HAZELNUTS 101

A Fact-Sheet Series for Hazelnut Growers in the Upper Midwest

Fact Sheet #5—Fertilization of Hybrid Hazelnuts in the Upper Midwest

Lois Braun, Senior Scientist, University of Minnesota

Introduction

This bulletin presents our best current understanding of how to fertilize hazelnuts in the Upper Midwest. We will refine it as our understanding improves. Our recommendations are based on a combination of recommendations for European hazelnuts in the Pacific Northwest (Olsen, 2013), recommendations for other woody crops, such as apples, in Minnesota (Rosen and Eliason, 2005), and our own research on nitrogen fertilization of hybrid hazelnuts in Minnesota. Our results show that concentrations of nitrogen in leaves of hybrid hazelnuts are similar to those of European hazelnuts, and we can reasonably assume that concentrations of other nutrients are similar as well. However, because European hazelnuts are grown as trees that grow to be much larger than our hybrid bushes and are grown at much lower population densities than hybrid hazelnuts in hedgerows, the per-plant quantities of fertilizer recommended in the Pacific Northwest are much too high for our system. Our soils are also much different, so some nutrients that are rarely limiting in the Northwest might be limiting in the Midwest, or vice versa, which is why we also need to draw on local recommendations. We advise you to contact your local Extension office to find out what nutrients might be limiting in your local area.

Fertilization of perennial plants is somewhat different from fertilization of annual plants because of the ability of perennials to store nutrients from year to year; that is, to recycle them. Whereas annuals can draw only on the nutrients and carbohydrates stored in their seeds for their initial growth, woody perennials, once they are established, have available to them nutrients stored in their roots and branches. In older plants these stores may become quite large. The larger the stores, the less dependent the plant is on current uptake from the soil, and the more the plant will be able to survive periods of low nutrient availability. Stored resources are especially valuable in early spring because they enable perennials to leaf out quickly and take advantage of sunlight for a greater part of the year than annuals. However, over time, fertilization is needed to replace nutrients removed by harvesting the crop. The primary nutrient losses in hybrid hazelnuts would come from harvest of the high-protein nuts.

Internal nutrient cycling makes perennial plants “frugal”. However, it makes developing nutrient recommendations for them more challenging than for annual crops. The nutrients available to annual crops can be estimated based on what is available in the soil, however for perennial crops the nutrients already stored within the plant must also be considered, and they are not as easily measured. Recommendations for established woody plants are thus based primarily on leaf analysis, which provide a window into the quantity of stored nutrients, and only secondarily on soil analysis. Although leaf analysis is not definitive, because it misses nutrients stored in stems, trunks, and roots, it is the best alternative to destroying the whole plant for analysis.

Table of Contents

Three Phases of Fertilization

The nutrient requirements of hazelnuts change over time as the plants mature.. There are three phases for hazelnut fertilization—pre-plant, establishment, and production.

1. **Pre-plant.** Recommendations for pre-plant fertilization and pH adjustment are based on soil analysis, to address nutrients that are relatively immobile in the soil and, if needed, should be applied before planting. These nutrients should be incorporated into the root zone, so it is much easier to apply them before planting than after. Lime to correct low pH should also be incorporated before planting for maximum effectiveness. Think of pre-plant fertilization as putting money in the bank for your plants to draw on for years to come. The nutrients in this group that are most likely to be limiting to hazelnuts in the Midwest include potassium (K), magnesium (Mg), and zinc (Zn). Phosphorus (P) is unlikely to be limiting but cannot be ruled out. Copper (Cu) is possibly limiting on organic (peat) soils and iron is possibly limiting on high pH (alkaline) soils, but copper and iron deficiencies have never been observed on hazelnuts in the Midwest. Nitrogen (N), sulfur (S) and boron (B), which are easily leached out of the soil, should not be applied pre-plant.

2. **Establishment Phase.** Recommendations for fertilization of hazelnuts during the establishment phase are based primarily on leaf analysis, combined with observations about annual shoot growth and leaf size and color. Overall nutrient requirements of hazelnuts start low, when the plants are still small, and increase as the plants grow. The establishment phase is when nutrients that leach easily from the soil, such as N and S, may be needed, but only if need for them is demonstrated with leaf analysis. Boron (B), while also leachable, is not likely to be limiting during this phase because it is primarily involved with hazelnut flowering and pollination. If the immobile nutrients were applied before planting as recommended, then they should not need to be supplemented during the establishment phase.

3. **Production Phase.** When hazelnuts reach reproductive age, nut load needs to be considered in addition to leaf analysis and observations about growth. The more nuts that are produced and harvested, the more nutrients that are exported with that harvest and the more that should be replaced to ensure continued productivity. Soil sampling at this stage helps with interpretation of leaf analyses, and identification of possible pH problems induced by previous fertilization.

How to Collect a Soil Sample

Soil sampling is one of the most important steps in planning a new hazelnut planting. It should also be done at least once every five years after planting to monitor changes in the soil or more frequently if problems arise. Use a soil probe or shovel and pull a minimum of 10 samples evenly distributed across the field, 20 would be better. If there are distinct differences in soil color or texture between different parts of the field, sample them separately because they may have different requirements. Testing the soil to a depth of 12 inches is recommended for woody crops. This is easiest to do in the spring when the soil is moderately moist. If using a shovel, collect a column that represents all depths of the soil equally. Crumble and stir these samples together in a clean bucket, put 2 cups of soil in a plastic bag, and take the bag to your local Extension office to be tested for pH, P and K, and whatever other nutrients have been found to be limiting in your local area for your soil type. Your extension office or testing lab can tell you what those are.

Modifying Soil pH

Although the optimal pH for hybrid hazelnuts in the Midwest is not known, and although wild hazelnuts in the Upper Midwest have been observed to grow on soils with pH as low as 4.5 (acid soils), if your soil pH is less than 5.6 it would be advisable to apply lime. Lime can make a big difference in the productivity of your soil because it affects the availability of many other soil nutrients. Be sure to apply liming agents at rates based on tables that consider buffer pH. Your local extension agent or your local ag coop should have these tables, or you can consult the tables in the bulletins listed at the end of this bulletin. If your soil is also low in magnesium (Mg), use dolomitic lime as the lime source.

Lime works best if incorporated into the soil as deeply as possible before planting. It should be applied several months to a year before planting. Because the application of other fertilizers and soil biological processes can change soil pH over time, retest the soil at least every five years and re-apply lime again as needed. Although it will not be possible to incorporate lime applied to established hazelnut plantings, surface-applied lime will be beneficial over time.

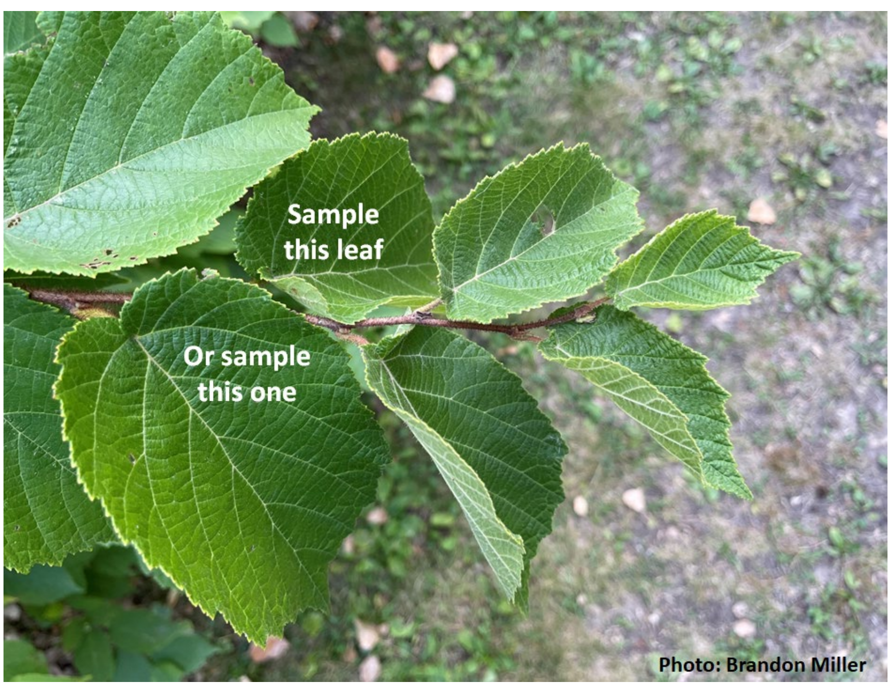
We are not aware of hazelnuts being planted on high pH (alkaline) soils, so we do not know if it is a problem for hazelnuts in the Upper Midwest. In many crops, pH higher than 7.2 renders iron unavailable to plant roots, resulting in iron deficiency chlorosis (leaf yellowing). If your pH is above 7.2 and you observe interveinal chlorosis, suspect iron deficiency. See the section on iron to learn how to address it.

How to Collect Leaf Samples

Leaf sampling gives a more definitive picture of the nutritional status of your plants than soil sampling because it is a function not just of what nutrients are present, but also what nutrients are being taken up. However, it is merely a snapshot of one plant part (leaves) at one point in time and cannot tell us what is stored in other plant parts (twigs, branches, roots, husks, nuts).

Ideally, collect leaf samples in the last two weeks of July. This is the period when nutrient levels are most stable, so the sufficiency-deficiency ranges shown in Table 1 are based on that timing. Leaf samples can be collected at other times to diagnose a suspected deficiency, but need to be compared with leaves from plants with no symptoms collected at the same time to enable interpretation.

Pluck the 1st, 2nd or 3rd fully developed leaf from the terminal ends of unshaded stems. That is, collect from the middle of stems. Ignore all the immature leaves that have a brighter green color, but do not collect from the parts of the branches that are shaded. Plants move nutrients around to where they get the most return from them, which in the case of leaves means those in full sun, to maximize photosynthesis. They also move nutrients from leaves into developing nuts, so do not collect leaves from stems with a developing nut cluster. Collect 20 to 40 leaves from different parts of the plants you are concerned about, collecting only leaves that look typical of those plants and collecting no more than two leaves per plant. As with soil sampling, if there are distinct parts of the planting that appear to be performing differently, sample them separately. Do not include leaves that are damaged, or dirty. Dry the leaves (a food drier works great, as does the dashboard of a car in the sun), then send them to a lab or your county agent for leaf analysis.



Leaf analysis for nitrogen costs $22.50 per sample at the University of Minnesota Research Analytical Lab (2021/22 prices). The sulfur test costs $25.50 per sample. All the other critical nutrients for hazelnuts, listed below in Table 1, can be analyzed in one test, the 15-element ICP, for $45 per sample. http://ral.cfans.umn.edu/ Prices at other labs are likely to be similar. We hope to develop a method to evaluate leaf nitrogen (N) with use of a chlorophyll meter. This would give users immediate results, at a fraction of the cost of leaf sampling, but would not eliminate the need to leaf sample to evaluate other nutrients.

How to Interpret Leaf Analyses

The sufficiency-deficiency ranges shown in **Table 1** were developed for European hazelnuts in Oregon, except those for nitrogen, which were developed in Minnesota. Research in Minnesota suggests that there is no benefit to applying more N to hybrid hazelnuts than necessary to raise leaf N above 2.2 %, so thresholds for N reflect this. Oregon State is currently reviewing the thresholds for all other nutrients, so these may be adjusted in the future as well.

Interpreting leaf analyses is a little more complicated than merely comparing their values to the sufficiency-deficiency ranges given in the table because leaf concentrations are affected by more than just the availability of nutrients. Applications of one nutrient may influence leaf

Table 1. Critical values for nutrients in hazelnut leaf tissue

Nutrient	Deficiency	Below normal	Normal	Above normal	Excess
Nitrogen (%) Midwest [1]	> 1.80	1.80 – 2.00	2.01 – 2.20	2.21 – 2.50	> 2.50
Phosphorus (%) [2]	> 0.10	0.10 - 0.13	0.14 - 0.45	0.46 - 0.55	> 0.55
Potassium (%)	< 0.50	0.50 - 0.80	0.81 - 2.00	2.04 - 3.00	> 3.00
Sulfur (%)	< 0.08	0.08 - 0.12	0.13 - 0.20	0.21 - 0.50	> 0.50
Calcium (%)	< 0.60	0.60 - 1.00	1.01 - 2.50	2.51 - 3.00	> 3.00
Magnesium (%)	< 0.18	0.18 - 0.24	0.25 - 0.50	0.51 - 1.00	> 1.00
Manganese (ppm)	< 20	20 - 25	26 - 650	651 - 1,000	> 1,000
Iron (ppm)	< 40	40 - 50	51 - 400	401 - 500	> 500
Copper (ppm)	< 2	2 - 4	5 - 15	16 - 100	> 100
Boron (ppm)	< 25	25 - 30	31 - 75	76 - 100	> 100
Zinc (ppm)	< 10	10 - 15	16 - 60	61 - 100	> 100

[1] Values for N are based on research by Braun in Minnesota, 2021, in review.

[2] All values except those for N are from Olsen, 2013, Oregon State University Extension Service.

concentrations of other nutrients. In some cases, these effects are due to direct competition between soil ions for sites on the root uptake mechanisms. For example, excessive ammonium (a form of nitrogen) may inhibit uptake of cations such as potassium, calcium and magnesium and vice versa. In other cases, what looks like suppression of uptake of some nutrients by others is merely a dilution/concentration effect. For example, a decline in concentrations of other nutrients in response to N application may be due to dilution of those nutrients in leaves stimulated to grow larger by the additional N. The total amount of those nutrients in the whole plant may be the same, just it is spread out over larger leaves. Conversely, if plant growth is inhibited, whether by a deficiency in one nutrient or for other reasons, other nutrients may become more concentrated in leaves. Yet another situation is when nutrients that stimulate root growth enhance the uptake of other nutrients that then appear in leaves.

For these reasons, leaf analysis should be interpreted in the context of the health of the entire plant and the entire growing system. If the plants are growing and yielding well, then low leaf nutrients should not be a cause for concern. If they are not growing well, first rule out other possible causes, such as moisture stress or poor weed control. Research at the University of Minnesota has shown that good weed control is often more important than fertilization. Herbivory can also limit growth. In one of our research plots, we suspected a magnesium deficiency only to discover that it was repetitive deer grazing that was holding the plants back. **Remember the law of the minimum: growth is dictated not by total resources available, but by the scarcest resource.**

If leaf analysis and plant health are both low, and there are no other explanations, collect a soil sample to determine whether the problem is lack of nutrient in the soil, or whether something is interfering with the ability of the plants to take it up, such as damage to roots. If the problem is merely lack of available nutrient, then in most cases it will be solved with application of that nutrient. (An exception is when the problem is due to high pH, which makes some nutrients, especially iron, unavailable to plants.) **Table 2** illustrates these concepts with nitrogen, but the same principles apply to other nutrients as well.

Table 2: Interpretation of leaf N

	Plant Vigor and Yield	
Leaf N	**Low**	**High**
< 1.8 % (severely deficient)	N is limiting— needs fertilization	Fertilization was optimal but more is needed now
1.8 to 2.0 (slightly deficient)	Something else besides N is limiting growth (or limiting N uptake)	Fertilization is optimal
2.0 to 2.2 % (optimal)		
2.2 to 2.5 % (high)	overfertilization (possible ammonium toxicity)	
> 2.5 % (excessive)		overfertilization (may result in poor nut fill)

How much should be applied to address a deficiency once it is identified?

Research on hybrid hazelnuts in the Upper Midwest has not yet answered that question, not even for nitrogen. At this time, our recommendation is to test the soil for the deficient nutrient, and base application rates on the tables for soil test results (from the section below). Another approach is to apply the recommended amount for very low soil tests if leaf analysis is very low, the same amount recommended for medium soil tests if leaf analysis is medium, etc. Leaf sample again the following year to see if the fertilizer was effective and apply more if it was not. If plants are clearly deficient in a nutrient, the fastest way to rescue them is with foliar sprays in addition to soil applications. Foliar sprays are discussed further at the end of this bulletin.

Primary Macronutrients

Nitrogen and How to Maximize Nitrogen Uptake Efficiency

Nitrogen (N) is the nutrient that gets the most attention, for good reason. Not only is N the nutrient that is needed in the greatest quantity, and thus most likely to be limiting to plant growth, but it is also the nutrient that causes the most problems if overapplied. N is mobile in soils, so it may move out of the root zone of the plants for which it was intended, becoming a pollutant of either water or air. Explaining the chemistry behind this and describing the harm to human health and the environment by excess N is beyond the scope of this bulletin, other than to state that orchard crops have the poorest nitrogen use efficiency (NUE) of any crops. In Oregon, only 28% of applied N is taken up by hazelnut plants on average, and research in Minnesota has shown even poorer N efficiency here. Overapplication may also be counterproductive, because it may stimulate higher nut set than the plant is capable of filling, leading to poor nut fill. What is needed is not usually more fertilizer but improved nitrogen use efficiency (NUE).

Strategies for improving NUE include applying the right amount of fertilizer, of the right type, in the right place, and at the right time.

The right kind. N fertilizers include organic composts and manures, urea, and ammonium and nitrate-based salts. Under the right soil conditions all these eventually break down to ammonia and nitrate, which are the primary forms taken up by plants. Unfortunately, ammonia is easily volatilized into the air and nitrate is easily leached into groundwater. The best way to limit these losses is to match the rate at which ammonia and nitrate are released, to the plants' ability to take them up. Plants cannot take up nutrients all at once. Use of slow-release or stabilized forms of N, such as polymer-coated urea, or urease and nitrification inhibitor-treated urea, which release N slowly over a period of months, is an excellent way to provide N as the plant needs it. Although these fertilizers are more expensive, they are worth it. Never use untreated urea unless you have a way to incorporate it, or time it before irrigation or a rainfall event; otherwise some will be lost by volatilization. Compost or manure (ideally composted), which act like slow-release fertilizers while also improving soil organic matter and soil biology, are also an excellent option for N. (For analyses of various sources of N, both organic and conventional, see tables 6 and 7 at http://hdl.handle.net/11299/197955)

The right time. Plants take up N fertilizer most efficiently when they are in full leaf and when temperature and moisture conditions are optimal for plant growth. This is because N uptake requires plant energy, which is most available when plants are photosynthesizing. In the Upper Midwest optimal conditions for plant growth are most likely to occur in mid-May through July. The earlier N is applied in this window, the more time plants have to take it up before winter. Conversely, heavy rains in this period may leach nitrate out of reach of plant roots, contributing to N contamination of groundwater, which is why it is important to apply slow-release forms of N. N applied during nut fill in August or after harvest in September may be effective, because demand for N from developing nut kernels is high, and N hunger improves uptake efficiency, though soil moisture and leaf health are less likely to be optimal at this time.

The right place. Apply N underneath the hazelnut canopy where it can leach down to their roots, or as close to that as you can. Although hazelnut roots extend beyond their canopy drip line, applying N outside of the drip line may benefit weeds or other ground cover more than the hazelnuts, and increase competition for other resources, especially for moisture. Because N fertilizers of all types are highly soluble, soil incorporation is not necessary to get them into the root zone, so surface applications are fine, except in the case of urea, which breaks down to highly volatile ammonia. Also, spread N fertilizers evenly; fertilizer concentrated in one spot is more likely to burn roots and may also overwhelm the uptake capacity of the roots.

The right amount is the difference between what is already available in the soil and what the plant needs. Neither is easy to measure. Although there may be abundant N in the soil bound up in organic compounds, these compounds must be broken down before plant roots can take them up. The quantity of plant-available N in the soil is in constant flux, with N being released via soil organic matter decomposition at the same time as N is lost via leaching and volatilization, etc. Standard soil tests do not test for N because any measurement would merely be a snapshot in time. Rather, N recommendations are based on the quantity of organic matter. The higher the soil organic matter, the less N fertilization needed. Contributions of N from legume cover crops or intercrops, such as those that might grow in hazelnut alleys, also reduce the need for N fertilization.

Plant requirements for N also change as they grow. Research in Minnesota has shown that new hazelnut transplants are usually able to get all the N they need from the soil for their first two or three growing seasons, on all but the most extremely low organic matter soils **(Photo 1)**. On higher organic matter soil, they often do not benefit from added N until the fourth or fifth year after transplanting. After that, their N requirements increase in proportion both to size of plant and nut yield. Larger plants have both the roots with which to take up more N, and greater demand for it, from both leaves and nuts. Developing nut kernels, which are about 3.5% N, exert especially high demand for N. Leaf N concentrations

Photo 1. University of Minnesota trials at Becker, where the soil is extremely sandy, found that young hazelnut transplants grew just as big with no N (left) as they did with annual applications of just 0.1 oz of N per plant per year (right). However, by the third year the unfertilized seedlings were starting to develop chlorotic (yellow) leaves, a symptom of N hunger.

reflect demand for N from all plant parts, and are thus basis for N fertilization recommendations (Table 3).

These principles for maximizing N use efficiency apply to other nutrients as well, even though most other nutrients are not significant environmental pollutants, apart from phosphorus,

Table 3. N recommendations based on leaf analysis and plant size. [1]

Leaf N Analysis (%)		**Apply this much N**		
		oz per cubic yard of plant volume [2]	**lbs per acre** [3]	**lbs per 100 feet of row** [3]
< 1.8	Severe Deficiency	2	76	2
1.8 – 2.0	Deficiency	1.5	57	1.5
2.0 – 2.2	Sufficient	1	38	1
2.2 – 2.5	High	None until nut bearing, and then apply N based on amount of N exported with harvest. [4]		
>2.5	Excessive	None		

[1] These recommendations are merely a guideline. After applying N, watch to see if there is a response. If N was deficient, then the most immediate response is likely to be a darker green leaf color. It may take more than a year for this to be translated into a growth response. Collect leaf samples again the July following applications to determine if more N is needed.

[2] Plant canopy volume is calculated as plant canopy area times plant height, where canopy area is calculated as a circle based on plant width. Use the average size of plants in your planting. Note that plants are not likely to reach 1 cubic yard in canopy volume until three or four years after planting. For the first few years the amount of N needed per plant will likely be a fraction of an ounces. One third of a cup of 46-0-0 granular fertilizer contains about 1 ounce of actual N.

[3] Lbs per acre and lbs per 100 linear feet of row are calculated assuming 12 by 6-foot plant spacing, 605 plants per acre, and assuming an average plant canopy size of one cubic yard. These will need to be adjusted depending on your plant density and plant sizes. Based on this calculation, the amount of N recommended will increase as the plants grow. However, in no case should more than 100 lbs N per acre be applied.

[4] Applying N based on N exported with harvest will be discussed at the end of this bulletin.

which is a major contributor of algal blooms in surface waters. Other reasons to avoid overapplication include inhibition of uptake of one nutrient when another is overapplied (such as Mg and K, as mentioned above); potential phytotoxicity of some nutrients when they are in excess (especially micronutrients such as boron); and the unnecessary expense of overapplication. For most nutrients it is best to get a definitive diagnosis through a combination of leaf and soil sampling, rather than just guessing.

Phosphorus

Although **phosphorus (P)** deficiency is rare in any nut crop, low P soils are common in the Upper Midwest, so it cannot be ruled out. The challenge with P, which is essential for photosynthesis and plant growth, is that in the soil it is readily bound up in forms that are unavailable to plant roots. In this respect it is almost the opposite of N. P forms insoluble compounds with iron and aluminum at pH below 6.0 and with calcium at pH above 7.5. Although the extent to which this is a problem depends on the soil type, in general P is most available between pH 6.0 and 7.5. Improving P availability is one of the primary reasons for liming soil to within that range.

Because not all the P present in the soil is available for plant growth, measuring the total P in the soil would be meaningless. Instead, soil tests measure only the portion of it that is available; they are an index of response to P fertilizer. **Table 4** shows how much P fertilizer to apply if soil tests indicate a need for it.

Table 4. Pre-Plant Phosphorus Recommendations

	Soil Test P Level (ppm)		P_2O_5 to apply
	Bray-P1 [1]	**Olsen-P** [2]	**(lbs/acre)** [3,4]
Low	0-10	0-7	150
Medium	11-20	8-15	125
Medium-high	21-30	16-25	100
High	31-40	26-33	75
Very high	41-50	34-41	50
	51+	42+	25

[1] The Bray-P1 test is used when the soil pH less than 7.4

[2] The Olsen-P test is used when the soil pH is greater than 7.4.

[3] Recommendations from Rosen and Eliason (2005) for Minnesota apples.

A further challenge with P is its immobility in the soil: it mostly stays where it is put. Consequently, it is important to incorporate P fertilizers into the soil profile, which is why P, if needed, is best applied before planting for perennial crops such as hazelnuts. Plant roots tend to proliferate in zones of high P, so distributing P in the root zone ensures that roots colonize a large portion of the soil profile. However, distributing P also puts it in contact with the minerals with which it forms insoluble compounds. Banding half of the recommended P in a trench near the root zone is sometimes recommended to keep it mobile, but this is a temporary solution. Using organic fertilizers such as compost and manure, which release P slowly and in synchrony with crop uptake, may help avoid P immobilization temporarily, as may planting permanent ground cover in the hazelnut alleys. Although the P taken up by the ground cover will be temporarily unavailable, it will become available when the ground cover residues decay. Nurturing mycorrhizal fungi, by minimizing soil disturbance, may also enhance availability of P through symbiotic associations with the hazelnut roots.

In the unlikely case of P deficiency in an existing planting (leaf P less than 0.10%), apply 75 to 150 lbs per acre of P, depending on the severity of the deficiency. For post-planting applications we recommend banding P because, although incorporating it would get it into the root zone faster, it would also damage roots and mycorrhizae. Roots and mycorrhizae tend to proliferate in high P zones under banded P and will slowly translocate it to the rest of the plant. Resample leaves the next year and reapply if needed.

Care must be used to keep P fertilizers out of surface waters, where it causes algal blooms. This is true for both synthetic P fertilizers and organic fertilizers such as manure and compost. Take measures to reduce the potential for soil erosion and polluted runoff, such as by laying out your hazelnut rows on the contour, and by maintaining permanent vegetation in the alleys.

Potassium

Potassium (K) is the nutrient that is second most likely to be limiting for hazelnuts (after nitrogen), which is not surprising given that hazelnut kernels and husks are relatively high in K, which is thus exported with hazelnut harvests. K deficiency is common in apples in the Upper Midwest, so K deficiency is possible for hazelnuts. **Table 5** shows how much K fertilizer to apply if soil tests indicate a need for it.

Table 5. Pre-Plant Potassium Recommendations [1]

	Soil Test K Level (ppm)	**K_2O to apply (lbs/acre) [1]**
Low	0-40	300
Medium	41-80	250
Medium-high	81-120	200
High	121-160	100
Very high	161-200	50
Excessive?	200 +	0

1. Recommendations from Rosen and Eliason (2005) for Minnesota apples

Like P, K is relatively immobile in the soil, especially in clay soils and glacial till soils, and thus it also is best applied and incorporated before planting. Incorporating half of the recommended K and banding the other half may improve K availability in soils high in K-binding clays. However, it does leach out of sandy soils, which are often low in K. A combination of pre-and post-plant applications are recommended if K is needed.

Take care not to overapply K on sandy soils low in Mg, to avoid inducing Mg deficiency. Also use caution if applying K as KCl (muriate of potash) because of its high salt content, which can burn plant roots. If applying amounts greater than 200 lbs/acre, be sure to apply and incorporate it at least 2-3 months before planting hazelnuts. If that is not possible, use K_2SO_4 (potassium sulfate) or $K_2Mg_2O_{12}S_3$ (SulPoMag) if magnesium is also needed.

If K deficiency is suspected in an existing planting (less than 0.80% leaf N), apply 100 to 200 lbs per acre of K as K_2SO_4, depending on the severity of the deficiency. If the deficiency is severe, use foliar sprays as well for a rapid response. Resample leaves the next year and reapply if needed.

Secondary Macronutrients

Calcium (Ca) requirements of hazelnuts are not high. Inadequate Ca is only likely to be a problem on low pH soils, in which case liming should solve the problem.

Magnesium (Mg) deficiency is most likely on acid sandy soils that are high in calcium, in which case it is most effectively corrected by using dolomitic lime instead of regular lime. Magnesium deficiency can also be induced by high rates of K fertilization on sandy soils low in Mg. If soil test Mg is less than 100 ppm and lime is not required, apply potassium-magnesium sulfate ("Sul-Po-Mag", 11% magnesium) or Epsom salts (10% magnesium) according to **Table 6**.

Table 6. Pre-Plant Magnesium Recommendations [1]

Soil Test Mg Level (ppm)		Mg to apply (lbs/acre)
Low	0-49	100
Medium	50-100	50
High	100+	0

[1] Recommendations from Rosen and Eliason (2005)

To correct Mg deficiency quickly during the growing season, foliar sprays at the rate of 20-40 lbs of Epsom salts per acre in 50 gallons of water may be helpful, but two to three applications, ten days apart, are required for foliar sprays to be effective.

Sulfur (S) deficiency is most commonly observed on low organic matter soils, from which S is susceptible to leaching. Sulfur deficiency in hazelnuts appears as yellowing of the newest leaves, in contrast to nitrogen deficiency, which is observed in the oldest leaves. It can also be diagnosed based on leaf analysis. If S deficiency is diagnosed, broadcast 20-30 lbs/ac of S. Because S is a component of several fertilizers that are commonly applied to address other deficiencies (such as N, K, and Mg sulfates) application of these fertilizers to fulfill requirements of these other nutrients will usually supply sufficient S.

Micronutrients

As their name implies, micronutrients are needed in very small quantities. Micronutrients can also be toxic to plants if overapplied. Most of the following are only rarely a concern in the Upper Midwest.

Boron (B). There is a fine line between too little and too much B: it is easily leached from soil, but in excess it is toxic. Even if it is needed, it is needed in quantities that are so small they are difficult to apply evenly, which commonly results in overapplication.

B plays an important role in hazelnut nut set at flowering, but research on its efficacy is equivocal. In Oregon, foliar sprays of B in May sometimes increase nut set, even in non-deficient plants, but no response to B has been observed in the Mediterranean. How important it is for hazelnuts in the Upper Midwest is unknown and needs research.

As with other highly leachable nutrients, B should not be applied pre-plant, and B deficiency is most likely on sandy soils low in organic matter. Because of the risk of B toxicity (the symptoms of which are small, burned spots on leaves), B should only be applied if a suspected deficiency is confirmed by plant analysis, with B deficiency indicated by leaf levels below 30 ppm. If deficiency is observed and confirmed by a soil test, apply B according to soil test levels as shown in **Table 7**. Resample the following year and reapply B until the deficiency has been resolved. For in-season correction of B deficiency, use foliar sprays, at rates up to 0.4 lbs B per acre, with multiple applications required. Discontinue sprays if leaf B exceeds 76 ppm.

Table 7. Boron Recommendations [1]

	Soil test B (ppm)	B to apply (lbs B/A)
Low	0.0 - 0.4	4
Medium	0.5 – 0.9	2
High	1.0 +	0

[1] Recommendations from Rosen and Eliason (2005).

Copper (Cu) deficiency in the Upper Midwest is most likely on organic (peat) soils, and it is only on organic soils that the soil test for Cu is reliable. Crop responses to Cu fertilization have not been observed on mineral soils so Cu fertilization is not recommended on them. In the unlikely case of a Cu deficiency in hazelnuts, treat it with a foliar spray. Apply 0.1 lbs Cu/acre if leaf Cu is less than 4 ppm, and 0.3 lbs Cu/acre if it is less than 2 ppm. Split applications of no more than 1.5 lbs Cu/acre at a time, at least a week apart, are recommended. Higher rates can burn leaves.

Iron (Fe) deficiency is usually limited to alkaline soils (pH greater than 7.2), because the Fe present in the soil in bound up in unavailable forms at high soil pH. Because Fe availability is more related to soil pH than to the actual amount of Fe present in the soil, soil tests for Fe are unreliable. If soil pH is above 7.2 and interveinal chlorosis (leaf yellowing between veins that are still green) is apparent, or if leaf Fe is less than 50 ppm, suspect Fe deficiency. The best treatment for Fe deficiency is foliar applications of iron chelate, applied at a rate of 0.1 to 0.15 pounds actual Fe per acre, according to the label instructions for the specific material applied. More than one foliar spray is usually required. Apply Fe as early in the season after leaf-out for best results. Although soil applications of iron chelate may work, the quantities required are usually uneconomical.

Interveinal chlorosis due to pH-induced Fe deficiency in coffee. We have not observed this in hazelnuts, but if you see it, please let us know.

Manganese (Mn) is most likely to be deficient in organic soils with a pH higher than 5.8. Conversely, Mn can be toxic on low pH mineral soils. Neither deficiency nor toxicity of Mn have been observed in hazelnuts, for which the range of observed leaf Mn is very high. It seems that hazelnuts are both efficient at Mn uptake and tolerant to high levels of Mn, so Mn is not a nutrient for growers to worry about.

Molybdenum (Mo) deficiency is unlikely except on acid sandy soils or acid peat soils, for which liming to a pH of 6.0 to 6.5 is the best solution. Critical leaf values for Mo have not been listed for hazelnuts in Oregon, and Mo is not included in regular tissue analysis in Minnesota, which suggests that Mo deficiency is not a problem in this region.

Nickel (Ni) has only recently been shown to be an essential nutrient for plants and is still not well understood. Neither soil nor leaf tests for nickel have been calibrated. Actual requirements of Ni are extremely low and adequate levels are believed to be present in most field soils. However, Ni deficiency has been observed in potted hazelnuts of some varieties growing in artificial peat-based media, in which it results in mouse-eared leaf growth. If nursery growers observe these symptoms, they should drench the pots with solutions containing 3 to 6 ppm Ni (higher levels might be toxic), but Ni deficiency should not be a concern for field plantings.

Zinc (Zn) deficiency in hazelnuts appears as small narrow yellow leaves and shortened internodes resulting in tufts or rosettes at the ends of new shoots. It is not common, but sometimes occurs on alkaline soils and sandy soils low in organic matter. High levels of phosphorus coupled with low levels of soil zinc may induce zinc deficiency. If leaf Zn is less than 15 ppm, apply Zn as a foliar spray. Consult label instructions for rates and timing for the specific material applied; some formulations are best applied during the dormant season whereas others are best applied during the growing season. Zn may also be blended with bulk fertilizers and soil-applied at rates based on soil test results as shown in **Table 8**.

Table 8. Zinc Recommendations [1]

Soil Test Zn Level (ppm)		Zn to apply (lbs/acre)
Low	0 - 0.5	10
Medium	0.6 - 1.0	5
High	1.1 +	0

[1] Recommendations from Rosen and Eliason (2005)

Foliar Fertilization and Fertigation

Although most plants take up most of their mineral nutrients through their roots, they are also able to take up small quantities through their leaves. Foliar fertilization is the quickest way to get nutrients into plants when critical deficiencies are diagnosed. Foliar sprays are also useful for bypassing the soil when soil conditions are not favorable to root activity, such as when soils are too cold, too moist, too dry or too alkaline. They are especially useful for applying micronutrients, which are often needed in such small quantities that it is difficult to apply them evenly over the soil. Foliar sprays have been considered less useful for applying macronutrients, for which the quantity required by the plants is much greater than the ability of the leaves to absorb them, though recent research is reconsidering that limitation.

Solubility of nutrients is a big consideration for materials used in foliar sprays. Fertilizers sold to be used in foliar sprays are usually formulated specifically to improve solubility and absorption through leaves, often by chelation. There are too many different products available to describe them all in this bulletin, other than to say that it is important to follow the label for the specific product. Product labels also include important information about dilution rates in water, adjusting the pH of the water for improved solubility, and timing of sprays. For most nutrients, multiple applications will be needed, spaced a week or more apart, in order to apply the quantity needed without causing leaf burn due to phytotoxicity.

Although fertilizers formulated for foliar application are more expensive than fertilizers for soil application, and although application equipment and labor costs are also more expensive, foliar fertilization is usually more efficient in terms of the proportion of applied nutrient that is taken up by the crop. This is especially the case for fertilizers that tend to be leached out of the soil, such as N and B, or to be immobilized by the soil, such as K. Research would be needed on applying N to hazelnuts in the Midwest through foliar sprays before we can recommend it.

Fertigation, which is the practice of applying nutrients through an irrigation system, might also improve nutrient efficiency and is more suited to applying the larger quantities needed of nutrients such as N and K. It would be most cost effective for hazelnuts that are already irrigated. Drip irrigation systems, which direct water efficiently to very close to the crop's root systems are especially suited to fertigation. The details of fertigation are beyond the scope of this bulletin, other than to say that some of the same considerations apply about solubility of fertilizer formulation and water pH as for foliar fertilization. Also, irrigation systems used for fertigation must be fitted with backflow valves to prevent accidental contamination of the water source due to irrigation system failure.

Both fertigation and foliar feeding improve fertilizer use efficiency by combining several of the principles of the right amount at the right place at the right time. They apply nutrients directly to where roots or leaves can take it up, in small doses, repeated over the period of maximum uptake. They both offer the advantage of enabling growers to adapt fertilization rates and frequencies to their observations of plant responses. However, they are expensive to implement and thus are likely to be cost effective only for hazelnut germplasm that is more productive than that currently available. When such germplasm is available, we hope to develop recommendations for drip and foliar fertilization of hybrid hazelnuts in the Upper Midwest.

Production Phase: Fertilization Based on Nutrients Removed with Harvest

Although many soils in the Midwest have adequate fertility to support healthy hazelnut growth through establishment and even early nut bearing, they do not support consistently heavy nut bearing indefinitely without additional fertilizer. Once hazelnuts come into nut production, fertilizer requirements can be estimated based on the amount that would be needed to replace the nutrients removed with harvest -- assuming the bushes have reached their full size and have been appropriately nourished to that point. For each nutrient, multiply yield by the concentration of that nutrient in the yield to calculate nutrient exports. Assuming perfect 100% uptake of applied nutrients, then nutrients in should equal nutrients out. If nutrient inputs exceed nutrient exports, then the excess nutrients will either become pollutants or build up in the soil, potentially becoming toxic. Conversely, if nutrients exports exceed nutrients imports, then the soil will eventually be depleted, and yields and plant health will eventually decline. Tables 9 and 10 show the concentrations of nutrients in the three components of a hazelnut harvest, kernels, shells and husks, and their relative proportions, on a dry weight basis, for calculating nutrients removed with harvest. Husks are included because with current harvest technology they are removed from the field along with the kernels. Although reality is that nutrient uptake efficiency is not even close to 100%, these tables show that nutrient removal is much lower than often assumed.

Table 9. Calculation of N concentration in the biomass removed from the field with hazelnut harvest, based on N concentrations of the three harvest components and their proportion of the harvested dry mass.

Harvest Component	N Concentration [1]	Proportion of biomass removed with harvest [2]	N Concentration X Proportion
Kernels	3.4 %	35 %	1.2 %
Shells	0.2 %	65 %	0.1 %
Husks	0.6 %	38 %	0.2 %
Concentration of N in Harvested Portions			1.5 ± 0.5 % [3]

[1] Data are means of 24 nut samples, taken from six plants each at four locations in Minnesota (Fillmore, Rosemount, Becker and Staples), with soils that ranged from silt loam to sandy loam to loamy sand. Actual N concentration varied between sites and increased with increasing levels of N fertilization, especially in kernels and husks, but not in shells.
[2] We are assuming germplasm that is 35% kernel and 65% shell on average, but this varies significantly with genotype. We are also assuming that yield is expressed in terms of in-shell nuts, to which husk mass adds an additional 37.5% on average; in other words, total mass removed is 137.5 % of in-shell yield, but this ratio also varies significantly with genotype.
[3] Putting the variance from N concentration in the three components together with the variance in the kernel to shell ratio and the in-shell nut to husk ratio, the total variance is quite large, meaning that actual N removal with harvest ranges from 1 to 2% of total biomass.

Table 9 shows calculations for N, as an example of the process used for all the other nutrients. The N concentrations in kernels, shells, and husks are each multiplied by the proportion of in-shell yield represented by these fractions.[1] By multiplying concentration and proportion together and adding the products, we estimated that the overall concentration of N in the entire biomass removed with harvest to average 1.5% of in-shell yield. Because of high variance in these measures, the actual concentration of N removed with harvest ranges from 1 % to 2%.

The same process used to calculate nutrient removal for N was used to develop **Table 10**, which shows most of the nutrients of interest. Column D shows the amount by which to multiply in-shell yield to calculate nutrient removal if husks are left in the field, and Column E shows the amount if husks are removed from the field. Columns F and G put these percentages into real-life perspective by multiplying Column E (removing husks) by yields that hybrid hazelnut growers in the Upper Midwest might expect to see. Column F assumes 1,400 lbs in-shell nuts per acre, which would be a good yield for a typical unimproved seedling planting. The 2,800 lbs in-shell yield in Column G is for a clonal planting of improved cultivars, which are not yet available to growers in the Midwest but which we hope will be available soon.

[1] The proportions are represented based on in-shell yield rather than total plant material removed from the field because growers typically report yield on an in-shell basis, and do not consider the mass of husks removed, which adds roughly 37.5% more dry weight. In other words, total mass removed is approximately 137.5 % of in-shell yield.

Table 10. Concentrations of five macronutrients and six micronutrients removed with hazelnut harvest in kernels, shells and husks, and calculations to determine amounts, in pounds per acre (dry weight), that would be removed with harvest in two different yield scenarios.

	Concentration of Nutrients in Plant Components					Nutrients Removed with Harvest [3] (assuming removing husks)	
	A	B	C	D	E	F	G
	Ker-nels	Shells	Husks	In-Shell Nuts (Kernels + Shells) [1]	Nuts plus Husks [2]	Average Midwest Hybrid Seedling Planting (1,400 lbs in-shell nuts per acre)	Clonal Planting of a Top Selection (2,800 lbs in-shell nuts per acre)
Macronutrients							
	%					lbs nutrient per acre	
N	3.4 %	0.2 %	0.6 %	1.3 %	1.5 %	21	42
P	0.6 %	0.02 %	0.2 %	0.2 %	0.3 %	4	8
K	1.0 %	0.3 %	2.1 %	0.5 %	1.3 %	18	37
Ca	0.4 %	0.3 %	0.5 %	0.3 %	0.5 %	7	15
Mg	0.3 %	0.04 %	0.2 %	0.1 %	0.2 %	3	6
Micronutrients							
	ppm					lbs nutrient per acre	
B	28	7	41	14	20	0.04	0.08
Cu	24	5	8	12	7	0.02	0.04
Fe	57	16	148	30	66	0.12	0.24
Mn	104	43	129	65	77	0.16	0.32
Ni	6	1	4	3	2	0.01	0.01
Zn	27	5	13	13	8	0.02	0.05

Data are means of 24 nut samples, taken from six plants each at four locations in Minnesota (Fillmore, Rosemount, Becker and Staples), with soils that ranged from silt loam to sandy loam to loamy sand.

[1] Column D. Concentrations for the entire in-shell nut = (concentration $_{kernels}$ x 35%) + (concentration $_{shells}$ x 65%), assuming that in-shell nuts are 35% kernel and 65% shell. (Column D = (A x 35%) + (B x 65%)

[2] Column E. Concentrations for the harvested nuts plus husks = concentration $_{in\text{-}shell}$ nuts + (concentration $_{husks}$ x 37.5%), assuming that the dry weight biomass of husks adds another 37.5 % to the biomass of in-shell nuts. This assumes that yield is measured on the basis of in-shell yield. (Column E = D + (C x 37.5%)

[3] Columns F and G. The amounts of nutrients actually removed with harvest depend on yields. Column F shows the amounts, in pounds per acre, that would be removed with typical current harvests from plantings comprised of seedling hazelnut plants (F = E x 1,400 lbs per acre) and Column E shows the amounts that would be removed from a planting comprised of a top cultivar. (G = E x 2,800 lbs per acre)

The key points to get from **Table 10** are that

1) Kernels have high concentrations of N,
2) Husks have high concentrations of K, and
3) N and K are the only two nutrients that are removed in any significant quantity by hazelnuts, especially by our current relatively low-yielding hazelnuts. A yield of 1,000 lbs in-shell hazelnuts per acre would only remove 15 and 13 lbs/acre of N and K respectively.

The ratio between N, P and K removed with harvest of Midwest hybrid hazelnuts is 6-1-5, which in terms of N-P_2O_5-K_2O (which is how fertilizers are described) is equivalent to 6.0-2.3-6.0, not close to the 10-10-10 ratio sometimes referred to as a "balanced" fertilizer. For hazelnuts, a balanced fertilizer would be 6-2-6 or a multiple of it. Applying 10-10-10 would lead to overapplication of P which is a problem because of the role of P in contamination of surface waters. Twice as much Ca and about as much Mg are removed with hazelnut harvests as P, but these two nutrients are not usually a problem because they are usually abundant in the soils of the Upper Midwest. Likewise, micronutrients are removed in such small quantities that they are not usually limiting either, especially if organic fertilizers such as manure and compost are used. That said, some of the nutrients listed may sometimes be limited or unavailable in some soils and corrective actions taken if a need is indicated by leaf or soil analysis.

Because N and K are the only two nutrients that are removed in any significant quantity by hazelnuts, these are the only two nutrients for which basing fertilization recommendations on harvest exports is likely to be useful. The challenge in doing so is that nutrient uptake is not 100%, so most likely more nutrients will need to be applied than are removed, especially N, for which uptake efficiency is notoriously low. Research is planned to determine how much more is needed, taking into consideration that N uptake efficiency is improved when the need for it is greatest.

Table 11. Summary of All Nutrients[1]

[1] Deficiency symptoms are taken from Rosen and Eliason, 2005, for fruit and vegetable crops. They may or may not apply to woody crops or hazelnuts in particular.

	Soil Test and Amend Before Planting?	Growth phase in which a possible concern		Deficiency Symptoms [1]	Treatment of Deficiency	Problems with Overapplication
		Establishment	Production			
N	no	possible	likely	leaf yellowing, older leaves first, stunted growth	soil applications, fertigation (foliar sprays for rapid response)	pollutant of water and air, may acidify soil, promotes excessive nut set at expense of nut fill
K	all soils	possible	likely	grey or tan leaf margins, oldest leaves first	soil (or foliar for immediate response)	salt burn, may induce Mg deficiency
Ca	only on acid sandy soils	unlikely	possible	stunted shoot growth, tip burn	lime if pH is low, foliar sprays if pH is okay	not observed
P	all soils, esp. very low or high pH	unlikely	possible but unlikely	reddish purple leaves, oldest leaves first, stunted growth	soil applications	pollutant of water, may induce Zn or Fe deficiency
Mg	only on acid sandy soils	possible	possible	leaf yellowing between veins, older leaves first, leaf dropped	dolomitic lime if pH is also low, soil applied or foliar sprays if pH is okay	may induce K deficiency
S	no	possible	possible	leaf yellowing, younger leaves first	soil applications	may acidify the soil
Mn	only on organic soils with pH less than 5.8	possible but unlikely	possible but unlikely	yellowing between veins of youngest leaves	foliar sprays	toxicity, especially on acid soils, causes leaf yellowing and necrosis
Fe	only on alkaline soils	possible	possible	yellowing between veins of youngest leaves	foliar sprays	rare, may induce Mn deficiency
B	no	possible on sandy low-organic matter soils	possible, applications may enhance nut set	growing points die, distorted leaf growth	foliar sprays	highly toxic, marginal leaf scorch, oldest leaves first
Zn	only on alkaline soils or low organic matter sandy soils	possible	possible	interveinal yellowing, younger leaves first; shortened internodes resulting in rosetting of shoot ends	soil applications or foliar sprays	may induce Fe and Ni deficiency
Cu	only on organic soils	possible	possible	yellowing of leaves, younger leaves first, often starting with interveinal yellowing	soil or foliar	may induce Fe chlorosis and stunt root growth
Ni	only in soil-less potting media	unlikely	unlikely	small, wrinked, cupped "mouse-ear" leaves; necrotic leaf margins, shortened internodes resulting in rosetting of shoot ends	Soil applications or foliar sprays	may induce Fe and Zn deficiency

For More Information

Nutrient management for commercial fruit and vegetable crops in Minnesota
Carl Rosen and Roger Eliason, University of Minnesota Extension Service, 2005
http://hdl.handle.net/11299/197955

- How to take a soil sample, interpret a soil test, and calculate fertilizer rates
- Soil pH modification
- Analyses of different kinds of fertilizers, both inorganic (Table 6 on page 7) and organic (Table 7 on page 11)
- Fertigation and foliar feeding
- Primary and secondary macronutrients and micronutrients
- Diagnosing nutrient deficiency and toxicity symptoms

Growing Hazelnuts in the Pacific Northwest—Orchard Nutrition
Jeff Olsen, Extension Horticulturist, Oregon State University Extension Service, 2013
https://catalog.extension.oregonstate.edu/em9080

HAZELNUTS 101 Fact Sheet #2—Planting and Establishment
Jason Fischbach and Lois Braun, Upper Midwest Hazelnut Development Initiative, 2020
https://www.midwesthazelnuts.org/uploads/3/8/3/5/38359971/fact_sheet_series_2_establishment_final_jan_22.pdf

Maintaining soil fertility in an organic system
Carl Rosen and Peter Bierman, University of Minnesota Extension Service, 2005
http://hdl.handle.net/11299/197961

Acknowledgements

Carl Rosen from the University of Minnesota's Department of Soil Water and Climate for advice and review of this bulletin.

The Minnesota Department of Agriculture for funding the nitrogen fertilization research that led to the N recommendations.

USDA-NIFA Specialty Crop Research Initiative for funding the time spent putting the bulletin together.

Forever Green

MINNESOTA DEPARTMENT OF AGRICULTURE

USDA
United States Department of Agriculture
National Institute of Food and Agriculture

UNIVERSITY OF MINNESOTA EXTENSION