Nitrogen Fertilization of Hybrid Hazelnuts
in the Upper Midwest of the USA

Implications and Conclusions of the Doctoral Dissertation of Lois Braun

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Hybrid hazelnuts (*Corylus avellana x americana x cornuta*) are one of several crops being promoted in the Upper Midwest as a "Third Crop", a crop to increase the diversity of an agricultural landscape dominated by corn and soybeans. A significant goal of this effort is to reduce the non-point source pollution, in the form of nutrients and sediment, that result from annual cropping systems, due to the long periods they keep the soil devoid of growing vegetation, combined with the annual tillage and high fertilizer applications they require. Thus, most of the crops being promoted are perennials, not just hybrid hazelnuts, but also alfalfa (*Medicago sativa* L.), native and non-native grasses, hybrid poplars (*Populus*), willows (*Salix sp*.), and various fruit crops such as Aronia berries *(Aronia arbutifolia)*. Whether grown in riparian buffer zones, as field windbreaks or shelterbelts, or as the main crop, perennials may reduce soil erosion, improve soil and water quality, sequester soil carbon, and reduce agricultural energy use at the same time as enhancing wildlife habitat and ecosystem diversity (Josiah, 2001; Thevathasan and Gordon, 2004).

Because they reputedly have a high capacity to take up N, hybrid hazelnuts have been proposed as a possible species for riparian buffer zones to capture N in runoff and subsurface flow from adjacent cornfields. For the same reason, proponents of hybrid hazelnuts have advised farmers growing them as a cash crop to apply high rates of N. But the N requirements of hybrid hazelnuts had not been substantiated. Nitrogen applied in excess of demand may become a pollutant (Weinbaum et al., 1992), so high N application rates may negate one of the goals for which hazelnuts are being promoted. Moreover, excess fertilizer may be harmful to the crop itself and is economically wasteful. The development of hazelnuts as a viable alternative crop thus requires the development of empirically derived fertilizer recommendations.

One of the challenges in developing new crops is that recommendations must be developed all at once for many different aspects of their agronomy. It is difficult to know where to begin research when changes in one set of recommendations may alter recommendations in another area. For example, weed control practices may affect N requirements, but N recommendations must be formulated before it is known what weed control practices will become standard. Likewise, transplant production practices, plant spacing, and irrigation have not been standardized. Variable genetics is an especially large challenge. If N responses vary by genotype, but selected genotypes are not yet available, how does one proceed with N research? The answer is that one must take an iterative approach: one must begin with the literature for similar crops, and go forward with the understanding that one's results will not be the final answer. That is how I approached my attempt to determine the N requirements of hybrid hazelnuts.

I made N research a priority, before addressing some of the other agronomic issues of hybrid hazelnuts, because of the potentially harmful effects of overapplication of N. Two other reasons were that I had the impression that the other issues had already been resolved, and that I had the impression that hybrid hazelnuts are somehow exceptional, that their N requirements are higher than for similar crops. Neither was correct. I was especially wrong in my assumption that I would be working with plants with relatively uniform genetics by half-sib line. The variability within each half-sib line was immense, and was a major challenge. Nevertheless, I now can make at least preliminary N recommendations for hybrid hazelnuts. This puts us in a better position to address some of the other issues, and hopefully help make hybrid hazelnuts a viable alternative crop for the Upper Midwest.

The most important lesson that I learned is that these hybrid hazelnuts respond to N fertilization in the same way that other woody crops do, indeed, in much the same way as all crops do, both woody and herbaceous. I learned that the recommendations given for other woody crops, but especially for European hazelnuts in the Pacific Northwest, are a good starting point for developing recommendations for hybrid hazelnuts in the Upper Midwest.

I learned that, as with all crops, hazelnuts will not respond to N applications if there is already enough available N in the soil, either from mineralization of soil organic matter or residual N from previous fertilization. Neither will they respond to N if other growth factors, such as other nutrients or moisture, are limiting to growth. Soil sampling before planting to identify potential deficiencies is useful so that the soil can be amended when incorporation is still possible, especially for nutrients with limited mobility, such as of P or K. And like with all crops, weed control is important to reduce competition, especially for moisture. The lesson is that N fertilization without attention to other factors required for growth may be worthless and wasteful, and may contribute to N pollution.

I also learned that for hybrid hazelnuts, like for most woody crops, leaf analysis is a more useful tool for estimating N application requirements than soil analysis. Although soil analysis is a useful complement for leaf analysis, by itself it does not provide information about how well the nutrients in the soil will actually be taken up by the plants. Soil analysis is a snapshot in time, whereas the roots of perennial crops are capable of taking up nutrients through most of the year, not just the summer months. By contrast, N concentration in leaves integrates information about N supply (both from the soil and from plant reserves), the ability of the plant to take it up, and plant N demand. Yet leaf analysis can be confusing. For example, when all factors are favorable to growth, leaf N may actually decline due to dilution by carbon compounds. Conversely, N may accumulate in leaves if N is abundant but other factors limit growth (Black, 1993). So N recommendations based on leaf analysis should also consider information about overall plant growth, vigor, and nut yield. That said, I found that the leaf N sufficiency levels that have been defined for European hazelnuts in Oregon (Olsen, 2001) are roughly applicable to hybrid hazelnuts in the Upper Midwest. However, I concur with Kowalenko (1996), who concluded that 2.2% leaf N, which defines the threshold between deficiency and sufficiency by Oregon standards, should be regarded as a target to be attained instead of as one to be surpassed.

In my ^{15}N study, I learned that hybrid hazelnuts show the same basic seasonal patterns of N allocation as found in other woody plants: N is allocated to the plant part with greatest need for N at the time it is applied. Thus early spring applications go to leaves, summer applications go to nuts and catkins (which in hazelnuts first emerge in the fall) and fall applications go to storage, to supply N for early spring growth the following year. Although my results weakly support the contention that N uptake efficiency (NUE) is highest when plants are most actively photosynthesizing in the mid-summer, I did not demonstrate the corollary that N uptake is low when they are leafless, because I did not test uptake during dormancy. My results showed that N uptake can occur from early April through mid-September, which is a much longer window than for annual crops such as corn. This supports the argument that perennial crops such as hazelnuts may help reduce N pollution, that is, if the N applied to hazelnuts is taken up efficiently. However, overall my research showed that NUE for these hybrid hazelnuts was very low, less than 10%. This NUE is even lower than typical for other woody crops, as reported by Weinbaum et al. (1992), who stated that woody crops generally have the lowest NUE of any kind of crop.

The low NUE I observed may have been due to competition for N from weeds, in which case it should improve when weeds decay and release the N they have taken up. Another explanation is that I may have applied N in excess of plant needs. Matching N applications to N requirements, or more precisely, N deficit, is the most important strategy for improving NUE (Weinbaum et al., 1992). Calculating N deficit is complicated in woody plants, because it is the difference between what is required for growth and fruiting, and what is already available either from the soil or from reserves within the plants, all of which are difficult to measure. The ability to store N in difficult-to-measure tissues, such as roots and woody biomass, is what sets woody crops apart from annual crops. This ability to cycle N internally makes them exceptionally efficient in their use of N (Millard, 1996), and, ironically, also accounts for the tendency of growers to overestimate their N requirements and thus to overapply N, leading to low NUE and N pollution.

My N rate trials confirmed the conclusion that the N requirements of hybrid hazelnuts are low. I found that, in all but soils with very low organic matter, N released by mineralization of soil organic matter, plus N stored in the large hazelnut seed, is enough to fulfill the requirements of seedlings from germination through their second growing season in the field. Nitrogen requirements increase as the seedling grows. Starting in their third season, hybrid hazelnuts may benefit from N applications that increase in proportion to plant size. But as the shoot grows, demanding more N, so does the root system, increasing the volume of soil that the plant can access for additional N. This may be enough to sustain growth with no supplemental N for many years more, especially in soils with high organic matter. My research did not evaluate the N requirements for nut bearing, which would be expected to increase N deficits because of N exported with harvests. However, I have observed that on soils with 4.8% organic matter and high levels of P and K, kernel yields in excess of 1 kg plant^{-1} year^{-1} may be maintained with no N fertilization.

The evidence that hybrid hazelnuts would be effective to reduce non-point source pollution, including N pollution, is mixed. On the one hand, they are deep rooted (personal observation) so they presumably could retrieve N from deep in the soil profile, and they are perennial, so they could take up N for a much greater proportion of the year than row crops. This supports their use in such environments as riparian buffer zones, to capture N in runoff or subsurface flow from adjacent corn fields. On the other hand, the N requirements for hybrid hazelnut growth are not high and thus their N uptake may be limited in high N environments. This suggests that they may not be the best choice for riparian buffers. However, nut production is likely to significantly increase their N requirements, because N removed with harvest is not recycled. Moreover, yields seem to increase in environments with high moisture availability, such as in riparian zones (personal observation), which would increase their effectiveness in removing N from these ecosystems.

Tagliavini et al. (1996) proposed basing N recommendations for orchard crops on N removal, that is, the product of yield and N concentration in harvested nuts, while subtracting soil inorganic N to avoid overapplication. At this point in the development of hybrid hazelnuts, yields are too variable to estimate crop N removal. Once genotypes have been selected with uniformly high yields, this calculation will be more easily made.

Fertilizing hybrid hazelnuts with excessive rates of N fertilizer would undermine their value as an environmentally sustainable crop. However, the low NUE reported for woody crops by

Weinbaum et al. (1992) is not inherent to them, but is more a consequence of poor N application practices borne from lack of understanding of the mechanisms of N uptake and assimilation by woody crops. Best management practices for improving NUE include attention to timing, placement, and type of N applications, but most importantly to matching N availability to N demand.

The environmental sustainability of growing hybrid hazelnuts as a cash crop will also depend on other aspects of how they are grown. For example, although weeds clearly slow the growth of hazelnuts, the environmental cost of some kinds of weed control, such as clean tillage or use of herbicides, may outweigh the benefits. This needs to be researched.   Alternative methods of weed control also need to be studied, such as mulching with woodchips, which may have the additional benefit of supplying N in a slow-release form. Finally, research is needed on the potential of leguminous intercrops to supply the N requirements of hybrid hazelnuts.

Roversi and Ughini (2005) called European hazelnuts “frugal” in their use of N; it seems that hybrid hazelnuts are as well. I regard this as good news. At a time when there is increasing concern not just about the consequences of N pollution for water quality, but also about the fossil fuel costs of manufacture of N fertilizer, both because of greenhouse gas production and fossil fuel depletion, any economically marketable crop that can grow and be productive with minimal N inputs should be promoted. The possibility that the N requirements of hybrid hazelnuts may be completely met from non-fossil-fuel-derived sources, such as from leguminous intercrops, makes them even more exciting.

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