Developing High-Efficiency Agriculture for Farmers, Rural Communities and the State of Minnesota

“A Forever Green Agriculture Initiative”

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- **College of Food, Agricultural and Natural Resource Sciences**
- **University of Minnesota Agricultural Experiment Station**
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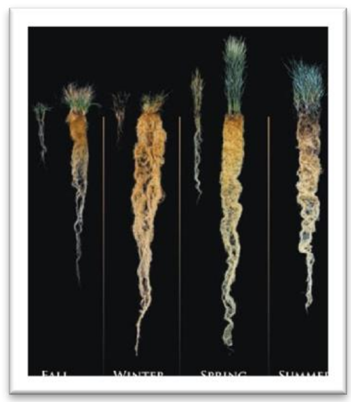


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Developing High-Efficiency Agriculture for Farmers, Rural Communities and the State of Minnesota

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Introduction. Minnesota has 27 million acres of farmland, occupying nearly half the 55.6 million acres in the state. Two highly productive and profitable crops, corn (8.7 million acres planted in Minnesota in 2012) and soybean (7.1 million acres) are the foundation of our agriculture, along with other important production systems such as animal agriculture, small grains, horticultural crops and others. The proposed initiative aims to build on these strengths by adding to the productivity and profitability of our current agriculture. Most of our current crops are 'summer-annuals' that are grown during the summer. By selectively adding winter-annual and perennial crops to our agricultural landscapes to create new crop production systems, we can enhance the prosperity of Minnesota agriculture, support rural communities, and provide major benefits to all Minnesotans. A strong base of evidence indicates that these new production systems will enhance yields of our summer-annual crops, enable production of new commodities, enhance our soils and wildlife, and improve our water resources. All of these benefits are possible because perennial and winter-annual crops are active during a large portion of each year, including many periods in fall, winter and spring when summer crops are absent. For this reason, perennial and winter-annual crops—working in tandem with summer annuals—can capture solar energy, water and nutrients with very high efficiency. Specifically, these production systems can:

- Diversify economic opportunities for Minnesota's farmers, through the production of new sources of food, feed, and high-value biomaterials, without interfering with current annual production systems;
- Improve the condition of vital resources including water, land and biodiversity;
- Enable abundant production despite climate variability and new pest and disease pressures;
- Enhance rural committees by creating new industries based on renewable agriculture resources- and employment opportunities; and
- Attract high quality talent to the University of Minnesota to meet the future workforce needs of the agriculture, food, energy and natural resource based industries in Minnesota.

These new production systems, combining summer-annual, winter-annual and perennial crops, use our precious resources of land, water and nutrients more efficiently than our current systems. For this reason, we call these systems **high-efficiency agriculture.** These high-efficiency systems are arguably the most promising vehicle by which we can rapidly improve the productivity of Minnesota agriculture, and its ability to withstand climate variability such as the drought of 2012. To realize the great potential of these systems, two kinds of research and development are critically needed: genetic improvement of plant materials, and development of new economic opportunities based on these systems. The University of Minnesota has significant strengths and ongoing efforts in both areas, providing the foundation for this initiative.

First, a focused effort is needed to rapidly improve the genetic quality of both annual and perennial plant materials that enable high-efficiency systems. These plant materials include cold tolerant annual species used as winter-annual crops, and perennial woody and herbaceous species. New breeding technologies can be used to make rapid improvements in these species.

To do so, breeding programs and associated agronomic research and extension programs must be expanded and intensified, as must be undergraduate and graduate education on breeding and management of these species. The University of Minnesota is well positioned to take these steps, with ongoing efforts in herbaceous perennial crops (perennial sunflowers, perennial flax, perennial wheat, forages and promising native species), winter-annual crops (pennycress, winter barley, hairy vetch, winter rye, camelina, winter pea) and woody perennial crops (willows, hazelnuts). The University of Minnesota is providing national leadership in new methods for breeding (e.g., the USDA's Triticae Coordinated Agricultural Project). Carefully targeted new investments will create a powerful program to develop improved genetic material and extension delivery system to develop high-efficiency production systems.

To make use of these new plant materials, it is absolutely crucial to create new economic opportunities that are based on production of high-value commodities such as oils and agricultural biomass from these new plants. These opportunities can produce new prosperity for farmers, landowners, and rural communities, but many barriers stand in the way. To overcome these, new 'incubators' are needed that focus on commercializing high-efficiency production systems based on these new materials, by linking effort and investments from private enterprise, government, NGOs and research institutions. The University of Minnesota is working to develop these commercialization incubators for creating new economic enterprises based on new crops.

Current University of Minnesota work on the high-efficiency agriculture initiative is focusing on a portfolio of highly promising options for improving Minnesota agriculture's productivity, efficiency and adaptability to variable climates. Here are brief profiles of these efforts:

Intermediate Wheatgrass is a perennial grass crop that can produce many different high-value products, providing economic opportunities that in turn support the environmental benefits that perennials provide. It produces large yields of seeds that are a high-quality substitute for wheat, while its dense root system and rapid regrowth after harvest build soil carbon, store water for later use, and prevent soil erosion. It can also be harvested for hay or biofuel and is highly tolerant of weather extremes, including droughts and intense storms.

Field Pennycress is being developed into a new winter-annual crop for corn/soybean farmers. It is planted after harvest of corn or soybean and resumes growth in early spring after winter dormancy. It provides crucial protection for soil during fall, winter and spring, and produces high-value oil and protein meal from unused fertilizer and water that would otherwise be wasted. As well, pennycress suppresses weed growth, reducing herbicide costs, and supports honeybees and other endangered pollinators. Overall, this crop is projected to produce $300 per acre in additional profit for corn/soybean farmers.

Winter Malting Barley has potential to serve as a cover crop and a high value crop that could be double cropped with soybeans in Minnesota. Current winter barley varieties do not consistently survive winters in Minnesota. Preliminary efforts to screen germplasm collections have shown that accessions with greater winter hardiness exist.

Perennial Flaxseed is a good example of the potential of natural products from Minnesota native perennials. It is an excellent source of omega-3 fatty acids, whose value as a dietary supplement is widely recognized, while offering the soil protection, habitat, and resource-use benefits of perennial crops. An emerging natural products industry, partially lead by Aveda, a Minnesota cosmetics company, is highly interested in sourcing key ingredients for many products from native and sustainably-grown crops.

Perennial Sunflower is an emerging perennial crop that can produce food oils that are highly valuable because they are free of trans fats, while also providing all of the benefits of perennial crops, including use of otherwise-wasted resources, soil protection, reduced costs, and better tolerance of droughts and floods that are predicted to become more common in coming years.

Hazelnuts are being developed into a new food and energy crop. Hybrids between native and European hazelnuts combine beneficial qualities of each. As a long-lived shrub, hazelnuts can fit profitably into many niches in the agricultural landscape. For example, farmers could gain significant revenue from hazelnuts grown as windbreaks, shelterbelts, and living snow fences. In addition to valuable nuts, mature hazelnuts can produce large yields of edible, heart-healthy oils or biofuel oils (doubling the yield per acre of soybean).

Willows provide a rapidly-growing woody perennial crop. As a small tree, this crop can provide many options for improving the habitat value of Minnesota landscapes, while providing all of the advantages of perennial crops and providing new bioproducts, including sustainably-produced construction materials and bioenergy. Grown and harvested on a three-to-five year cycle, willows can bring substantial revenue streams to farms that can support the environmental benefits that they provide.

Alders are woody trees and shrubs with the capacity to be grown on sites that cannot support traditional row-crop agriculture. Due to the symbiotic relationship alder's form with the nitrogen fixing bacterium *Frankiia alni*, the trees can be gown on low nutrient soils without the need for additional nitrogen inputs. The species naturally occur on wet margins and saturated soils, areas that are not typically farmed. As such, alders represent a potential bioenergy crop that will not compete with food crops for growing space on the landscape. Preliminary trials revealed three species with high survivorship in five diverse environments across Minnesota. These species will be the focus of future studies.

Kura Clover has a unique application in soil conservation and as a living mulch crop. We propose to promote use of Kura clover as a living but suppressed perennial sod into which corn or other grain crops is planted into strips killed with an herbicide. When the crop is harvested, Kura clover, which has spreading underground rhizomes, can regrow into the space where the corn was grown. The Kura clover can then be grazed in the late fall and following year.

As these examples show, the state of Minnesota and its land-grant university have the resources and capacities needed to become a national leader in high-efficiency agriculture. Our state has world-class resources of soil, land, water and climate. It is time to put these fully to work to help secure a better future for farmers, rural communities, and the state of Minnesota.

NOTES

Intermediate Wheatgrass as a Perennial, Multifunctional Food and Energy Crop

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We are developing intermediate wheatgrass (*Thinopyrum intermedium*), a perennial grass with the potential to produce food grain, biofuel, and forage as well as environmental services. The goal of this project is to increase yield of grain and biomass of Intermediate wheatgrass and enhance grain quality for food products through plant breeding and genetics in order to obtain a commercially viable perennial grain/biomass crop within the next decade. A multi-use perennial grain/biofuel/forage has potential to be transformative because it would allow crop residue to be harvested for biofuel or forage use while still building soil carbon and protecting the soil from erosion. The dense root system and rapid regrowth after harvest that is seen with perennial grasses ensures that the system is environmentally benign relative to annual grain cropping. If a grain–producing crop with the perennial habit were developed, these same environmental benefits could be achieved on grain fields. Furthermore, perennial grain and biofuels are likely to produce a win–win situation, where the dual harvest provides economic viability for the system, while supporting the environmental benefits.

Intermediate wheatgrass (IWG) has historically been used as a perennial forage, known for its winter hardiness and disease resistance. It can be crossed with common wheat and has been the source of important wheat genes for stem rust and barley yellow dwarf virus resistance. Domestication of IWG as a grain crop was begun by the Rodale Institute in 1989. The Land Institute in Salina, KS obtained the improved populations from the Rodale program and began a selection program for seed size, seed yield, and threshability in 2003. Two selection cycles had approximately doubled both Average yield per head and average seed weight, were approximately doubled with just two selection cycle, indicating that rapid breeding progress is possible in this species. IWG plots at the University of Minnesota were first established in the fall of 2010 and were expanded to three locations in 2012.

Grain Crop. Research thus far has shown that the flavor, nutritional and baking properties of IWG are potentially similar to that of bread wheat in many respects. IWG flour has been used pure or in blends to make breads, muffins and cookies with promising results. Different IWG varieties, blends, formulations and ingredient will be tested to achieve desirable flavor, texture and appearance. Large domestic food processing companies such as General Mills, Inc. have shown interest in developing businesses based on the use of sustainable practices. They have market data showing that customers are interested in spending their food dollars on products that will help the environment, and secure it for future generations. Understanding some key functionality attributes and flavor components of IWG to produce traditional cereal food products a vital if the dual use of this crop is to be realized. Farmers will be reluctant to plant the crop if there is not a strong market for the grain from IWG, and this market pull cannot be established unless the grain is well characterized and developed for food use.

Biofuel. The environmental benefits of perennial biofuel crops relative to annual grain crops are widely recognized: reduced soil erosion, reduced soil nitrate leaching, increased carbon sequestration, and reduced inputs of energy and pesticide. To avoid encroaching onto wilderness areas or lands growing annual grains for food, there are projections that dedicated biofuel crops must be grown on abandoned agricultural lands. We aim to develop an alternative by breeding IWG as a competitive perennial grain that can also be harvested as a biofuel or forage. As a biofuel, IWG has been shown to be a good alternative to switchgrass, a warm season perennial, for northern climates.

Breeding and Genomics Technologies. The field-based breeding effort will be accelerated by DNA marker technologies that are revolutionizing animal and plant breeding. The cost of markers and DNA sequencing are being dramatically reduced by new technologies, driving innovations and their application in breeding. DNA marker technologies allow breeders to more precisely identify important genes and assemble them in combinations to create superior crop.. These same DNA marker technologies have been applied to crops such as corn and soybeans by the major seed companies, but the technology is only now inexpensive enough for wider applications with new crops such as IWG. For example, a cost per unit of information is now less than a hundredth of what it was just two years ago. Genes regulating photoperiodism, semidwarfism, threshability, grain hardness, gluten proteins, and other traits specific to flavor and overall functionality that have been identified in other cereals can be applied to IWG to further inform and accelerate our breeding efforts.

Research Needs. Our specific short term objectives are to 1) Develop improved populations with greater seed size, seed yield, and biomass yield; and 2) Characterize advanced breeding lines for food applications, specifically focusing on flavor and functional qualities. These traits are necessary to make IWG a more attractive dual purpose crop option. Past results indicate that 5% annual improvements in seed size and yield are possible. Standard breeding methods will be complemented by modern genomics approaches that utilize rapid and newly inexpensive DNA sequencing technologies to make the most efficient improvements in these traits. IWG flour will be subjected to several trait measurements to assess the potential use in food applications and to provide feedback for the breeding program. Standard bake tests will be performed to assess starch and protein functionality. Additionally, proteins will be profiled and flavors will be characterized and correlated with overall performance in a food system.

Field Pennycress: A Potential New Short Season Winter Annual Oil Seed Crop for Use in the Corn/Soybean Rotation.

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Throughout Minnesota and the Midwest, large portions of the landscape do not have a living cover from the time of soybean, corn, wheat, or pea harvest in late summer and fall until these crops establish a canopy cover in June the following year. This lack of plant cover leaves the soil vulnerable to soil erosion and to the loss of nutrients. Soil erosion results in sediment loading of streams, and to the loss of nitrate-N through surface flow and leaching into surface waters which reduces fresh water quality and contributes to the development of the "Dead Zone" in the Gulf of Mexico. Many farmers have considered planting cover crops, such as winter rye, clovers, and tillage radish, into standing corn in the fall or following wheat, pea or corn harvest, to provide living plant cover during this period of time to reduce soil erosion and nutrient loss. However, to date, these cover crops have only been used by a limited number of farmers. Most farmers find that the cover crop options currently available are difficult to establish, not easy to terminate, can increase the risk of drought stress to the main crop, and do not directly contribute to the profitability of the cropping system.


Pennycress stand in late May

Double Crop. Field pennycress (Thlaspi arvense L.) is a native plant to Eurasia but has become naturalized throughout North America including Minnesota. It is a winter annual species, meaning it can be planted in the fall, survive over winter and flower and produce seed in the spring. Field pennycress is generally considered a weed but several companies, including SarTec of Anoka MN, are considering it as a viable source of oil for energy. In a corn/soybean rotation it would fit after the corn: it would be planted into standing corn or immediately after corn harvest, grow in the fall, go dormant in the winter and resume growth as the snow melts, then flower, produce seed and be harvested in time for no-till soybean planting. The pennycress seed can be marketed as an oil seed crop. The most productive University of Minnesota lines of pennycress currently produce about 1,500 lb/acre (25 bu/a) of seed with approximately 40% oil by weight with a composition that is suitable for conversion to biodiesel, aviation biofuels and other industrial products. It is estimated that a 1,500 lb/acre seed yield would produce between 600 lb of oil/acre (40% oil) and 500 lb/acre (32%) of protein meal. The addition of pennycress as a winter annual double crop has the potential to add an additional $300 profit/acre for corn and soybean producers.


Soybean crop following pennycress

Weed Management. Pennycress can also reduce the cost of soybean production by enhancing weed management. As a winter annual, it develops in the fall and covers the soil between corn harvest and soybean or other crop planting the next spring. Pennycress seedlings establish in the fall and have rapid vigorous growth early in the spring, thus out competing most spring weeds. The result is a reduction in weed populations of up to 98% at the time of pennycress seed harvest and soybean planting. This eliminates the need for an herbicide burn down treatment and the first post emergence herbicide treatment, resulting in a cost saving of $30/acre.

Insect Management Pennycress can also promote populations of beneficial insects, especially pollinators and crop pest predators. Nearly a third of the nation's honey bee colonies reside in MN, ND, and SD, yet these and many other beneficial insects are limited in this region by the low abundance and diversity of food sources in early spring, which can contribute to "colony collapse disorder." Pennycress begins flowering in April and early May when honey bee colonies are returning to the upper Midwest from states such as CA where they are used to pollinate almond orchards and other high-dollar value horticultural crops. Thus, pennycress can serve as a nutritious food source for honey bees and native pollinators in early spring. They also provide over wintering habitat for predatory insects, increasing their control of pests.

Breeding Program. Long-term funding is needed to support a pennycress breeding program that would develop pennycress varieties for use by Minnesota farmers. We will initially develop our pennycress breeding program based on 50 wild pennycress lines collected from Minnesota, Wisconsin, North Dakota, and on the 18 pennycress accessions present in the ARS Germplasm Resources Information Network (GRIN), including European accessions, to identify the range in flowering, physiological maturity, winter hardiness, oil quality and quantity, seed shattering, glucosinolate content, and seed size. Oil quality and quantity is good in this species, so the goal of this program will be to maintain or increase the oil traits while optimizing traits like early maturity, seed yield and size, and glucosinolate levels.

We are currently in the process of developing the molecular tools for pennycress that could be used to support a breeding program. We have recently entered a new era in plant breeding where it has become easier to identify and analyze traits and the genes underlying them, even in species without substantial genomic resources. The cost of whole genome sequencing has decreased 100,000 times over the last 10 years and it is now possible to quickly and inexpensively obtain whole genome sequences for candidate breeding lines. We have initiated a pennycress genomics program, and have already sequenced the genome of one pennycress line. The resulting annotated draft genome will be invaluable for identifying markers to rapidly maximize the agronomic potential of pennycress through traditional breeding.

Pennycress is closely related to the model species Arabidopsis and the oilseed crop Canola (*Brassica napus*). This close relationship is especially important because Arabidopsis has been extensively researched over the past 25 years. Through studies on Arabidopsis a fundamental understanding of the genetic mechanisms that control many aspects of plant development have been achieved. For example, we now know how flowering time is controlled, how plants control water loss and mineral uptake, how seeds develop and so on. Given the close relationship between pennycress and Arabidopsis it is expected that the knowledge gleaned from work on Arabidopsis will directly translate into rationale strategies to improve pennycress. For example, some pennycress seeds exhibit secondary dormancy, which can reduce the germination rate of seeds sowed in the fall and can lead to unwanted germination at other times of the year. In Arabidopsis, a mutation in a single gene prevents secondary seed dormancy without affecting other aspects of plant development; by manipulating this gene we can eliminate secondary dormancy.

Due to the vast knowledge of Arabidopsis, we are currently in the process of comparing the sequence of pennycress genes to those in Arabidopsis. The sequence similarity between Arabidopsis genes (with known function) to those of pennycress allows us to predict the function of those related genes in pennycress. We are currently devising a novel scheme in which we will use this information to identify mutations in every gene in pennycress without the need for use of recombinant DNA techniques used to create GMOs. Within our population we expect to be able to identify lines with beneficial traits such as the lack of the secondary dormancy, early maturity, high oil content, low glucosinolate content and shatter resistance. Using new technologies, these traits can rapidly be introgressed into pennycress lines using classical plant breeding. This will allow us to rapidly develop high quality pennycress lines ready for commercial production by Minnesota farmers.

This new breeding effort will be carried out as a collaboration among members of the Departments of Plant Biology, and Agronomy and the Plant Genetics at the University of Minnesota. The University of Minnesota Research and Outreach Centers in collaboration with University of Minnesota Extension Faculty as well as farmer’s fields will be used as research sites to evaluate the new pennycress materials as a relay crop in corn and soybean rotations.

Developing Economically Valuable Natural Products from Native Perennial Minnesota Plants

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Plants have co-existed with the microbial world and environmental pressures such as UV radiation for a very long time. Unlike motile animals, sessile plants cannot defend themselves by moving to ideal settings; instead they chemically synthesize a vast array of defensive molecules, to protect themselves and interact with their environment. These highly diverse and chemically complex metabolites are the source of many of the molecules that we use as medicines, and as preservatives in foods and personal care products. These "natural products" from plants are especially well suited to act as antimicrobials and antioxidants, because that is their biological role in plants. They may have better antimicrobial and antioxidant action than those synthesized in the lab because they are more chemically complicated and diverse than synthetics. Because of this, the company Johnson & Johnson, driven by market pressure, has recently pledged to replace synthetic materials with natural products in their line of baby products, with the expectations to expand to additional products. Minnesota native plants have been shown to be a highly promising source of untapped biologically active molecules. Extracts from these plants can be developed into safer, ecologically-conscious, consumer-supported preservatives to replace petroleum derivatives, formaldehyde donors, and parabens in personal care, cosmetic and packaged food products.

The past decade has seen increasing interest in the use of perennial crops. Biologically active natural products from native Minnesota plants are the type of marketable commercial commodity that can add value to a biomass crop. This development of plants native to Minnesota as crop species allows them to be incorporated into multifunctional agricultural landscapes. Many Minnesota native plants can be grown on steep slopes, river banks, and other marginal land not suitable for row crop production. There are many species that could co-exist with and enhance traditional row crops, such as corn and soybean, by attracting pollinators, beneficial insects, and increasing macro level biodiversity to decrease pressure from pests and diseases. These benefits specific to agricultural production would be in addition to the overall ecosystem services that the perennial plants would provide simply by being present on the landscape. Some of these ecosystem services include: carbon sequestration, erosion control, wildlife habitat, water filtration and stabilization, and many more.

Market Demand. There is a growing interest in environmentally-conscience products among consumers world-wide, as seen in the strong marketability of products branded "green", "natural", and "local". Companies are being pressured by consumers to use more environmentally conscious ingredients in their products; however, the basic research needed to fulfill demand for these ingredients is incomplete. Using Minnesota native plants extracts in products easily extends this highly profitable branding to them. Aveda, a high end cosmetic company headquartered in Blaine, MN, is currently interested in being able to source these natural preservatives from Minnesota for use in their products. Their tagline, to unite "the art and science of pure flower and plant essences" drives their goal to replace all synthetic and petroleum based materials with natural products. Although they are currently based in Minnesota, many of their natural products are sourced from faraway places such as the Nepal and India. This natural products outsourcing is taking away potential income from our local economy, **simply because we have not sufficiently invested local resources towards developing native Minnesota plants for these growing economic opportunities**.

Partnerships. Another player, the White Earth Indian Nation located in Minnesota has an interest in transitioning much of the land on their reservation from row cropping back to the traditional prairie in order to better fulfill the spiritual, nutritional, and environmental goals of the tribe. If high value natural products were harvested from these perennial plantings the result would be tangible benefits for our Minnesota economy as well as the environment and society, within the White Earth community and as a whole.

The University of Minnesota (U of M) is partnering with Aveda and the White Earth Nation to develop native Minnesota plant resources for use as natural preservatives in personal care and cosmetic products. Much of the research is being performed in Dr. Adrian Hegeman's plant metabolomics laboratory located on the Saint Paul campus of the UMN. This research mainly involves the extraction, isolation, and structural elucidation of compounds from plant extracts that are found to be active in bioassays testing preservative activity. The U of M is well equipped with state of the art instrumentation such as mass and nuclear magnetic resonance spectrometry and biological assay facilities to perform this research.

Nurturing Young Scientists. Not only is this instrumentation essential to getting the work done, but it also attracts young talent. A Fulbright Scholar from Bordeaux, France, has recently joined the project as a post-doctoral researcher and is helping to train a National Science Foundation graduate student fellow and others at both the U of M and at Aveda R&D. It is essential that the state recognizes that a meaningful investment in Minnesota native plants as potential crops will act to continually recruit highly talented researchers and industrial collaborations.

These scientists at the undergraduate, graduate, and post-doc level will perform research that will ultimately enhance our local economy while simultaneously building a highly skilled workforce for the future, a workforce that is not only technically proficient, but also holistically educated and prepared to lead us into a sustainable future both for our environment and our economy.

Research Needs. In order for natural products from Minnesota native plants to be developed as marketable commercial commodities large scale screening, isolation, and product testing efforts need to be expanded. Specifically, there are an ever increasing number of important biological targets with relevance to multiple industries in Minnesota and elsewhere, which require additional human and monetary resources to find naturally derived molecules for diverse purposes. Currently, an extensive library of diverse plant material is being sourced from different locations around the state. This library is being developed for high-throughput testing against a vast array of highly relevant targets. Additionally, resources must be made available to enable preliminary activities for development of plant germplasm for an agricultural setting such as pilot plantings to perform field test for harvest optimization and ecotype evaluation.

Most importantly, we need to be able to continue to attract highly qualified students and post-doctoral researchers to train and carry out this work. Because several aspects of the research is labor intensive, it requires a solid foundation of scientists working together in order to bring a potentially highly profitable product to the market. This product is of high impact since it results from activities that can enhance both the local economy and the environment. These benefits range from the production of perennial native plants on Minnesota farms and otherwise unusable land, to the final product by local companies. U of M is poised to be in the vanguard of this innovative field, where for the first time there is both market pressure and interest from large companies to use the research on these plants, many of which have never been looked at for this purpose, to carry products to market. The production of Minnesota native plants for use in the production of economically important natural products is an exciting and unique opportunity that, with state support, will lead to a profitable and sustainable future for our economy and our environment.

Development of a Perennial Sunflower for Oil Production

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This project aims to bring perennial sunflower crops into agricultural systems to allow farmers to diversify their operations, improve profits, improve environmental quality, and reduce inputs of labor and supplies. Existing perennial crops, such as alfalfa, protect against soil erosion and nutrient loss and improve water use efficiency. Fall tillage is not necessary during the multi-year lifetime of the crop stand. Perennial crops provide living ground cover for longer periods during the year than annual crops because the plants can emerge from dormancy early in the growing season and are in many cases less susceptible to fall frosts. During this extended growing season, plants take up soil moisture, which decreases year-round drainage line flow and loss of nitrogen, a vital plant nutrient, from the soil. Nitrogen from tile drainage contributes to the pollution of surface waters throughout Minnesota.

Commercial sunflower is an annual species that is grown in north-western part of Minnesota. It produces valuable seed oil that makes it profitable for farmers to grow. In particular, commercial sunflower has high-oleic and mid-oleic (also known as NuSun®) oil profiles; these oil profiles are important for the production of trans-fat free vegetable oil. The demand for NuSun® is mostly from processed food manufacturers such as Frito Lay. Additionally, the black-and-white seeded sunflowers are grown for the production of snack-type sunflower seeds. This is a particularly high-value market.

Our goal is to develop a perennial sunflower that is equally productive as the current commercial annual varieties, but offers superior profit potential and ecosystem services for Minnesota farmers. To achieve this goal, we are using conventional breeding methods that involve crossing commercial annual sunflower with wild perennial sunflower relatives. This strategy initially produces a hybrid offspring that is perennial, but is not as productive as the current commercial varieties. However, we have found that mating the different hybrid plants with one another in the next generation can generate offspring that maintain the perenniality trait, and also show improvement in terms of agronomic performance and productivity. Our hypothesis is that subsequent rounds of mating and selection within these populations will continue to drive our populations towards a perennial sunflower with an agronomic performance that is comparable to the current commercial sunflower varieties. To date, we have been using the species Helianthus tuberosus as the wild perennial donor, as this species is easily crossed with the annual commercial sunflower. In fact, H.

tuberosus has previously been used by sunflower breeders to bring in novel disease resistance traits. Given this history, we suspect that H. tuberosus may make an excellent species for introducing the perenniality trait as well.

Research To-Date. The wild perennial sunflowers were first collected in 2001 from the UMore Park, near Rosemount, MN. These plants were transplanted to the St. Paul Agricultural Experiment Station, and continue to live as a permanent collection in UMore Park. During the first phase of the breeding program, 18 wild H. tuberosus and three elite commercial sunflower inbred lines were used to develop an initial interspecific hybrid population (Hulke and Wyse, 2008). During the initial investigation of this population, we developed efficient methods to identify true hybrids and get multiple generations of crosses per year. Furthermore, we compared the relative diversity of the 18 wild parents to the diversity of the greater H. tuberosus germplasmin the GRIN (Germplasm Resources Information Network) collection, and investigated the relationship between traits that are important for plant improvement. We are confident that our breeding strategy is working, as our trait evaluations indicate that the populations continue to show improvement with each generation of mating and selection. Furthermore, recent work has shown that the genetics of perenniality (development of perennial organs) may not be complex, several studies have identified only a few quantitative trait loci (QTL) that are necessary for perennial organ development (Wang et al., 2009; Sacks et al., 2007; Hu et al., 2003). These findings give added credibility to the notion that it may be possible to incorporate perenniality traits into annual crops without completely disrupting the existing genetic composition of the species.

Future Direction. The goal of the U of M sunflower breeding program is to develop a perennial sunflower for production of oil while performing ecosystem services at the landscape level. In 2-5 years, the breeding program hopes to release an open pollinated perennial sunflower variety with seed yield 50-60% of annual sunflower and biomass yields equal to or greater than either parents. In North Dakota, South Dakota, Minnesota, and Montana, this released variety could be used as a trap crop to mitigate blackbird predation in commercial oilseed sunflower production. In 6-12 years, the breeding program hopes to release the first inbred perennial sunflower variety. This line will have all of the domestication phenotypes that make commercial sunflower a productive crop: it will meet standards for the oil market and serve as a basis for future production of perennial hybrid varieties similar to current commercial varieties. During this time we will determine if a perennial inbred is more productive than open pollinated synthetics. In 13-18 years, the breeding program hopes to produce the first perennial hybrid variety with agronomic performance similar to current commercial varieties. Such a perennial sunflower may be able to expand in the marketplace and become a viable alternative to annual oilseed hybrids due to lower input costs, a secondary market for biomass produced as by-product, and high oil yields. We project that continued plant breeding on these populations will lead to productive perennial sunflower varieties that will be released from the University of Minnesota Agricultural Experiment Station to Minnesota farmers.

Native and Hybrid Hazelnuts: A Potential Perennial Food and Energy Crop for Minnesota
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Two species of hazelnuts are native to Minnesota and the greater Midwest, the American and Beaked hazelnut (*Corylus americana* and *cornuta* respectively). These natives produce small but tasty nuts, are adapted to the extreme weather conditions of the region, and are tolerant or resistant to Eastern Filbert Blight (EFB), a fungal disease which threatens the European hazelnut (*Corylus avellana*), which is the basis of worldwide commercial hazelnut production. In contrast to the American species, European hazelnuts (also called filberts) produce high yields of large commercially desirable nuts, but are highly susceptible to EFB and are not hardy in Minnesota. Hybrids between the native and European hazelnuts combine the nut quality and yield of the European hazelnuts with the hardiness and disease resistance of the natives, and have potential as a new perennial crop for the Upper Midwest. Selected accessions of American hazelnut may have potential in their own right.

Hazelnuts on the Landscape. Long-lived woody perennials such as hazelnuts are likely to be foundation crops for diverse evergreen agricultural systems, with multiple ecological benefits. Their deep fibrous root systems hold soil in place and reduce leaching, thereby preventing soil erosion and protecting water quality, both from sediments and nutrients. They photosynthesize for a greater portion of the year than annual plants, thereby increasing carbon sequestration and supporting more resilient soil ecology. They also provide habitat for wildlife.

Because they are suited to both small and large scale production, hazelnuts can be fit into many small niches in the agricultural landscape. They add economic value to windbreaks, shelterbelts, and living snow fences (where their bushy growth form makes them especially valuable), wetland and riparian buffers, contour strips, CRP and other marginal land. They make it profitable for farmers to retire from annual agriculture those portions of agricultural landscapes that are least suited to it and which contribute the most to environmental degradation, such as steep slopes and areas prone to flooding. Because they are less sensitive to drought and flooding than annual crops, because they have lower requirements for tillage, fertilizers, and pesticides, and because the timeliness of most management practices is not critical, they enhance the resilience of farmers facing increasing uncertainty in the face of threats such as climate variability.

A Food and Bioenergy Crop. Hazelnuts have strong market potential: their nuts may be eaten directly, used as an ingredient in healthy processed foods, or pressed into oil with properties similar to olive oil, with both culinary and cosmetic uses. These markets are likely to grow as appreciation of the health value of tree nuts increases: they are high in heart-healthy monounsaturated fatty acids, vitamin E, thiamin and fiber. Another potential market could be as a renewable liquid fuel, because the oil has properties desirable

for biodiesel. Because the nuts average 65% oil, compared to 20% oil for soybeans, hazelnuts could potentially produce twice as much oil per acre as soybeans.

Challenges and Accomplishments. The major obstacle to adoption of hazelnuts in the Upper Midwest is lack of consistently high performing germplasm. Although hybrid hazelnut seedlings have been planted on more than 130 farms in this region (Minnesota, Wisconsin, Iowa, and the Dakotas) since the early 1990s, these have been almost entirely seed-propagated from open-pollinated stock. This means that that the superior genetics responsible for the outstanding yields found in some individuals are not consistently passed on to their progeny. A few progeny may be like their parents or better; however, most will be inferior. More uniformity and predictability is needed if hazelnuts are to become a commercially viable crop, and that can be achieved only through vegetative propagation. Moreover, evaluation of parent material for the currently available planting stock has not been replicated, and thus parents assumed to have outstanding characteristics may have been selected due to locally favorable environmental conditions rather than due to outstanding genetics.

Starting in 2008, researchers at the University of Minnesota (U of M), and their colleagues at the University of Wisconsin (UW), started work to improve hazelnut germplasm adapted to the region. They first identified the best individual bushes from existing plantings of hybrid hazelnuts in the region, then they propagated them by mound layering (a low tech method of vegetative propagation), and planted the resulting clones into five replicated performance trials for long term evaluation under controlled conditions. Nearly 120 accessions are now represented in these trials, with new ones added every year. In 2013, accessions of pure American hazelnut, selected from the wild over the past two years, will start to be added.

The oldest accessions are now coming into production, and in 2012 a few stood out as being better than the others. After about five years, those that have consistently high yields, and that have durable resistance to EFB, will be selected for mass propagation for release to growers as improved varieties with relatively uniform plant architecture, maturation date, and nut quality. The best selections will also be crossed with germplasm from the hazelnut breeding programs at Rutgers in New Jersey and at Oregon State, to introduce traits needed for even better varieties.

An essential component in the germplasm improvement work is development of commercially viable methods of mass vegetative propagation. The method that has been used to produce clones for use in the germplasm performance trials, mound layering, is relatively reliable, but highly inefficient, capable of producing only one or two dozen new clones per year. More productive vegetative propagation methods will be needed to produce enough clones of improved varieties to make a difference on the landscape. The most promising method is by micropropagation, which can produce thousands of new plants within a season. Researchers at UW are developing this method for wild hazelnuts. In 2012 a graduate student at the U of M started work to understand the physiological basis for why this method sometimes works and sometimes does not, so as to make it work more consistently.

One of the challenges of developing a new crop is that agronomic systems and technologies must be worked out concurrently with crop genetics and propagation. Much basic production information is unknown, such as optimal plant spacing, fertilization, weed control and pruning requirements. Some of these may influence determinations about genetics. For example, the best germplasm for dense plantings may not be the same as the best germplasm for widely spaced plantings. Initial attempts to answer these questions were confounded by variable genetics within research trials but, starting in 2011, enough vegetatively propagated material was available to establish replicated agronomic trials with the genetic uniformity needed for good research to address these questions.

Nowhere is the interaction between technology and genetics more apparent than in harvest and nut processing. For example, whereas European hazelnuts are trees and are harvested by sweeping the nuts off the ground below them, the hazelnuts grown in the Midwest are bushes (which have more value for windbreaks and erosion control than trees), and thus they have to be harvested by picking the nut clusters directly from the stems. Currently they are harvested by hand, but mechanization will be needed eventually. The design of picking machines may influence choices about such things as how strongly nut clusters are attached to stems. Likewise, shelling technology may determine what nut shell characteristics are most desirable. Whereas hazelnut growers have taken the lead on developing processing technology, researchers must consider the requirements of these technologies when selecting crop germplasm.

Yet another challenge in the development of a new crop is marketing. Some growers are currently marketing their nuts on a small scale directly to consumers, but larger markets will be needed if hazelnuts are to become important enough to benefit Minnesota's agricultural landscape. Yet larger markets are difficult to access without production volume; and it is hard to build production capacity without the income from marketing. The Minnesota Hazelnut Foundation, a group of key Minnesota growers, is considering possible cooperative marketing strategies to pool their production and access larger markets.

Research Needs. Our long term goal is to develop a hazelnut industry in Minnesota. To do that we need to 1) develop selected lines of hybrid and native hazelnuts with consistently high nut yield and desirable nut characteristics, including harvest and shelling ability; 2) develop commercially viable methods of clonal propagation; 3) develop agronomic recommendations for growing them; and 4) develop mechanical harvest and processing equipment as well as markets. Since a Strategic Planning Meeting of hazelnut stakeholders in October 2007, we have made progress towards this goal with a succession of small public grants. In 2011, a five year USDA-NIFA Specialty Crop Research Initiative Grant, split between Minnesota and four entities in Wisconsin, gave us a solid footing. But the long breeding cycle required for long-lived perennial crops such as hazelnuts (which require seven or eight years per generation) demands even longer term funding. The security of long-term funding would enable the U of M to hire additional staff dedicated to seeing the development of this promising crop through to fruition.

Developing Woody Perennials for Biomass and Ecosystem Services

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Potential for Use in a Multifunctional Agricultural System

Woody perennial biomass crops are an important component of a comprehensive agricultural strategy that provides high quality feedstock for bioindustrial applications. Woody biomass is a prime feedstock for generating steam to produce heat and electricity or in the production of biofuels and other high-value bio-based products. These crops include fast growing short cycle plants (typically 3-5 years) that can be continued over multiple cycles and plants that through association with soil microbes are capable of adding nitrogen to the soil. Moreover, woody biomass crops are adaptable to a wide range of soil and climate conditions allowing them to be planted in areas where annual crops do not grow well. The perennial nature of woody biomass crops also offers significant environmental and ecological benefits. This offers Minnesota farming systems the potential to improve economic vitality in rural communities while achieving broader public goals of clean water, reduced soil erosion and carbon sequestration. In order to take advantage of that potential, research is needed which will allow us to ensure a consistent, productive, and high-quality supply of biomass at a reasonable price across a range of soils in a way that offers needed environmental/ecosystem services.

Woody perennials can and have been used for: 1) provision of feedstock for energy and high-value bioproducts; 2) riparian buffers which protect our surface waters and stabilize stream banks by preventing erosion; 3) windbreaks that protect croplands from erosion and lower heating costs and energy use on farms and homesteads; 4) remediation of contaminated sites or as a filter for solid or liquid wastes; and 5) adding nitrogen to the soil to render it more agriculturally productive. When it is possible to combine bio-fuel production with high value, bio-based products the entire production system becomes more profitable and robust. In addition, woody biomass production reduces climate-changing atmospheric carbon in two ways: 1) renewable biomass fuels substitute for fossil fuels, and 2) unharversted roots and residues contribute to sequestered soil carbon.

These multiple benefits will be most readily obtained from an integrated biomass production system based on perennial crops planted in strategic areas of the landscape close to local and regional processing centers. Research is needed to develop reliable highly productive germplasm to support a comprehensive eco-industrial system that 1) integrates perennial crop production, processing and conversion technologies to create diverse high-value products, and 2) supports the use of low-value residuals for energy production in concert with other renewable energy sources.

Economic Potential
The emerging bioeconomy presents new opportunities for farmers to improve economic return and reduce risk through integration of a wide range of bioenergy crops into the farming enterprise. The economic prospects for woody perennial systems are improving with the growth of new bioproducts and bioenergy industries. Several businesses have supplemented their current energy needs with renewable sources of energy such as Rahr Malting in Shakopee, Chippewa Valley Ethanol Company, and the Virginia and Hibbing Public Utilities in Northern Minnesota that burn biomass to meet local energy demand. There is a need to ensure that these new initiatives to develop renewable energy options have sufficient woody feedstocks available at a reasonable cost to be able to meet the State's Renewable Energy Mandate.

Current Work with Promising Woody Perennials
Hybrid poplars have been subject to much production research and genetic improvement over the past several decades. However, most of the genetic improvement work has targeted paper/timber production in northern Minnesota. Recently, there has been an effort to expand the genetic improvement program to include southern Minnesota with a focus on the production of biomass to support bioindustrial sectors. U of M agronomists and foresters (NRRI group) are collaborating on several field trials to evaluate new genetic lines of poplar in southern Minnesota.

Hybrid willow is just now being established in Minnesota as a raw product for the bioenergy sector. Most of the genetic work for willow in the U.S. is being done at SUNY in Syracuse, NY. Genotype performance is often location specific; thus the U of M is collaborating with SUNY Syracuse to conduct trials across Minnesota to evaluate genetic performance of willow clones from New York. Efforts are currently underway to begin introducing native willow genetics into highly productive hybrid clones to enhance their long term resilience. U of M researchers and Extension are also working to develop production strategies that fit with the soils and climate of Minnesota, reduce establishment costs, and improve harvest efficiency to increase overall profitability.

Native and introduced alders are also being evaluated for biomass production. A trial of thirteen alder species in five diverse, non-agricultural sites in Minnesota revealed three of the species to exceed 90% survival at all five sites. On a low-nitrogen site with coarse sandy soils, these three alder species demonstrated biomass production that exceeded that of all other materials in the trial, including commercially available poplar and willow selections. Future alder research will focus on these three species.

Our group is also exploring ways that perennial bioenergy crops can support biological control services to surrounding food crops. For example, we are conducting field research to evaluate perennial woody and herbaceous crops as habitat for beneficial organisms to keep soybean aphid, a devastating soybean pest, in check. Finally, U of M Extension has established a program to educate farmers and other land managers about the benefits of woody biomass crops and how to grow and manage these crops for various end uses.

Research and Development Needs.

In order for woody perennial biomass crops to become economically sustainable, we need to be able to provide industry with custom-grown feedstock that meets very specific requirements set by a given end use, such as lower lignin content to improve conversion efficiency, or longer fiber length for composite materials. By providing a custom-grown product, farmers and industrial partners will both benefit. In addition, for less well known woody crops such as alder, efficient cropping systems will need to be developed that take into account nitrogen budgets altered by the species nitrogen fixing capacity. Research needs to be conducted regarding the potential to us alder as a nurse crop with other woody species on low fertility sites. Other uses for woody crops such as extracting natural plant chemicals and increasing carbon storage should also be considered. Support is needed to conduct research that considers woody crops as: 1) a feedstock for multiple and highly valued products and 2) a potential solution for sensitive environmental and ecological issues. A site-specific approach to biomass crop placement is paramount. We hope to develop knowledge-based decision tools that can be used by farmers and other land managers to design cropping systems that meet market demands for food, fiber, and biomass, address critical environment issues (water quality, soil stabilization, carbon sequestration, nitrogen budgets and wildlife habitat), and optimize profitability (multiple high value profit centers). We believe that industry will provide even greater efficiencies by creating small regional processing centers that take advantage of unique feedstock characteristic inherent in a given region thereby increasing efficiency and diversifying industry presence across the state.

Key to the success of these efforts will be a robust program of woody germplasm development and improvement to guarantee highly productive planting material adapted to diverse Minnesota conditions with the specific characteristics that the industry will require**.**

Managing Grasslands for Biomass and Environmental Services on Underutilized Farmland

Jacob Jungers, Conservation Biology Graduate Program; Clarence Lehman, College of Biological Sciences; Donald Wyse, Craig Sheaffer, Agronomy and Plant Genetics. University of Minnesota.

Biomass from mixtures of perennial grassland plants can be harvested annually as a source for bioenergy production; a new source of potential income for rural Minnesota. Grassland biomass can be grown on underutilized farmland, land which is not suitable or economical to grow commodity crops. Therefore, grassland biomass can serve as a source of revenue for farmers on land that has been considered marginal. Reestablished native grasslands provide a number of additional environmental services besides biomass for renewable energy.

1. Grassland biomass stabilizes soil and prevents wind and water erosion.
2. Grassland biomass intercepts nutrients from runoff, therefore protecting natural waters.
3. Grassland biomass provides habitat for wildlife.
4. Grassland biomass provides resources for pollinators and enemies of crop pests.

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, water, and providing habitat with perennial cover. A self-sustained grassland bioenergy system can lead to growth and prosperity for rural Minnesota.

Past research and accomplishments. State and federal funds have supported UMN research on grassland biomass in experimental plots and farm-scale studies across Minnesota. We have learned how to measure the energy potential of grassland biomass in terms of liquid fuel, direct combustion, and alternative energy production systems, including gasification and anaerobic digestion. We know what traits make a grassland biomass system more suitable for certain energy conversion technologies, and now we are ready to learn how to grow mixtures of plants that maximize those traits for the most economically viable system.

Much progress has been made on measuring the environmental services from small-scale (less than 1% of an acre) grassland plots. There is still uncertainty as to how the results from small-scale plots translate to large-scale fields (more than 20 acres). Some studies are underway to explore how wildlife responds to biomass harvest, but even these studies are limited by size and time.

Needs and objectives. A better understanding is needed to learn how to quickly establish grassland biomass for specific energy conversion needs. What species should be included to boost biomass yields during the early years of establishment, and what species should emerge during later succession to further improve yields as the stand matures? Also, we need to learn how to identify methods to economically and effectively convert abandoned pastures into high-yielding grassland biomass systems. What agronomic practices should be used to prepare old pasture fields and what species should be added to those fields to improve productivity?

Many logistical and biological challenges relate to the handling and storage of biomass for bioenergy needs. What is the best way to store biomass for the producer: chopped, pelleted, or as whole bales? What form is most efficient for converting to cellulosic ethanol, co-firing with other products for electricity, or for mixing with livestock effluent for anaerobic digestion? These questions can be answered using production-scale research and will help advance a local, sustainable bioenergy industry.

Long-term and large-scale planning. To build upon the foundation of our knowledge in grassland biomass, the next phases should be set up as long-term projects on large-scale fields. For instance, projects that are 40 acres or larger could provide useful information about how grassland biomass systems interact with other components of the environment at a landscape scale. Also, cost-benefit analyses are lacking for large-scale projects. These projects can serve as potential models for producer systems. Long-term monitoring of existing and future projects will allow planners to initiate new, and adapt current projects to maximize grassland biomass production.

Developing Cover Crops for the Major Cropping Systems of Minnesota

Craig Sheaffer, Nancy Ehlke, Paul Porter, Donald Wyse, Agronomy and Plant Genetics, U of M; John Baker, USDA-ARS, St. Paul, and Debra Allan, Soil, Water and Climate, U of M

Cover crops are crops that are grown to provide soil coverage during seasons when a crop is not actively growing. Cover crops are useful management tools for enhancing the sustainablity of agroecosystems and reducing negative environmental impacts in the corn and soybean system. Cover crops have potential to decrease soil erosion, provide green manure for incorporation and to produce bioenergy, forage or grain for harvest. Cover crops also improve agroecosystem functioning by recycling nutrients, improving soil structure, increasing soil organic matter, suppressing weeds, and disrupting pest and disease cycles. Cover crops play a unique role in remediation of excess soil nitrogen that can damage water quality by taking up water and nitrates from the soil in the late fall and in early spring when substantial amounts of nitrogen leach through the soil. We will present both annual and perennial crover crops solutions. Winter annual cover crops lengthen the "green phase" of a corn-soybean croppping system by growing in the months between harvesting and planting. We have ongoing programs on five annual cover crops: winter barley, winter peas, hairy vetch, winter rye, and brassicas, and one perennial cover crop: Kura clover.

Winter Barley - A High Value Winter Cover Crop

Spring barley has been grown historically in Minnesota as a high value crop to provide grain for the malting and brewing industries. Acreage of spring barley has declined dramatically in recent decades due to increased risk from diseases and competition with other crops such as corn and soybean. Winter malting barley has potential to serve as a cover crop and a high value crop that could be double cropped with soybeans in Minnesota. Current winter barley varieties do not consistently survive winters in Minnesota. Preliminary efforts to screen germplasm collections have shown that accessions with greater winter hardiness exist. Ongoing research to define the optimal planting window for winter barley have shown that planting in early October provides better winter survival and would accommodate typical harvest of a prior soybean crop. Current winter varieties mature in early July, however, some winter barley accessions mature much earlier. The proposed scenario would be to plant winter barley in the fall after soybean harvest and harvest winter barley crop mid to late June to allow for late planted soybeans. The potential combined income from the two high value crops would likely compensate for the lower yields that would likely occur for each crop independently in a double cropping system, however, research to address this question is needed.

Four years ago the University of Minnesota established a winter barley breeding program to develop new varieties with improved winter survival. This effort has involved screening large collections of germplasm for winter survival and using them as parents in breeding. In addition, we are developing and testing methods that use genetic markers to accelerate the rate of trait improvement. Farmers and the malting and brewing industries in Minnesota would benefit from expanded agronomic and breeding research effort to add winter barley production into our current cropping systems. Specific research objectives would be: 1) Determine optimum management of a barley- soybean double cropping system; 2) Increase the scale of the existing breeding activities; 3) Develop marker-based prediction models for agronomic, malting quality, and winter survival traits to implement in selection; 4) Expand field based testing to include more locations in Minnesota to better identify new adapted and highly productive winter barley varieties.

Winter Peas - A High Value Winter Cover Crop

Winter pea has potential for dual use as a winter cover crop and as a high value food crop.

Current cultivars lack sufficient winter hardiness to consistently survive as a winter annual in the Midwest. A Minnesota cropping system use scenario would consist of peas being planted during September and harvested for grain the following June. Following pea harvest, corn would be planted. Austrian winter peas, often referred to as 'black peas', have been produced in the Pacific Northwest as a green manure and for mature dry seed production since the 1930s. The USDA-ARS Grain Legume Genetics and Physiology Research Unit at Pullman has been developing improved breeding lines with greater winter hardiness for their climate and higher food quality.

The University of Minnesota has established collaborative relationships with pea breeders from the USDA-ARS and North Dakota State University to evaluate plants for testing in Minnesota. However, our ongoing experiments have shown that plant materials developed by these programs have only a moderate level of winter hardiness and inconsistent winter survival. Minnesota farmers would benefit from the establishment of a dedicated winter pea breeding program, which could provide lines adapted to the state's unique conditions including winter temperatures, snowfall, spring freeze and thaw cycles, and soil moisture patterns. Specific plant breeding objectives for a winter pea breeding program involve identifying winter pea germplasm that: 1) has sufficient winter hardiness to consistently survive winter conditions, 2) has increased biomass production, 3) nodulates and has a high potential to fix atmospheric nitrogen in the fall and/or early spring, and 4) has early maturity to allow double cropping of corn or soybean after pea seed harvest.

In addition, agronomic research is also needed to reduce the risk of planting winter peas for growers.

Our research has shown that winter hardiness in pea is highly sensitive to time of seeding. Survival also depends greatly on snow cover, which is increased by the presence of stubble or other plant material that can hold snow in place over the course of the winter. Agronomic research objectives include 1) determining which areas of Minnesota are most suitable for winter pea production, 2) establishing recommendations on timing and methods of planting, and 3) determining suitable methods of providing cover to catch snow, including no-till planting into stubble and intercropping with other fall-planted cover crops.

Hairy Vetch - A Traditional Legume Cover Crop to Improve Modern Crop Rotations

Hairy vetch is an annual legume that has been used as a winter annual cover crop. It is unique in that it is the only legume that can be fall seeded and reliably overwinter in Minnesota. In addition to providing winter cover and reducing soil erosion potential, hairy vetch can capture and fix nitrogen for subsequent crops through biological nitrogen fixation. A use scenario for hairy vetch consists of planting it late in the summer in standing crops or late in the fall following corn and soybean harvest, killing regrowth in the spring, and planting a grain crop in the spring that requires high nitrogen fertility. In our ongoing research, we have selected Minnesota ecotypes for increased winter hardiness. However, there is a need to enhance this initiative and develop a breeding program with the objectives being 1) to select for additional reliable winter hardiness to allow for later planting dates in October and November after soybean and corn harvest and 2) to select for earlier maturity in the spring.

Winter Rye - Using a Traditional Small Grain Cover Crop to Improve Modern Crop Rotations.

Winter rye grain is an excellent winter cover crop especially in the upper Midwest because of its winter hardiness, ability to scavenge nitrogen and sequester carbon, and ability provide effective ground cover in the fall, winter and early spring. It is the only small grain with sufficient winter hardiness to reliably overwinter in Minnesota. In addition rye herbage contains chemicals that upon decomposition suppress the growth of weeds. A use scenario for winter rye consists of planting it in a standing crop in late summer or late in the fall following corn harvest, then killing the regrowth in the spring, and planting a crop with low nitrogen requirements like soybean in the residue. Unfortunately, there has been no recent variety development of winter rye varieties and all commercial varieties mature in late June nearly a month later than the recommended soybean planting dates. The objectives of the winter rye cover crop breeding program are to develop varieties that: 1) flower earlier in the spring to allow earlier seeding of the subsequent crop, and 2) have increased early season biomass (by May 15) compared to existing varieties.

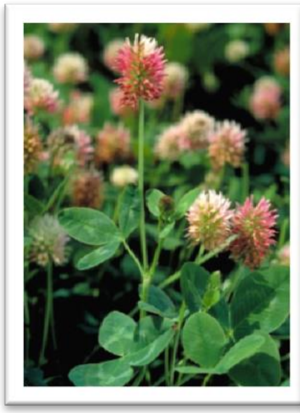
Brassicas - A Traditional Non-legume Cover Crop to Improve Modern Crop Rotations

Brassica cover crops include radish, turnip, mustards, and winter rape or canola. They are fast-growing, deep-rooted, and excellent nitrogen scavengers. Their rapid growth and high protein content means they have great potential for use as an emergency forage. Spring canola is also grown as an oilseed crop. The University of Minnesota has tested brassica cover crops over the past two years in partnership with Michigan State University. Radish and mustards winterkill in our climate, which makes them well-suited for situations in which an overwintering cover crop is not desired. Winter rape and turnip showed some ability to overwinter in variety trials conducted in St.

Paul over the past two winters, but do not overwinter reliably. A use scenario for brassicas consists of planting them in late summer following a processing vegetable or small grain crop or into a standing grain crop, grazing them in late fall, allowing them to winterkill or killing the regrowth in spring, and planting corn and soybean. There is a need to develop a breeding program to select for improved forage quality and increased winter hardiness.

Kura Clover - Living Mulch for Corn and Livestock Production Systems

Kura clover is a rhizomatous, perennial clover that has shown considerable promise in the north central United States as a long-term alternative to other short-lived legumes. Kura clover is remarkably persistent and can withstand extreme environmental conditions including drought, water logging, and cold. It can also tolerate a wide variety of defoliation intensities. First introduced to the United States in 1911 from the Caucasus region of Europe/Asia for use as a honey crop, Kura clover has shown superior yield, persistence, and forage quality under a diversity of grazing systems and livestock. Kura clover also has unique applications in soil conservation and as a living mulch crop. We propose to promote use of Kura clover as a living but suppressed perennial sod into which corn or other grain crops is planted into strips killed with an herbicide. When the crop is harvested, Kura clover, which has spreading underground rhizomes, can regrow into the space where the corn was grown. The Kura clover can then be grazed in the late fall and following year.



The Minnesota Kura clover breeding program has selected germplasm for a diversity of traits related to forage and cover crop utilization. These include seedling vigor, early flowering, forage yield, plant architecture, and spreading ability.

However, inadequate seed supplies remain a significant limitation to widespread use of Kura clover. We propose to expand our plant breeding program using our improved populations with the objectives being to 1) improve seed yield and 2) to increase the harvest ability of the seed with improved ease of threshing.

Developing Forage Grasses and Legumes for Grazing, Forage, and Duel Use Systems. Nancy Ehlke, Craig Sheaffer, Donald Wyse, Department of Agronomy and Plant Genetics, and JoAnn Lamb, USDA-ARS, St. Paul.

About 25% of Minnesota's cropland acres are grasslands on which perennial grasses and legumes are grown. Grasslands are truly multifunctional, providing food and fiber for livestock and humans and multiple ecosystem services if properly managed. These ecosystem services include soil erosion control, water remediation, wildlife habitat, soil fertility improvement, and carbon sequestration. Grasslands have potential for new uses to meet evolving societal needs including cellulose production for conversion to biofuels, and carbon sequestration to mitigate atmospheric C increases. In addition, there is an increasing consumer demand for meat and dairy products from organic and grass-fed animals because of health benefits to both livestock and humans.

Grassland species in Minnesota that have been traditionally harvested as forage include cool season grasses and legumes. Traditionally-used cool season grasses include smooth bromegrass, orchardgrass, and timothy. Cool season legumes that are grown in pure stands or mixtures with grasses include alfalfa that is grown on over 1 million acres annually; red clover that is a replacement for alfalfa on acidic soils; and white clover that is used in pastures. Native warm season grasses that dominated the prairies prior to settlement are used primarily for restoration and conservation purposes. These include big bluestem, switchgrass, and Indiangrass, in addition to a diversity of perennial forbs.

Unfortunately, there has been a long-term trend for a decrease in grassland acreage. This trend is associated with a decline in diversified farms with livestock enterprises and the growth of acreage of annual crops like corn and soybean. However, in the coming years, we have an excellent opportunity to increase the grasslands in Minnesota. This will occur because of public concern about environmental degradation; increased costs of concentrate feeds fed in confinement livestock operations, and increased consumer awareness about the benefits of meat and milk produced from grasslands.

Research needs:
While there are many grassland species that have been used for production of livestock feed in grazing and harvested systems, we have an opportunity to improve several grassland species to enhance their value in multifunctional systems.

Meadow fescue. Meadow fescue is a perennial bunchgrass adapted to cool climates. On fertile soils it grows to 30 inches in height. It thrives in deep, rich soil, but also grows well on calcareous or sandy soils. In trials in other states, meadow fescue performs well and persists when it is rotationally grazed at a height of 8 to 10 inches. Our equine grazing research in Minnesota has shown it to be a palatable grass with uniform forage productivity throughout a May to October grazing season. There is a need to select for disease-resistant, winter hardy varieties that are adapted to rotational grazing systems and that perform well in mixtures with other grasses and legumes in Minnesota.

Perennial ryegrass. Perennial ryegrass is a cool season perennial grass used in cool, temperate climates throughout the world. It has many worthy attributes and is considered the best overall pasture grass for many areas. Ryegrasses, in general, grow best on fertile, well-drained soils, but perennial ryegrass can tolerate wet soils better than most other grasses. It does not generally tolerate drought or extended periods of extreme temperatures. Perennial ryegrass is known for its production of high quality forage especially late in the fall. In that capacity, it has great potential to extend the fall-grazing season when other cool season grasses become dormant. Despite its many attributes, perennial ryegrass use is limited by its susceptibility to diseases that reduce yield and forage quality and its lack of reliable winter hardiness. Specific plant breeding objectives involve selecting varieties for increased foliar disease resistance, increased winter hardiness, and increased forage yield under grazing/multiple cutting systems.

Alfalfa. Alfalfa is the most widely grown perennial forage legume in Minnesota. Winter hardy, disease-resistant varieties have been developed. Alfalfa conducts biological nitrogen fixation that results in high yields of a protein-rich forage and nitrogen available for following annual crops in rotation. The major thrust of private plant breeding efforts for commercial markets has been the development of upright, rapid re-growing varieties that are suitable for intensive harvest management systems. We propose to increase the use of alfalfa through two approaches:

Novel biofuel alfalfas. Novel biofuel alfalfa varieties are being developed by USDA-ARS and University of Minnesota faculty. These alfalfa lines are capable of producing a high protein, leafy co-product for livestock feed and stems for biofuel processing. Typically, standard alfalfa varieties designed for producing high quality hay, are harvested 3-4 times during the growing season. This harvest regime requires frequent trips into the field, exposes cut forage to the weather, and is very detrimental to nesting wildlife. There is a need for increased selection for biofuel varieties that have leaf disease resistance, lodging resistant and that can be harvested less frequently than commercial alfalfas. Large scale seed production is needed to allow for field scale evaluation of these alfalfas.

Grazing tolerant alfalfas. Most alfalfa acreage is mechanically harvested for hay or silage. However, alfalfa has great potential for use in rotational grazing systems. Unfortunately, alfalfa selections that are currently marketed for grazing in Minnesota show no yield or persistence advantage over hay type alfalfas. Faculty at the USDA-ARS affiliated with the University of Minnesota have selected alfalfas for tolerance to frequent mechanical mowing under Minnesota conditions, but these have not been evaluated in grazing trials. Hence, there is an excellent opportunity to conduct selection to develop grazing tolerant alfalfas for use in rotational grazing systems.

Commercialization and Enterprise Development of "Forever Green Agriculture" Products

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Minnesota agriculture has tremendous assets and capacities. It also faces major challenges, including meeting increasing demand for commodities and other ecosystem services in the face of increasing climate variation and other forms of global change. Meeting these challenges will require substantial innovation and development creating, in turn, new economic opportunities for farmers, landowners, rural communities, and commercial enterprises on many scales. Many of these opportunities will be created by development of the new crops that will be developed under this initiative. To make the most of these opportunities, the University of Minnesota is using state-of-the-art approaches to commercializing new crops and new agricultural products. Specifically, the University is working to create commercialization pathways that are profitable, provide environmental benefits, and support rural communities. To do so, the University is developing a new approach to commercialization and enterprise development. Key to this approach is the development of active incubators for enterprise development, which we call 'Landlabs'.

The most important function of a Landlab is to coordinate technological, economic and policy innovations, all of which are needed to create maximum benefits from commercialization of new crops. Commercialization is challenged by many 'chicken & egg' barriers, such as coordinating supply and demand in early-stage commercialization. To overcome these barriers, Landlabs emphasize development of all necessary parts of new enterprises, including production systems and related supply and value chains. Establishment of these depends on obtaining and coordinating technical capability and financial resources, managing risk, and meeting societal expectations for new enterprises in economic, environmental and social terms. To meet these key needs in enterprise development, Landlabs coordinate innovation and development within three critical areas: landscape configurations (i.e., types and arrangements of land uses), supply/value chains (i.e., processing and utilization), and policy. Moreover, Landlabs, link and leverage resources from multiple societal sectors to drive innovation across domains. These 'incubator' functions of Landlabs are critically important because private enterprise, government, NGOs and research institutions are increasingly investing and innovating in new agricultural enterprises, often based on new crops. However, these efforts are largely uncoordinated, and neglect key areas such as early-stage commercialization and policy development. Landlabs are needed to coordinate these investments and to provide a crucial function: lowering barriers to the emergence of new enterprises by 'derisking' these new enterprises for farmers, landowners, and a wide range of investors.

By using state-of-the-art methods for decision support and enterprise design, Landlabs coordinate a broad range of innovation and other related activities and reduce risk in enterprise development. In particular, Landlabs use methods for developing new enterprises that increase total agroecosystem productivity by capturing value from undervalued resources, e.g., water and nutrients that are released from current agroecosystems. To pursue commercialization pathways that capture and create value in this way, Landlabs place emphasis on certain essential activities. These include communication, innovation and collaborative action by multiple stakeholders, whose concerns range from agriculture to rural communities, water, wildlife, and renewable energy.

Landlabs will feature and leverage the established capacities of the University of Minnesota Extension Center for Community Vitality (CCV), which helps communities retain and expand local business, know and grow the retail sector, make informed public finance decisions and develop successful tourism opportunities. The CCV will engage with a wide range of stakeholders, entrepreneurs and investors from private enterprise, government, NGOs and research institutions to develop strategies for commercialization of new enterprises based on new plant materials, using its well-established model of technology-transfer distribution. Dr. Brent D. Hales, Associate Dean of Extension, Center for Community Vitality will co-direct the initiative along with participants in the pilot-scale Landlab efforts being conducted by the University of Minnesota. Through these collaborative efforts, the Landlab will identify scalable distribution strategies to develop supply and value chains for new products. Emphasis will be placed on local development of the supply chain, thereby increasing the likelihood that ownership of the product and processes will result in the greatest return on investment for the region(s) and thereby increasing local and regional economic growth from enterprise development. The CCV will work with its partners to identify communities/regions with workforce, land and other resources needed for enterprise development.

The Landlab approach to commercialization and enterprise development is designed to catalyze the wide-ranging innovation needed to efficiently produce a wide range of goods and ecosystem services from our land and resource base, thereby developing agricultural enterprises that meet the ‘triple bottom line’ of high performance in environmental, economic and social terms. Such enterprises will benefit farmers, landowners, rural communities and the State of Minnesota. By focusing on creating enterprises that meet the triple bottom line, Landlabs help advance the mission of the University of Minnesota as a 21st-century land-grant university.

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