Nitrogen Fertilization and Weed Control for Hybrid Hazelnuts in the Upper Midwest

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University of Minnesota
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Upper Midwest
Hazelnut
Development Initiative

You don't know how happy I am to be able to give this presentation today. I got my start working with hybrid hazelnuts trying to figure their nitrogen requirements, but failed to develop a definitive answer to that question. Although the majority of my effort is now towards improving hazelnut germplasm, I am still trying to figure that out. I'm now happy to report a bit of progress—though I still have a ways to go.

Forever Green

MINNESOTA DEPARTMENT OF AGRICULTURE

USDA

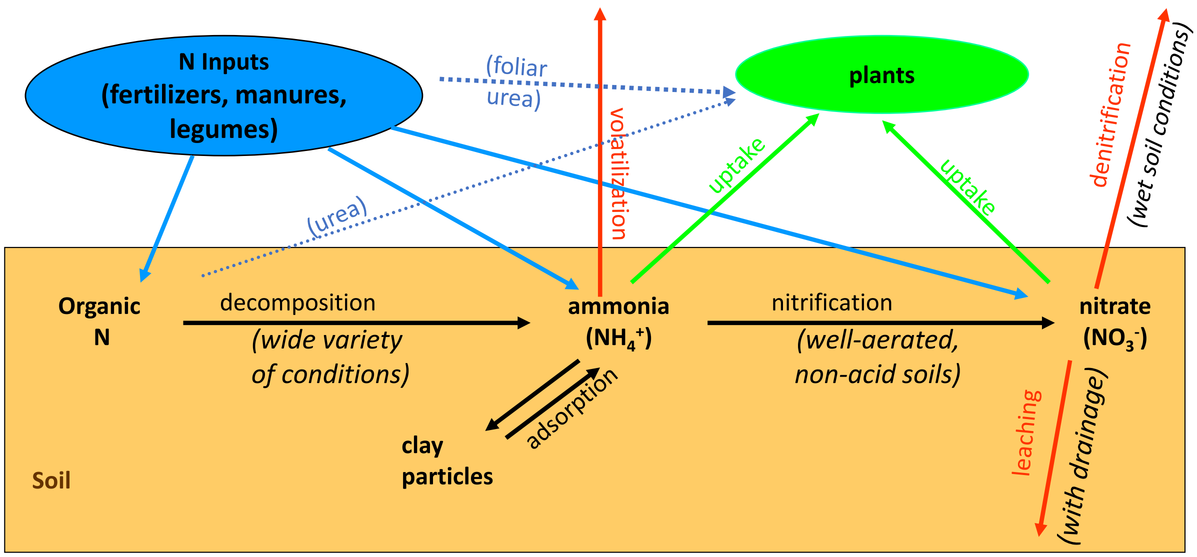
United States Department of Agriculture
National Institute of Food and Agriculture

I like to acknowledge my funders at the beginning of my presentations, so that they don’t get forgotten if I run out of time at the end.

Why do we focus on Nitrogen?

- N is the nutrient most likely to be limiting.
- N is mobile: its levels in the soil fluctuate as a result of the balance between losses and gains.

Soil N Transformations



This is VERY simplified. (Nitrification is actually 2 steps, with nitrite as an intermediate)

Key points are

1. N inputs are of three basic forms: organic N, ammonia, or nitrate
2. Most uptake is as either ammonia or nitrate (Although some plants can also take up urea and amino acids, which are organic forms of N, through their leaves or root, these are insignificant compared to uptake of ammonia and nitrate.)
3. N transformations usually run all the way through to nitrate, meaning that nitrate is more abundant than ammonia, but if conditions are unfavorable for nitrification (acid or waterlogged soils) then ammonia may be more abundant than nitrate.
4. N as nitrate is more likely to be lost from the system becoming a pollutant (red arrows), but ammonia is more likely to be immobilized (become unavailable to plants).

Why not just apply more N than likely to be needed and hope for the best?

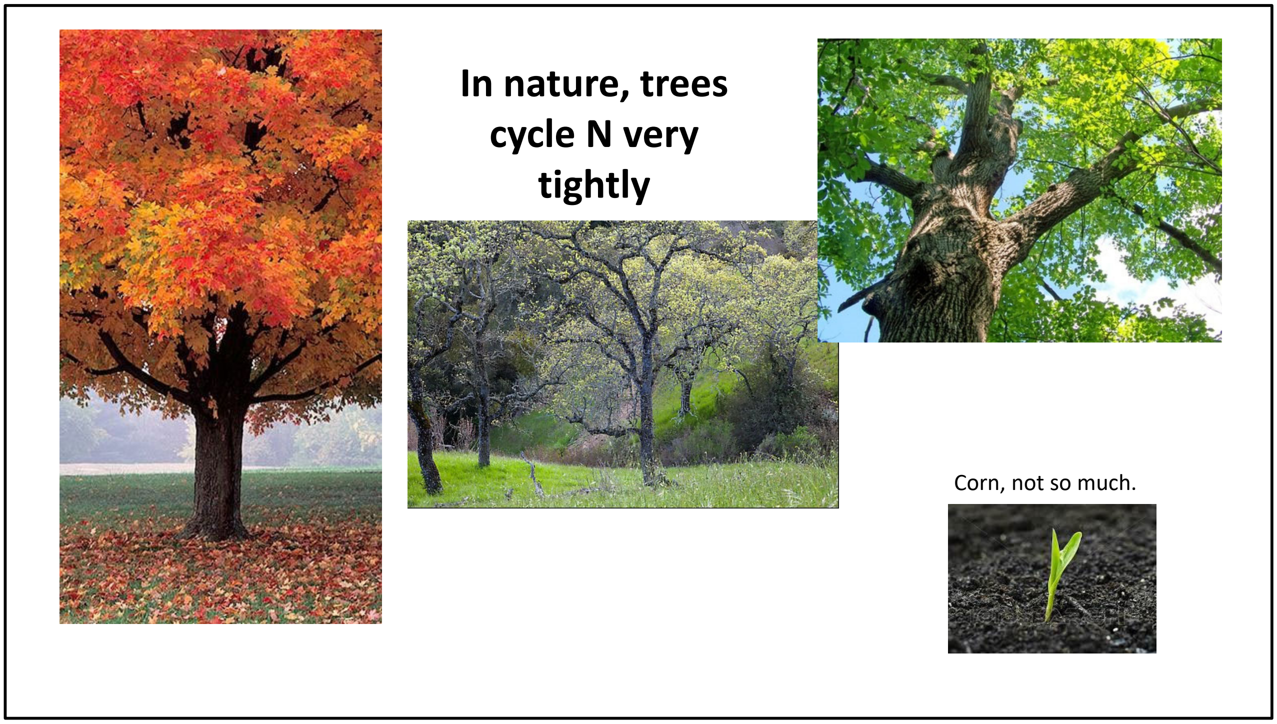
- ➢ Wastes money →reduces profitability
- ➢ Wastes energy required to manufacture the fertilizer
- ➢ Excess N is likely to become a pollutant:

Pathways of N Loss:
- leaching into water
- volatilization into the air
- denitrification into the air

In water, N contributes to:
- blue baby syndrome,
- algal blooms (like the "dead zone" in the Gulf of Mexico)
- and is carcinogenic

In the atmosphere, N contributes to:
- greenhouse gases
- acid rain

Weinbaum et al (1992) found that orchard crops have some of the lowest nitrogen use efficiency (NUE) of any type of crop. Olsen et al. (2001) found that hazelnuts grown in Oregon have an NUE of only 28%.



You all probably learned this in elementary school. In the fall, nitrogen and other mobile nutrients are translocated (moved) from the leaves of trees into their woody branches, then their trunk, and ultimately into their stems for winter storage. The autumn reds and golds are the colors of the compounds that are left behind because they are not mobile. But we are not taught so much about the reverse process that happens in the spring. It is one of my favorite times of year. It happens very subtly at first. One day you notice a light hush of green. Then, in no time at all it seems, the world explodes in emerald. Wow! Where did all that come from?!!! It's all those stored nutrients, much of it nitrogen, mobilized very quickly to take advantage of the warmth and sunlight of the lengthening days.

By contrast, an emerging corn seedling only has the amount of nitrogen that can be stored in a single grain of corn to draw on. It must get the rest of what it needs from the soil, but the available N in the soil is subject to loss, as I explained in the previous slide.

It is the ability of woody plants to conserve their nutrients and recycle them for re-use season after season that makes them so efficient. Have you ever walked under an oak tree in the fall, feet crunching over acorns, and wondered who fertilizes the forest?

N Recommendations for Oregon Hazelnuts [1]

For Young Plants

- based on age of plant

Age in Years	Application Rate (lbs N/tree)
0-2	0
3-5	0.25 – 0.33
6-7	0.33 – 0.20
8-10	0.50 – 0.75

[1] Olsen, J. 2001. Nutrient management guide--hazelnut. Ore. State Univ, Ext. Serv. Bul. EM8786.

Older (and bigger) plants have

- Greater capacity to take up N, due to
  - Deeper and wider roots
  - More leaves to provide energy for uptake
- Greater demand for N
  - More leaves and more nuts

That isn't to say that woody crops such as hazelnuts don't need fertilization. A big difference between them and a wild oak crop is that the N in hazelnuts grown commercially are harvested, and removed from the system. An acorn might be eaten by a squirrel, but the squirrel will likely defecate nearby, and may eventually die nearby, or its neighbors will, so it's a nearly closed system.

To figure out how much N a crop that is harvested needs, one much consider how much N will be exported with harvest, but also how much is already available to them from the soil and how much is already stored in the plant, which is much harder to measure than measuring available N in the soil.

For most woody crops, there are two sets of recommendations, one set for young plants and a second set for mature plants. Young plants are like growing children: the amount they need and the amount they are able take up increases as they grow. There are two reasons for this:

1. The ability to take up N is somewhat proportional to the size of their root systems, which grows larger with age.
2. Nitrogen uptake is an energy-intensive process, so the more leaves they have, with which to convert the sun's energy into plant energy, the better they can fuel N

uptake.

Nutrient uptake is also driven by demand, so the more nitrogen rich leaves and nuts a plant is working on producing, the more it will invest its energy into taking up N.

N Recommendations for Oregon Hazelnuts [1]

For Mature Plants - based on % N in leaves

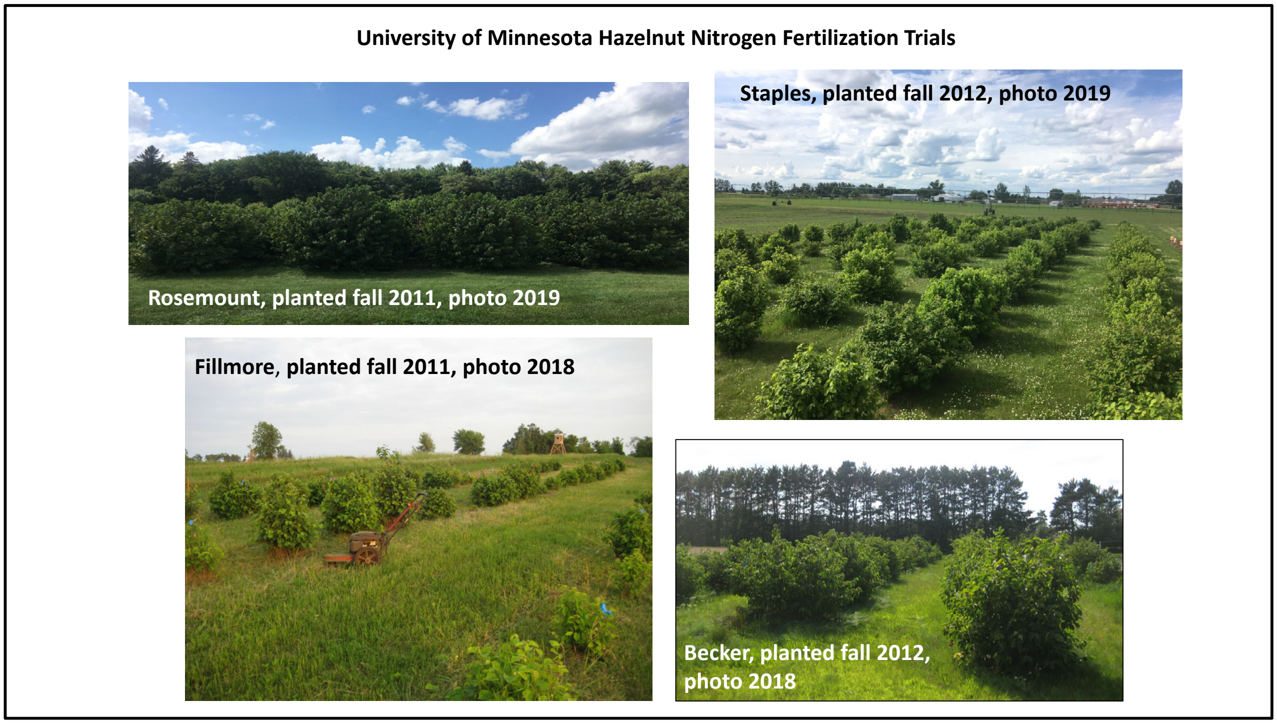
% Leaf N		Application Rate (lbs N/tree)
< 1.8	Severe deficiency	3.0
1.8 – 2.2	Deficiency	2.0 – 3.0
2.2 – 2.5	Optimal	1.5 – 2.0
> 2.5	Excess	0

[1] Olsen, J. 2001. Nutrient management guide--hazelnut. Ore. State Univ, Ext. Serv. Bul. EM8786.

Two problems with these recommendations:

1. Midwest hazelnuts are a lot smaller than Oregon hazelnuts.
2. The leaf N thresholds are likely too high.

For mature hazelnuts, N recommendations are based on leaf analysis. The more that leaf N falls below the established deficiency threshold, the more N fertilizer is recommended. But do these N deficiency thresholds established for European hazelnuts in Oregon apply to hybrid hazelnuts in the Midwest? Are they even accurate in Oregon?



To answer that question, in 2011 and 2012 we established four hazelnut trials using clonal plant material at Rosemount, Staples, Becker and Fillmore Minnesota. Using clonal plant material was essential, because my previous trials had used seedling plant material, and the variable performance of the seedlings obscured the N responses. Unfortunately, due to our continued challenges with propagation, we were not able to have any more than three replications of any genotype at a site, and were generally not able to replicate genotypes across sites.

Three-plant-plot research design

Each treatment unit consisted of three plants, all of which received the same N applications, but of which data was collected only from the middle plant. This was to prevent lateral movement of N between data plants' confounding the results.

Again, because of challenges with propagation, the border plants were of different genotypes than the data plants, though the genotypes of border plants within each experimental block were consistent. In other words, every third plant, whether data plant or border plant, was of the same genotype. This pattern was especially evident in their autumn colors. It was also evident at Staples, where a late spring frost in 2015 severely damaged some genotypes but not others.

Our Nitrogen Threshold Trials
Five N Treatments

- N applied annually
- N applied only when leaf N falls below thresholds of:
    - 1.8 %
    - 2.0 %
    - 2.2 %
- No N

These treatments were started in 2016 at all sites except for Staples, where they were delayed a year because of frost damage in 2015.

(Pre-treatment N applications were made in 2015 to set up variable leaf N levels.)

Treatments were no N ever (the negative control), versus annual N (the positive control), versus three treatments based on leaf N thresholds.

For the three treatments based on leaf N thresholds, no N at all was applied if leaf N did not fall below the assigned threshold. Depending on the site and the year, sometimes there were no plants that fell below the 1.8 % threshold, and only a few that fell below the higher thresholds.

Our Nitrogen Threshold Trials

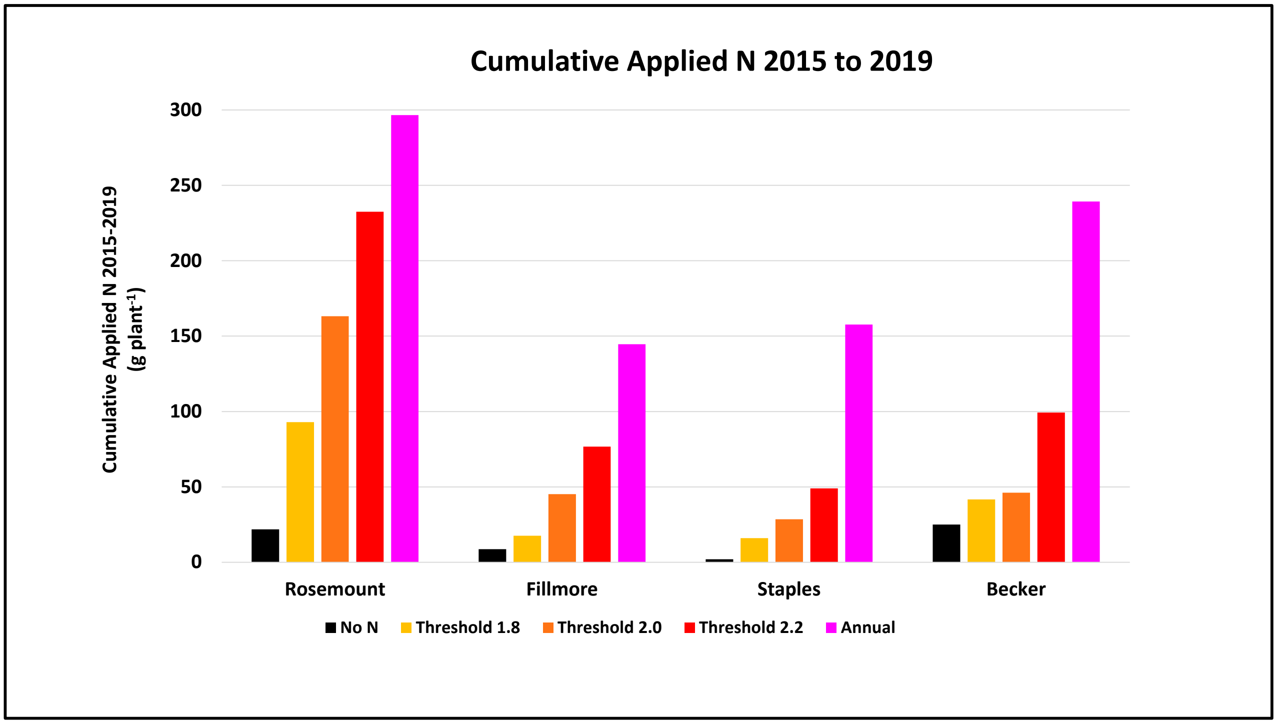
- When N was applied,
  ~ 30 g N m^{-3} of bush volume.
  = ~ 0.8 oz per cubic yard of bush volume
  (Bush volume was calculated as a cylinder: canopy area (πr^2) times bush height.)

- Used a slow-release form of N (UMAXX, with urease and nitrification inhibitors)
- Applied late May-early June

As recommended, we calibrated the actual amount of N applied to the sizes of plants, which increased each year. I report "approximately" 30 g N per cubic meter of bush volume because it would have been too much work to calibrate the amount applied to every single bush, so we applied it based on average bush size in a planting instead.

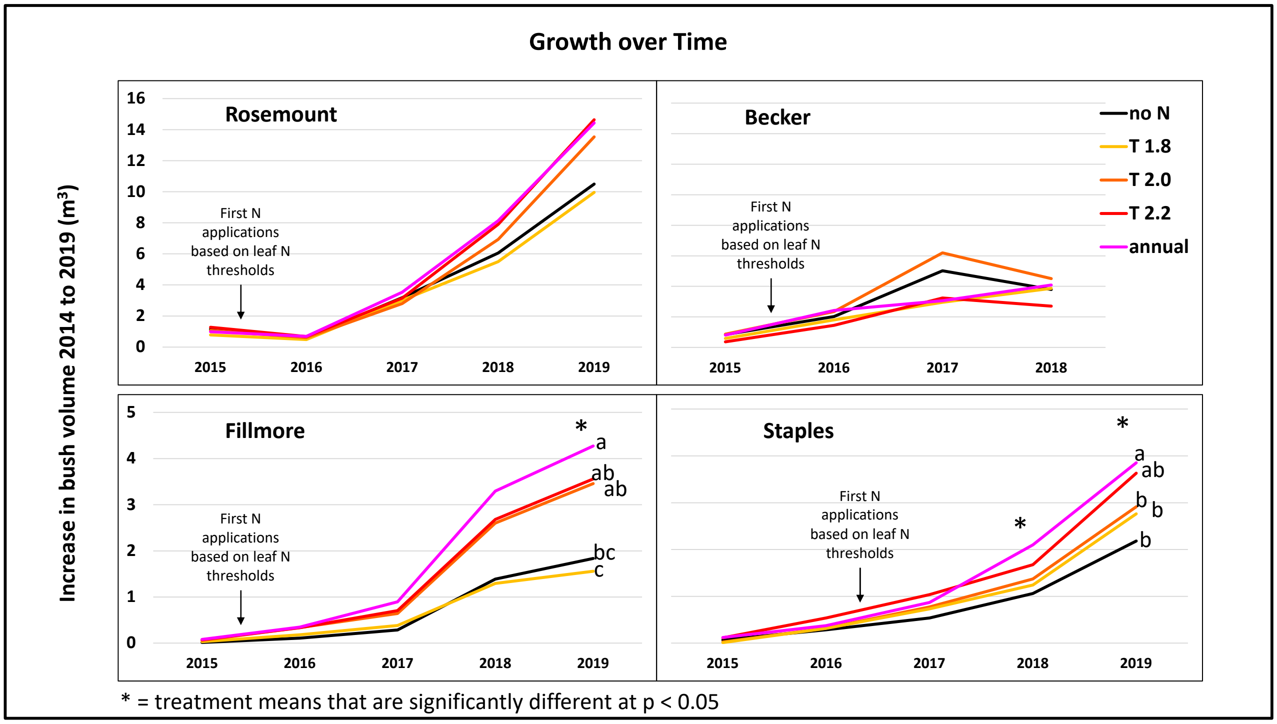
Most people want me to describe N application rates in terms of lbs per acre. But the conversion between ounces of N per cubic yard of bush volume and lbs per acre depends on the sizes of the plants and the number of plants per acre. That said, the amount applied to the plants at Rosemount and Becker in the final year of the trial, when plants were largest, extrapolated out to about 100 lbs/acre, whereas at Staples and Fillmore, where plants were smaller, the maximum amount applied in a given year only extrapolated out to 28 and 35 lbs/acre respectively.

We used a slow-release kind of N fertilizer, to reduce environmental losses and improve uptake.
We applied the fertilizer at a time of year when previous research had shown uptake to be best.



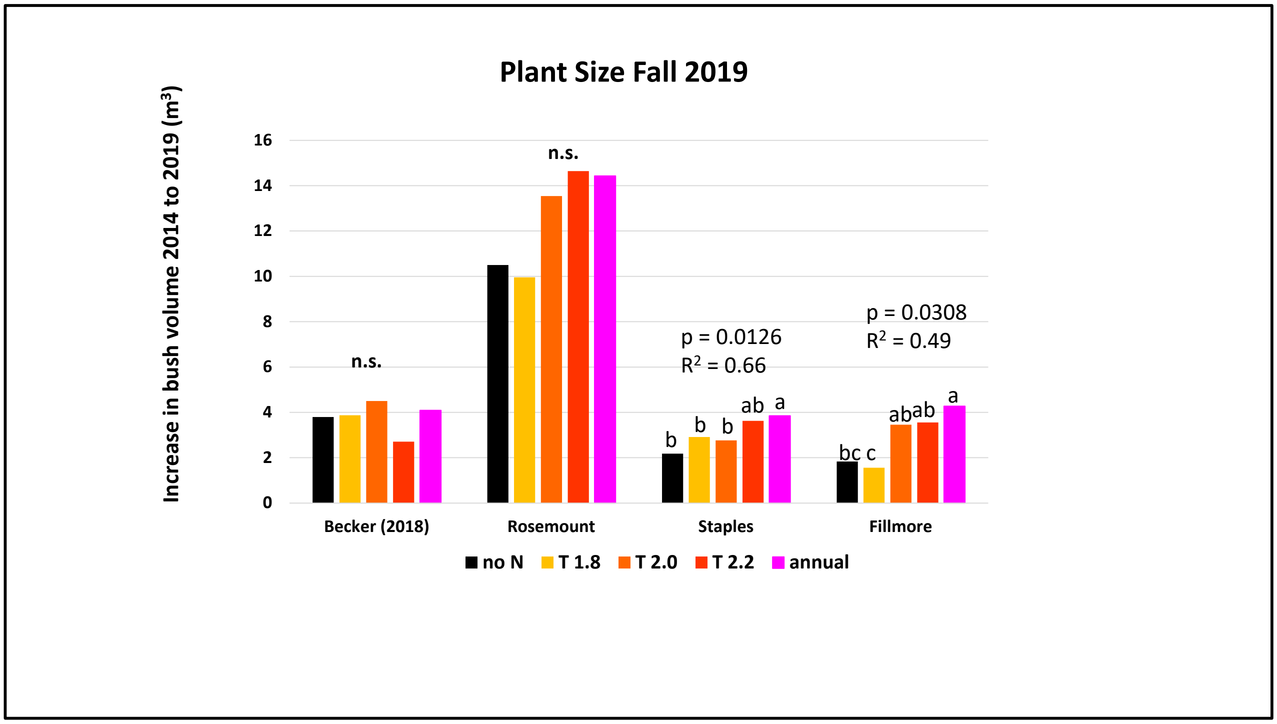
As one would expect, the cumulative amount of N applied was higher the higher the leaf N threshold, with annual N applications resulting in the highest cumulative N applications of all.

The black bars show the N that was applied a year before the start of the trial in order to set up variable leaf N levels.

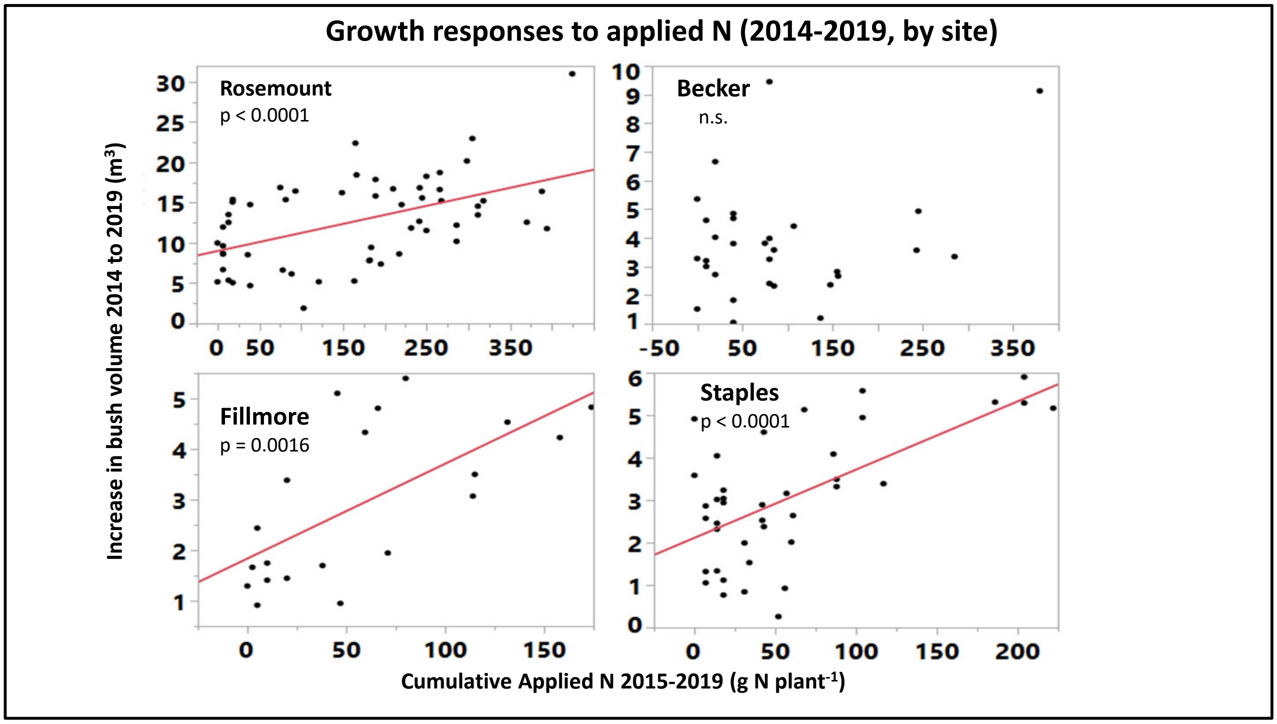


Treatment means with the same letter are not significantly different at the $p < 0.05$ level.

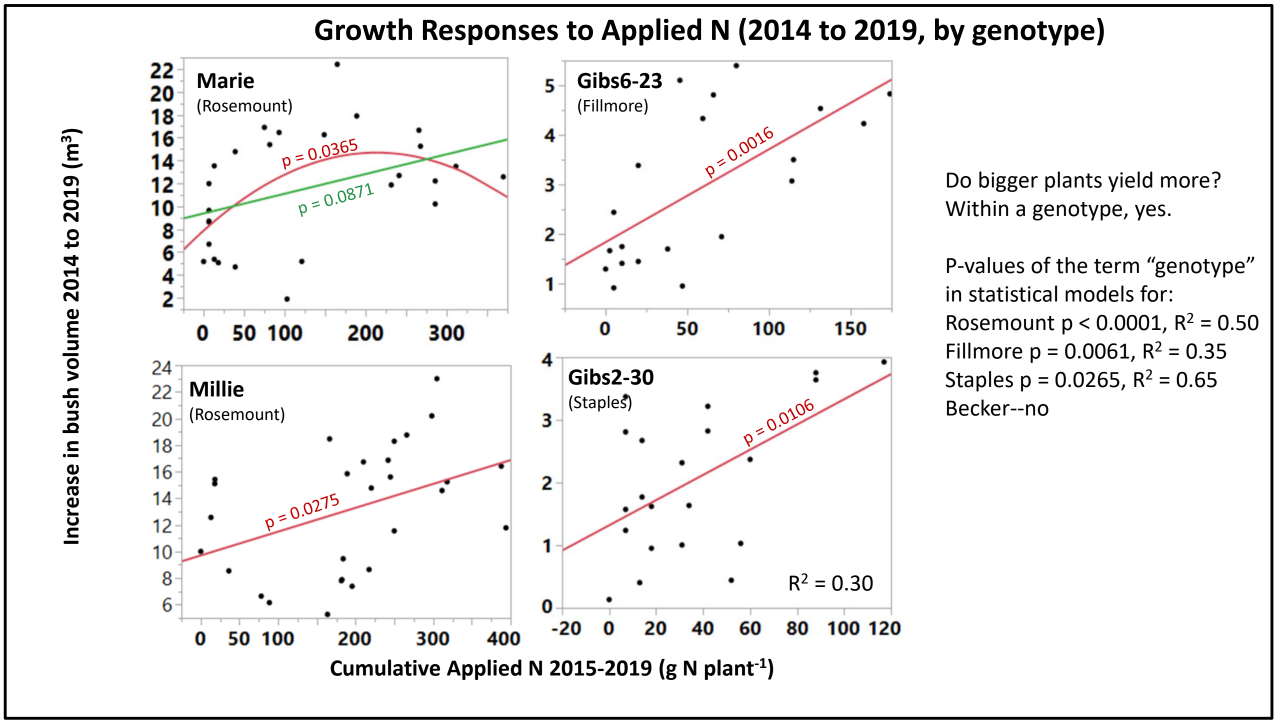
Also as one would expect, the more N that was applied, the more the plants grew, at least at all sites except for Becker. However, treatment effects were only significant at Staples and Fillmore, and only after two and four years of applications respectively.



This is the same data, just looking at the final year of the trial, and presented slightly differently. At Staples and Filmore, although plants receiving annual N applications were significantly larger than plants receiving no N and plants receiving N based on a leaf N threshold of 1.8%, there was no difference between the annual applications and applications based on a leaf N threshold of 2.2%, or even 2.0% at Fillmore. Moreover, there were no significant differences in plant size due to N treatment at Becker or at Rosemount.



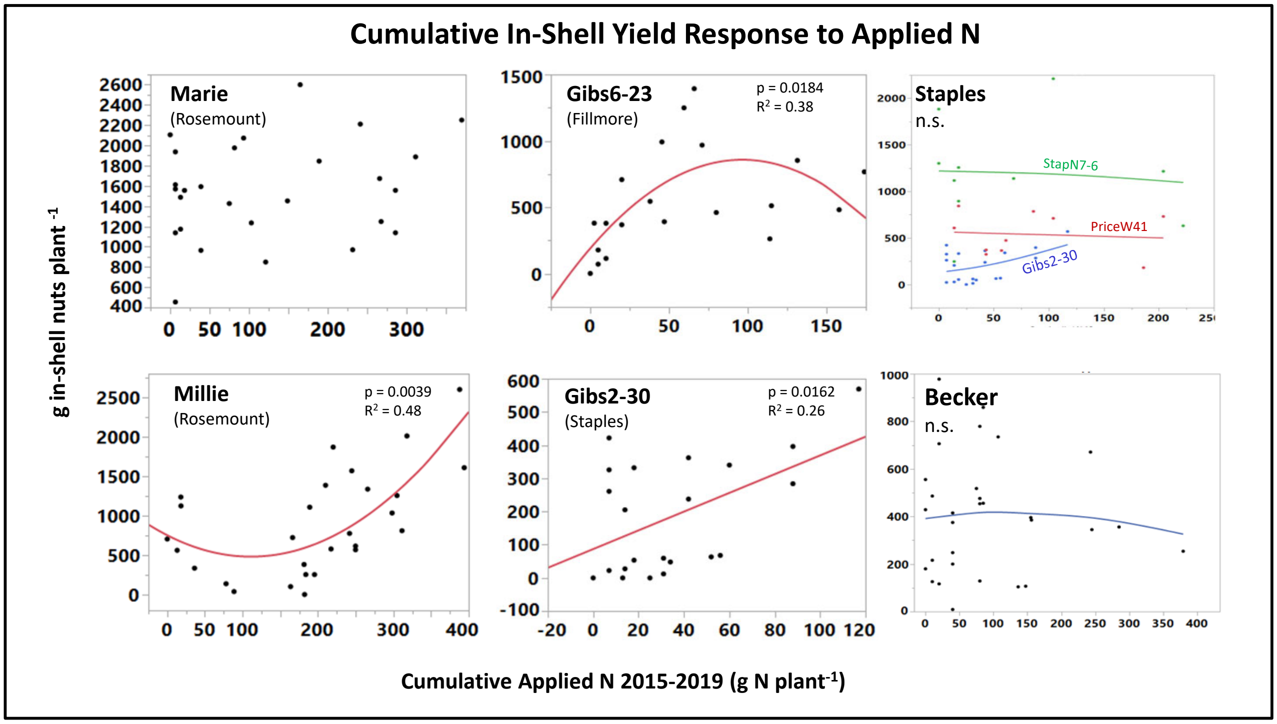
Ignoring treatment, but just looking at the actual amount of N applied, we see a linear increase in growth with increased N applications at all sites except for Becker.



These figures break the results down further by genotype, and support the same conclusion that growth increased linearly with increasing N applications.

These results are not helpful in developing recommendations for how much N to apply. For that we would prefer to see a plateau response, more like what we observed with Marie at Rosemount: growth increases with increasing N up to a level, then levels off above that level. The point at which it levels off is the optimal level. The figure for Marie suggests that the optimal level of N fertilization is about 150 g N per plant cumulative over four years, but this is not easily translated into a specific amount per year.

An important question is whether bigger plants yield more. In our germplasm evaluation work we see plenty examples of small plants that yield much more than large plants. However, within a genotype, it is clear that yes, the larger the plant the higher the yield.



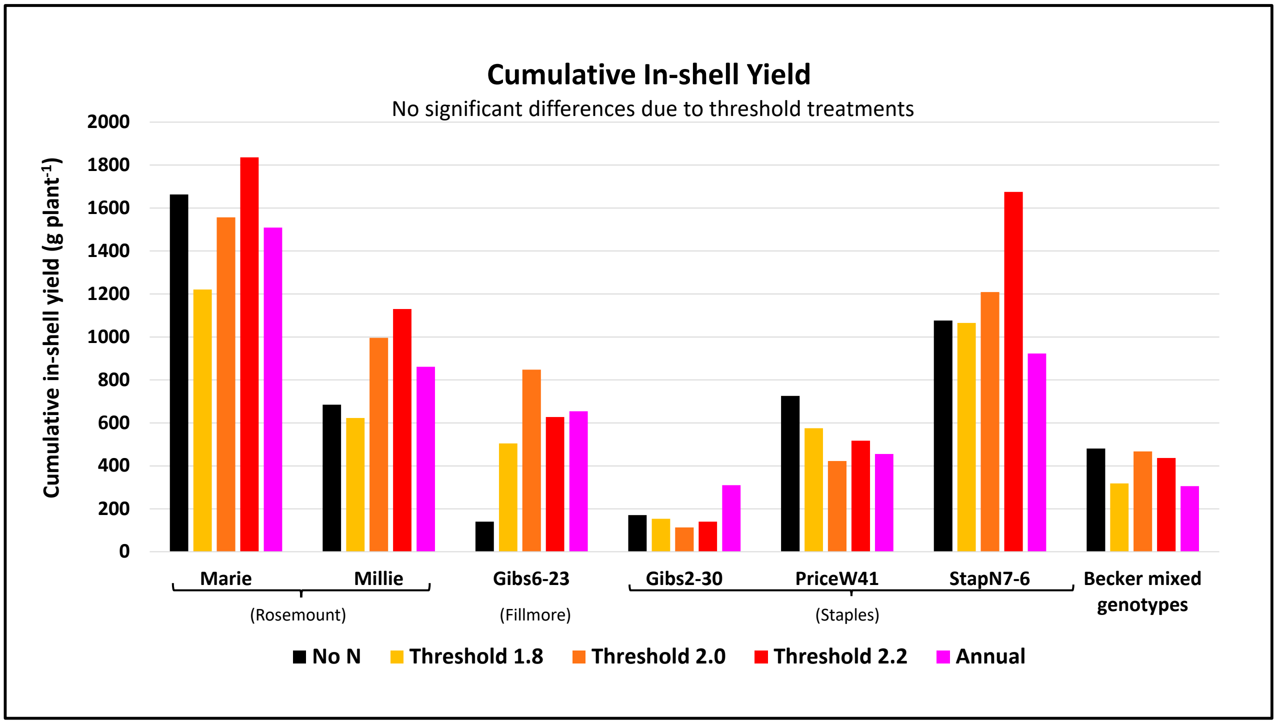
So if higher N grows bigger plants, and bigger plants yield more nuts, does it follow that higher N applications result in higher yields? The answer is equivocal. For Gibs6-23, Gibs2-30 and Millie, the answer seems to be "yes" but for Marie and the other genotypes at Staples and Becker there was no yield response to applied N. At Staples there was only one replication per genotype, so it would be hard to see one. At Becker there was another problem.

What happened at Becker?

Why did the plants at Becker fail to respond to applied N? It was drought!

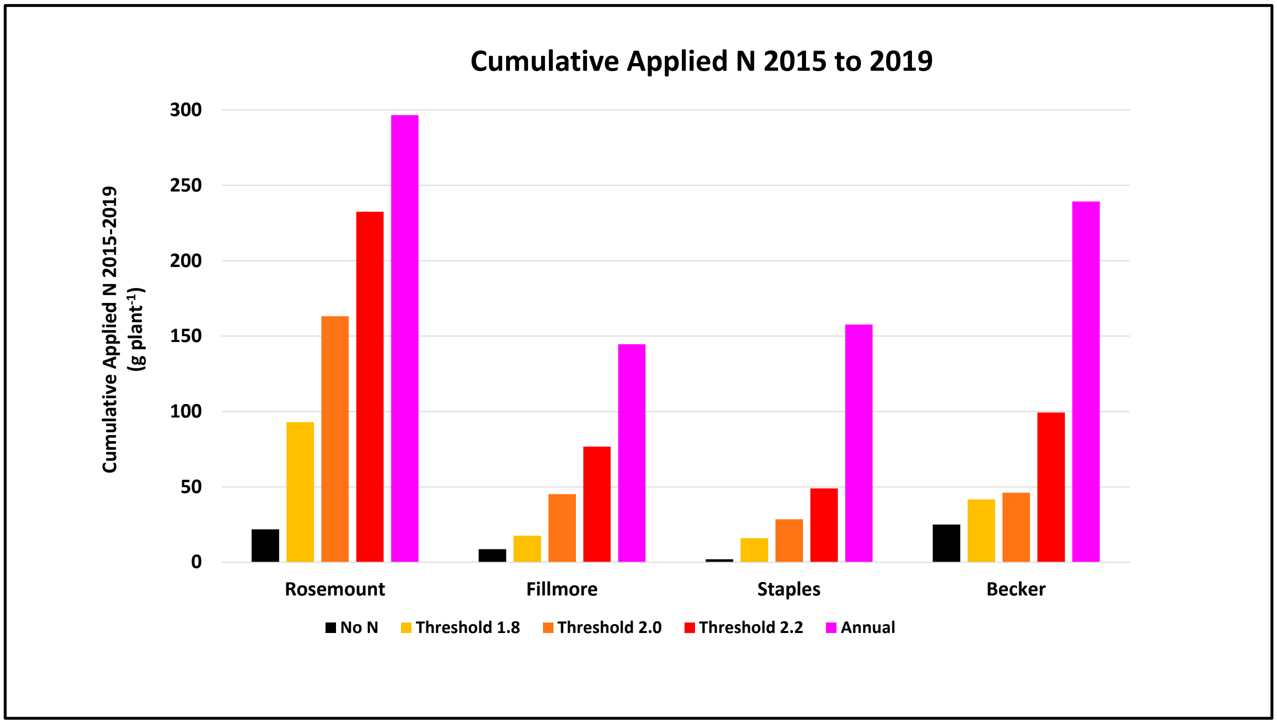
This took me by surprise. Although Becker has a very sandy soil, and most other crops grown there are irrigated, I had assumed that hybrid hazelnuts must be very drought tolerant because there are abundant wild hazelnuts growing on similarly sandy at the Sherburne National Wildlife Refuge not far away. Wrong! When I visited and took this picture in early August 2017 I was surprised because we had been having usually wet weather in St. Paul just 50 miles away. I especially did not understand that, although the plants might survive, nut fill is severely impacted by drought during the three-week nut fill period that occurs just before nut maturity in August. Having learned that lesson, I believe that irrigation is essential for hazelnuts on sandy soil.

The lack of a growth response to nitrogen under drought conditions also illustrates a fundamental principle of plant nutrition: no amount of fertilizer of any type will do any good if something else—whether it is deficiency of a different nutrient, drought, insects, disease, whatever, is limiting growth. You have to address the limiting factor first!

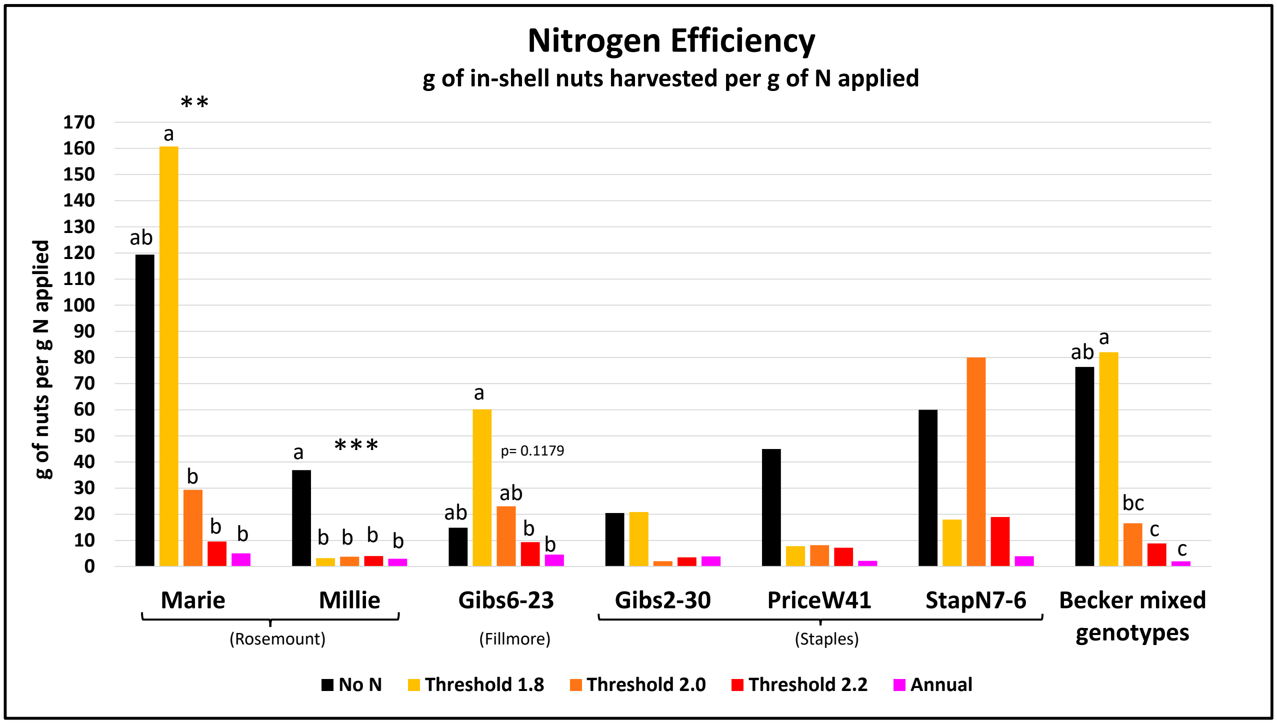


Going back to the threshold treatments, we find no significant differences in yield due to the threshold treatments.

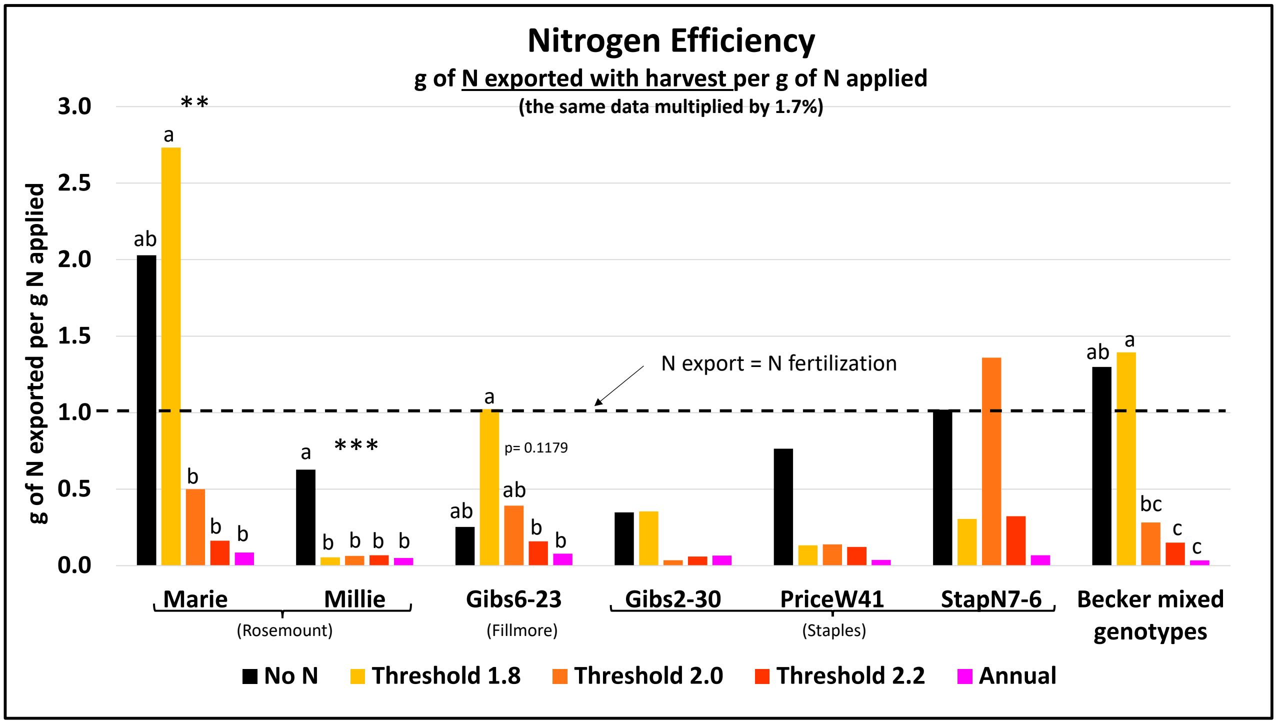
What this figure does show is very large differences in productivity between genotypes. It looks like we selected some dud genotypes when we set up this trial.



This was in spite of much higher amounts of N applied with the annual treatments. (This is a repeat of a slide I showed earlier, just as a reminder.)



What really matters is nitrogen efficiency, that is, return in nuts for the nitrogen applied. This figure shows that for most of the genotypes in this trial, there was no yield benefit to N application.



This is the same figure with a different y-axis, derived by multiplying the same data by 1.7%, which is the average concentration of N we have measured in the harvested portions of a hazelnut crop, which includes not just kernels, but also shells and husks. (We'll discuss that more later.)

The dotted line at 1.0 indicates perfect fertilization efficiency, which is unlikely. Weinbaum (2001) found that hazelnuts in Oregon have a Nitrogen Use Efficiency (NUE) of only 28%. However, we would like it to be as close to 1.0 as possible. This figure shows ratios of less than 0.1 for annual applications, which is abysmally inefficient, even compared to Oregon hazelnuts. Where did the rest of the N go? Although some of it may have gone into growing the plant (in which case we may yet reap a yield benefit from it in future years), or been taken up by weeds or immobilized in the soil, much of it likely ended up in our water as a pollutant.

Conversely, values that exceed 1.0, however, indicate a system that will eventually deplete N stores unless replenished from other sources, such as, perhaps from N fixation from adjacent clover. If the soil is high in organic matter to start with, it may take many years for N depletion to occur, though I have observed cases where I suspect it has.

The best treatments, based on this figure, seems to be applications based on the 1.8 or 2.0 % leaf N threshold, which averaged across sites and genotypes, had NUEs of 86 and 40% respectively.

Profitability of N Fertilization

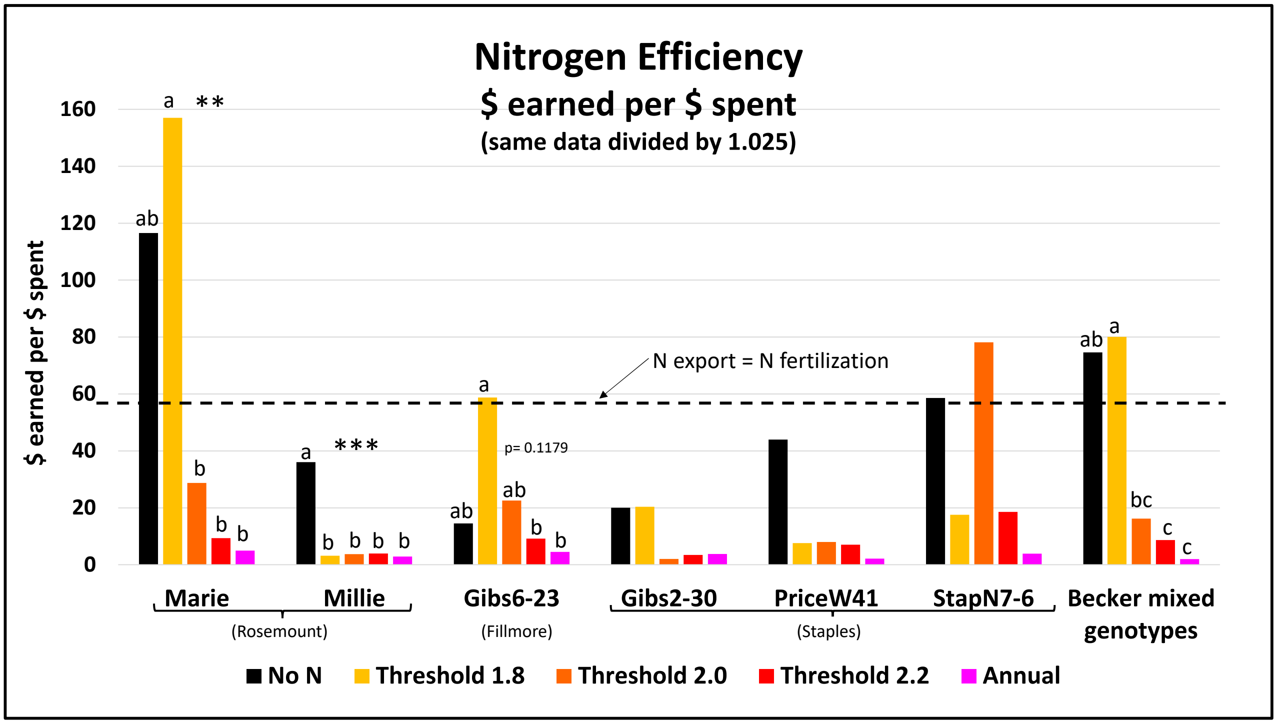
Value of 1 lb of in-shell nuts = $1.55 (AHC prices)

Cost of a 50 lb bag of UMAXX fertilizer = $36.50
Cost of 1 lb of UMAXX = $0.73
Analysis UMAXX 46% N
Cost 1 lb N from UMAXX= $1.59

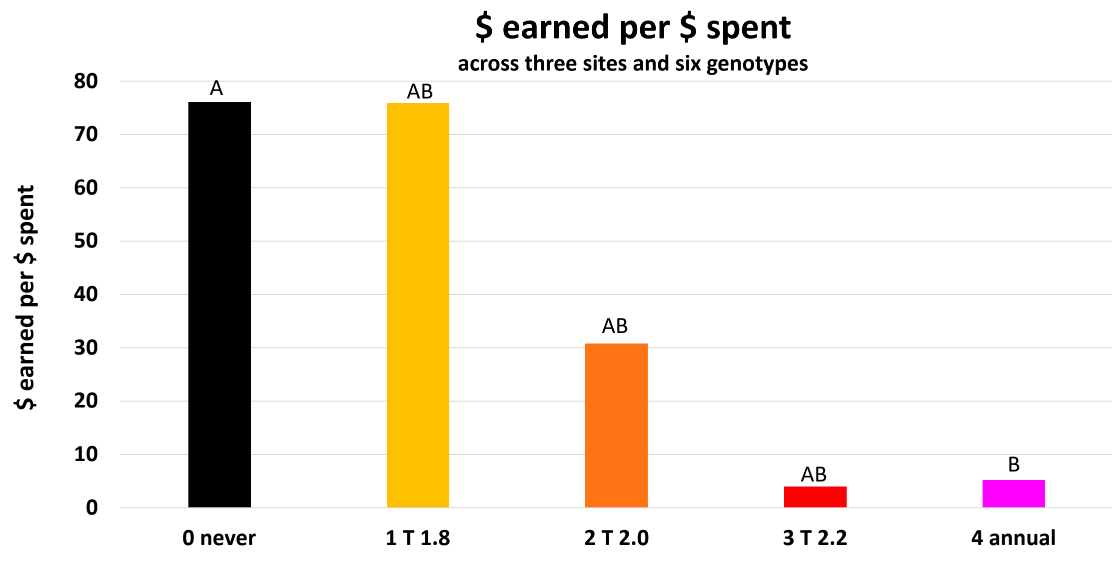
Ratio cost of N to value of nuts = $1.59/$1.55 = 1.025

AHC = American Hazelnut Company, our Midwest-based grower-owned marketing company

Or, to put it in economic terms, N fertilization only pays for itself if it increases yield by more than 1.025 pounds per pound of N applied.

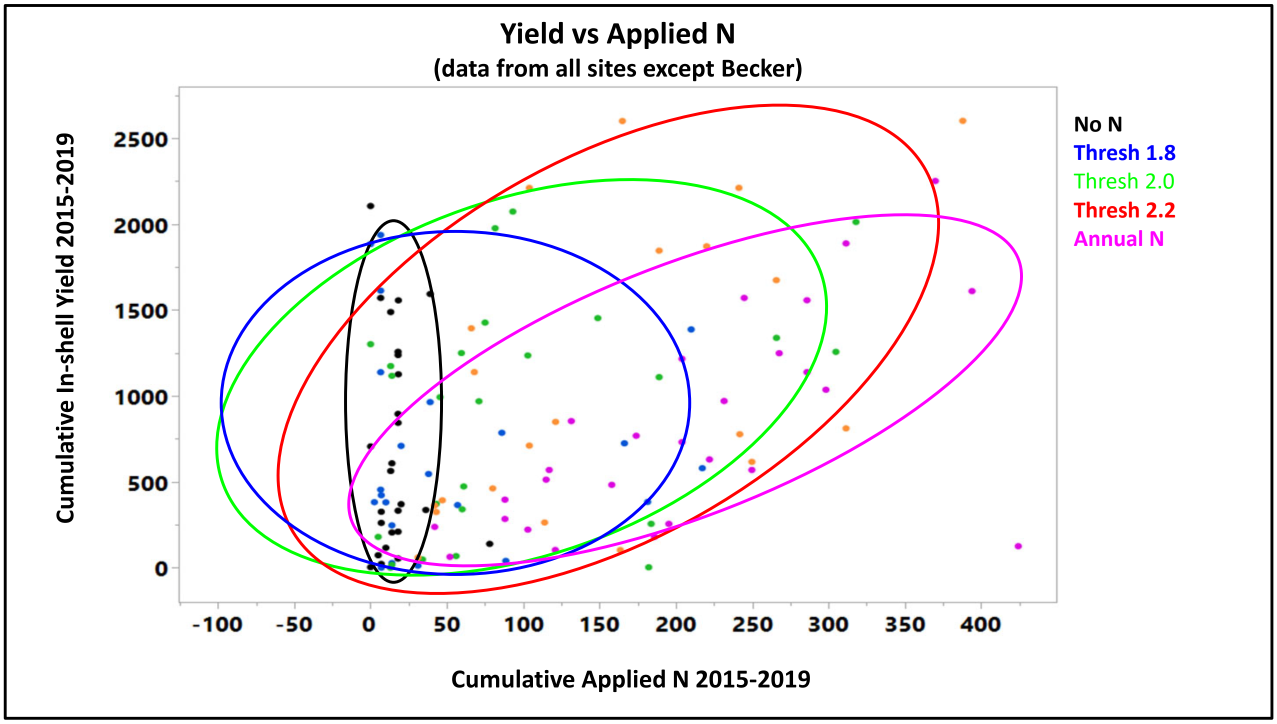


Looking at the data from an economic perspective makes N fertilization appear slightly more beneficial, since it appears that at least a little money is being earned even with annual N applications. However, this fails to take into account all the other production costs, such as land rental, costs of seedlings, weed control, herbivory control, harvest costs, etc. I tried to calculate those costs using Jason' Fischbach's enterprise analysis spreadsheets, but those expenses are too variable to come up with definitive amount, other than to say that all together they are substantial.



Data are least squared means across all four sites in a model including genotype.
$p_{genotype}$ = 0.0020, $p_{N\ treatment}$ = 0.0051, p_{model} = 0.0002, R^2 = 0.20

My hunch is that unless fertilizer applications earn you $20 or $30 more for each dollar you spend on fertilizer, it is probably a losing proposition. If that is the case, averages across genotypes and sites suggest that applying N fertilizer is economically justified only when leaf N falls below 1.8% (the deficiency threshold), or perhaps 2.0%. That is, <u>with these particular genotypes</u>. More productive genotypes may justify fertilization based on a higher threshold.



This figure is probably the most honest way to look at this data because by showing a point for every single data plant it shows how variable the results are even within a treatment. Cumulative applied N is on the horizontal axis and cumulative in-shell yield is on the vertical axis. The best treatment is the one that clusters furthest to the top (high yields and furthest to the left (low applied N). Again, it looks like applying N based on leaf N thresholds of 1.8 % (blue) to 2.0 % (green) is best.

Conclusions from N Threshold Trial

1. N fertilization increases growth
   (if nothing else is limiting)
2. Larger plants produce higher yields
   (germplasm and other factors being equal)

Therefore,

3. N fertilization may increase yield.

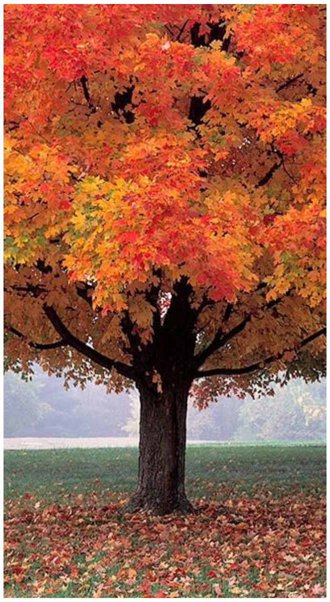
However,

4. N uptake is extremely inefficient,
5. N that is not taken up becomes a pollutant and costs $.

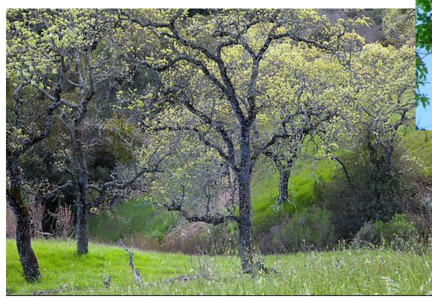
Therefore,

6. It is wasteful to apply N when it is not needed.
7. N is not needed if leaf N is above a sufficiency threshold of about 2.0 to 2.2 %.

IF nitrogen is needed, how much should be applied? Our results so far do not answer that question. What we look for in fertilizer trials is a plateau response, that is, increased growth with increasing amounts of fertilizer up to a point, above which there is no response. The point at which the response levels off is the ideal level. But we didn't see a plateau response. Instead, we observed a linear growth response, which suggests that we would have observed even more growth if we had applied more N. It suggests that 30 g N m^{-3} of bush volume was not enough. But how much more might be too much? Only further trials can tell.



In nature, trees cycle N very tightly



I brought this slide up again to remind you about how woody plants hold onto and recycle their nutrients, which is what makes them so efficient. That is why I used "cumulative" nitrogen applications as the predictor in so many of my statistical models, instead of amount of nitrogen applied in the current year—because past N applications continue to count for many years after N application.

How much N to Apply?
(assuming it is needed)

- **Apply and resample method?**
  - Apply only when leaf N falls below about 2.0 or 2.2 % N and retest the next year.
- Based on plant size?
  - 30 g N m^{-3} of bush volume per year does not seem to be enough,
    (at not least for highly productive plants)
  - Trials are planned to fine tune this.
- **Based on N removal with harvest?**
  - Uptake is inefficient so this is probably not enough.
  - Trials are planned to test 1x, 2x, 3x, where x = N removed with harvest

This experiment suggests that perhaps the best way to fertilize hazelnuts is to base it just on leaf N analysis.

Leaf sufficiency thresholds must be interpreted together with plant vigor and productivity.

Interpretation of Leaf %

<table>
<tr><th></th><th></th><th colspan="2">Vigor and Yield</th></tr>
<tr><th></th><th></th><th>Low</th><th>High</th></tr>
<tr><td rowspan="3">Leaf N</td><td>Low
< 1.8 or 1.9 %</td><td>Needs fertilization!</td><td rowspan="2">Fertilization is optimal</td></tr>
<tr><td>Optimal
1.9 to 2.2 %</td><td rowspan="2">Something else besides N is limiting growth</td></tr>
<tr><td>High
2.2 – 2.5 %</td><td>Past overfertilization
(may result in poor nut fill)</td></tr>
</table>

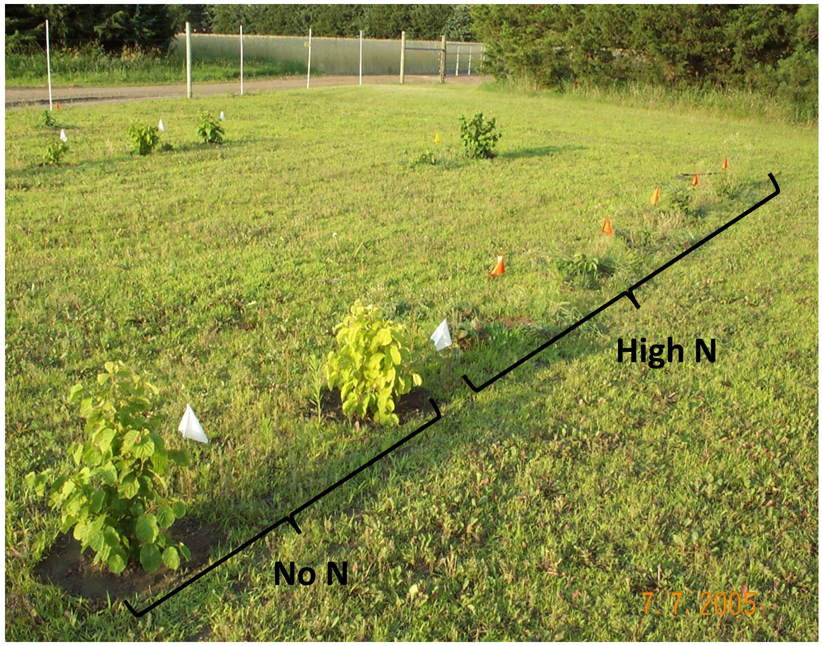
These numbers are not precise!

I wish it was that simple!

Low leaf N does not always signify N deficiency; sometimes it merely signifies that growth has been good, resulting more and larger leaves, diluting the amount of N per leaf. So if leaf N is low, but the plants look healthy and are producing nuts well, the fertilization program is probably optimal.

Conversely, high leaf N does not always signify plant health. Sometimes it signifies that growth has been inhibited by other factors, such as drought, deficiencies of other nutrients, or perhaps by toxicity from excessive N, which is especially likely if N was applied as usea or ammonia without a nitrification inhibitor.

Becker, July 7, 2005



I already discussed how drought inhibited response to N fertilization at Becker. This photo (of a different trial at Becker, shows plants (with orange ribbons) that were stunted because of N toxicity. Afflicted leaves were dark green, but much smaller than normal and some had leaf N in excess of 2.5%, which is the threshold for excessive N. Too much N can be a problem too.

By contrast, leaves on unfertilized plants (white flags) were chlorotic (yellowish), signifying N deficiency, but the plants grew much bigger.

By the way, these plants should not have been given much N at all, if any—they were too young and did not have the root system or leaf demand to take it up.

How much N to Apply?
(assuming it is needed)

- **Apply and resample method?**
  - Apply only when leaf N falls below about 2.0 or 2.2 % N and retest the next year.
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  - 30 g N m^{-3} of bush volume per year does not seem to be enough, (at not least for highly productive plants)
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Thus far we have been calibrating application rates to bush plant volume, calculating plant size as a cylinder, based on plant width and height. But it is likely that nitrogen demand is more highly correlated with leaf volume, or perhaps root volume, which are much harder to estimate, combined with nut load, which is partly determined by genotype. More productive genotypes are likely to have a much stronger demand for N. (I have a strong hunch that our previous trials would have given us much more definitive results if we had used more productive germplasm which had a stronger demand for nitrogen.)

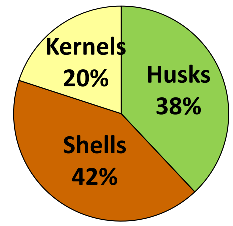
Another approach would be to apply an amount of N that would replace the N removed with harvest, assuming a certain uptake efficiency. A big advantage of this approach is that it also takes into account the productive capacity of the plants' genotype.

We have trials planned to test this approach. A key question will be what uptake efficiency we can count on. But what should that efficiency be? Weinbaum (2001) found only 28% NUE in Oregon hazelnuts, so assuming 25 or 50 % efficiency is probably a good starting point for trials looking at this approach, though we'd certainly prefer much higher efficiency.

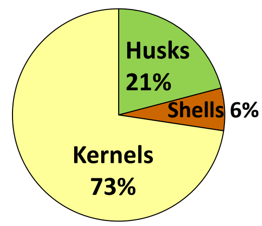
Calculating N Removal with Harvest
Example 1: with Our Highest-Yielding Germplasm

Harvest component	N concentration (%)	Proportion of dry in-husk mass (%)	Material Removed if husks taken out of field *			Removed if husks left in field
			Biomass removed (kg/ha)	N removed (kg/ha)	N removed (lbs/ac)	N removed (lbs/ac)
Husks	0.5 %	38%	1701	8.5	7.6	None
Shells	0.1%	42%	1880	2.6	2.3	2.3
Kernels	3.3%	20%	895	29.5	26.4	26.4
Total removed from field			4475	40.7	36 lbs/ac	29 lbs/ac

Proportion of Biomass Removed (dryweight)



Proportion of N Removed



* Assumptions:
- A yield of 895 kg kernel/ha (800 lbs/ac), which is the avg. yield of our top eight selections. (or 2557 kg in-shell/ha =2286 lbs in-shell/ac)
- 35% kernel.

How do we calculate N removal with harvest? The first step is to calculate the concentration of N in the harvested portions of hazelnuts. We did that by measuring the proportion of material removed from the field comprised of kernel, shells and husks and the concentration of N in those three components.

From the pie diagram, you can see that most of the dry weight removed is in shells, followed by husks, but that most of the N removed is in the kernels, followed by the husks.

We included husks even though they aren't marketed, because our current harvest system here in the Midwest removes husks from the field with harvest. Husks and shells together constitute about 80% of what is removed from the field with harvest on a dry weight basis. So although the concentration of N in them (0.5 and 0.1% in husks and shells respectively) is much lower than the concentration of N in kernels (3.3%), it adds up: over a quarter of the N removed with harvest (27%) is in the husks and shells.

Assuming a yield of 800 lbs kernel per acre, which is the average yield of our top eight selections to date, we calculated that 36 lbs of N per acre would be removed with harvest if harvest included husks, or 29 lbs/acre if husks were left in the field (or returned to the field after husking). That is in the ballpark of the maximum amounts we applied in our trials at Staples and Fillmore, though we applied three times that much at Rosemount and Becker (and still saw only linear responses there, suggesting it wasn't enough).

Calculating N Removal with Harvest
Example 2: with typical seedling germplasm
300 kg kernel/ha or 261 lbs kernel/ac, based on Fischbach et al., 2011

	N Concen-tration (%)	Pro-portion of dry in-husk mass (%)	Material removed if husks taken out of field			Removed if husks left in field
			Biomass removed (kg/ha)	N removed (kg/ha)	N removed (lbs/ac)	N removed (lbs/ac)
Husks	0.5%	38%	570	2.9	2.5	None
Shells	0.1%	42%	630	0.9	0.8	0.8
Kernels	3.3%	20%	300	9.9	8.8	8.8
Total removed from field			1500	13.6	12.2	9.6

This table assumes the much lower yields that we typically observe with ordinary seedling germplasm. Only 12.2 lbs per acre of N are removed with harvest with husks, or 9.6 lbs without husks. These quantities are only about 10% of the 100 lbs/acre we applied for the annual treatment in the last year at Rosemount. In other words, N uptake with annual applications appears to have an efficiency of only about 10 %, just as we calculated elsewhere, which is abysmally low.

How to calculate N removal
Rule of thumb:

If leaving husks in the field,
N removed = In-shell yield x 1.2%

If removing husks from the field add another 0.3%
N removed = In-shell yield x 1.5 %

This assumes that
- in-shell nuts are 35% kernel,
- husk dry matter adds another 37.5% to the mass of what is removed from the field

Before I move on, here is the rule of thumb I suggest for calculating N removal based on your in-shell yield. I tried to put together a table to help you calculate it yourself based on alternative assumptions, such as a different percent kernel (I used 35% here) or a different amount of husk material left in the field, but I couldn't figure out how to make the table easily understandable.

Calculating N Removal with Harvest
Example 1: with Our Highest-Yielding Germplasm

Harvest component	N concentration (%)	Proportion of dry in-husk mass (%)	Material Removed if husks taken out of field			Removed if husks left in field
			Biomass removed (kg/ha)	N removed (kg/ha)	N removed (lbs/ac)	N removed (lbs/ac)
Husks	0.5 %	38%	1701	8.5	7.6	None
Shells	0.1%	42%	1880	2.6	2.3	2.3
Kernels	3.3%	20%	895	29.5	26.4	26.4
Total removed from field			**4475**	**40.7**	**36 lbs/ac**	**29 lbs/ac**

Calculating N concentration out of total N removed
on basis of dry in-shell yield (yield with shells but without husks)

N removed in shells and kernels only: 2.6 + 29.5 = 32.1 kg/ha
N removed in husks, shells and kernels: 40.7 kg/ha
In-shell yield: Shells 1880 kg/ha
Kernels 895 kg/ha
Total: 2775 kg/ha

If not removing husks: 32.1/2775 = 1.2%
If removing husks too: 40.7/2775 = 1.5%

Removing husks removes an additional 0.3%

How do we calculate N removal with harvest? The first step is to calculate the concentration of N in the harvested portions of hazelnuts. We did that by measuring the proportion of material removed from the field comprised of kernel, shells and husks and the concentration of N in those three components.

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			Biomass removed (kg/ha)	N removed (kg/ha)
Husks	0.5%	38%	570	**2.9**
Shells	0.1%	42%	**630**	**0.9**
Kernels	3.3%	20%	**300**	**9.9**
Total removed from field			1500	13.6

Calculating N concentration out of total N removed
on basis of dry in-shell yield (yield with shells but without husks

N removed in shells and kernels only: 0.9 + 9.9 = 10.8 kg/ha
N removed in husks, shells and kernels: 10.8 + 2.9 =13.7 kg/ha
Biomass removed: Shells 630 kg/ha
Kernels 300 kg
Total: 930 kg

If not removing husks: 10.8/930 = 1.2%
If removing husks too: 13.7/930 = 1.5%

Removing husks removes an additional 0.3%

This table assumes the much lower yields that we typically observe with ordinary seedling germplasm. Only 12.2 lbs per acre of N are removed with harvest with husks, or 9.6 lbs without husks. These quantities are only about 10% of the 100 lbs/acre we applied for the annual treatment in the last year at Rosemount. In other words, N uptake with annual applications appears to have an efficiency of only about 10 %, just as we calculated elsewhere, which is abysmally low.

How to Improve N Uptake Efficiency?

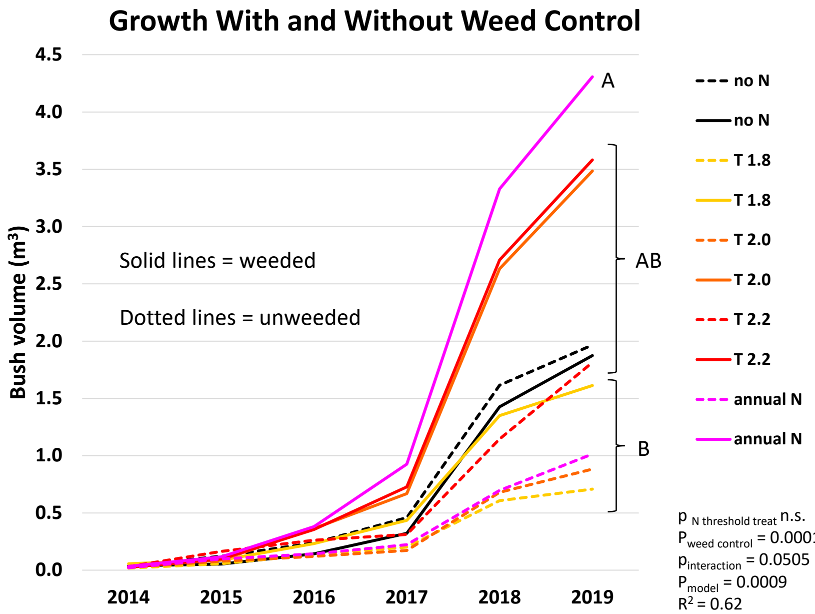
1. Apply only as much as needed
2. Appropriate timing
   - When plants are fully leafed out and healthy
   - When soil moisture is optimal (not too dry, not too wet)
     - →Typically late May through early Sept
3. Apply slow-release forms of N
   - Organic forms (compost or manure)
   - Urease or nitrification-inhibitor treated urea
   - Polymer-coated urea
   - Split applications
4. Careful placement
   - Under the plant canopy
   - Control weeds

One of the take home points I'd like to make is that, under current practice, utilization of N fertilizer is abysmally inefficient. If hazelnuts are to live up to their potential as an environmentally sustainable crop and also to be profitable, we must use as many of these tools as possible to improve N uptake efficiency.

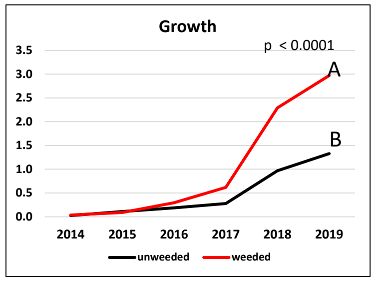
Don't fertilize the weeds!

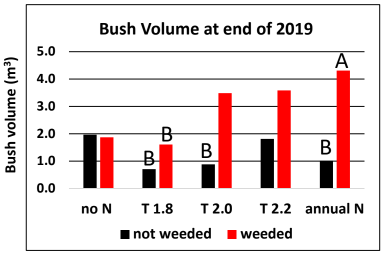
Once again, this photo is from Becker. I had tied blue ribbons to the plants to be fertilized, and came back a month later to find very definitively that the grass in the alleys adjacent to the hazelnuts just loved the fertilizer!

Not fertilizing the weeds is easier said than done, because we advocate keeping grassy alleys for conservation purposes, and also for keeping a firm harvest surface. But mature hazelnuts do a pretty good job of shading out the weeds underneath their canopy, and that's where their root system is densest so that's where we should apply N fertilizer—right under the canopy. (When we start doing this mechanically we'll have to figure out better technologies to do that.)

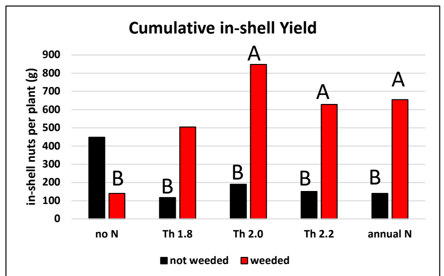


This brings me to the second topic of my presentation: weed control. The most definitive data I have on the importance of weed control is from the Fillmore N threshold trial, which was done as a factorial experiment with and without weed control. (The weed control treatments were started in the fourth year after planting; all plants were given moderately good weed control before then.) The N treatments here are the same ones I reported earlier: no N vs. annual N vs. N applied only when leaf N fell below thresholds of 1.8, 2.0 and 2.2 %. This figure shows that the growth response to weed control was far greater than the growth response to N fertilization.





$p_{\text{N threshold treat}}$ n.s.
$P_{\text{weed control}} = 0.0001$
$p_{\text{interaction}} = 0.0505$
$P_{\text{model}} = 0.0009$
$R^2 = 0.62$



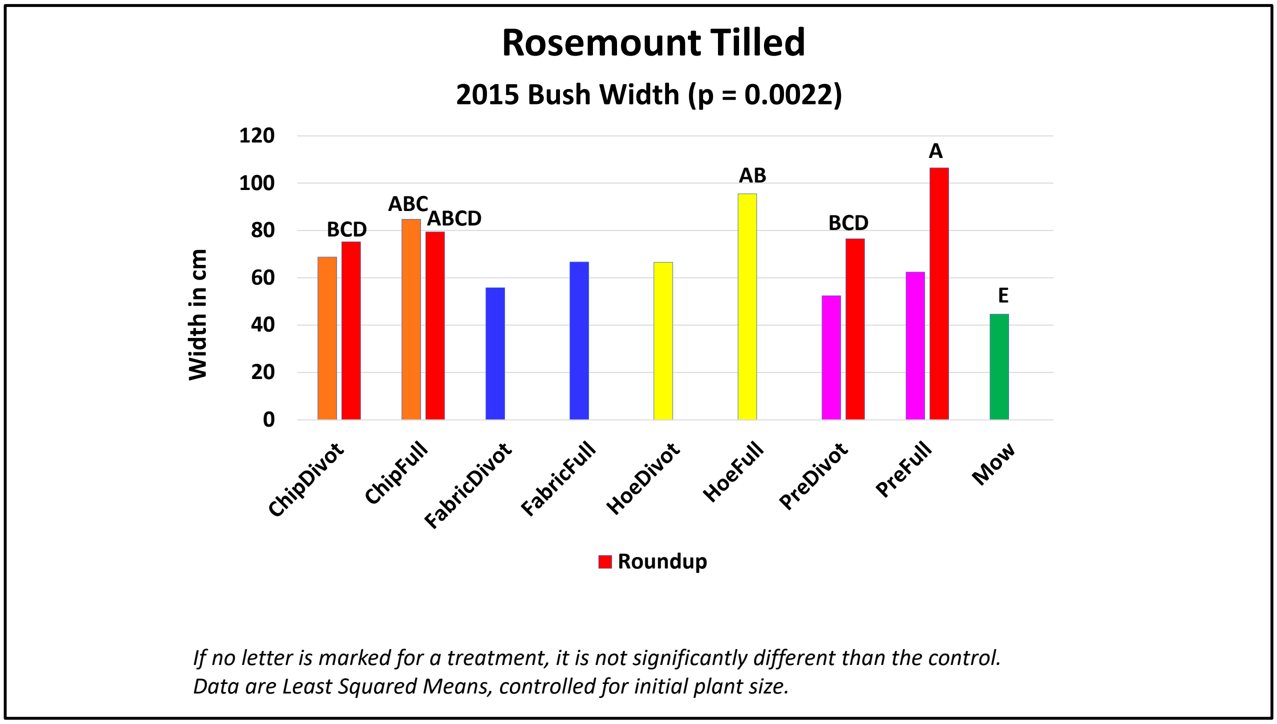
$p_{\text{N threshold treat}}$ n.s.
$P_{\text{weed control}} = 0.0022$
$p_{\text{interaction}} = 0.0468$
$P_{\text{model}} = 0.0134$
$R^2 = 0.51$

over 4 x as much yield with weed control as without

The best growth was attained with plants that received good weed control plus N fertilization either annually or when leaf N fell below 2.2 or 2.0%. Considered by itself, N fertilization did not significantly increase plant growth, though there was a weakly significant ($p = 0.0505$) interaction between weed control and fertilization, such that annual fertilization with no weed control actually performed worse than no fertilization. This was probably because N fertilization without weed control stimulated weeds, which then competed with the hazelnuts for other nutrients, moisture and sunlight. Shading was probably a significant form of competition, as can be seen from this photo in which the unweeded hazelnuts can hardly be distinguished from the weeds.

Revisiting Old Weed Control Trials

Now I'm going to switch gears and revisit the old weed control trials started in 2013. At the 2016 UMHDI conference I presented data that showed a strong positive growth response to three years of active weed control. However, I got a lot of pushback from growers who said that weed control was not cost effective. I could not argue because at that point I did not have any yield data to show that the faster growth attained with good establishment phase weed control would result in higher yields. I could not even say for sure that the plants that were larger after three years of intensive weed control would still be larger three years after those measures were discontinued. Now I can answer both questions in the affirmative.



This is one of the figures I presented in 2016, showing growth responses to weed controlled in the Rosemount "Tilled" trial. ("Tilled" means that it was established in a previously tilled row crop field, as opposed to a sod field.)

This graph shows hazelnut plant width. I could have shown height instead, but width is the most dramatic. (Height actually increased slightly with heavy weed pressure in the first two years, which is a common response to weeds: crops grow taller to escape shading. It does not necessarily result in bigger or more productive crops though; often it is just the opposite.)

Brief lesson in statistics. The "p-value" is the probability of being wrong. The smaller the p-value, the more certain we are of being right. Scientists are conservative folks and generally reject the significance of a result if the p-value is larger than 0.05; that is, if the probability of being wrong is greater than 5%. If it is between 5 and 10% we pay attention, but hesitate to come to hard conclusions.

The p-value for this graph, at 0.0022, supports the conclusion that weed control makes a difference. At least some of the weed control treatments produced significantly wider hazelnut plants than the mowed control. However, it does not specifically say which methods of control are better than which. For that we have to look at the letters on the tops of the bars. If bars share a common letter, it means that they are not significantly different from each other, at $p < 0.05$. I decided to only present the letters that are significantly different than the control for this graph to reduce clutter and make it easier to read.

Based on the letters, you can see not all of the treatments were <u>significantly</u> better than simply mowing. The ones that were significantly better included all treatments with Roundup (red bars), the full plot woodchips without Roundup (orange), and the full plot hoed treatment (yellow).

There are several patterns that also are evident in this graph:

1. Full plot treatment (3 foot wide strips parallel to the row) applications resulted in better growth than divots of 1 ½ feet in diameter.
2. All treatments that included Roundup resulted in equal or better growth than the same treatment without Roundup.

Hoed

Pre-emergent Herbicide + Roundup

Control (Mowed Only)

These photos show plant response to two of the more effective weed control treatments--hoeing and pre-emergent herbicide plus spot applications of Roundup—in contrast to the control, which was merely mowed. Note not just bush size but also leaf color and leaf size.

Conclusions in 2015

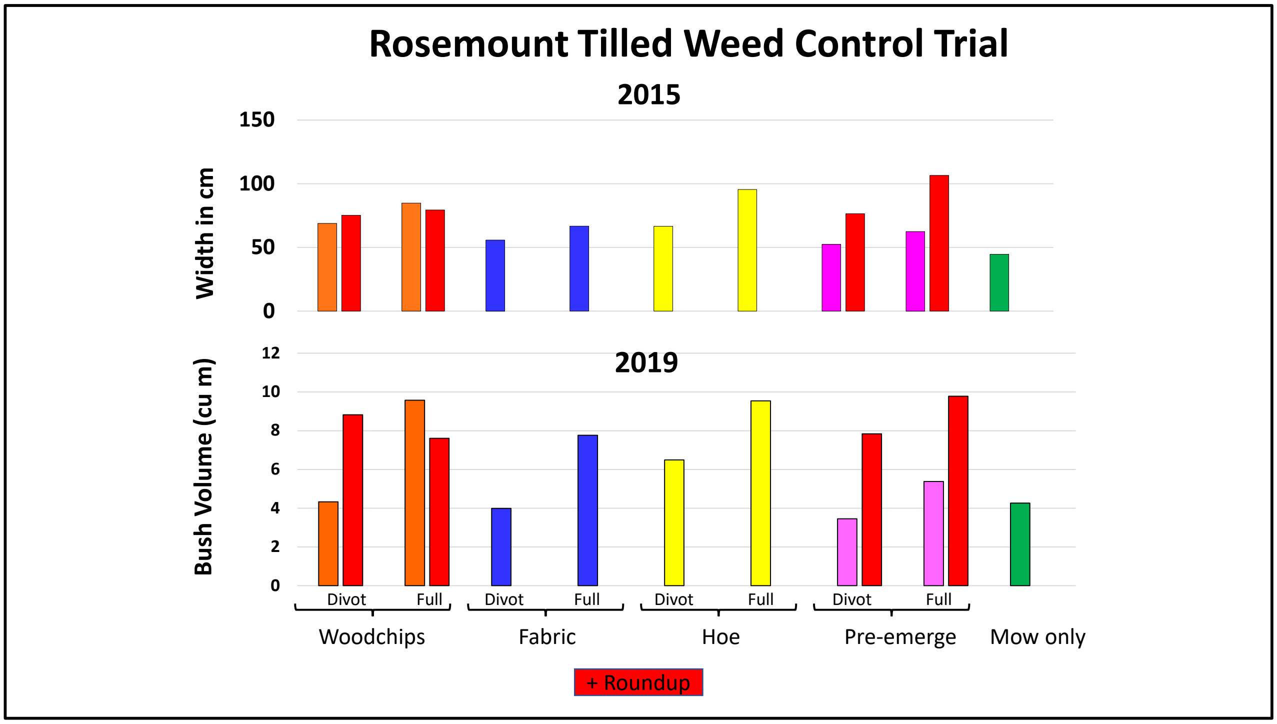
(after three years of weed control treatments)

1. Effective weed control increases plant survival and growth
2. It doesn't matter what kind of weed control is used as long as it is effective:
   a. Effective methods include:
      - Woodchip mulch
      - Landscape fabric
      - Hoeing (cultivation)
      - Pre-emergent herbicides
      - Post-emergent herbicide such as glyphosate (Roundup ®)

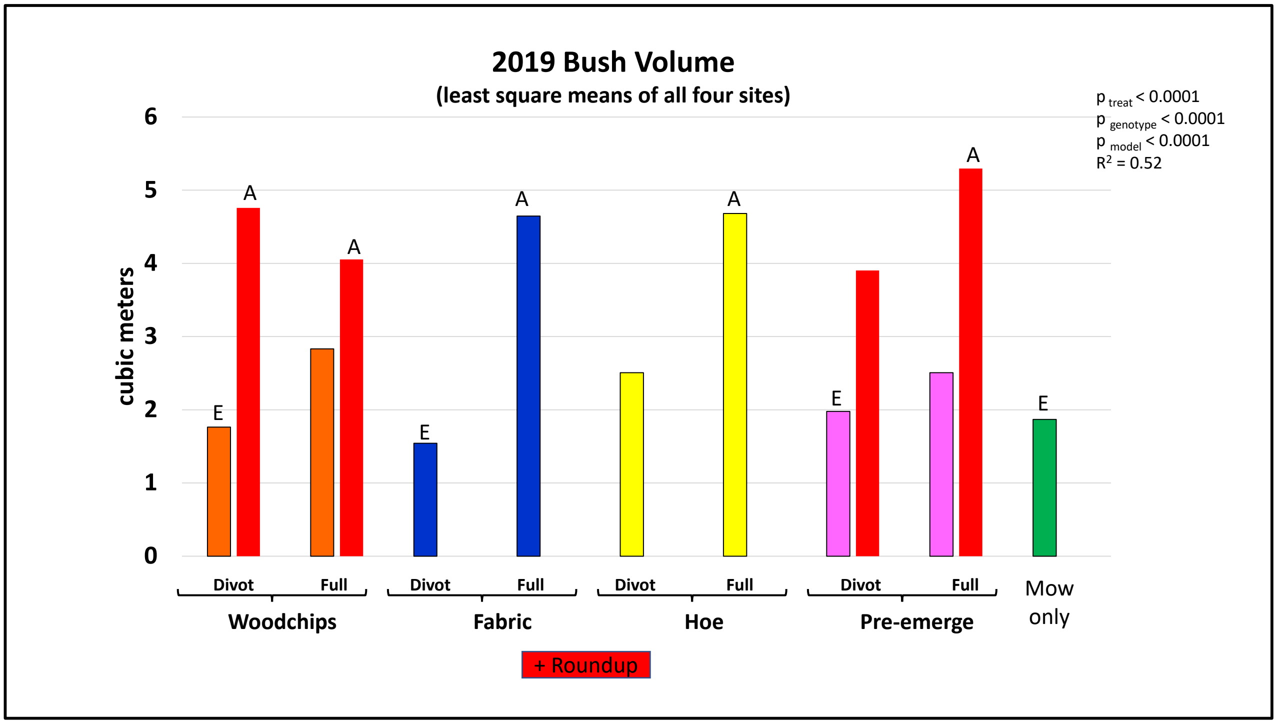
   b. Simply mowing is not enough.
3. Three foot-wide weed control better than 1 ½ foot wide.

Questions:

1. For how many years does weed control need to continue?
2. Does it pay for itself?

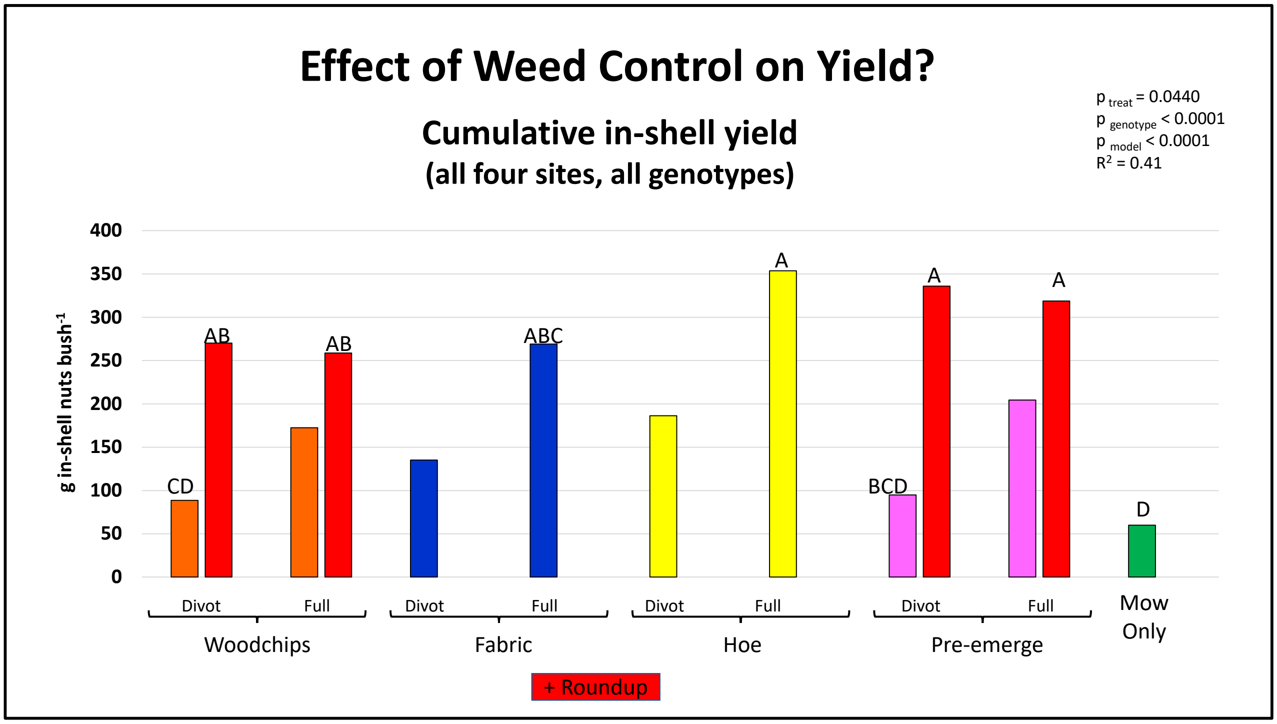


Isn't it remarkable how similar the 2015 and 2019 figures for plant size look? (Please excuse that I didn't use exactly the same unit of measure, but they're close enough.) So yes, establishment phase weed control significantly impacts plant size later in life, <u>even three years after weed control measures are discontinued.</u>



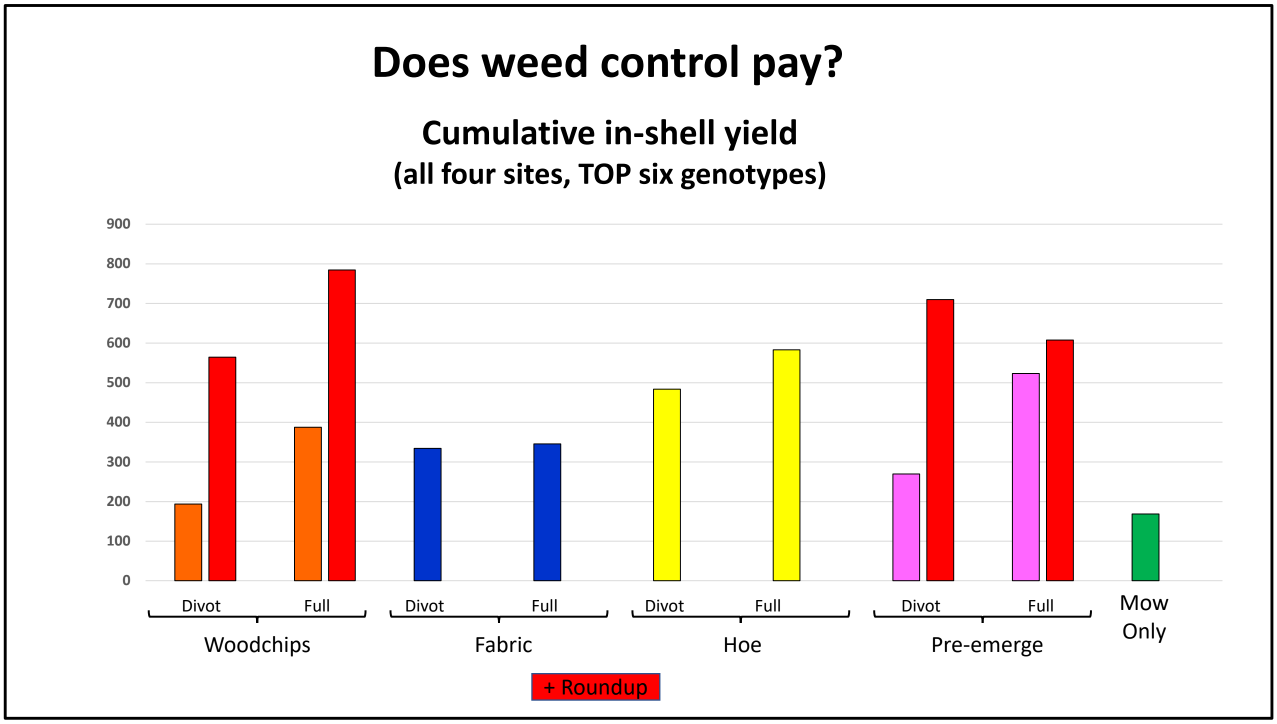
The same patterns were evident at all four sites. This figure, showing least square means of all four sites supports the same conclusions we came to three years ago:

1. Weed control needs to be implemented over a larger area than just a 1 ½ foot wide "divot" around each plant. (That might be because weeds growing just outside the divot lean in and shade the hazelnut within it, or because their roots infringe upon the divot below ground.)
2. Neither woodchips nor pre-emergent herbicide by themselves are effective methods of weed control. Both need to be supplemented with other methods as their effectiveness starts to break down in the second or third year. Spot-applying Roundup is a very effective method of secondary weed control.
3. Landscape fabric and cultivation are very effective methods of weed control, but need to control weeds out at least 2 ½ feet from the center of the hazelnut.



Now for the big question: is there a yield response to weed control? The answer is yes, the pattern is pretty similar.

This is even true when unproductive genotypes are included in the model, though genotype was a more significant determinant of yield than weed control treatment. ($p < 0.0001$ for genotype vs $p = 0.0440$ for weed control.) (Unfortunately, many of the genotypes in our trials turned out to be duds. We used what we had clonal material available for, and at the time that we established them we didn't yet know what was going to be productive and what not.)



Just looking at the six top-yielding genotypes, the same pattern holds, but the statistical significance disappears. (That's probably because of inadequate replication, since each genotype was one replication.)

But the question remains: does weed control actually pay for itself economically. I honestly can't answer that question because it depends on your situation: what are your land costs? how cheaply can you apply the weed control and still have it be effective, how low can you keep your other production costs, and what kind of price can you get for your nuts? I assert that, although it might be difficult to turn a profit with our current low-yielding seedling hazelnut germplasm, good weed control has to be part of any profitable planting.

How many years do you need to continue intense weed control?

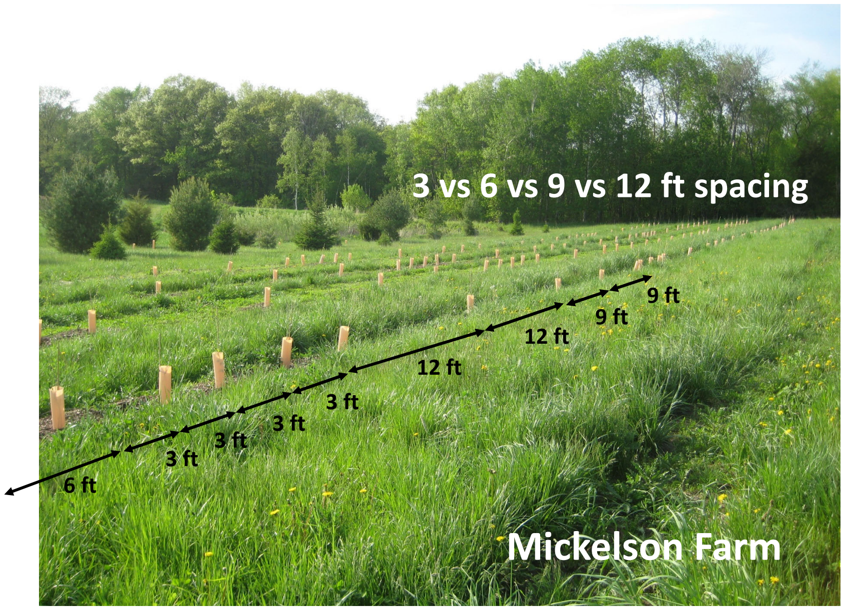
In our weed control trials we implemented the measures for three years and then discontinued it except for mowing. By the end of three years the plants with good weed control were well enough established that they were able to shade out the weeds on their own. This photo shows a planting (the Rosemount N threshold trial) where hazelnut canopy cover was so good that not only did it very effectively shade out weeds within the hazelnut rows, but it also suppressed the fescue/clover ground cover in the alleys, which consequently didn't need to be mowed very frequently. (Whether that was a good thing is to be determined, since we suspect the hazelnuts were also competing with each other, reducing yields.)

So, although we did not test it specifically, I would say that two or three years of good weed control should be sufficient in most cases. But there will be exceptions, such as at Fillmore, where three years of establishment phase weed control was not enough, and variable weed control treatments started in year four made a huge difference. So it would be a good idea to continue intensive weed control measures until the plants start to inhibit the weeds growing under them on their own.

Woody Weeds

There are some kinds of weeds that will never be inhibited by hazelnut shade, namely weed tree seedlings. The maples in this photo are adapted to getting established under the low light conditions of a forest canopy, so hazelnut shade does not phase them. I have figured out no method of controlling them other than by hand: walk the rows and eliminate them when you see them. Do this in the early spring or late fall when the hazelnut canopy is thinner so that the weed tree seedlings are more visible. In my experience, if you do this early and often (at least twice a year), when the weed tree seedlings are still very small, they are generally easy to pull, especially after a good soaking rain. If they are too big to pull, a sharp long-handled hoe is good for reaching under the arching hazelnut branches and cutting them out at ground level.

If they are too big for that, you've got a problem, as does the planting on the right, where the weed trees are taller than the hazelnuts and getting in the way of mechanical harvest. To deal with weed trees this big you need a chain saw or brush saw, and to treat their stumps with a stump-killing herbicide immediately after cutting them, a job best done with two people. It is better to walk your planting twice a year (once in early spring and again it the fall), to keep this problem from developing in the first place.



Plant Spacing Trials

Tentatively, we recommend:
Rich sites: 15 ft by 6 ft
Poor sites: 12 ft by 4 ft

I can't say much about our plant spacing trials yet, because they are still young, but just want to let you know that we are doing them. As my slide of the closed hazelnut canopy at Rosemount suggests, there are pros and cons to close spacing. Close spacing helps with earlier canopy closure and better early weed suppression, and may result in higher early yields. But if the plants start to crowd each other out, this may be a short-term benefit. Wider spaced plants are more likely to yield more on a per plant basis, but they use land less efficiently, at least initially, and may actually produce lower yields on a per acre basis. That is why we are doing these trials, that compare 3, 6, 9 and 12 foot spacing. We now have three such trials: at the Mickelson Farm, established in 2014, at the Lilja Farm, established in 2016, and at Rosemount, established in 2019.