grain to provide two cash crops in a single year, a possibility which has previously proved difficult to achieve in our climate.

Summer annual grains like millet, sorghum, teff, and amaranth have become more prevalent in mass-marketed products and on restaurant menus. Additionally, there may be a price premium for summer annual grains if locally produced. The availability of high value summer-planted, short-season grain crops will complement the development of FGI winter cover crops. These cropping systems will provide ecosystem services and profitable double-cropping opportunities to growers, nutritious and culturally valuable local foods to consumers, and highly marketable ingredients to local food processing enterprises.

Each of these grains has a long and rich culinary and agronomic history, but none is currently well known in Midwestern farming systems. Consumers show increasing interest in including diverse grains in their diets for reasons including greater nutrition, unique flavors, gluten-free options, and the lack of GMOs. Many are consumed as whole grains and have even become prevalent in mass-marketed products, including crackers and breakfast cereals. Some, such as teff, are staple crops in the cultures of new immigrant groups, whose traditions are bringing new richness to Minnesota's food markets and culture.



Research Status and Goals

This project will invest in faculty, post-doctoral researchers, graduate students, technicians, undergraduate employees, and community collaborators who will assess the performance and marketability of these crops and determine how they can be managed to complement the growth periods of winter annual crops.

Activities: Multiple cultivars of each summer grain species will be evaluated at five on-farm sites and Minnesota Experiment Station Research Centers. We will evaluate weed competitiveness, maturity dates, standability, reaction to diseases, seed shattering, and grain yield. We will also conduct soil tests to determine the influence of these crops on soil nutrient status. We will measure nutritional content of the grains, and work with colleagues in food science, nutrition, applied economics, and other fields to explore their potential to fit into Minnesota's local foods markets and diverse culinary traditions.

Outcomes: Agronomic production guides, as well as cultivar recommendations for Minnesota's double cropping systems, with emphasis on traits such as improved yield, greater competitiveness against weeds, reduced shattering, and maturities consistent with double cropping with winter annuals.

Pilot Studies

We have recently conducted some small-scale evaluations of summer annual grains, particularly the different types of millets. We have been actively pursuing funding for more comprehensive research. We plan to conduct our agronomic trials in the southwest and south central regions of Minnesota, where the most intensively-farmed and least-diversified cropping land is located. Because in many cases these grains are unfamiliar, or familiar to only a portion of Minnesota consumers, we will incorporate tastings and cross-cultural culinary exchange into our field days, as well as planning cooking and tasting events in the Twin Cities area.

COMMERCIALIZATION PLAN

Organic, natural, and local food markets are the most likely targets for commercialization. We believe that alternative crop production must be advanced simultaneously with market development to reduce risks for producers. Thus, we will also identify local markets and develop a supply chain analysis for summer annual grain product entry into local and regional marketing channels. Our desired outcome is that local enterprise development will enable these locally produced crops to reach consumers who may be already seeking them out through ethnic markets as imports. We will also reach out to food processors, particularly those who are already engaged with the FGI's intermediate wheatgrass project, to gauge and develop interest in using these grains in high-value packaged products targeted to nutritionally and environmentally conscious consumers.





Winter Barley

AN ANNUAL COVER CROP THAT WILL SUPPORT
MALTING AND BREWING INDUSTRIES

Overview

Fall planting of barley (*Hordeum vulgare*) as a winter annual has many features that make it attractive to producers and end-users, particularly craft brewers, distillers and maltsters. Fall planting and earlier harvest in the summer gives growers additional options to integrate winter cover crops and realize important ecosystem services including limiting soil erosion, sequestering carbon as organic matter, providing wildlife habitat, and reducing nutrient leakage to surface and subsurface water reservoirs. Winter barley will typically have higher yields than spring barley in many regions, and earlier harvest may help avoid diseases such as stem rust and Fusarium head blight that can have a devastating effect on barley and small grain production in Minnesota.

Researchers are also investigating whether it may also be possible to double crop or relay crop winter barley with soybeans, enabling winter barley to potentially share some of the large soybean acreage in Minnesota. There is a strong demand for barley in Minnesota from malting companies (i.e. Rahr Malting, Shakopee, the largest malt production site in the world), a vibrant and diverse brewing industry (over 190 breweries), a rapidly growing distilling market, and consumers interested in local food and beverage production.

Spring barley has a long production history in Minnesota with over two million acres in the 1930s. While the current acreage of spring barley is less than 100,000 acres, there is a mature supply chain and a wealth of production knowledge that can be seamlessly transferred to winter barley. Currently, winter barley is not in commercial production in Minnesota. However, we have been conducting research over the past decade to develop barley as a winter annual crop that can produce high quality grain for the malting, brewing and distilling industries. In general, winter barley is less winter hardy than winter wheat or winter rye. Thus, a primary focus of our breeding and genetics research is to increase the winter hardiness of winter barley. This is being facilitated by studying the genetic and physiological basis of low temperature survival.

Research Status and Goals

AGROECOLOGY

Best management practices for producing spring barley in Minnesota are well established and production guidelines are easily available through Extension: extension.umn.edu/agriculture/small-grains. Many of these practices will be applicable to winter barley; however, additional research is being conducted that is specific to winter barley. Initial recommendations for winter barley in Minnesota are also available through Extension: extension.umn.edu/small-grains-crop-and-variety-selection/winter-barley-emerging-crop.

Activities: The timing of planting and seeding rate can be manipulated to optimize the number of plants that survive the winter. A planting date near Oct. 1 is optimal for southern Minnesota to maximize winter survival. Winter survival is also influenced by snow cover, so tillage practices that leave crop residue to trap snow will enhance yields of fall-sown barley. Maltsters prefer low protein barley so less nitrogen fertilizer and more efficient uptake of nutrients in the fall and spring will reduce nitrogen loss to the environment.

Outcomes: A Winter Barley Production Guide and risk mapping tools to help Minnesota producers successfully integrate winter barley into their cropping systems.

BREEDING AND GENETICS

The biggest obstacle to winter barley variety development is improving winter hardiness. Current varieties exhibit inconsistent survival during St. Paul winters, and cold temperatures and little to no snow cover present the biggest challenges.

Activities: To identify sources of winter hardiness, the University program has collaborated in the screening of over 2,000 accessions from around the world for survival in Minnesota winters and identified around 20 that are being used in breeding. We use genomics resources and new breeding methods like genomic selection to develop “facultative” barley, which is capable of surviving winters, but does not require the six-week cold period necessary to transition to flowering. Facultative barley provides flexibility for breeding and producers as it can be planted in the spring or fall. This will be important for seed production as seed increases can be planted in the spring to provide seed for fall planting. We currently have advanced breeding lines with improved winter survival and good malting quality that will soon enter industry testing.

FOOD SCIENCE

Many grain and malt characteristics determine the malting quality of a barley variety. New varieties must meet current industry standards to be utilized.

Activities: The barley breeding program works with the USDA Cereal Crops Research Unit and Rahr Malting to evaluate the malting quality of breeding lines. These laboratories process hundreds of samples each year from yield trials conducted across the state.

Outcomes: Advanced lines that are potential new varieties will be evaluated at a pilot scale by local brewers and in the American Malting Barley Association pilot studies, visit ambainc.org to learn more.

Pilot Studies

The University barley breeding program coordinates a national winter malting barley trial that provides useful information for variety selection. We will expand variety testing to additional Minnesota on-farm trials to provide similar information for our growers. We have initiated a dual cropping system experiment where soybean will follow winter barley in either a double or relay cropping system.

COMMERCIALIZATION PLAN

Barley is a significant U.S. crop with average annual production of 212 million bushels valued at \$894 million as a raw agricultural commodity (2004–13). The impact of barley on the U.S. economy is even more significant if the value-added products resulting from its utilization as an animal feed, in malt beverages, and in food products are considered. About 100,000 acres of barley are planted in Minnesota annually. However, as recently as 1988 more than a million acres were planted. New winter barley varieties that perform well in the field and in the malt house and brewery will easily find their way into the marketplace. The recent explosion in small craft brewers, over 190 in Minnesota alone, will create increased demand for locally produced malting barley. Publicly released varieties will be distributed through Minnesota Crop Improvement Association.

TIMELINE

Agroecology research in the next five years will establish solid guidelines for winter barley production in Minnesota. Ongoing genetics research will provide new selection tools that will be implemented in the breeding program as developed.

- Studies will quantify the potential of this summer and winter annual cropping system and be expanded to compare dual and summer cropping systems for soil moisture, total biomass, and nutrient loss.
- Data will provide information to quantify the value of environmental impacts.
- Breeding work to improve grain yields and develop new varieties.
- Winter barley variety candidates will begin to enter industry testing in 2022.
- Malting quality research will accompany breeding activities to assure new varieties fit end-user needs.
- Food science research to analyze food quality characteristics, benefits and applications.



Winter Camelina

A NEW SHORT SEASON WINTER ANNUAL
OILSEED CROP FOR USE IN DIVERSE ROTATIONS

Overview The University of Minnesota is a leading institution worldwide for developing new winter hardy cash cover crops. Winter camelina (*Camelina sativa*), which can be grown in the Midwest in conjunction with traditional summer crops like soybean and corn, is showing exciting potential as a new cash cover crop that can provide both ecosystem services and economic benefits to farmers in the Upper Midwest.

Industry is showing great interest in the wide range of end-use and co-product uses winter camelina provides, including healthy edible oils, biodegradable (plastic) packaging materials, lubricants, and biofuels. Camelina seeds contain about 36–45 percent oil with very high levels of α -linolenic acid, which is a heart-healthy omega-3 fatty acid, and tocopherol (i.e., vitamin E) that adds nutritive value. The oil is available for human consumption as well as for pet food and animal feed. The oil is also being researched for industrial biofuel and bioplastic products. The seed meal remaining after oil processing is a nutritious FDA-approved livestock feed that is rich in protein, essential fatty acids, and fiber. All of these products and uses equate to additional and appreciable economic returns for Midwestern farmers who grow winter camelina as a winter cover crop.

Winter camelina can be sown after harvesting crops like spring wheat or silage corn, or interseeded during summer in field corn, soybean, or sunflower. The emerged seedlings form rosettes in the autumn and

cover the soil surface prior to entering winter dormancy. As rosettes, they protect the soil surface from erosion caused by high winds, intense rains, and/or snow melt. Additionally, these rosettes absorb nearly all labile soil nutrients, like nitrates, in autumn and spring, thereby almost completely eliminating nitrate and phosphorus contamination of ground and surface waters. This keeps well water safe for drinking, and it improves the quality of water in our wetlands, streams, rivers, and lakes.

In spring as the rosettes bolt (elongate) to form flowering stems, summer crops like soybean can be interseeded into the camelina crop. The camelina plants continue to mature and flower as the soybean germinates and emerges. Camelina flowers throughout the month of May in Minnesota, providing large quantities of nectar and pollen to pollinators in early spring when little else is in bloom. Winter camelina seeds are harvested in June while the understory soybean plants are still short enough not to be damaged by the cutting bar of a conventional combine. The soybean continues growth after the camelina harvest and matures at the normal time in September.

The successful development of adapted winter camelina varieties and planting of those varieties in millions of acres across Minnesota and surrounding states has enormous potential to generate economic rewards for Minnesota farmers while simultaneously protecting soil health and alleviating critical water quality issues.

TIMELINE

2020–25 AND BEYOND

- Agroecology research to develop best management guidelines for winter camelina production and integration into Minnesota cropping systems and track long-term impacts of this new crop on the environment.
- New and improved winter camelina germplasm will be evaluated for improved seed yield and early maturity resulting in new variety releases specifically adapted to Minnesota's diverse cropping systems and environments.
- Partnering with interested growers and commercial stakeholders to scale up production, postharvest handling, storage, cleaning and processing.

Research Status and Goals

Investing in people, tools and research drives the mission of Forever Green Initiative forward.

AGROECOLOGY

Develop the tools and knowledge to successfully integrate winter camelina in Minnesota agriculture.

Activities: UMN and USDA-ARS researchers and other collaborators have demonstrated that winter camelina is cold and freeze tolerant and can be double- and relay-cropped with traditional food and forage crops such as wheat, sweet corn and soybean. Our team has shown that these dual crop systems are economically viable, require low agronomic inputs (e.g., fertilizer and water), and provide much needed ecosystem services including pollinator resources, soil erosion prevention, and soil nitrate-N scavenging to improve water quality.

Future research goals include a) improving management practices to enhance double- and relay- cropping opportunities and economics, b) piloting new cropping systems that employ other companion crops with winter camelina in dual crop systems, and c) fully evaluating environmental benefits of using camelina as a cover crop (e.g., suppressing herbicide resistant weeds, reducing phosphorus run-off, and enhancing the diversity and abundance of beneficial insects).

Outcomes: Best management guidelines for winter camelina production and integration into diverse rotation systems; Extension documents, field days and workshops to address challenges with winter camelina production; and scientific reports identifying the ecosystem services provided by winter camelina.

MORE INFORMATION:

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FOREVERGREEN.UMN.EDU

BREEDING AND GENETICS

Activities: The winter camelina breeding program, which was launched in 2016, is focusing initial breeding efforts on identifying high yielding, early maturing lines with improved winter hardiness. Future breeding targets include a) higher oil content, b) reduced glucosinolate content, and c) improved protein and meal quality. These traits will expand the range of food and feed products that can be made with camelina. Studies to evaluate camelina traits that will improve establishment and yield in relay-cropping systems are also in development. The camelina genome will be used as a guideline to identify the genes controlling these traits and develop improved winter camelina varieties using non-GMO techniques.

Outcomes: High yielding, early maturing camelina varieties adapted to the climate in Minnesota and the Upper Midwest with valuable commercialization traits such as improved oil and protein quality.

FOOD SCIENCE AND NUTRITION RESEARCH

Global demand for plant-based proteins continues to grow at an accelerated rate. In order for winter camelina's proteins to compete in this market, researchers must demonstrate that the proteins sourced from winter camelina are equivalent or superior compared to existing protein alternatives. UMN Food Science researchers are evaluating the functional and nutritional value of winter camelina, specifically its protein component. Work underway is multifaceted and requires a concerted effort between breeders and food and nutrition scientists. Specific objectives are: 1) Develop flavor-guided protein extraction methodology for optimal protein quality and yield following innovative approaches; 2) Screen lines for protein nutritional quality and functionality to develop optimal lines for food use. One camelina line will be selected for optimization of protein isolation

conditions. Wild type seeds and defatted meals will be subjected to two protein extraction procedures and extraction conditions will be optimized for extraction yield, purity, flavor, and functionality. Breeders will provide seeds from 5 camelina lines with potential variation in protein composition and profile and will be used to produce protein isolates following the flavor guided optimized extraction. Protein structural, functional, and nutritional properties will be determined. Generated data from this work will feed back into the breeding program to continue to develop camelina as an edible protein crop for food applications.

COMMERCIALIZATION AND PILOT SUPPLY CHAINS

Market opportunities for winter camelina exist with a range of regional, national and international companies interested in using the oil, meal and protein for food, feed, biofuel and bioproduct uses. Industry stakeholders are showing increased interest in winter camelina because of its winter hardiness and its ability to keep the soil covered during midwest winters. These partners are also interested in utilizing winter camelina cropping systems for sequestering carbon, reducing nitrate leaching and mitigating GHGs (greenhouse gas emissions) in their supply chains. Forever Green researchers are actively partnering with stakeholders to pilot large scale production acreages and supply chains of winter camelina. Plantings of several thousand acres will be strategically sited to maximize ecological services, including plantings on vulnerable well-head areas and important watershed regions. Additionally, these pilot supply chains will include investment in scaling up postharvest handling, storage, cleaning and processing. Importantly, research is also underway to study the life cycle of winter camelina production systems and gather more complete data on the ecological services a winter camelina cropping system provides.



Winter Pea/Spring Pea

DEVELOPING PEA FOR WINTER COVER AND ADVANCING MARKET OUTCOMES IN MINNESOTA

Overview

Dry pea (*Pisum stivum* L. *ssp. Arvense*) presents unique opportunities for Minnesota farmers to build soil health, protect water quality, reduce inputs and provide a high demand plant-based protein for food products.

Winter pea and spring dry peas are part of the pulse family of crops that also includes lentils, chickpeas and dried beans. Pulses are recognized globally as an excellent source of low fat, high fiber protein and are expected to play an increasingly important role in feeding a growing global population. Additionally, increased consumer demand for foods that contain plant-based proteins makes pea a potentially highly profitable spring-sown cash crop. For growers, winter pea is one of a very few annual crop legume species capable of surviving harsh winters and is thus a good candidate for winter cover cropping that may also increase profitability.

To meet these exciting opportunities, a pea breeding and genetics program was recently launched. A top priority for the team is identifying the best genetic plant material, or germplasm, that has survived other northern environments and thus could successfully overwinter in Minnesota. Researchers are also assessing the physiological mechanisms that support winter survival among species and are developing tools to more rapidly assess which plants are likely to survive Minnesota winters.

The UMN Food Science and Nutrition team will be working with both spring and winter peas to develop platforms that quickly and efficiently assess protein functionality in winter and spring pea varieties. This information will be shared with industry partners and stakeholders through the Plant Protein Innovation Center, a one-of-a-kind center based on the UMN St. Paul campus that brings together food and ingredient companies from across the world to share information and advance plant protein research and development.

The highly collaborative efforts between the breeders and the food scientists will enable and accelerate data-driven decisions for the breeding pipeline that facilitate variety development tailored for Minnesota growers.

COMMERCIALIZATION

The demand for protein ingredients surged over the last few years and the global protein ingredient market was valued at USD 38 billion in 2019 and is expected to grow at a rate of 9.1% from 2020-2027. With a growing interest in plant-based proteins, the market for plant protein ingredients is expected to reach USD 3 billion by 2029. There are multiple factors driving the demand for plant proteins and these include increases in the vegan, vegetarian and flexitarian populations, increase in consumer demand of healthy ingredients and foods, and the high demand for sustainable protein sources. Therefore, developing winter and spring pea varieties will benefit Minnesota growers and provide unique crop supply to ingredient companies.

MORE INFORMATION:

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[FOREVERGREEN.UMN.EDU](https://forevergreen.umn.edu)



Research Status and Goals

BREEDING AND GENETICS

Activities: Winter survival trials on a collection of pea accessions have been initiated in two Minnesota locations: St. Paul and Lamberton. The accessions tested in this trial were selected from within three different collections:

(1) Accessions from a preliminary winter survival trial being conducted by public sector researchers working on cover crops throughout the USA;
 (2) Advanced selections from the USDA pea breeding program in Pullman, WA;
 (3) Private sector accessions that have exhibited winter survival in other northern environments. This initial evaluation will establish a baseline of variation in winter survival in these collections, and provide insight into the potential to select for superior survivability. Genotyping diverse materials from a broader germplasm collection will also provide a basis for testing similar and diverse materials in subsequent seasons.

Outcomes: A breeding program will be developed by identifying the best current germplasm for Minnesota as parents for initial crosses. Early selections will be conducted based on identifying the most winter hardy progenies and advancing these to more extensive testing in subsequent years. The best parental lines will be identified based on winter survival of their progeny. These parent lines will be used more frequently as parents in future crosses. The development of breeding lines and ultimately new varieties will be conducted in subsequent years. However, if we find existing breeding lines or varieties in initial evaluations that are suitable for Minnesota growing conditions, those varieties will be promoted and used to bring winter pea into the Minnesota farming portfolio at an earlier timeline.

AGROECOLOGY

Activities: The development of winter and spring peas for Minnesota cropping systems will occur from an ecological perspective to develop products that are economically valuable and beneficial to the overarching ecosystem. To increase winter survivability, we will evaluate growing practices such as seeding depth and date to determine optimal practices for Minnesota. Next, we will evaluate companion cover crops, such as cereal rye, for their influence on winter pea survival and vegetative cover. Lastly, we will study and improve the present cropping system compatibility of winter and spring peas with established summer annual crops and newly developed perennial crops such as Kernza.

Outcomes: Pea is an environmentally friendly crop. First, as a legume, growing peas provides nitrogen credits to the soil. Furthermore, a successful winter hardy pea would reduce soil erosion and field water runoff in the spring, protecting both fields and our Minnesota waterways. Acquiring knowledge of optimal growing practices for winter and spring peas will improve grower profitability and the ecosystem services provided. It will also provide a contextual framework to guide the breeding program. Additionally, understanding the timing and nuances of pea production in relation to other Minnesota-grown annual and perennial crops will improve the function and productivity of sustainable cropping systems.

FOOD SCIENCE

Activities: Pea protein is gaining traction in the protein ingredient marketplace, however it is lagging behind soy protein in functional and nutritional quality. Hence there is a need to investigate ways to bring pea protein up to speed. First it is crucial to understand the impact of protein composition and distribution in pea on the overall functionality. Therefore, we will determine the impact of varying the proportion of pea storage proteins on functional and nutritional properties for enhanced breeding efforts. Storage pea protein components, namely legumin, vicilin, and convicilin, as well as the albumin fraction, will be separated and purified. Separated fractions as well as reconstituted protein isolates will be subjected to structural and functional characterization. We will utilize these wet chemistry-based data to model spectral information using infra-red spectroscopy to develop rapid means of screening many lines for protein quantity, protein profile (i.e. globulin protein distribution) and functional quality. Data generated will aid in determining the association between different pea protein components and functional properties, as well as identifying the optimal protein profile.

Outcomes: Understanding the association of protein profile and functional property will help with screening for pea protein cultivars that could potentially have superior functionality and nutritional quality, which could be used as parental cultivars in breeding for improved functional aspects of pea protein and not just yield. Additionally, the development of rapid method of screening will aid in rapid phenotyping for protein functionality traits in spring-sown pea lines. Identifying DNA molecular markers that predict the best functionality traits for a specific market class will further enhance the efficiency of breeding for this trait by cutting down the research time devoted to phenotyping efforts. Ultimately, this information will be used to release varieties desirable to Minnesota growers and food processors.



Woody Perennials

FOR BIOMASS FEEDSTOCK AND ECOSYSTEM SERVICES

Overview

Woody perennial biomass crops, such as hybrid poplars, are an important component of a comprehensive strategy providing a range of high-quality feedstock, or raw materials, for bioindustrial applications while offering significant environmental and ecological benefits.

Woody biomass crops are fast-growing with short harvest cycles (typically three to five years) providing a continuous, productive living cover for up to 20 years. Moreover, woody biomass crops are adaptable to a wide range of soil and climate conditions, allowing them to be planted on marginal land where annual crops do not grow well.

The challenge with woody perennials is providing a consistent and economically viable source of biomass that meets productivity and quality benchmarks. An alternative approach is to establish dedicated woody biomass crops in agricultural areas of the state where high density plantings in monocrop or mixed-species agroforestry systems can be used to provide a consistent source of biomass with known productivity and quality parameters.

Our overarching goal is to provide farmers, land managers, policymakers, and other end-users with information needed to design and evaluate integrated strategies that use woody biomass cropping systems to meet unique economic and environmental goals. This work offers a viable crop that can fit into a strategy aimed at optimizing profitability and sustainability through the use of continuous living cover.

Research Status and Goals

Investments made in faculty, staff, graduate students, Extension educators, farmers, and other program collaborators support field research, development of decision support systems, and education to ensure a profitable and consistent supply of biomass across a range of soils in a way that offers needed environmental/ecosystem services.

Activities:

We are evaluating yield and stability of 18 elite hybrid willow clones in southern Minnesota, as well as identifying any potential production risks from insects and disease that may reduce yield potential. We are evaluating the performance of willow varieties native to Minnesota when grown in high density biomass production systems. We are working with poplar to explore strategies for production of feedstock in support of bioproducts and bioenergy sectors. Our work has shown that integrating woody and perennial biomass crops in an alley cropping (agroforestry) strategy provides excellent total biomass yield potential, as well as nutrient scavenging capabilities that address water quality issues. Field research is also being conducted to evaluate the use of perennial woody and herbaceous biomass crops that support beneficial predator insects of soybean aphid to surrounding soybean crops while providing quality biomass feedstock. We are exploring the use of woody biomass crops as a living snow fence to keep snow off of roadways while providing added economic advantages through biomass production.

Goals include the assessment of woody perennial feedstock yield and quality across environments and systems. Although current work provides a basis for identifying the most efficient and productive willow and poplar cultivars, there is a critical need to expand this testing to include evaluation of the newest willow and poplar clones across the state. Specifically, we need detailed information about biomass productivity and quality across different environments, both regionally and locally, as well as across systems (e.g., monoculture versus alley cropping/agroforestry). For example, growers need to provide industry partners with custom-grown feedstock that meets very specific productivity and quality requirements set by a given end use (e.g., lower lignin content to improve conversion efficiency, longer fiber length for composite materials). By providing a custom-grown product, farmers and industrial partners will both benefit.

We also want to quantify ecosystem services provided by woody biomass crop production. Data related to carbon sequestration, nutrient uptake, water use, habitat for beneficial insects, and other ecosystem services need to be obtained on marginal lands across the state to help growers meet their unique environmental and production goals. This information is also needed to assign tangible values to environmental benefits provided by woody biomass crops on a regional and local scale. Reducing establishment costs and improving harvest efficiency associated with woody biomass crop production is essential to improving overall profitability and adoption. Developing local infrastructure, value chains and employment and income opportunities around the production, harvest, processing and transport of biomass and the subsequent conversion to bioproducts is critical.

COMMERCIALIZATION PLAN

Our goal is to use the Madelia Model along with research-based information to guide expansion of the biomass industry and inform future research efforts across the state.

TIMELINE

2020–2024 AND BEYOND

- Assess biomass crop production impacts on ecosystem services
- Measure biomass quality across environments and cultivars
- Determine optimal cultivar across environments
- Evaluate mixed crop/species agroforestry options
- Evaluate strategies for reducing production costs
- Expand CE2T website

Outcomes:

Increase awareness and knowledge about woody perennial biomass crops as a potentially viable way to obtain multiple values on the landscape, including both economic and environmental.

We recently established a new web-based biomass crop enterprise and environmental budgeting tool for biomass, forage, agroforestry, and annual crops, CE2T: ce2t.umn.edu. This tool calculates the break-even price needed to cover the costs of producing biomass from conventional and alternative feedstocks. CE2T describes a variety of biomass crops, including shrub willow and hybrid poplar, and various agroforestry design options such as alley-cropping. It also provides an environmental report, comparing changes in soil carbon storage and soil erosion between current management practices and future scenarios comparing both conventional crops and herbaceous and woody perennials.

We have worked closely with Rural Advantage, an NGO dedicated to addressing water quality problems in the Minnesota River Basin and linked to initiatives in the Mississippi River Basin. Many of those efforts are built around the concept of continuous living cover and getting more perennial crops on the landscape to address both water quality and water storage problems. Rural Advantage, in collaboration with several NGOs, state and county agencies, and companies in the private sector, developed the Madelia Model. The Madelia Model is an integrated effort to identify locations in the Madelia watershed where perennial crops for biomass for energy can be produced while optimizing the potential positive environmental impacts by sourcing biomass from environmentally sensitive areas and creating corridors for wildlife while storing carbon. The background information is available to move ahead with a project in Madelia once the economic conditions and policy support are amenable to development of renewable energy options.

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