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Wisconsin Hazelnut Production Trials
2019 (Age 9) Yield and Performance

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Introduction

The Wisconsin Hazelnut Production Trials were established in the summer of 2011 at three locations in Wisconsin (Bayfield, Spooner, Stoughton) with American hazelnut seedlings (*C. americana*) from the WI DNR and full sibling progeny from a controlled cross between two hybrid hazelnuts selected by Forest Agriculture Enterprises (Viola, WI). A full description of the plantings and prior year results are reported by Fischbach and Chediack (2018), Fischbach and Zuiches (2017), and Fischbach and Tibbals (2016). This Bulletin reports on the 2019 performance at age 9. The purpose of these plantings is to demonstrate hazelnut production to interested growers and to evaluate the plant material across three very different environments.

Photo 1. WI Hazelnut Production Trial at the Stoughton location in August 2018.

Methods

The plantings were established in June 2011 with wild-type American hazelnut (*C. americana*) seedlings and full-sibling (F1) hybrid hazelnut seedlings. The *C. americana* plants were sourced from the WI DNR, but the seed source is unknown. The hybrid seedlings are from a controlled cross between two select hybrid parents made by Forest Agriculture Enterprises. These hybrid seedlings are currently being sold by Forest Agriculture Enterprises as "F12 Controlled-Cross Selected Seedlings". The plantings were established with 6ft in-row plant spacing and 15ft between-row spacing. Every fourth plant in a row is a C. *americana* seedling. The Bayfield planting is on private property on sandy soils near Bayfield, WI. The Spooner planting is on sandy loam soils at the Spooner Agricultural Research Station in Spooner, WI. The Stoughton planting is on private property on silt loam soils near Stoughton, WI. See Fischbach and Tibbals (2016) for a full description of the three planting sites.

For 2019, all plants at all three locations were visually rated for nut production in mid-August on a scale of 0-5 with 0 being no nut production, 1 being at least one nut, 2 being some nuts mainly on one branch, 3 being nuts on multiple branches, 4 being nuts all over the shrub, and 5 being exceptional nut production. The visual ratings were used to determine which plants to harvest.

For all three locations (Bayfield, Stoughton, Spooner), all plants (*C.americana* and hybrid) rated 4 or 5 were individually harvested to determine the total yield of 4-rated and 5-rated plants. In addition, randomly chosen 3-rated plants for *C. americana* and the hybrids were harvested and used to determine an average yield per 3-rated plant. Total planting yield for the 3-rated plants was determined by multiplying the average yield of the harvested 3-rated plants by the total number of 3-rated plants. At Bayfield, because there were so many 2-rated plants, a random selection of plants were harvested to determine total yield from the 2-rated plants. At Bayfield, 62 of the 126 3-rated plants were harvested and 35 of 163 2-rated plants were harvested. At Spooner, 100 of the 147 3-rated plants were harvested, and at Stoughton 39 of the 153 were harvested. No nuts were harvested from plants rated 0 or 2 at the Spooner and Stoughton plantings.

All harvested nuts were dried in mesh onion bags laid on benches in a greenhouse until the husks were dry. The in-husk nuts were then further dried with forced air at 90F for 24-hours. Husks were removed with a barrel husker and aspirator. Total in-shell weight was measured for each harvested plant. A 20 nut sub-sample from each plant was cracked and the kernels were weighed to determine percent kernel and average single kernel weight. Per plant kernel yields were calculated by multiplying percent kernel by the total in-shell weight. The kernel production of a single plant is due to cluster density but also the size of the plant. To calibrate for plant size, the width of each plant was measured at the widest point perpendicular to the row. This diameter measurement was used to calculate the radius and the cross-sectional surface area of the plant canopy at its widest dimension. Yield density was calculated by dividing the plant's kernel yield by the canopy surface area. Values are shown in grams per square foot of canopy coverage for ease of communication.

Results and Discussion

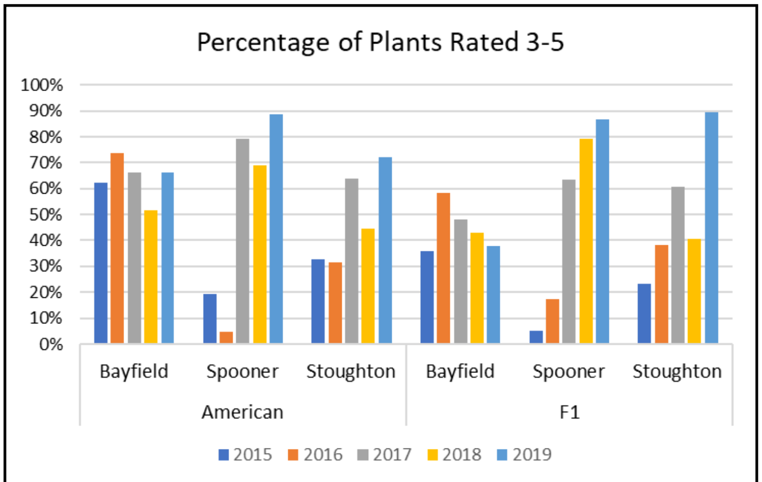


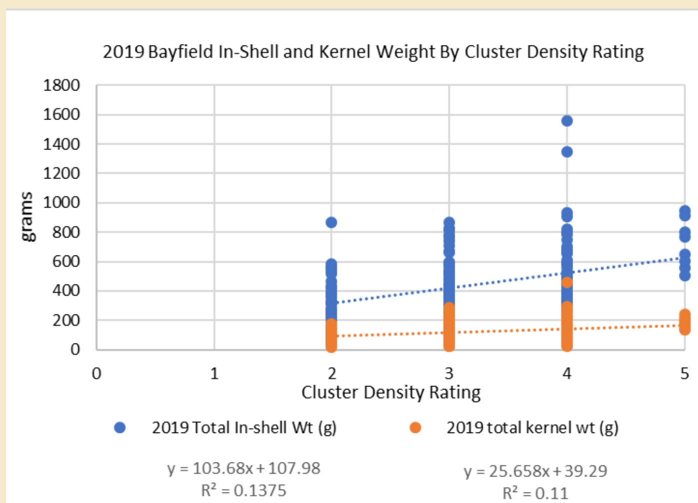
Figure 1. The percentage of *C. americana* and hybrid plants that produced nuts at age 5 (2015) through age 9 (2019) at each of the three trial locations.

<u>Cluster Density Ratings</u>
Figure 1 shows the percentage of *C. americana* and hybrid plants at each of the three trial locations that had a cluster density rating of 3 or higher for age 5 (2015) through age 9 (2019). These ratings are affected both by genetic factors, such as precocity and density of flower production, and also by environmental factors such as herbivory, overall plant vigor, and success of pollination. At Bayfield, the ratings have been relatively consistent from year -to-year, but overall ratings have remained low with roughly only 45% of the hybrids on average each year rating 3 or higher. Interestingly, on average, 64% of the *C. americana* hazelnut plants have rated 3 or higher each year, suggesting *C. americana* hazelnuts may be better adapted than the hybrids to the climate and sandy soils of Bayfield.

The significant increase in yield ratings at Spooner after 2016 coincides with installation of a perimeter fence to exclude deer. Though hazelnuts are not preferred browse for deer, at least compared to species like dogwood, red maple, or oak, there was sufficient herbivory of tip buds to reduce yields. Since then, more than 60% of both the *C. americana* and hybrid plants have had ratings of 3 or higher each year. Cluster density ratings at Stoughton have remained relatively low each year, with the exception of 2019 when almost 90% of the hybrid plants were rated 3 or higher. The reason for the relatively low average density at Stoughton in prior years is not entirely clear. As Figure 2 shows, the plants are much larger at the Stoughton location and thus the plants may have simply stayed vegetative longer.

For a hazelnut planting to be economically viable, at least 90% of the plants should be producing a high density of clusters each year, and ideally, by as early as age 4 or 5. The two seedling populations evaluated in these trials have not done that. In part, this is due to growing conditions, such as the poor soils and cold climate at Bayfield, the deer browse at Spooner, and the rank vegetative growth at Stoughton, but mainly it is due to the high level of genetic and phenotypic variability in the plant material. Too many plants aren't consistently producing nuts.

How Good Are Cluster Density Ratings at Predicting Yield?



The cluster density rating (see methods) is used as a quick method to identify plants with lots of clusters. But, how well do the ratings correlate with nut yield? Figure 2 shows the ratings and in-shell and kernel yields for the 160 individual plants harvested in 2019 at Bayfield. In general, the ratings are not very predictive of yield. This is due in part to the rating being subjective (and thus variable), but mainly because the percent kernel and kernel size are unknown when the ratings are made. A plant with a high cluster density might have very small nuts and thick shells and, thus, a low kernel yield. More significantly, the rating is done independent of plant size. A large plant with a low cluster density could have more kernel then a small plant with a high cluster density rating. Plant size can be controlled with the yield density metric (see methods), but the R^2 value for yield density is even lower at 0.078. Cluster density ratings are good at separating plants with little to no clusters from plants with lots of clusters, but once a plant has lots of clusters the cluster density rating can't be used alone to find plants with high yields. The clusters have to actually be harvested and the nuts dried, cracked, and weighed to determine yields.

Plant Size

Figure 2 shows the average height, width, and crown diameter of the *C. americana* and F1 hybrid plants at the three locations at age 9. In general, the *C. americana* hazelnut plants tend to be slightly shorter, wider, and with a more spreading base than the hybrid plants. Among the sites, the plants at Stoughton are both taller and wider on average, which is not surprising given the longer grower season and more fertile soils. The plants at Bayfield are generally smaller due to the sandy soils and short growing season, but interestingly, the crown diameters of both the *C. americana* and hybrid hazelnuts at Bayfield are wider than the other two sites. The reason why is not entirely clear, but may be due to lower overall plant vigor leading to less apical dominance from any single stems or possibly less shading from top growth. There has also been considerable damage from big bud mite at the Bayfield planting, which has slowed growth.

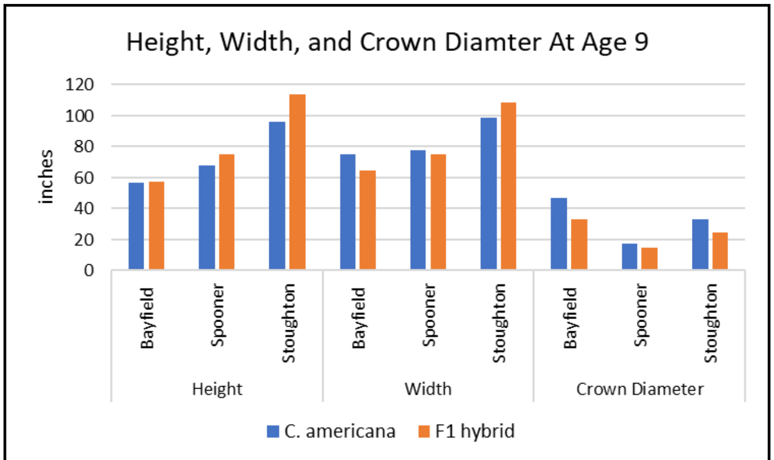


Figure 2. Average plant height, width, and crown diameter of *C. americana* and F1 hybrid plants at three locations at age 9.

There is considerable diversity in soils and climate across the Upper Midwest and it remains unknown where the "best" place is to grow hazelnuts, or even, for that matter, what constitutes "best". Performance comparisons among sites are best done with genetically uniform material, but the large population size of these *C. americana* and hybrid plantings do allow some useful comparisons, especially as it relates to plant size and implications for mechanical harvest. The hedgerow production system proposed for the Upper Midwest includes mechanically harvesting the nuts directly from the shrubs using straddle harvesters. Smaller plants will allow for smaller and less expensive equipment. Pruning is one method to manage plant size, but is an added input cost. A preferred method is finding the right genetics x environment (G x E) combination that results in high-yielding compact plants. The data suggest that by age 9, the plants at Stoughton are already too tall and too wide for effective straddle harvesting, but they are still very manageable at the Spooner and Bayfield locations. The question then is how per acre yields differ across the sites. If the per acre yields are similar than the sites with smaller plants would be preferable.

Site	# of plants	total yld (lbs)	lbs/plant	lbs per acre
		C. americana		
Bayfield	95	20.7	0.22	106
Spooner	71	27.0	0.38	184
Stoughton	83	54.1	0.65	315
		F1 hybrids		
Bayfield	340	65.1	0.19	93
Spooner	172	66.4	0.39	187
Stoughton	263	308.4	1.17	568

Table 1. Age 9 (2019) kernel yields of *C. americana* and hybrid hazelnuts at three locations. "# of plants" is the total number of plants in the planting, including all plants rated 0-5. Per acre yield was calculated by multiplying the average lbs/plant times 484 plants per acre.

Kernel Yield

Table 1 shows the age 9 (2019) kernel yields at each of the three trial locations. On a per acre basis, Stoughton yields were highest at 568 lbs/acre for the hybrids and 315 lbs/acre for the *C. americana*. These extrapolated yields include the 0-2 rated plants. If the 0-2 rated plants are excluded from the extrapolation, Stoughton yields would increase to 635 lbs/ac for the hybrids and 436 lbs/ac for the *C. americana*. For perspective, kernel yields in mature Oregon orchards average around 1100 lbs/acre. Extrapolated yields from top hybrid genetics developed by the Upper Midwest Hazelnut Development Initiative average around 950 lbs/acre. Interestingly, the hybrid plants tended to yield more than the *C. americana* plants at Stoughton, but not at Bayfield or Spooner.

Yields at Stoughton were higher than at Bayfield and Spooner in part because the plants at Stoughton are much larger. Thus, when using an extrapolation of lbs per plant times plants per acre, sites with larger plants will have larger yields. This does not necessarily mean that a site with larger plants is more productive. Likewise, larger plants are not necessarily desirable as they can limit options for mechanical harvesting. A better measure is how much kernel is produced per square foot of canopy coverage.

Yield Density

Yield density is a measure of how much kernel a plant produces per the two dimensional space it occupies in the field. Table 2 shows the 2019 yield densities of the plants that were rated 3, 4, or 5. It is important to note that these yield densities do not represent the plantings as a whole as they do not include the plants rated 0, 1, or 2.

But, for the highest yielding plants, hybrid hazelnut yield densities tended to be higher than *C. americana* hazelnuts at all three sites. Also, yield densities were highest at Stoughton for both *C. americana* and hybrid hazelnuts.

	Americana			Hybrid		
Rating	Bayfield	Spooner	Stoughton	Bayfield	Spooner	Stoughton
3	4.0	5.0	6.4	5.6	5.5	7.2
4	5.3	8.8	8.1	5.6	8.2	11.0
5	6.8	6.1	9.9	7.9	11.1	11.4
average	**5.4**	**6.6**	**8.1**	**6.4**	**8.2**	**9.9**

Table 2. Age 9 (2019) average yield density (grams kernel/sq ft of canopy

Table 3 shows canopy coverage and kernel yields as calculated on a canopy coverage basis, including all plants rated 0-5. Because the plants at Bayfield and Spooner are smaller, they occupy a lower percentage of the planting area. On a per acre basis, the canopy coverage ranges from 36% for hybrid plants at Bayfield to 60% for hybrid plants at Stoughton. It is not entirely clear what canopy coverage percentage is optimal for the hedgerow production system, but the 60% coverage at Stoughton leaves very little open space between the rows at the 15 foot row spacing. Using this 60% coverage, Table 3 shows the equivalent yields for the *C. americana* and hybrid plants at all three locations. Achieving this canopy coverage by age 9 at locations like Bayfield and Spooner would require higher planting densities, such as 12' row spacing instead of the 15' used in these plantings. As Table 3 shows, even when correcting for plant size through use of the yield density method of extrapolation, the Stoughton planting is still more productive than the Bayfield and Spooner sites, though interestingly, more so for the hybrid plants than the *C. americana* plants.

	# of plants	ave per plant canopy coverage (sq ft)	per acre canopy coverage equivalent (percent)	ave plant yield (g/sq ft)	total planting yield (lbs/acre)	total planting yield (0.60 acre basis)
			C. americana			
Bayfield	95	30.6	42%	3.2	129	187
Spooner	71	32.9	43%	5.2	217	302
Stoughton	83	52.8	55%	5.6	294	323
			Hybrids			
Bayfield	340	22.9	36%	3.8	131	219
Spooner	172	30.0	42%	5.8	234	336
Stoughton	263	64.3	60%	8.3	478	477

Table 3. Age 9 (2019) kernel yields as calculated using yield densities.

Kernel Size and Percent Kernel

The kernel yield density of a single hazelnut plant depends mainly on the cluster density, but is also determined by the percentage of the nut that is kernel and the size of the kernel. Table 4 shows the average individual kernel weight and kernel percentage of the *C. americana* and hybrid plants at the three trial locations. Interestingly, there was little to no difference in percent kernel or individual kernel weight for *C. americana* across the three locations. The hybrids tended to produce larger kernels with higher kernel percentages at the Stoughton location, which explains in part why the yield densities at Stoughton were higher. In general, the hybrid plants tended to produce slightly larger kernels with higher kernel percentages than *C. americana* plants, though less so at the Bayfield location compared to the Spooner and Stoughton locations. Even so, the average kernel size of the hybrids at Stoughton was 0.41 grams, less than half the kernel size of most commercial *C. avellana* cultivars.

location	n	% kernel	Stdev	ave kernel weight (g)	Stdev
		C. americana			
Bayfield	40	27.6%	4.1%	0.27	0.07
Spooner	41	27.8%	4.9%	0.26	0.08
Stoughton	69	27.5%	4.5%	0.33	0.07
		Hybrids			
Bayfield	124	26.6%	4.2%	0.32	0.08
Spooner	127	33.7%	4.2%	0.35	0.08
Stoughton	254	34.3%	5.1%	0.41	0.10

Table 4. Average kernel percentage and individual kernel weight of *C. americana* and hybrid plants at three locations.

Potential as a Commercial Crop

One of the objectives of these plantings when established in 2011 was to evaluate the two seedling populations for commercial potential. The kernel yields in 2019 were the highest yet measured at all three locations for both the hybrid and *C. americana* plants, as measured both on a per plant and per sq foot of canopy coverage basis. At a retail kernel price of $10/lb, per acre revenue at the Stoughton location for the hybrids would have been around $5000. However, prior year yields have never been greater than 200 lbs kernel per acre, primarily because so many plants did not produce nuts (Figure 1). In other words, 2019 was an exceptional year. Time will tell if successive years produce the same kind of yields, but regardless, waiting until year 9 for the first meaningful yields makes commercial viability almost impossible given the delayed breakeven and negative cash flows. The opportunity costs are just too high. That said, these plants can produce significant volumes of kernel to enjoy for subsistence or as a hobby if growers are willing to wait and are ok with a significant number of plants that don't produce much kernel.

Planting seedling populations may provide some genetic resiliency, but such populations have many plants that produce little to no nuts, which suppresses average per plant yields and, thus, per acre yields. One way to avoid this problem is to vegetatively propagate and plant only the best genotypes, as is done with most other woody crops. Figure 3 shows the in-shell nuts, shells, and kernels from the top plants at the Stoughton location. They were selected based on precocity, consistently high annual yields, large kernel size, and high kernel percentage. Eight of these plants are currently being propagated for further evaluation in replicated trials across multiple sites. Growing plantings of just these plants would greatly increase yields. For example, the average 2019 kernel yield density of the top 8 plants in Figure 3 was 18.5 g/sq ft, compared to the 2019 average of all the 3-5 rated plants of: 9.9 g/sq ft. Assuming 60% canopy coverage in a mature hedgerow planting, this would mean per acre yields of 1,070 lbs compared to 570 lbs.

Figure 3. The top performing plants at the Stoughton location based on 9 years of data.

There is concern that reducing the genetic diversity to just 8 genotypes in a planting would decrease overall resilience to disease, climate change, etc. Another potential approach to mitigate this concern would be to use genetic fingerprinting of all F1 plants (or any seedling population) just after germination to identify the "duds" so they aren't planted into the field. Though costs of such fingerprinting are getting low enough to make such testing possible, the genetic markers for identifying the many genes and alleles that would be necessary to separate the "duds" from the good plants don't yet exist. A lower-tech strategy that could be used immediately is to plant at a high density such as with 3ft in-row spacing and remove the poor performing plants around age 5 or 6 after seeing initial nut production.

Conclusions

The Wisconsin Hazelnut Production trials were established in 2011 with the goal to demonstrate hazelnuts to potential growers, determine input costs for growing hazelnuts, and evaluate the yield and performance potential of an F1 hybrid progeny family and a population of wild type *Corylus americana.* After 9 years, the trials have shown that although the average yields of the two populations may not be high enough to support commercially viable production, there are very promising individual genotypes that warrant propagation and further evaluation in replicated trials. The trials have also demonstrated clear site differences in hazelnut growth and production. Clearly, the plants respond to more fertile sites in longer growing seasons, though there is concern that plant size may get too large on the most fertile of sites. It will be important for the industry (and growers) to find the "goldilocks" zone in the Upper Midwest where plants are vigorous and produce high yields, but that remain manageable in size without labor and input-intensive pruning.

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