Tree Crop Improvement

Achieving widespread agroforestry on the landscape requires investment in tree crop research at a level more proportional to the transformational benefits agroforestry can provide.

Savanna Institute's Tree Crop Improvement Program is constructing large breeding populations for several key agroforestry species, assembled using the progeny of the highest-performing varieties currently available. Our approach is relatively simple, but also unique for the breeding of tree crops: by combining precise measurements of plants' performance with molecular genetic markers, we will be able to achieve rapid rates of crop improvement. Predictive selection models built on these datasets will allow us to identify new varieties for wide-area testing, as well as enable rapid screening of progeny families in order to more efficiently utilize acreage at our research sites at Savanna Institute's Campus in Spring Green, Wisconsin.

Why Tree Crop Breeding?

Agricultural research on tree crops has always seen systematic underinvestment, and this disparity has intensified over the last century. The handful of major annual grain crops that dominate Midwest agriculture have achieved and maintained this level of ubiquity on the landscape in part through a diverse, well-funded and long-term agricultural research effort to develop and steadily update superior crop varieties and agronomic management techniques. Savanna Institute's Tree Crop Improvement Program has selected a variety of nut, fruit and timber crops well-suited to temperate agroforestry systems that thrive in the Midwestern US. The improved cultivars we will release through this program will enable agroforestry systems to realize their true potential, playing a significant role in helping to mitigate climate change through carbon sequestration.

Selected Tree Crops

NUTS FOR SPECIALTY AND COMMODITY MARKETS

Existing specialty crop demand for chestnuts and hazelnuts in the US far outstrips domestic supply, providing immediate, high-value markets while production of these crops is still scaling up. Meanwhile, these crops have starch (in the case of chestnut) and protein and vegetable oil (in the case of hazelnut) characteristics broadly analogous to corn and soybean, aligning them with large-scale markets for bulk food ingredients, livestock feed, and bioproducts. This latent potential will help inform crop improvement efforts directed at improving yields and reducing production costs.

HAZELNUT

Hazelnuts (*Corylus* spp.) produce a valuable nut crop, and in the Midwest, interspecific hybrids of the commercially dominant European hazelnut (Corylus avellana) and the native shrub American hazelnut (Corylus americana) can be cultivated as high-density hedgerows. Strong market potential is being driven by growing demand for nuts as a snack food and confectionary product. Outside of such existing end uses, large-scale cultivation can also be supported by pressing the kernel for oils rich in linoleic acid, which also yields a protein-rich press cake that can be used as a feed supplement for livestock.

Our team has planted thousands of seedlings descended from controlled crosses between the best existing Midwest varieties, along with clones of these parental varieties, on research acreage at the Savanna Institute Campus in Spring Green, WI. This breeding orchard is sited within a highly uniform field, and bushes are widely spaced to minimize competition even at maturity. This planting – unique in terms of its design and the genetic background of the seedling progeny families – will facilitate successful evaluation of yield density (using drone imagery) and machine-harvestability (using custom-designed single plant combines), which together are the two key traits in need of improvement before a large-scale industry can be established in the Upper Midwest.

CHESTNUT

Chestnuts (*Castanea* spp.) are grown profitably for fresh markets across the Midwest, but markets for processed nut products are largely dominated by Chinese-grown imports. In order for Midwest chestnut production

to scale for these processed markets, we need to breed for consistently high-yielding cultivars. Fortunately, the Midwest is populated with farms already growing seedling progeny families – all that is needed are scalable methods to evaluate this existing material.

This production practice stands in contrast to many tree crops, where production is based largely on clonal systems, because of the underperformance of grafted chestnut trees in colder climates. As such, the existing genetic diversity offered by these seedling orchards presents a unique opportunity for on-farm improvement. We are using aerial imagery to identify desirable cropping traits (e.g., maximal density of nuts within the canopy), which is enabling the identification of new varieties for immediate release. This will also allow us to select parents to include in an improved seed orchard, which will supply new farmers with improved seedling trees, while simultaneously advancing our breeding efforts to the next generation.

SMALL FRUITS FOR FOOD AND NUTRACEUTICAL MARKETS

Nutraceuticals have garnered immense attention in recent years due to an uptick in worldwide trends surrounding human health and nutrition. Black currant and elderberry are an emerging solution for meeting the increasing demand for potential "superfoods", food & dietary supplements, and functional foods & beverages. These crops also represent "quick wins": they bear rapidly, and are important early revenue streams for farms implementing diverse agroforestry systems. This reduced time to flowering accelerates the rate of crop improvement as well, and thus we hope to make the most rapid progress on these species.

BLACK CURRANT

Black currant (*Ribes nigrum*) is used as a popular flavor additive that is widely cultivated across temperate Europe, Russia, New Zealand, parts of Asia and to a lesser extent, North America. Though black currant is easily harvested with existing mechanical berry pickers, large-scale cultivation in the Midwest has been

historically inhibited due to existing European cultivars' limited climate adaptation and disease resistance. Improved performance in the Midwestern climate is needed in order to expand black currant's potential in this region and beyond.

Our breeding program for black currant has begun by making crosses with the most resistant, best performing cultivars in North America: the collection of McGinnis varieties from British Columbia. We will use the resulting progeny families to select for increased disease resistance, while maintaining large fruit size, appealing flavor, and growth habits that are able to be machine harvested.

ELDERBERRY
Though most of the world's elderberry production is based on cultivars of European elderberry, *Sambucus nigra*,

the Midwest is home to the American black elderberry (*Sambucus canadensis*). Research suggests American elderberry may possess a number of superior nutraceutical and food-value qualities relative to European elderberry, and a surge in demand for such dietary supplements is driving a rapid expansion of product markets for this fruit.

The commercially grown American elderberry cultivars cannot currently be machine-harvested, significantly restricting the potential acreage on which they can be profitably cultivated. Our improvement targets will therefore focus on developing cultivars with traits which allow machine harvesting: eliminating early berry drop, increasing the uniformity of fruit ripening both within fruiting clusters and across entire plants, and increasing fruit firmness. To accomplish this, we have constructed full-sib families descended from crosses between existing commercial varieties. We will also indirectly breed for resistance to cane borer by selecting elderberry varieties which are able to be coppiced annually without significantly negatively impacting yield. Together, increased machine harvestability and ease of pest management will drive improved realized yields and facilitate farmer adoption on larger scales.

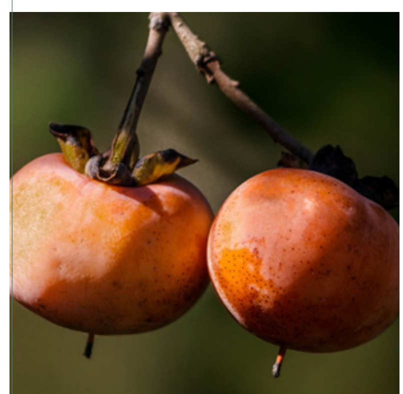
MULTI-USE TREES FOR LIVESTOCK FODDER AND HIGH-VALUE FOOD OR TIMBER
In addition to the use of persimmon and mulberry as specialty fruit crops, or black locust as a timber crop, these species have immediate, widely-scalable potential in silvopasture systems. Relative to orchard and intercropping contexts in which farmers need to learn to produce new saleable crops, silvopasture has relatively lower barriers to adoption — the trees provide supplemental forage for livestock and benefits such as shade and resilience to drought. The three species which are the focus of this aspect of our Improvement Program have to date

undergone minimal genetic improvement for silvopasture use, and are poised for rapid gains.

BLACK LOCUST
Black locust (*Robinia pseudoacacia*) is a high-quality hardwood tree species known for its fast growth, rot-resistant wood, nectar-filled flowers and nitrogen-fixing capacity for soil improvement. Despite being native to North America, the black locust is a more important commercial species in Europe and Asia than in the U.S. due to a native borer, which limits the size and density of commercial-scale black locust plantings at present.

In order for black locust to be planted across the Midwest, two improvement targets must be achieved: seed sterility and borer resistance. Black locust, though native, is listed as a noxious species in many states, due to its prodigious annual seed production. Our improved selections will produce no viable seeds, compared to 400 million seeds produced per acre by unimproved stands over their lifetimes. We are accomplishing this through the generation of triploids (via tetraploid x diploid crosses), which in addition to being seed sterile, have been shown to have increased vigor, thereby shortening the time to harvestable maturity. We will then breed for borer resistance by selecting within these triploid populations for thicker, smoother bark, as well as the straight, unbranching "Shipmast" growth form.

PERSIMMON
American persimmon (*Diospyros virginiana*) is the most nutritionally-dense fruit native to North America and has a cultural history in the U.S. as both an



indigenous perennial staple and as a silvopasture crop. When grown on pasture, persimmon's canopy allows for the generous transmission of light, allowing grasses and forages to thrive. This increases the carbon sequestration of such systems, while also providing high-quality pasture for grazing livestock. However, despite the multiple uses and markers for American persimmon, it has remained untouched by public and private breeding programs.

Due to the pre-existing disease and pest resistance of American persimmon, and consequent ease of on-farm adoption, our main crop improvement target is to expand its range northward by selecting for cold hardiness, which will include

selecting for early ripening of the fruit. We have established high-density nurseries with tens of thousands of half-sibling seed harvested off of existing, cold-hardy varieties. We will identify the most cold-hardy seedlings at the nursery stage. As American persimmon is diecious, we are also designing sex-linked markers to facilitate the intentional design of plantings with known distribution of male and female trees. We will then genotype cold-hardy selections for these markers, and establish breeding orchards in order to enable the evaluation of fruit quality at maturity. In a silvopasture context in particular, breeding for high carbohydrate values of the falling fruits will provide an affordable livestock feed offset to help reduce the fodder costs that are becoming increasingly volatile.

MULBERRY

Mulberry (*Morus* spp.) is a multi-purpose tree that can occupy fallow farm areas ill-suited to traditional agriculture, arable acreage (as a climate-friendly alternative to fodder crops such as alfalfa), or pastureland (as a silvopasture crop which drops fruits to help supplement early-season livestock feed). Historically, mulberry and persimmon were grown together in

silvopasture systems in the American South to provide livestock food and shade for half the year. Despite its exceptional qualities for feeding livestock and humans, and its wide geographic range, mulberry improvement has remained largely unexplored by breeding programs in the United States.

Mulberry is a strategic crop to alleviate the impacts that climate change poses towards the annual livestock forage industry. A resilient source of high-quality forage that shines when feed is scarce or low quality, mulberry's perennial root systems enable the crop to remain productive when annual forages have run out of available water. Already adapted to the Upper Midwest, our improvement program is selecting for vigorous plants with large, high-protein leaves that can be harvested multiple times per season using existing farm equipment. In addition to leaf forage, we are evaluating female trees for their fruiting habits, selecting for "everbearing" fruit production to extend seasonal production of fruits.

SAVANNA INSTITUTE

Tree Crop Improvement Team

Fred Iutzi
Director of Research & Commercialization

Scott Brainard
Tree Crop Breeder

Eliza Greenman
Germplasm Specialist

Malachi Persche
Field Technician

Adam D'Angelo
Breeding Operations Manager

Lily Hislop
Tree Crop Breeder

Kathleen Rhoades
Tree Crop Breeder

Zack Loken
Imagery Analyst