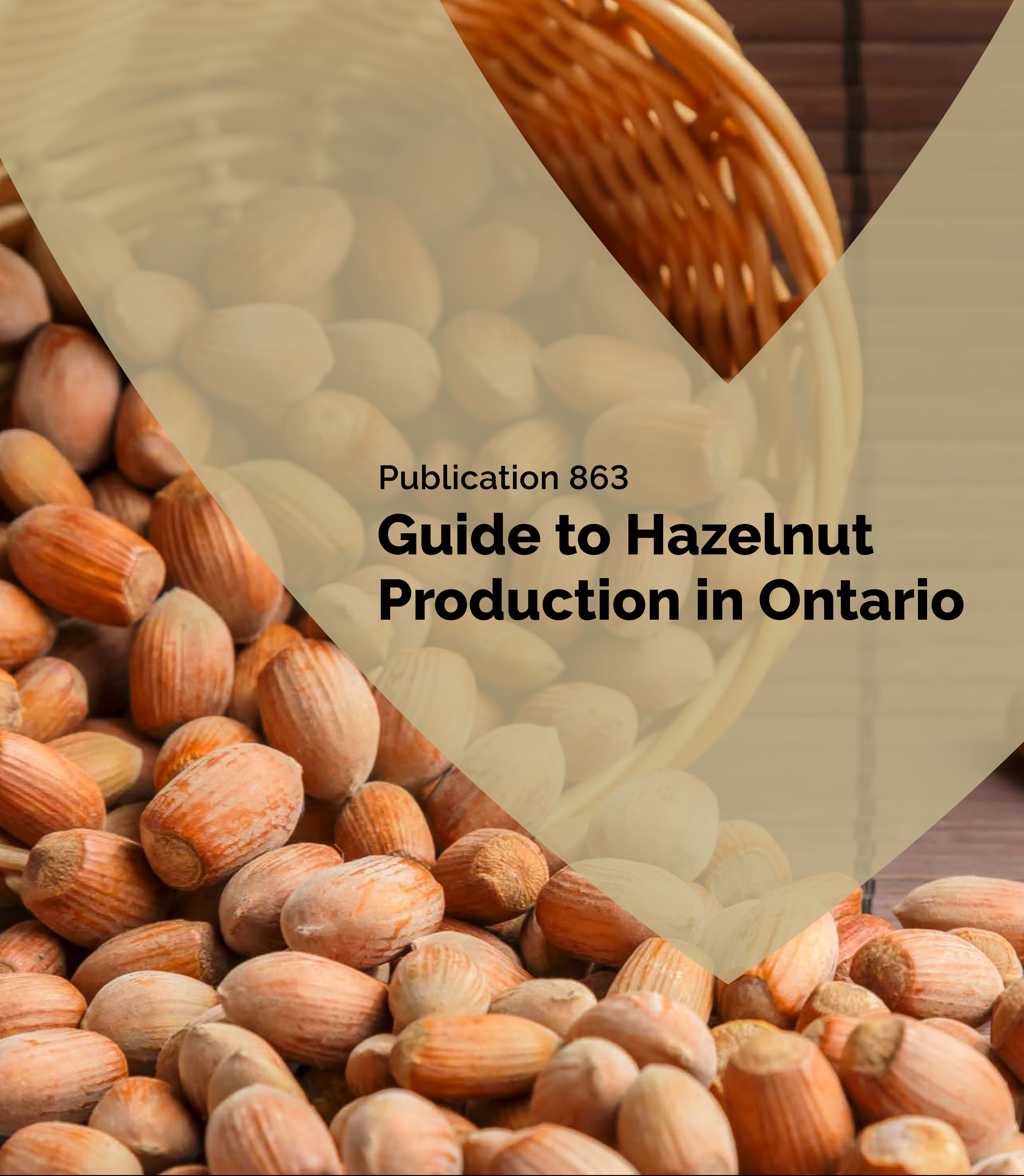

Publication 863

Guide to Hazelnut Production in Ontario

Ministry of Agriculture,
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Ontario

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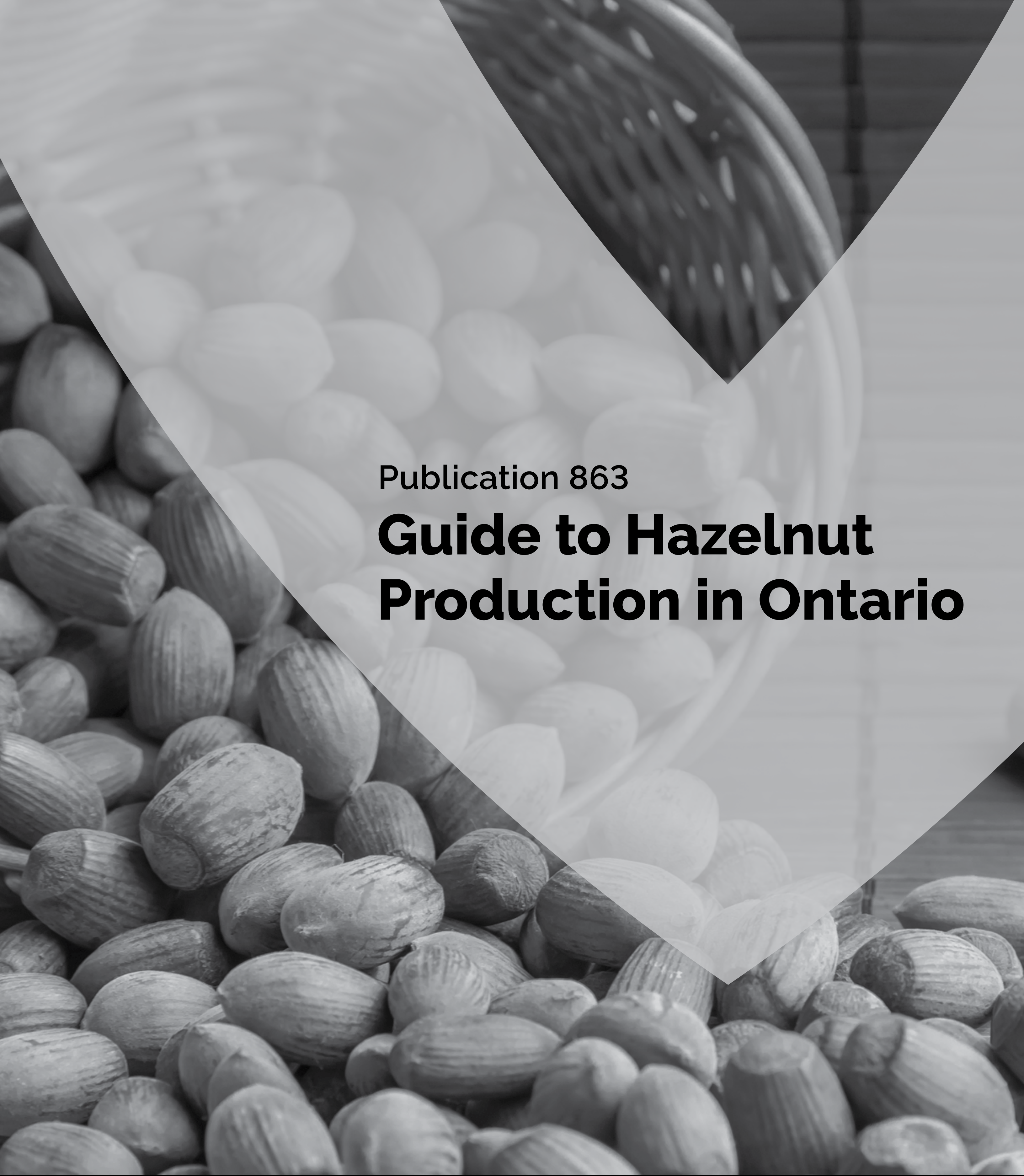
Front Cover: Hazelnuts in-shell. *Source:* shutterstock.com

Back Cover
Top: A harvester picking up ripe hazelnuts.
Middle: Green developing nut cluster
Bottom: Hazelnut orchard in winter.



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Resources
Information used in this guide has been compiled from a number of sources including Ontario hazelnut industry experience as well as scientific research and extension publications from: University of Guelph, Oregon State University (OSU) and OSU Extension Service, University of Wisconsin, Lincoln University (New Zealand), Rutgers University, University of Maine, Tuscia University (Italy), University of Mohaghegh Ardabili (Iran) and Trakya University (Turkey). Some material used in this publication was adapted from the following OMAFRA resources: Ontario Crop IPM, Specialty Cropportunities, Orchard Network Newsletter, Bird Control in Horticultural Crops factsheet, Publication 360 *Fruit Crop Protection Guide*; Publication 310 *Integrated Pest Management for Apples*, Publication 848 *Guide to Ginseng Production*, and Publication 811 *Agronomy Guide for Field Crops*.

This publication replaces the OMAFRA Hazelnuts in Ontario factsheet series: *Hazelnuts in Ontario – Biology and Potential Varieties*; *Hazelnuts in Ontario – Pests*; *Hazelnuts in Ontario – Growing, Harvesting and Food Safety*. This publication does not contain specific information on pest control products registered on hazelnuts. For pest control product information on hazelnuts, refer to the resources listed in appendix B of this publication.

Need technical or business information?

Agricultural Information Contact Centre
1-877-424-1300
1-855-696-2811 (TTY)
Email: ag.info.omafra@ontario.ca

Looking for information on hazelnut production in Ontario on the internet? Check out:

- the OMAFRA website at ontario.ca/crops.
- the Ontario Specialty Crops Blog at onspecialtycrops.ca.
- the Ontario Fruit Blog at onfruit.ca.

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1. Introduction to Hazelnuts in Ontario

This guide was written to help growers understand basic and advanced methods used in the commercial production of hazelnuts under Ontario growing conditions.

Hazelnuts and other tree nuts are gaining in popularity as a healthy food, in both domestic and export markets. In Ontario, there is potential for diverse market opportunities for locally grown hazelnuts including food processors, farm gate and fresh market sales, and as value-added products.

As of 2020, annual world production of hazelnuts averages 850,000 tonnes and is valued at approximately $3 billion. Production has been increasing worldwide, mainly for confectionary and other value-added hazelnut products. Most of the world's hazelnuts are grown in the Mediterranean climates of Turkey and Italy and the moderated climate of Oregon, U.S. Hazelnuts thrive in these climates, which have mild winters and cool summers — unique conditions common in the vicinity of large bodies of water.

Other countries are expanding significantly into hazelnut production, where climate and soils are favourable and industry support is available for skilled orchard growers. This expansion has been aided by the development of new varieties of hazelnuts that have made production possible in climatic regions that were previously considered too cold and inhospitable for commercial hazelnuts.

Hazelnut Production in Northeastern North America

Globally, most commercial hazelnut production involves European cultivars of *Corylus avellana* (the common hazel). This species, native to Europe and western Asia, produces large, thin-shelled, free-falling nuts that are desirable for commercial production. Unfortunately, the European hazelnut is not cold hardy and is highly vulnerable to eastern filbert blight (EFB), a fungal disease native to eastern North America which causes cankering and rapid death of susceptible trees. There are two wild hazelnut species native to eastern North America, *C. americana* (the American hazelnut) and *C. cornuta* (the beaked hazelnut). Both are cold-hardy and tolerant of EFB, however they produce small, thick-shelled nuts that are not desirable commercially.

Eastern filbert blight was largely responsible for the North American hazelnut industry concentrating in the northwestern part of the continent. All early attempts at commercial hazelnut production in eastern North America failed when European hazelnut trees died of blight. EFB is an eastern disease that was not initially present west of the Rocky Mountains. The absence of disease on the west coast, coupled with a milder climate, allowed growers in Washington, Oregon and British Columbia to establish a successful hazelnut industry using European hazelnut cultivars a century ago.

While there were several historical attempts to cross European hazelnuts with other species of *Corylus* to create hardier, disease-tolerant hybrids, significant progress was not made until EFB was accidentally introduced to Washington in the 1960s. As it spread northward, widespread losses to hazelnut trees led to extensive investment in breeding research and, after several decades of plant breeding, the development of EFB-tolerant varieties.

These varieties have been widely adopted on the west coast, but they are not well adapted to either the climate or strains of disease present in northeastern North America. Since the late 1990s, breeding efforts led by Rutgers University in New Jersey have built on work done in Oregon to develop commercially viable hazelnut cultivars that have advanced tolerance to EFB. This leading-edge breeding research, which has attracted international support, is starting to yield promising varieties for the Northeast.

Developing a Hazelnut Industry in Ontario

Hazelnuts have been grown in Ontario for many decades by hobbyists. Production expanded to include commercial growers as profitable orchard ventures 10–15 years ago. Early efforts to expand acreage were hampered by an assumption that hazelnut production required low inputs, low maintenance and required little concern for pest management. However, as with any other high-value horticultural commodity, hazelnuts are planted and grown in intensively managed orchards using improved propagated cultivars. As acreage has expanded, there has been an increased understanding of the requirements for successful production of commercial hazelnuts.

As for any orchard crop, developing effective production practices that incorporate good agricultural practices (GAPs) and good manufacturing practices (GMPs), effective integrated pest and nutrient management strategies for optimum plant health and practices to reduce food safety risks will be required. These practices will help secure confidence within the industry and establish reasonable assurances of annual profitability.

The successful establishment of a large-scale industry in Ontario depends heavily on obtaining varieties that are cold-hardy, have an acceptable level of tolerance to infection by EFB and are acceptable to the markets. Currently, growers are using varieties from the Pacific Northwest that tolerate some level of infection by EFB but still require significant management inputs, mainly annual pruning for orchard sanitation and applying protective sprays.

Early commercial progress in hazelnut culture in Ontario is directly attributed to the generous sharing of information and propagated hazelnut varieties previously developed by Cornell University and currently by Oregon State University. To help Ontario hazelnut producers become competitive and profitable in the hazelnut industry, on-farm and research trials have been conducted at various sites in Southern Ontario since 2008. These have focused on evaluating performance of hazelnut varieties from both established US breeding programs (Oregon, New York) and Ontario farms in their susceptibility to infection by fungal diseases and other pests, sensitivity to cold winters (winter hardiness), kernel quality and yield potential. As of 2020, efforts are underway to include new and promising varieties from the Rutgers University breeding program in newer research trials.

A number of suitable varieties have proven to be winter-hardy when grown in Ontario's traditional fruit orchard regions near the Great Lakes. Winter temperatures in these areas are moderated by lake effect to reduce sharp drops to sub-freezing temperatures. Freezing injury caused by deep winter cold is therefore less frequent. Fall is also more moderated in these traditional fruit growing regions with a more gradual onset. This facilitates the hardening off process (acclimation to cold temperatures) for dormancy and winter survival of trees. As winter ends, prolonged periods of cold air from the Great Lakes delays bud development and new growth reducing the risk of injury due to early spring frosts. All the inter-related components of hazelnut trees, including roots, wood, dormant buds, male catkin flowers and female flowers must be able to survive deep winter cold and occasional spring frost.

With blight-tolerant and winter-hardy varieties becoming available, growers will need to evaluate which varieties are suitable for different markets. This will require understanding the demand for the unique varietal characteristics that will satisfy buyers. For example, many of the EFB-tolerant varieties identified by initial Ontario research trials are not currently acceptable to some major processors. However these varieties may still be suitable for value-added products, fresh markets and cold-pressed hazelnut oil.

Cost of Production for Hazelnuts

A thorough understanding of the costs associated with the establishment and annual maintenance of a hazelnut orchard is important for growers and often for lending institutions. Having guidance on reasonable expectations of annual crop yield and profitability can provide assurance that risks can be managed.

Growers can find a report summarizing hazelnut production costs for Ontario on the OMAFRA website at ontario.ca/agbusiness (search for *Establishment and Production Costs for Hazelnuts in Ontario - 2018 Economic Report*).

This report is based on current grower practices and input costs. Input costs can be used as general guidelines to help growers identify strengths and weaknesses in their business, make business decisions and planting plans. Costs and profitability will vary with soil condition, cultivar selection, individual grower management decisions, the unique meso-climate of Ontario and markets where hazelnuts are sold.

An Excel-based hazelnut budgeting tool is also available on the OMAFRA website. This tool allows growers to assess the potential impact of production and marketing decisions on costs and profitability. It is available at ontario.ca/agbusiness search for "budgeting tools tree nuts".

Marketing

A critical factor in the decision to grow hazelnuts is determining how you will sell your crop. While there are several promising potential market opportunities in Ontario, hazelnuts are still an emerging, low acreage crop and at present there is no single established market in the province. As a new grower, do not assume you will immediately be able to drop your hazelnut crop off at any one location for an established price, at least while acreage and crop volume in Ontario is small.

For successful production of this crop, it is critical to have a well-defined marketing strategy in place, ideally before the crop is planted. Identify a variety of potential markets before starting large-scale production on the farm. Start small to build the market over time and ensure the business is cost-effective before spending large amounts of money. Consider what will set your farm or products apart.

Marketing is the process of planning and implementing product pricing, promotion and distribution in a way that satisfies individual organizational and customer needs. Marketing is more than just selling a product or service. It consists of strategic decisions made "behind the scenes" that affect customer perceptions.

Some key questions to consider while developing a marketing strategy are outlined below. This research should be done before the final decision to plant the crop is made.

- What are your objectives in growing the crop and what is your timeline for expected results?
- What is the ideal and minimum price you can accept for your crop or product? A detailed production budget (search for *Cost of Production* on the OMAFRA website) can be helpful in determining this.
- Target market – who is most likely to buy the product?
- Market demand – how many possible buyers exist?
- Can you cultivate relationships among individuals from various value chain sectors (e.g., agricultural input suppliers, distributors, end users, consumers)? Networking will provide a better understanding of current trends, issues and future contacts for your business.
- Have you spoken with other growers, OMAFRA crop specialists and others to ask for advice on agronomics and markets for your crop and potential value-added products?

- What volume of product is needed? If your potential market has larger volume requirements than you can meet as an individual grower, are you able to partner with others to meet this need?
- If you do not have the capacity to process the crop yourself, do facilities exist in your area?
- Is the market seasonal or year-round?
- Distribution – what is the best way to reach target buyers?
- Competition – what are the competing products and companies, both in Ontario and from other geographic areas?
- Trends – how stable is consumer demand for the product?
- Expected price – what price range can be expected? Is the lowest price still profitable?
- Expected sales – how will potential changes in market conditions impact quantity of product sold?
- Does the market have specific requirements that affect production decisions? For example, many EFB-tolerant varieties of hazelnut currently available for Ontario are not acceptable to some major processors but may be appropriate for fresh market sales.

Hazelnuts have diverse market opportunities in Ontario. Processors, in particular confectionary companies, often receive the most attention, however prices may be lower than fresh market or value-added sales. Other potential markets for Ontario crops may be broadly broken down into food retailing and food service. Retailing includes the over 12,000 food retailers in the province, including convenience and grocery stores, farm markets, roadside stands, warehouse clubs and internet food sales. Service includes the more than 30,000 foodservice outlets in Ontario, including bakeries, caterers, cafes and others.

For more information on identifying markets and developing a marketing strategy for hazelnuts, search the OMAFRA website at ontario.ca/omafra for the following resources or refer to the information included in Appendix B:

- **Specialty Cropportunities** – This interactive tool includes an overview of business planning and marketing in Ontario.
- ***Growing Non-traditional Crops in Ontario*** – An introduction to growing new crops with information on developing markets.
- **Direct Farm Marketing Resource Guide** – This guide provides an overview of best practices for direct farm marketing, along with case studies, infosheets and template forms for record keeping. Topics covered include: marketing research, social media, costing, pricing, and selecting the right market.
- **Starting a Farm in Ontario** – Provides an overview of business information and planning for new growers.
- **Programs and Services for Ontario Farmers** – Lists programs available to Ontario's agri-food industry.
- **Specialty Crops Blog – For updates about** marketing of specialty crops, including hazelnuts, refer to the OMAFRA specialty crops blog at www.onspecialtycrops.ca.

Resources and Other Information

Information on production of hazelnuts in Ontario can be found on the OMAFRA website at ontario.ca/crops. The ONspecialtycrops blog (onspecialtycrops.ca) provides timely information on crop production, pest management and events affecting hazelnut and other specialty fruit producers. The ONfruit blog (onfruit.ca) provides similar information to fruit producers in Ontario. OMAFRA specialists also periodically host training sessions for hazelnut producers – event details are posted on the blogs.

The Ontario Hazelnut Association (OHA) is the official voice for the Ontario hazelnut industry (ontariohazelnuts.com). The OHA organizes numerous meetings and hands-on workshops throughout the year, providing many opportunities for information exchange. The OHA collaborates with international hazelnut researchers and world leaders in commercial hazelnut production.

The Northern Nut Grower's Association (NNGA) and the Society of Ontario Nut Growers (SONG) are also good sources of technical and production information for Ontario growers and researchers. Both organizations periodically host interactive meetings and hands-on workshops in cold-climate (temperate) provinces and northern states that share an interest and passion in northern nut culture. See the websites www.nutgrowing.org (NNGA) and www.songonline.ca (SONG) for events.

Information is also available from other hazelnut growing regions with a longer history of production and experience with this crop. Resources from these areas are useful but Ontario growers need to be aware that information from these areas is not always directly applicable to Ontario due to differences in cultivars, environmental conditions and pest complexes, among other factors. Additionally, regulations on pest control technologies, nutrient and irrigation management and other farming considerations can vary dramatically between Ontario and other regions. Consequently, guidelines from other regions may not be permitted in Ontario. It is the grower's responsibility to ensure that all practices on their farm are legal in Ontario.

In North America, Oregon State University has been a leader in hazelnut research and extension. A series of educational factsheets on hazelnuts can be found on their website at catalog.extension.oregonstate.edu. Information from collective organizations working on behalf of the Oregon hazelnut industry can be found on the Oregon hazelnut industry's website www.oregonhazelnuts.org. In Canada, British Columbia has a significant hazelnut acreage. Information relevant to hazelnut production in that region can be found on the Government of British Columbia's website at www.gov.bc.ca (search for hazelnuts) and from the B.C. Hazelnut Growers Association (www.bchga.ca).

Many of these organizations host annual meetings and field days. One of the largest meetings for the hazelnut community is the International Congress on Hazelnut, a conference held once every 4 years and for over 30 years in different countries with significant hazelnut production. It is coordinated by the International Society for Horticultural Science (ISHS) and attracts scientists, academics, farmers, industry and governmental organizations involved in the hazelnut industry around the world. See the events calendar on the ISHS website: www.ishs.org.

2. The Hazelnut Plant

Corylus Species

Hazelnuts (known also as filberts or cobnuts) are members of the genus *Corylus* in the Birch family. Within *Corylus*, there are about 15 species. Of these, five shrubs and four tree species are most commonly recognized and commercialized for food production and ornamental uses. Almost all varieties utilized in commercial orchards today were selected over many centuries from local wild populations of the European hazelnut, *C. avellana*.

The European hazelnut is native throughout most of Europe (except some islands and in the extreme north and northeast), east to the Caucasus and Asia, North Africa and temperate western Asia. European hazelnuts grow and are cultivated in countries and regions where summer temperatures are comparatively cooler and winter temperatures uniform and mild. Ontario climatic conditions are more extreme than these ideal conditions, with colder winters and hotter summer weather. Winters with alternating periods of freezing and thawing cause most damage to the trees.

In North America, pure European hazelnut varieties have been most successful in temperate climates on the West Coast, from Oregon to British Columbia. European hazelnuts are less successful east of the Rocky Mountains, where they are very susceptible to multiple strains of the native hazelnut disease eastern filbert blight (EFB), and all or parts of the plant can be killed by the cold winters.

A strain of EFB was introduced to the West Coast in the late 1960s and spread northward until it appeared in British Columbia in the 1970s. There was considerable destruction to hazelnut orchards, leading to a shift in breeding research priorities to development of new, disease-tolerant cultivars. Hybrid crosses between European varieties and native wild hazelnuts by researchers in Oregon eventually resulted in cold-hardy cultivars with improved tolerance to disease. These tougher genetic traits reflect some of the survival advantages found in native wild hazelnuts.

These Oregon hybrid cultivars have been tested in Ontario and other hazelnut-producing countries since 2006 in several on-farm and research station trials. Although Ontario has infection pressure from a greater variety of EFB strains than are present in Oregon, some of the older Oregon cultivars are exhibiting a manageable level of tolerance to infection, as well as survival of cold winters. Ontario trials have shown encouraging crop yield results in young bearing orchards, however these promising varieties are not currently acceptable to some major hazelnut processors. More recently, trials have begun with newer Oregon and Rutgers varieties which may have improved tolerance to disease strains and weather extremes present in Ontario.

Two hazelnut species are indigenous to Ontario: *C. americana Walt.*, the American hazelnut, and *C. cornuta Walt.*, the beaked hazelnut. The American hazelnut grows from the St. Lawrence along Lake Ontario westward to Lake Huron (approximately the Carolinian zone) and in the Lake-of-the-Woods region near the Ontario–Minnesota border. This matches the major fruit-growing areas of Ontario. The beaked hazelnut grows throughout Ontario and farther north to about 50° N, near southern James Bay.

Hazelnut breeding conducted previously at Cornell University, by private growers around the Great Lakes region and in central Canada, has focused on developing hybrid crosses having a more prominent genetic component of native *C. americana*, interbred with European varieties. Some of these trees have also been tested in Ontario research trials.

Descriptions of the major characteristics and growth habits of the three *Corylus* species found in North America are found in Table 2-1.

Table 2-1. Description of American, European and beaked hazelnut plants

Characteristics	American Hazelnut	European Hazelnut	Beaked Hazelnut
Growth habit and height	Multi-stem shrub, 2–3 m tall	Multi-stem shrub, 3–10 m, occasionally 15 m tall	Multi-stem shrub, 3–4 m tall
Bark	Smooth, grey	Smooth, dark-brown	Smooth, grey
Leaves	5–12 cm long and 2.5–7 cm wide, bright green on the upper surface and pale green on the lower surface, round or heart-shaped at the base and tapered point at the apex, margins sharply and irregularly serrated	5–10 cm long, rounded oval with pointed tip, hairy on both sides, margin doubly serrated (larger teeth are made up of smaller teeth). Green leaf and red leaf varieties	6–10 cm long, ovate or narrowly oval, finely serrated margins, scattered hairs on the upper and lower surfaces
Pollen flowers (Catkins)	Up to 7 cm long, hanging loosely, grouped in clusters of 1–3	2–8 cm long, hanging loosely, grouped in clusters of 1–4	Up to 5 cm long, hanging loosely, grouped in clusters of 1–3
Seed flowers	Tiny cluster with red filaments (stigma) protruding from bud	5 mm long, tiny cluster with red filaments (stigma) protruding from bud	Tiny cluster with red filaments (stigma) protruding from bud
Nuts	In clusters of 2 to 10, 1–1.5 cm long, hard-shelled, enclosed in green husk	In clusters of 1 to 12, 1.5 –2 cm in diameter, hard-shelled, enclosed in a green husk	Light brown, single or in small clusters, up to 1.2 cm long, hard-shelled, enclosed in a spiny green husk
Husks	Twice the length of the nuts, flared out beyond the nut	Can vary from one quarter to twice as long as nuts, flared out, tube-shaped or narrowed beyond the nut. Green and red varieties.	Long flask-shaped husks ending in jagged toothed beak, may be covered in tiny spines

The Hazelnut Tree

The following section gives a general description of the plant habit, the flowers, nuts and the root system.

Longevity

Hazelnuts are perennial plants that produce an annual crop of nuts, however, they have a strong tendency to bear larger crops in alternate years. They often begin to bear nuts within 3 or 4 years of planting (Figure 2-1), with larger yields beginning after 5–6 years. Full production can be reached in 10–12 years on well-drained fertile orchard soil. Hazelnuts can survive for 40 years by following effective pest management practices. However, if left unmanaged, hazelnuts may survive for 15–20 years, then often succumb to wood diseases.

Figure 2-1. Trees in this four-year-old hazelnut orchard have begun to bear nuts.

Growth Habit

The shape of the hazelnut tree is determined by branch angle, training and pruning as the orchard trees establish. Orchard hazelnuts are not grafted to rootstock and are planted on their own roots. The tree grows naturally as a multi-stem shrub often having profuse sucker growth each year from the base of stems and roots. Tree shape varies from very erect to very spreading or drooping, depending on the variety grown.

Figure 2-2. Training. (A) This hazelnut tree has been trained to have only one trunk, which is common in west coast orchards. (B) Multi-stem training is more common in Ontario.

In Oregon and Washington orchards, hazelnuts are trained to have only one trunk, to facilitate mechanized harvest and ground-cover management (Figure 2-2A). In Ontario and European countries, hazelnuts are trained as multi-stem bushes having three to five stems (Figure 2-2B). Multi-stem training allows for continuous nut yield from fruiting wood, where a percentage of stems may require selective removal each dormant season to eliminate infection by blight disease. New suckers are readily available each year to replace missing stems and renew fruiting wood, a benefit of self-rooted production.

The upright spreading growth habit of 'Barcelona' has been considered a desirable trait, since this variety facilitates mechanical harvesting. 'Barcelona' is not suggested for planting in Ontario due to its susceptibility to eastern filbert blight, however it is still used as a standard comparator among varieties in many countries. Some newly released varieties from Oregon have a more spreading, open canopy (such as 'Yamhill'), which requires some training and pruning to allow sunlight to penetrate through and machinery to pass underneath.

Leaf density of trees is determined by several factors, including the cultivar, internode length, number of lateral buds that grow, length of "blind" wood, degree of apical dominance and size of the leaves. Leaf density ranges from very open to very tight and thick.

It is desirable to have moderately dense trees, which allow more sunlight to penetrate the canopy to promote fruit bud formation and facilitate nut set during pollination. Trees having moderately dense canopies allow for better spray coverage throughout the canopy when applying pest-controlling sprays. The size of the tree is determined by the vigour of the annual growth and fertility of the site. Trees having moderate growth vigour are generally preferred in commercial orchards.

Nut Development Calendar

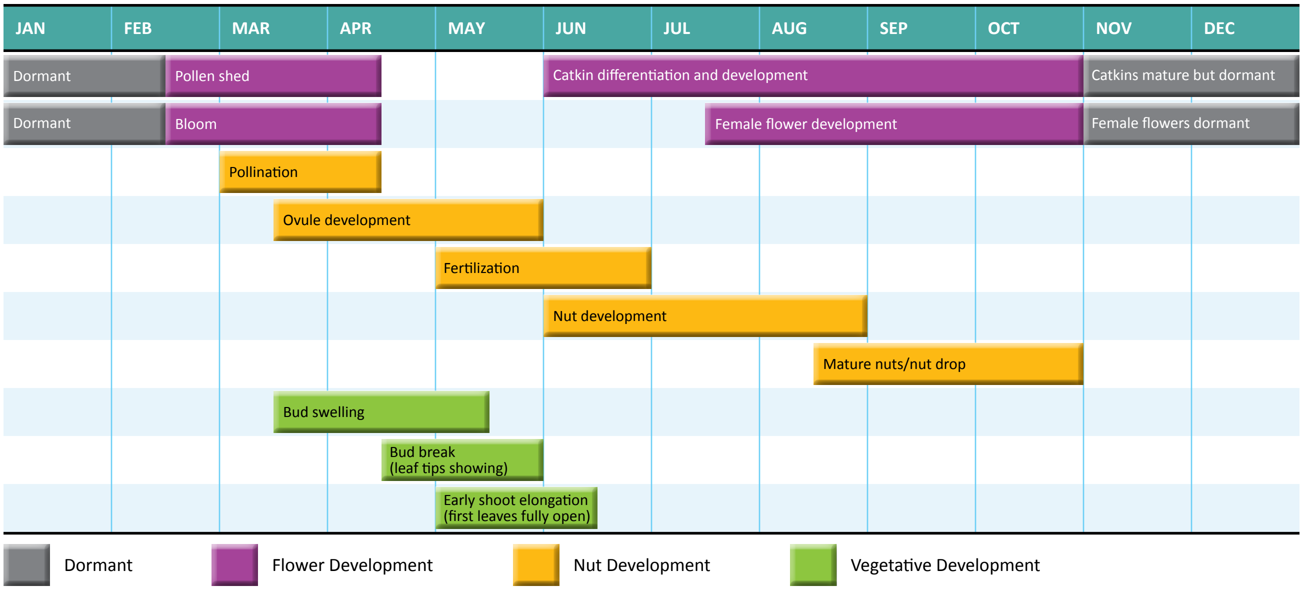

Figure 2-3. Nut, flower and vegetative bud phenology for hazelnuts in Ontario. Information is based on Ontario industry experience, University of Guelph research and Oregon State University factsheet EM9074, *Growing Hazelnuts in the Pacific Northwest: Pollination and Nut Development.*

Flower Development

Hazelnut trees have a complicated development with male and female flower formation beginning more than a year before harvest, and a significant gap between pollination and fertilization. Figure 2-3 provides a visual description of nut development from flower to mature crop.

Male Catkin Flowers

Male flowers are borne in catkins on the current season's stem (Figure 2-4). A small protective bract or pouch encases each individual male flower (Figure 2-5), and 150–200 male flowers on a single stem form the catkin. Inside the catkin, each male flower is encased in a protective bract (pouch). Each bract contains bun-shaped pollen sacs. Catkins begin to form around June and develop rapidly from August (Figure 2-6) and reach maturity in December. Catkins remain dormant during the winter, as long as temperatures remain cold and temporary winter thaws do not occur.

Figure 2-4. Male catkin flowers of hazelnut.

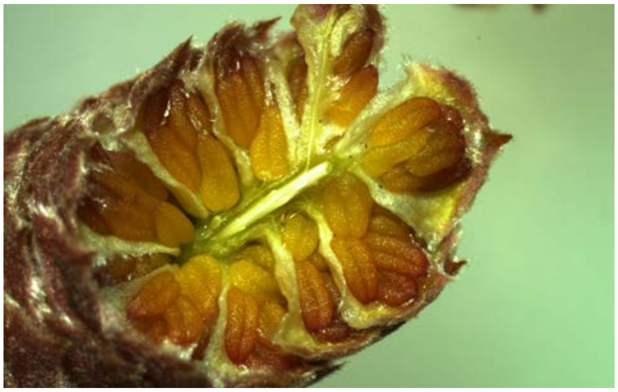

Figure 2-5. Interior of elongating catkin.

Figure 2-6. Catkins begin to develop in June and mature by December. Catkins remain dormant during winter and shed their load of pollen in March the following year.

Female Flowers

Female flowers are very small and are borne in tight clusters at three locations: singly at the basal leaves on 1-year wood, in groups of one to six with catkins and on very short spurs on older wood. There is no visual difference on the outside between the flower buds and leaf buds until the female flowers emerge. Female flowers start to open in mid-March (Figure 2-3) as 4–18 red styles emerge at the tip of the bud (Figure 2-7). Initially, the styles appear as a small red dot and then continue to elongate, thread-like and splayed outwards.

Figure 2-7. Female hazelnut flower. Each red filament can produce a nut if a compatible pollen grain attaches.

Stigma, the portion of the flower that receives the pollen, develop on the surface of the styles as bumps. These mature first at the tip, and then progressively downwards as the style lengthens. Over 80% of the style length may be receptive. If unpollinated, stigmas may remain receptive for up to 2 months. If the exposed parts of styles are damaged by frost, have abrasions or are dried out by wind, the lower-protected parts may turn into functional flower tissue.

Pollination and Nut Set

Male and female flowers that develop on the same tree do not open together. Under Ontario conditions, female flowers bloom first in early March (called protogynous), and the male flowers open approximately 10 days later (Figure 2-3). In some varieties, however, the order of flower emergence is opposite, male first, female flowers second (called protandrous). The pollen sheds within a few days after the catkins open. Hazelnuts are pollinated primarily by wind.

Hazelnut has a sporophytic self-incompatibility system that is governed by a single gene having multiple forms of alleles (called S alleles). Therefore, hazelnuts must cross-pollinate with other hazelnut trees that are not genetically identical. In an orchard, there must be at least two or three compatible varieties spaced near enough to transfer pollen onto female flowers. To ensure that the combinations will cross-pollinate, growers must find varieties with different S alleles and plan the orchard design carefully. Pollen compatibility is explained later in more detail (see *Variety Selection*).

Pollen is released from catkins when the temperature warms above freezing and the relative humidity drops. In still air, released pollen will drop on top of the bracts below and be held there until it is blown off by the wind. When they are open, the catkins lose their rigidity and flex readily in the wind, which helps release the pollen. Once the female flowers are pollinated, the exposed parts of the styles wither and turn black.

Hazelnut pollination is a two-step process and differs from pollination in fruit crops. For most plant species, an ovary with egg cells is present in the flower at pollination. In hazelnut flowers, only the stigma, style and a small quantity of immature ovarian tissue are present at pollination. Once pollen has been transferred to a receptive female flower, a pollen tube grows from the pollen grain to the base of the style within 4–7 days. When it reaches the base of the style it stops growing, the tip of the pollen tube containing the sperm forms a walled-off structure and enters a 6–8 week resting period. During this period, the immature ovarian cells, stimulated by pollination, begin to develop into a mature ovary. As the weather warms up in late spring, the pollen tube resumes growth, then grows into the ovary and fertilizes the egg. After fertilization, the embryo grows and develops for 5–6 weeks and continues to differentiate for 2 more weeks (Figure 2-8).

Figure 2-8. Hazelnuts maturing inside the husk.

When the nut has reached full size in July, the ovary wall begins to lignify to form a hard shell, hardening first at the tip and gradually progressing to the base of the nut. In late August, the nuts start to change colour from the base upwards. At the same time, the nut begins to separate from the papery husk (involucre), as the cells at the base of the nut die. Once this separation is complete, the nut is ripe and ready to drop. As the husk matures and dries, it gradually opens to release the nut. In Ontario, ripe nuts within each cultivar usually fall for 2–4 weeks. Across all hazelnut cultivars grown in Ontario, harvest can span from late August through late October (Figure 2-3).

For nuts to develop successfully, compatible pollination must occur. Without pollination, the flowers wither and fall off. Blank nuts are nuts that develop with a full-size shell but are empty and lack a kernel. Blank nuts occur because compatible pollination may have occurred but the embryo (seed) has failed to develop for reasons not entirely understood (for more information see *Blanks, Deformed Nuts and Poor Nut Fill* in Chapter 5). The micronutrient boron is believed to play an important role in improving nut set. The nutrient management program should ensure trees have enough boron to prevent deficiency. Annual soil tests and leaf tissue analysis will be able to determine the nutrient levels in the soil and hazelnut plants.

Root Growth

Hazelnut trees are shallow-rooted and require deep, fertile, naturally-drained sandy loam or loam soil. Soil suited for apple and peach orchards will also work well for hazelnuts. Tile drainage is recommended since hazelnut roots do not tolerate flooded or saturated soil, especially during early spring through to fall. Feeder roots are concentrated in the top 20 cm of the soil, growing outwards from the trunk to beyond the spread of the limbs. Below this level, the feeder roots rapidly decrease, and below 90 cm, there are virtually no roots.

Hazelnut trees have very few deep anchoring roots, although during dry seasons, anchoring roots can grow several metres deep to find moisture. Roots that are present in soil below an advancing water table will drown and die due to a lack of adequate oxygen. For this reason, hazelnuts often grow poorly on heavy, slow-draining clay and silt soils, regardless of the presence of tile drainage.

Almost all hazelnut varieties form root suckers. Root suckers are vegetative shoots that emerge every year off shallow roots or near the trunk base. The number of suckers and prolific rate of their growth is a characteristic of each variety.

Hardiness and Phenology

Cold winters in Ontario and Eastern Canada have limited the growing of sensitive Oregon hazelnuts to the most moderated regions.

These include areas typically used for peach and apricot orchards. In sensitive pure European varieties, such as those from Italy, Ontario winter temperatures can injure or kill stem tissue, vegetative buds, female flower buds and catkins. The roots of sensitive European varieties may survive under insulating snow and can re-sprout new stems the following spring, however this level of extreme winter injury will not allow nut production of important Italian or Turkish varieties in Ontario.

Varieties that are native to North America and originate from northern temperate climates, or those that are hybrid crosses between European and native temperate hazelnuts, are more tolerant of cold winters and can be grown in orchard regions that are typically used for apple and peach production. Apple regions are slightly colder than tender fruit production areas.

For terminal buds to break in spring, they must have completed dormancy or physiological rest and receive sufficient warmth to begin growing. To complete dormancy during a typical Ontario winter, various tissues require 0°C–7°C for varying durations: 100–990 hr for catkins, 290–1,645 hr for female flowers and 365–1,550 hr for vegetative buds. These requirements are normally met by late winter in Ontario, and therefore a sudden warm spell in February or March can cause premature development of these tissues, making them sensitive to freeze injury.

Vegetative growth follows pollination (Figure 2-3). Varieties that leaf out earliest in the spring are subject to frost injury. The timing of terminal bud break and initiation of stem and leaf growth is therefore an important consideration for hazelnut growers. In a planting of 1-year-old hazelnut trees at Simcoe, Ontario, buds broke in several Oregon varieties on April 6, 2009, 2 weeks earlier than New York cultivar selections (‘Grimo 186M’ and ‘Gene’) in the same orchard. The terminal buds of several varieties with European background selected by a grower in Courtland, Ontario, broke 11–13 days later than the Spanish variety ‘Barcelona’.

Variety Selection

A selection of hazelnut varieties from various hazelnut-growing regions has been under evaluation in Ontario since 2008 at the University of Guelph, Simcoe Research Station. The choice of varieties for Ontario growing conditions should be based on results from Ontario research trials and on local grower experiences. New local varieties are also available from private nurseries for on-farm evaluation by growers. Research trials with newer cultivars from Oregon and Rutgers breeding programs were approved in 2020 and will provide information from several sites in Ontario.

To see a provisional list of hazelnut crop varieties and pollenizer varieties for Ontario, refer to the OMAFRA website at ontario.ca/crops (search for "hazelnut varieties").

Since 2008 and with expansion of international cultivar trials in Ontario, mainly with Oregon varieties, much has been learned about variety selection and “better practices” in hazelnut orchard management.

When choosing a variety, consider the following factors:

- intended market and quality characteristics of the nuts, for example, kernel shape
- tolerance to eastern filbert blight (EFB), bacterial blight diseases and other pests (e.g., bud mites)
- winter hardiness of the buds, wood and male catkin flowers
- compatible pollenizers, time of female flowering and pollen shed concurrence

When nut quality and potential markets are considered, the first important nut characteristic is the shape of the nut. Large, round or oblong nuts are suitable for fresh markets. Currently, round nuts that have a medium uniform size are preferred for whole-nut-manufactured products, because a round shape flows most efficiently through mechanized and robotic processing equipment. Consistency in size and shape of the nuts is a very important consideration for processors. Perfecting the roasted flavour of hazelnuts is a high priority for some confectionary manufacturers.

Main crop varieties of hazelnuts that are planted in multi-row blocks must have three or more suitable pollinizer varieties planted nearby to set a good crop of nuts each year. Pollen source varieties should be placed no farther than 20–30 m from crop trees. This is because hazelnuts are self-incompatible, which means they require pollen from another compatible variety to produce nuts. The pollinizer variety must be compatible with the crop variety. The timing of pollen shedding is also a factor. The pollen source variety must shed its pollen when the female flowers of crop varieties are open and receptive to pollen, and not shed pollen during periodic thaws that can occur during winter.

Pollenizer varieties can also be good nut producers to contribute to the total crop yield. In fact, as with apple orchards in a block planting design, all trees can be crop trees in a hazelnut orchard if the varieties provide compatible pollen with neighbouring blocks. Growers and researchers are still learning how pollenizer varieties will react in a climate like Ontario's, where the flowering season is very short compared to Oregon's long flowering period.

There is sometimes confusion among hazelnut growers about the terminology for cultivars versus varieties. Almost all hazelnuts available today for commercial production are selected through breeding and their characteristics are maintained through vegetative propagation. Consequently they are cultivars (cultivated varieties) rather than true varieties, which tend to occur naturally and have seeds with the same unique characteristics as the parent. However, in agriculture the terms "cultivar" and "variety" are often used interchangeably, as is done in this publication.

3. Site Selection and Orchard Establishment

Site Selection

Climatic Requirements

Plant hazelnut orchards close to large bodies of water, such as the Great Lakes or regions of the province that are known to support other fruit orchard industries, such as apples or peaches (Figure 3-1). This will maximize the annual cropping potential of hazelnut orchards and minimize the risk of winter freezing injury or spring frost injury. Many hazelnut varieties that are new to Ontario require further testing to fully determine their tolerances to cold and eastern filbert blight disease.

The most cold-hardy hazelnut varieties, including those from Cornell University, midwestern Canada and Ontario growers, will be killed by temperatures below -40°C, and some varieties may be severely damaged or killed below -28°C. Avoid planting cold-hardy hazelnuts in any area of the province where -40°C occurs at least once every 15 years, and exercise caution in areas where temperatures frequently drop below -28°C. Cold-hardy varieties are less sensitive to winter conditions but will still benefit from the moderated winters found near the Great Lakes.

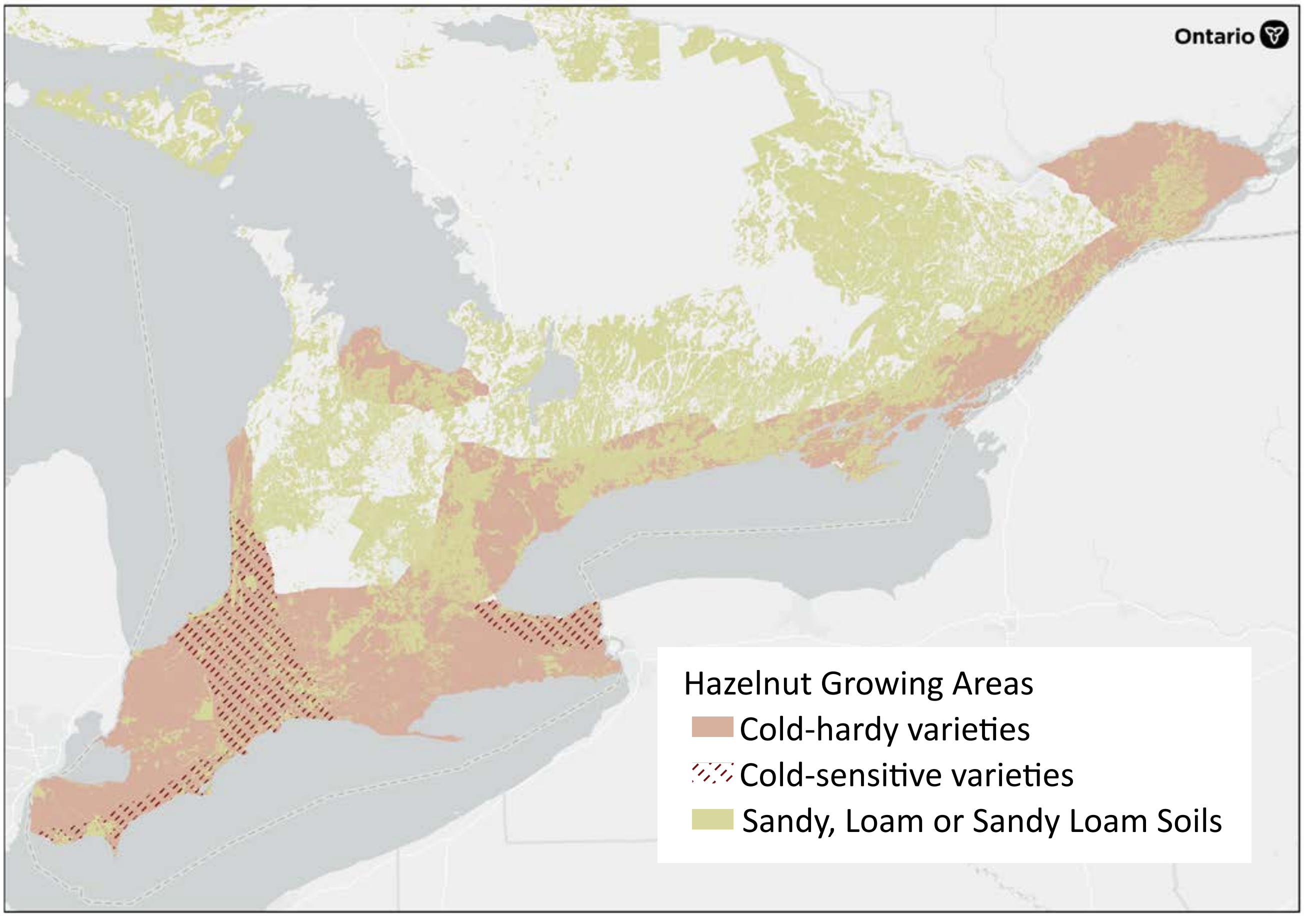

Figure 3-1. Growing regions for cold-hardy and cold-sensitive varieties of hazelnuts based on temperature (number of years with temperature above -30°C). Ideal soil conditions for hazelnuts (sandy, loam or sandy-loam) are overlayed onto growing regions.

Cooler regions that typically support commercial apple or pear orchard production and warmer regions where tender fruit is grown would be suitable for cold-tolerant hazelnuts. European hazelnut varieties, such as varieties originating from Italy and Turkey, have extreme sensitivity to cold and will not survive Ontario winters. Hybrid crosses developed by Oregon State University's hazelnut breeding program can be killed by temperatures below -28°C. Oregon varieties are most susceptible to winter freezing and spring frost injury and have climatic requirements similar to peaches, apricots and other tender fruit. Oregon varieties are only suited to the most moderated regions of the province, such as fertile orchard areas of the Niagara peninsula or along the north shore of Lake Erie on well-drained sandy loam soil.

Hazelnut orchards located too far from moderated orchard regions, that is, too far from the Great Lakes, are likely to sustain winter injury, spring frost injury and reduced annual cropping. Stressed or injured hazelnut orchards are also more susceptible to infection by disease and attack by insect pests.

Soil Type

Hazelnuts will grow best in deep, well-drained, fertile, loam to sandy loam soil (Figure 3-2A) having good aeration and a soil pH of 6–7. Tile drainage is recommended for all soil types to help guarantee a healthy hazelnut orchard, as is recommended for other commercial fruit orchards.

Sample the soil of the orchard site 1 or 2 years before planting trees to determine soil pH, fertility and the variability of soil characteristics across the field. Have soil samples tested at an accredited soil testing lab. Avoid planting in soil with a pH below 5.5, or, based on soil test results, add enough lime to raise the soil pH, before establishing the orchard.

As with lime, if preliminary soil testing indicates a potassium deficiency or boron deficiency, a prescribed amount of potassium and boron can be incorporated into the soil prior to planting hazelnuts. For more information, see Chapter 5: Nutrient Management.

Hazelnuts will grow less vigorously and less productively on heavier soils, such as clay or clay-loam soil, where soil aeration and drainage may be limited or slow (Figure 3-2B). Hazelnuts grown on heavy, wet soil are also more susceptible to root rots, and a number of pest species that colonize weak, stressed trees (see Chapter 6, Insects, Diseases, Wildlife and Disorders). Moist or saturated clay soil may not adequately support heavy orchard equipment during orchard maintenance and harvest activities, often becoming deeply rutted even where permanent ground cover is established. During harvest, the heavy sweep-brush harvesters require an absolutely flat, drained, stone-free soil surface to effectively pick ripened hazelnuts off the ground.

Figure 3-2. (A) Loam to sandy-loam soils are ideal for hazelnuts. (B) Stunted, weak hazelnut trees growing on clay to clay-loam soil with poor aeration and drainage.

Slope of the Orchard

Avoid planting orchards in low areas of land, which can create a microclimate that favours frost injury and has poor soil drainage. Higher areas of land that have a gentle slope and a cleared lower area beyond the orchard boundary will have improved air drainage, thereby preventing frost pockets from forming in spring, and will have better soil water drainage. Where air cannot drain, spring frosts can be a recurring problem. Frost pockets can damage sensitive flowers and new vegetative growth. Growers in Niagara orchards have used wind-generating machines successfully to prevent frost injury in hazelnuts during moderate-to-heavy spring frost conditions.

Windbreaks and Wind Protection

Hazelnut plantings, like all horticultural crops, benefit by having shelter from damaging winds. Hazelnut trees and their annual nut crops are sensitive to damage caused by strong winds, yet still require gentle wind for cross-pollination. With excessive wind, young hazelnut trees can grow skewed-over or can uproot without support (Figure 3-3). Hazelnut orchards also benefit from wind protection during cold, dry winter months, which can kill sensitive male catkins and pollen.

Figure 3-3. Frequent westerly winds have caused this row of hazelnut trees to lean to the east as the trees grow.

An ideal windbreak will be 50% porous, that is, the volume of the canopy consists of roughly half airspace and half branches, twigs, needles and leaves. One or two rows of conifer or evergreen trees can provide an ideal porosity. A 1:1 porosity ratio in a windbreak provides for movement of air through the conifer tree row, moderates wind for hazelnut pollination and helps dry a wet orchard quickly following rain or morning dew.

If they are not already established, consider planting conifer windbreaks around the perimeter of new orchards as soon as possible or, ideally, several years prior to planting hazelnuts. A single or double row of conifers, such as white spruce, Norway spruce or Serbian spruce, will provide adequate wind protection throughout the entire year (Figure 3-4). Eastern white cedar is a good windbreak species to include, however, if used alone it can become too dense, limiting air movement through the canopy. It is better to alternate three to five different species of conifers into the windbreak to create diversity and to provide healthier windbreaks. Unlike native conifers, Colorado blue spruce and Austrian pine are tolerant to the desiccating effects of drifting winter road salt spray that can occur adjacent to highways and are effective windbreak species.

Figure 3-4. Looking north, a windbreak consisting of Norway spruce shelters a young hazelnut orchard from strong damaging westerly winds.

In some cases, dense windbreaks located directly adjacent to hazelnuts have increased problems with squirrels and other vertebrate pests by providing habitat and shelter from predators in close proximity to the orchards. Ensure that windbreaks are far enough (3m or more) from orchards that squirrels cannot easily jump from windbreak trees to hazelnuts. Keep the area between the windbreak and the orchard clear of excess vegetation so rodents are exposed to predators when moving from the windbreak to the orchards.

Conifer windbreaks also improve the conditions for applying pest and weed control sprays in the orchard and reduce spray drift off-site. Having a visual barrier can also reduce neighbour complaints when pest sprays are necessary. A dense canopy of conifers can significantly reduce noise from farm equipment and can reduce the temptation for trespassers to enter onto private property. Any improvements made toward aesthetic appearance often improves neighbour relations, such as trees that show bright fall colours or provide the year-round benefits of conifers. Plan to renovate (renew) a conifer windbreak approximately every 30–40 years.

Site History and Surrounding Crops or Forested Areas

It is important to be aware of the cropping history of the area and what the surrounding crops are. When removing a crop, soil pathogens with wide host ranges (e.g., *Phytophthora*, *Pythium*, etc.) can carry over to a subsequent crop. Growers should be aware of this potential when planting into a field that had high levels of disease the previous season, especially if replanting into land that was recently hazelnuts. Planting into land that was previously forest may also be a source of disease. In Oregon, hazelnut trees have become infected with the fungus *Armillaria mellea* when their roots have come into contact with the roots of decaying forest trees (see the section on Root Rots in Chapter 6: Insects, Diseases, Wildlife and Disorders).

In addition to general build-up of diseases, many perennial crops have a condition called replant disease which only occurs when the same crop species is grown twice on the same land, even if a different crop was grown in between. Replant disease is characterized by poor establishment or reduced productivity, likely as a result of weakening of the host crop by a complex of soil factors. In Ontario, replant disease is a problem in apple and tender fruit. Replant has not been reported for hazelnuts, either in Ontario or elsewhere, however this crop is new to Ontario so there are few instances where orchards have been replanted onto land that previously grew hazelnuts. Replant disease is a possibility in any perennial crop, so if possible, avoid planting new hazelnut trees in land where hazelnuts were previously planted, particularly in the last 2–8 years. If possible, stagger planting rows to avoid planting directly into old hazelnut tree sites, especially if those trees were diseased.

Plant pathogenic nematodes are also not known to be a problem in hazelnuts in other growing regions. However, the sandy soils of southern Ontario which are ideal for hazelnuts also tend to have high levels of nematodes, especially the root-lesion nematode (*Pratylenchus penetrans*) and the northern root-knot nematode (*Meloidogyne hapla*). Consider a soil nematode test if planting on land with a past history of nematodes. For more information on replant disease or nematodes in perennial fruit crops, refer to the resources listed in Appendix B.

Forested areas are sanctuaries for wildlife and should remain valued for this purpose and all their diverse ecological benefits. Although natural forested areas promote a healthy environment and can help shelter nearby crops from wind damage, hazelnut orchards are often affected by insect, disease and vertebrate pests commonly found in Southern Ontario forests. For example, wood-boring insects common to birch and beech trees can girdle young hazelnut trees since these species are genetically related. Some insects (e.g., gypsy moth) that defoliate forest trees can also defoliate orchard trees.

Where new hazelnut orchards grow close to forested areas, monitor the health of the orchard and crop weekly during the entire growing season. Learn to identify the symptoms of disease, insect and vertebrate pests of hazelnuts that tend to invade from surrounding areas and develop an effective pest management program. See Chapter 6: Insects, Diseases, Wildlife and Disorders for a detailed description of each insect pest and disease that can potentially affect commercial hazelnut orchards.

Mapping Out the Area

A detailed map of the production area is essential for proper planning of the hazelnut orchard and making management decisions. There are many things to consider before planting and during the productive life of the orchard. In addition to the outline of the orchard area and property, include crops growing in adjacent fields, the location of ponds and water courses, woodlots, neighbouring private land and residences or public buildings that could be affected by noise, dust or spray drift, the location of underlying tile drains, tile outlets and the direction of water flow in tiles. Include details of topography, soil characteristics and areas of concern across the intended orchard site.

Ensure that natural water courses and riparian areas are well-protected using vegetative buffers. Use buffer widths established by environmental farm planning and stipulated on pest control product labels. Permission to apply certain pest control products and other agricultural chemical products may be contingent upon protective buffers being located adjacent to water and sensitive areas.

Water Management in New Orchards

Drainage

Adequate drainage is crucial for the survival of crops grown in Ontario and particularly permanent crops such as hazelnut trees. The most common and effective method of field drainage in Ontario is subsurface tile drainage (using corrugated, perforated plastic pipes).

The benefits of tile drainage include:

- continuous soil aeration and survival of trees
- promotion of deep root growth (roots will die in saturated soil)
- drought resistance (because of deep roots)
- reduced damage to soil (tractor can pass over soil without rutting)
- improved soil health
- reduced root diseases

Figure 3-5. The row of hazelnuts on the left shows tree death due to late spring flooding injury. The soil is heavy clay with no tile drainage.

Currently there is no research in Ontario on hazelnut drainage requirements. However, hazelnuts are considered equally sensitive to poor soil drainage as tender fruit and apple orchards, where systematic tile drainage is necessary. Hazelnut roots do not tolerate oxygen-deprived soil due to waterlogging, especially during the growing season (Figure 3-5). As is recommended for other tree crops, tile drainage should be installed between every row or every other row (Figure 3-6). On some very deep sandy soils, tile drainage may not be necessary. Drain depths should be 0.75 m or deeper (maximum 1.2 m).

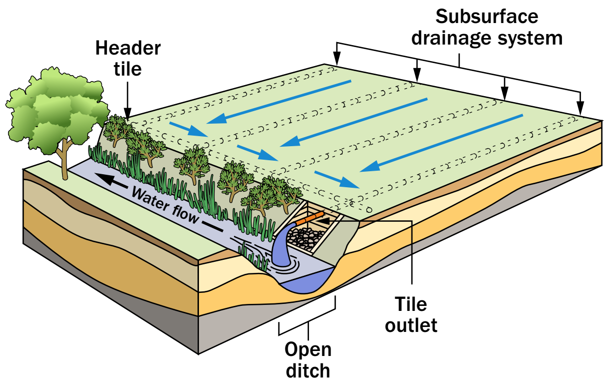

Figure 3-6. Drawing of a tile drainage system.

To intercept seepage and prevent prolonged flow into lateral drains, install an interceptor drain along the higher end of the orchard. This reduction in lateral drain flow will deter the roots of trees or weeds from entering lateral drains.

Where the hazelnut planting is occurring on a field with an existing systematic tile drainage network, it may be possible to orient the tree rows with the lateral drains every other row (typically tile drains are 9 m, forcing a narrow row spacing of 4.5 m). It is also possible to orient the tree rows perpendicular or diagonally to the lateral drains, however this presents some risk of roots entering the tile drains. Although crossing the tile drains with the tree rows is not recommended for new tile drainage systems, drainage benefits can still be realized when working with existing systems. Fortunately, hazelnut roots typically do not plug underlying tile drains because the roots cannot tolerate flooded or poorly aerated surroundings. For the same reason, fruit trees rarely plug underlying perforated tile drains.

A key consideration for every drainage system is the outlet used to discharge the collected water. Ensure that you have the legal right to use the outlet before starting any planning or work. Also confirm that the outlet can handle the amount of water to be discharged.

Drainage contractors are professionals experienced in designing and installing drainage systems. In Ontario, the *Agricultural Tile Drainage Installation Act* (R.S.O. 1990) regulates the installation of agricultural tile drainage systems. The work must be done by a licensed drainage contractor unless the landowner chooses to do the work themselves. Ask for quotes and ensure the contractor has experience installing drainage systems for commercial orchards, berry crops or vineyards.

For the most up-to-date information on drainage in Ontario, visit the Ministry of Agriculture, Food and Rural Affairs (OMAFRA) website at ontario.ca/omafra.

Planning for Irrigation

Hazelnut trees are medium-rooted, with the majority of the root system developing in the upper 0.5–1 m of soil if the field has adequate drainage. Hazelnut trees should be irrigated every growing season during periods of low rainfall, using enough water to wet the entire rooting zone. Irrigation is most important during orchard establishment to promote adequate root development and promote earlier nut production. Research in Europe and Oregon has shown that moisture stress leads to reduced productivity. Additionally, moisture stress in young hazelnut trees can increase susceptiblity to invasion by pests, such as bacterial blight.

Supplemental irrigation of hazelnut trees in Ontario has the following benefits:

- ensures survival of young trees after transplanting and during the first 1–4 years of establishment
- increases vegetative growth (shoot growth, shoot elongation and trunk growth)
- helps bring trees to nut production faster
- increases nut weight and size
- increases nut yields
- reduces number of blank nuts
- provides healthier buds for the following season's crop

Irrigation planning should begin prior to planting of hazelnut trees. Ideally, irrigation systems should be in place at the time of planting, so trees receive benefits of supplemental moisture throughout the life of the orchard, however irrigation can be added to an orchard after planting as well.

The following sections outline key considerations when deciding on irrigation systems for hazelnut orchards. For information on when and how much to irrigate, see the section *Irrigation* in Chapter 4: Orchard Management.

Water Supply

Before establishing a hazelnut orchard, invest in developing an adequate water supply. Irrigation requires large amounts of water. A mature orchard will require up to 185,000 L of water/ha/week.

A suitable irrigation water supply will:

- supply sufficient water for the number of hectares of production
- be available during drought conditions
- be available for irrigation pumping without impacting the natural environment (e.g., drying up streams or wetlands)
- be available for irrigation pumping without impacting other takers (i.e., neighbouring wells)
- have suitable water quality for safely irrigating edible crops

Permit to Take Water (PTTW)

A Permit to Take Water (PTTW) from the Ontario Ministry of Environment, Conservation and Parks (MECP) is required for any irrigation taking of more than 50,000 L/day. This applies even if the taking only occurs a couple of days per year. This applies to all water sources, wells, streams, lakes, ponds and even water supplies on the farm property that have been built by the landowner. For more information, visit *Permits to Take Water* at ontario.ca/page/permits-take-water.

Irrigation Equipment

Hazelnut orchards in Ontario can be irrigated by drip irrigation (on the surface or buried) or by overhead irrigation (travelling guns or sprinklers).

Drip Irrigation

Drip irrigation is based on the concept of preventing rather than relieving moisture stress. The crop response to this approach is positive. Some advantages of drip irrigation include:

- easily automated
- can be applied on windy days or during spraying operations
- does not wet the foliage, which reduces disease problems and does not remove crop protection materials from leaf canopy or nuts
- the uniform water distribution is well suited for fertigation (application of fertilizers through irrigation water)

A drip irrigation system supplies a small amount of water (2–8 L/hr) to the root zone of each tree (Figure 3-7). The system components can be downsized because water is delivered on a more continuous basis (usually daily, when needed) and only the rooting areas are watered (not between the rows). As compared to an overhead irrigation system, the pumps required for drip irrigation are smaller, less power is required, less energy is used and the water conveyance lines are smaller.

Figure 3-7. A drip irrigation line along the soil surface, feeding a row of young hazelnut trees.

In a hazelnut orchard, one to two lines of drip hose (Figure 3-8) will supply each row of trees. The emitters (equivalent to sprinklers in other systems) are evenly spaced along the lines.

Figure 3-8. Two drip irrigation lines being buried along each side of a row of young fruit trees.

Drip systems require filtration units to provide clean water and avoid emitter plugging (Figure 3-9). Water high in calcium and magnesium may form calcium carbonate and magnesium carbonate precipitates and cause plugging of a drip irrigation system. Regular or periodic acid injection may be required. Provide a water quality analysis to the irrigation designer before purchasing an irrigation system, as some water sources can pose challenging plugging problems.

Drip systems also require pressure regulators at the head of each sub-main or other appropriate locations.

A high level of design is imperative for this system to operate properly, especially on rolling terrain. Seek a professional drip irrigation designer. Choose high-quality drip hose (not thin-walled tape) with a minimum expected performance of 15 years. Choose a product where the manufacturer's coefficient of variation (Cv) for the emitter type is less than 0.07. A Cv of less than 0.03 is excellent. Choose an emitter with a low "x" exponent of 0–0.5. Fully pressure-compensating emitters will have an "x" exponent approaching 0. Using pressure-compensating emitters ensures that each tree is receiving the same amount of water even if it is far from the pump or up a hill. The cost of pressure-compensating emitters is higher than non-pressure-compensating emitters. A system using emitters with a somewhat higher "x" exponent (such as 0.5) may be satisfactorily offset by a skilled system designer. (Note: "Cv," standing for "Coefficient of variation" should not be confused with "cv," the abbreviation for "cultivar").

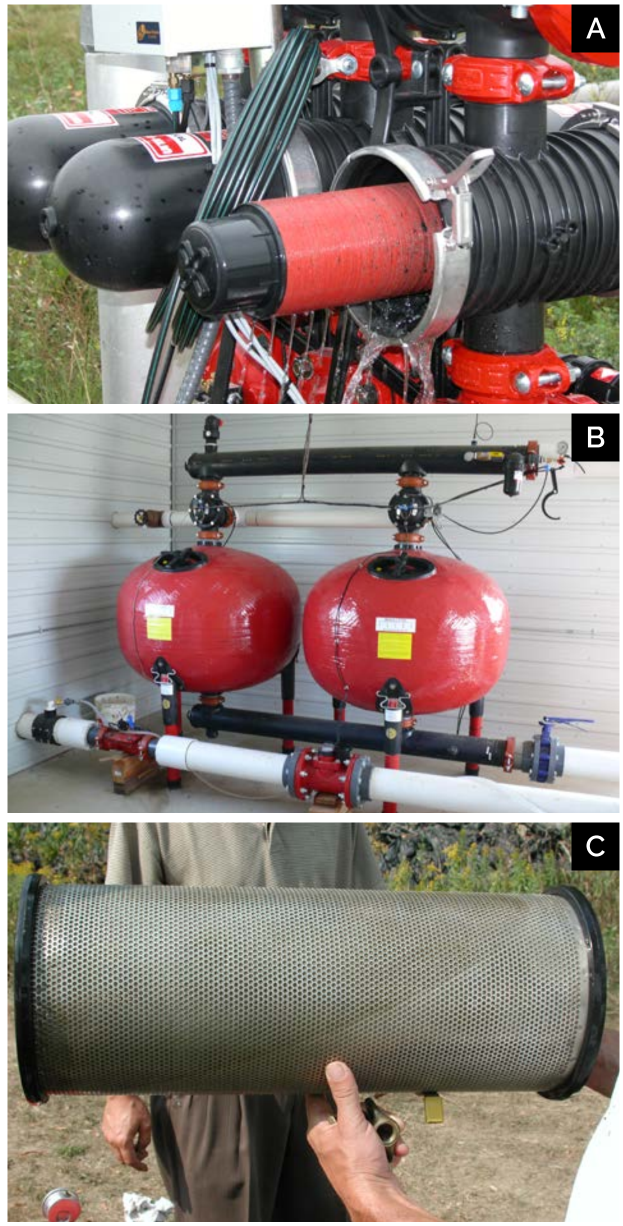

Figure 3-9. Examples of filters used in drip irrigation systems. (A) disk filter (B) sand filter (C) screen filter.

Overhead Irrigation

Overhead irrigation (Figure 3-10) is based on replacing the amount of water used by the tree after a certain time period, usually every 5–10 days. Some advantages of travelling gun irrigation include:

- the equipment purchasing cost can be lower than drip irrigation
- the system is portable, can be moved between farms

Some disadvantages of travelling gun irrigation include:

- is labour intensive
- has high pressure/energy requirements
- requires high flow rates
- is not suited for automation
- irrigates the entire orchard floor
- can wash pest-controlling sprays off the orchard canopy

Figure 3-10. Travelling gun irrigation system watering mature pear trees.

Additional information on irrigation use, design and maintenance, can be found on the OMAFRA website at ontario.ca/crops.

Site Preparation the Year Before Planting

Start preparing the soil for a new hazelnut orchard the year before the trees are planted. Break hardpan soils with an appropriate subsoil blade passing in two directions. Hardpan layers may be located up to 45 cm below the soil surface. Breaking up hardpan layers will ensure that excess water can drain freely through the subsoil naturally or to underlying tile drains. Disk and cultivate the soil surface 15–20 cm deep to loosen the soil, to allow rainwater to penetrate and the root zone to be aerated. Because it is not an ideal soil type for hazelnuts, heavier clay soil will require more preparation effort than sandy loam soil to ensure that drainage will be adequate for hazelnuts.

If the soil pH is too acidic for hazelnuts (below pH 6.0), apply lime and till it into the soil. Soil tests can determine whether lime application is necessary and how much lime to add per hectare to achieve a soil pH that is more suitable for hazelnuts. Soil tests can also help in planning nutrient management decisions. See Chapter 5: Nutrient Management for more information.

Soils often lack organic matter and hence may lack a healthy soil structure. To improve soil health, plant a cover crop the year before planting the trees. A green-manure cover crop can be planted and grown for a full year, then tilled under the following spring.

Another option is to establish a permanent ground cover, such as an orchard sod mixture, the year before planting the hazelnuts. Once the permanent ground cover is established, mark out the tree rows and till up a 1.5–2.0 m-wide strip the following spring for each tree row to be planted.

Perform weed control in the fall prior to planting, to mark the tree rows and kill ground cover so the area can be tilled more effectively. This reduces the preparatory work before tree planting the following spring and ensures a weed-free soil for several weeks after the trees are planted. See the resources listed in Appendix B and

Chapter 7: Weed Management for additional information on preplant site preparation to reduce weeds.

Orchard Layout and Planting Design

Plant tree rows parallel to existing fence lines, or in the most convenient direction of travel for orchard equipment, while allowing for air drainage. Leave adequate space at the ends of tree rows and between fence lines to easily turn tractors and the largest implements around.

The spacing of rows and the distance between trees will depend on the varieties chosen. Oregon varieties grow larger than other hazelnut varieties. Oregon varieties can be planted at 6–7 m between rows and 5 m between trees. Smaller hybrid varieties can be planted closer, for example, 5 m between rows and 4.5 m between trees (Figure 3-11).

Figure 3-11. A young hazelnut orchard, 5 m between rows and 4 m within rows, with herbicide weed management and ground cover established.

Hazelnuts must cross-pollinate with other compatible hazelnut varieties. Locate pollen trees no more than 18 m–21 m away from crop trees to ensure pollen reaches receptive hazelnut flowers. Ontario producers who are growing Oregon hazelnut varieties can follow existing guidelines on pollinizer compatibility, so that crop yield is maximized. In Oregon orchards, approximately 15% of the trees are pollinizer trees, interspersed throughout the main blocks of crop variety. In Ontario, 20% or more of the trees should be pollenizers.

Plant hazelnuts in large blocks that consist primarily of the main crop variety plus sufficient numbers of pollinizer varieties (Figure 3-12). Blocks of compatible hazelnut varieties can also be carefully positioned to cross-pollinate with each other (Figure 3-13). Pollinizer varieties must provide adequate amounts of compatible pollen at the appropriate time — when female flowers are open and receptive to pollen.

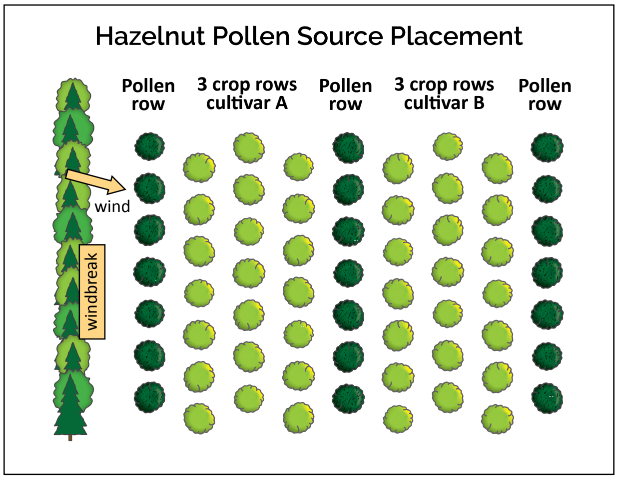

Figure 3-12. A minimum of three compatible varieties having overlapping pollen release periods is suggested to ensure pollen is transferred to female flowers of crop trees in larger block plantings.

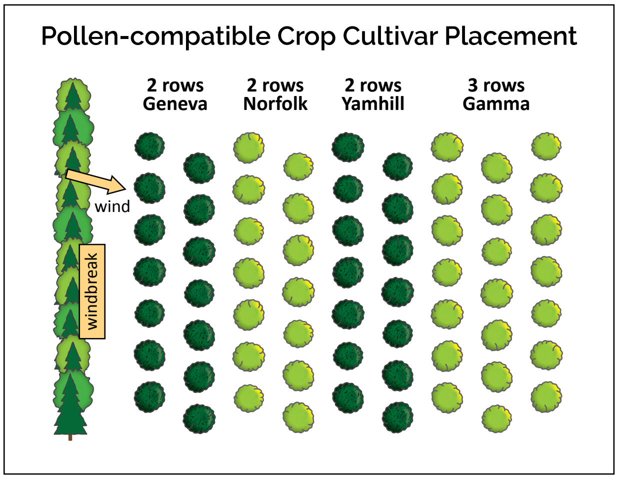

Figure 3-13. Similar to the design of apple orchards, blocks of compatible hazelnut varieties can be carefully positioned to cross-pollinate with each other. Supplemental pollen source trees can also be interplanted into each block if necessary.

Large blocks consisting of one main crop variety plus pollinizers will enable the majority of the hazelnut crop to mature and drop to the ground at the same time throughout the block. Even ripening of nuts and simultaneous nut drop allows a mechanized harvester to collect the crop in two or three passes, helping to minimize the cost of harvesting the crop.

At present, some growers include diverse hazelnut trees as pollinizers planted within the main crop variety, to ensure that sufficient compatible pollen is transferred. For example, plant every third row within a cropping block with pollinizer trees. Whenever possible, these pollinizers should be clones rather than seedlings, however in some cases they may only be available as seedlings.

Ordering and Handling Nursery Stock

Order hazelnut trees well in advance from a reputable nursery, to ensure that the trees can be planted at the right time and coordinated with other fieldwork. Ensure that nurseries have good pest management practices, particularly for eastern filbert blight and bacterial blight, since these diseases can be inadvertently introduced to new orchards through asymptomatic seedlings. A partial list of Ontario nurseries that supply fruit trees can be found on the OMAFRA website at ontario.ca/crops.

Contact the nursery or nurseries at least 2 years ahead of planting to determine whether they have the appropriate hazelnut crop and pollinizer varieties, and to know if trees will be available in sufficient quantities. For large orders, place the order with the nursery 2 years in advance, since it requires 2 years for nurseries to root propagated varieties or produce seedlings to a point where they are ready to ship to growers. Nurseries often have orders from many growers and must plan for their own production schedules.

Nursery trees should arrive at the farm in good condition with a large mass of healthy, moist roots that have not been allowed to dry out. Stems should be thick, with lots of healthy dormant buds along the length. There should be no sign of disease on the roots or stem, such as spore-forming structures of eastern filbert blight disease on the stem surface.

The nursery stock should arrive at the farm just before planting. If the trees arrive early or planting is delayed, keep the trees in a dormant state in a cold storage facility with roots always moist, until they can be planted. Never store nursery stock with roots sitting submerged in water, since roots, and therefore the trees, will eventually die or be severely damaged from a lack of oxygen. If nursery trees need to be stored temporarily before they are planted and cold storage is not available, keep the trees in cool shade with roots fully buried in moist, loosened soil or in moist wood shavings until the trees can be planted. Never allow the roots to dry out.

Planting the Orchard

Plant hazelnut trees in early spring, beginning in early April, while the young trees are still fully dormant. This timing allows the roots to settle and begin to develop in advance of bud break and warm spring weather. New shoot growth is proportional to root growth. Therefore, development of healthy green foliage and vigorous shoot elongation during spring indicates that the roots are developing and elongating in their new soil environment.

Trees planted after bud break and too late in the spring will be stressed, as the roots will be unable to take up enough water to supply expanding leaves. This explains why trees often die or are severely stunted during the first year.

In larger orchards, trees can be planted with a tractor-mounted tree planter blade. In smaller orchards, trees can be planted by hand with a tree-planting spade. Tractor-mounted augers can be used to dig planting holes, however the auger tends to hard-pack the soil on the sides and bottom of the holes as it spins. This can reduce water drainage or impede root growth through the packed soil layer. To prevent hard-packing the soil, growers sometimes weld one or two small metal slabs to the outer edge of the auger, which cut through packed soil surfaces as the holes are dug.

Care After Planting

If the soil is dry or only partially moist at planting time, water each tree immediately with 12–19 L of water per tree. Usually, the trees do not need fertilizing during the first year, which encourages new roots to grow outwards to access a larger area of soil nutrients and anchor the trees. However, where the soil lacks fertility, apply a dilute starter fertilizer (dilute 5-5-5 NPK) right after planting. Also, use a hand hoe to keep a weed-free area, 1–2 m in diameter, around the young trees, since new trees can be easily damaged by herbicides.

In large orchards, trickle (drip) irrigation is most efficient when installed as soon as trees are planted, to keep the soil moist and new trees free of stress. See the section *Irrigation* in Chapter 4: Orchard Management.

To help control weeds, place a ring of organic mulch around each tree, a few days after it has been planted (Figure 3-14). The mulch will also prevent the soil from drying out, provide a better environment for roots to grow and insulate the roots from freezing injury during winter. Organic mulch and moist soil will attract earthworms and promote beneficial micro-organisms in the soil to help incorporate organic matter, and improve soil structure, aeration and water percolation to the roots.

Hay or straw that is free of weed seeds can provide a good mulch layer. Avoid fresh wood chips or sawdust because, as the wood begins to decay, it will bind up too much nitrogen, making it unavailable for the hazelnut trees. Wood chips in an advanced stage of decay provide a good mulch for hazelnuts. Keep mulch clear of the tree trunks to prevent mice from chewing the bark and girdling trunks during winter. Place the mulch in a layer, 7.5–10 cm thick, in a 1–2 m diameter circle around the trunk. For more information on weed control in very young trees, see Chapter 7: Weed Management.

Figure 3-14. Young hazelnut trees can benefit from a 7.5–10 cm thick layer of organic mulch, in a 1–2 m diameter circle around each tree. Source: T. Taghavi, University of Guelph.

4. Orchard Management

Hazelnuts require accurately timed management activities in order to achieve maximize yields and ensure trees remain healthy, ensuring a long-lived, productive orchard. These activities include pruning and sucker control, water and nutrient management, weed and pest control, orchard floor management and harvest. These activities need to be performed at the appropriate times to ensure long-term health and productivity of the orchard. Figure 4-1 provides a general guide to the timing of hazelnut management activities for Ontario. These timings may vary depending on cultivar, yearly variability in weather patterns, pest activity, production system and geographic location of the orchard in Ontario.

Orchard Management Calendar

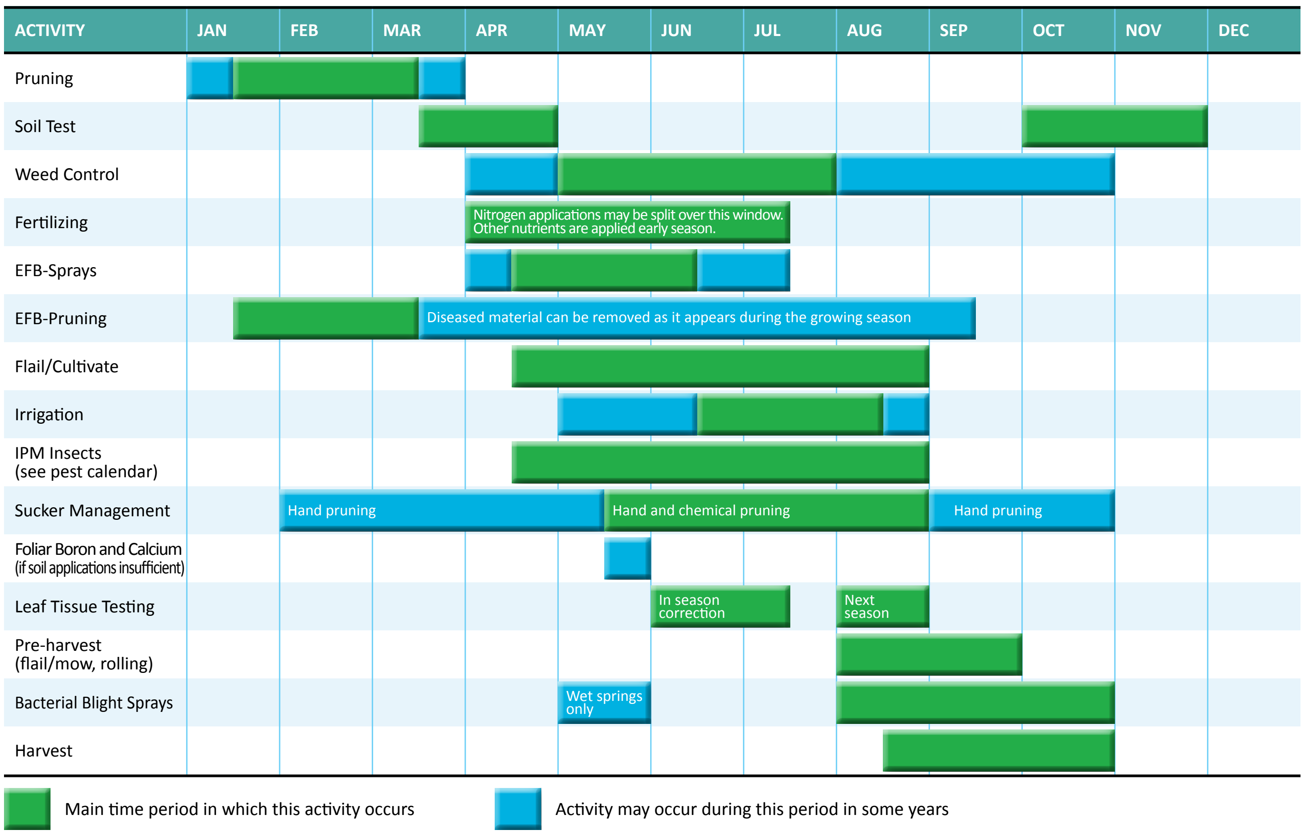

Figure 4-1. Calendar of orchard management activities for hazelnuts in Ontario. Times are approximate and will vary with cultivar, yearly weather patterns, pest activity and location of the orchard.

Pruning and Training

Hazelnut trees usually do not require pruning until the second year, except where a damaged stem needs repair pruning. In the second year and annually thereafter, pruning hazelnuts is important for two main reasons:

- to remove branches and entire stems that become infected by disease to maintain orchard health and encourage new stem replacement from the roots as needed
- to train and maintain the shape and size of the supporting scaffold limbs to optimize annual crop yield.

Prune hazelnuts in late winter and early spring (mid-February to mid-March) before dormant buds begin to grow and preferably before pollination begins.

Pruning during late fall or early winter (before trees are fully dormant) may result in tree injury. Sudden, sharp drops to freezing temperatures may kill exposed cambium tissue in fresh pruning cuts, and possibly spread into main scaffold branches or the trunk before the cuts begin to heal the following spring. A small pruning wound can become a large injury during a cold, dry winter.

Complete removal of stems to the ground due to overcrowding of multi-stem trees or disease in the wood can be done easily in the fall, when dead stems are easily discernible among living stems.

Adjust the pruning and training strategy according to the type of hazelnuts being grown. Hazelnuts will naturally grow as a multi-stemmed tree or dense shrub. In Italy and Turkey, European hazelnuts are trained to have 5-7 main stems per tree (Figure 4-2A), while in Oregon, hazelnuts are trained with a single trunk and eventually take on a large form, similar to an old-fashioned apple or sweet cherry tree (Figure 4-2B).

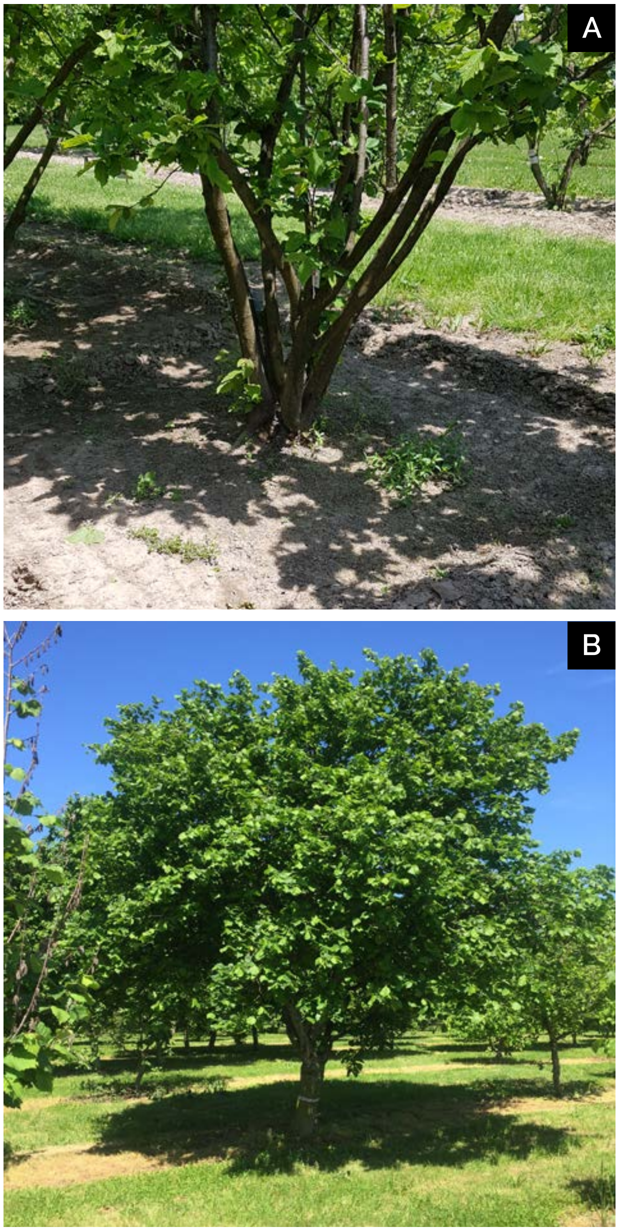

Figure 4-2. (A) Hazelnut tree trained to have multiple main stems. In Italy and Turkey hazelnuts are often trained to have 5-7 main stems. (B) Hazelnut tree trained to a single trunk. This is a common form of training in Oregon hazelnuts.

The advantage of having a single trunk is that it allows mechanized harvesting and maintenance work to be completed efficiently. The disadvantage is that if the stem is killed by disease, the whole tree dies, whereas a multi-stem shrub will have other fruiting stems even if one is killed by disease.

Hazelnuts grow on their own root system and are not grafted to a rootstock. This means stems that are removed due to disease infection can be quickly replaced by training one or two sucker shoots up from the ground (Figure 4-3).

Training suckers to become new scaffold limbs or stems is also done after removing old limbs, to rejuvenate multi-stem hazelnuts and keep the trees fruiting profitably during the life of the orchard. Hazelnut suckers can be trained to scaffold limbs because they are not grafted trees, which is different from other fruit trees that are grafted.

Figure 4-3. The main trunk of this hazelnut tree has been killed by root disease and is being pruned out. The healthy sucker will be trained to take its place.

Ontario growers train hazelnuts both ways, however most growers who begin with a single trunk eventually switch to multi-stem training after they have experienced loss of the single stem through disease. By the third year, the main trunks should be formed and be free of side branches 1–1.5 m above the ground, and the main scaffold limbs are developed above this height. This height will allow a mechanical sweep harvester to pass under the lowest branches.

Once main scaffold limbs have grown, prune them each year to remove diseased, dead or old branches to encourage new fruiting branches to grow at the top and sides of the canopy.

Remove all pruned wood from the orchard before the trees begin to grow in spring to prevent spread of disease. Burn or bury prunings, or chip prunings and compost them at a location distant from the orchard.

Hazelnut nuts form on the new season's growth, therefore much of the crop will grow at the outer canopy of the trees. To avoid removing too much fruiting wood, do not prune young trees excessively. Once trees have attained a mature size, a pruning plan may consist of pruning a quarter of an orchard every year over a 4-year period (or a third every 3 years) to sustain hazelnut orchards with adequate new fruiting wood.

Sucker Shoot Control

During summer, repeated pruning is required two or three times per growing season to remove the prolific growth of sucker shoots that emerge from shallow roots and from main scaffold branches near the soil surface (Figure 4-4). For small orchards, suckers can be removed using hand pruners or loppers. Do not use powered weed-eater machines to de-sucker hazelnuts, as they can severely injure main trunks by removing bark.

In a large commercial orchard where hand-pruning suckers is not practical, suckers can be removed using a registered contact herbicide, where available, that is carefully applied only to the suckers to chemically burn them off (Figure 4-5). For a list of herbicide products registered for use for chemical sucker removal for hazelnuts, consult the resources listed in Appendix B or contact an OMAFRA crop specialist for advice.

Sucker control products are classified as contact herbicides, which only kill green plant tissue, (leaves and young tender stems), and do not penetrate thickened bark and harm the entire tree. To prevent injury, chemical control of suckers must be directed carefully, only at the base of the tree where suckers grow, and not towards the upper tree canopy. Never apply chemical sucker control during windy conditions that could lead to drift and tree injury and only use herbicides specifically registered for control of suckers on hazelnuts in Ontario.

Figure 4-4. Sucker growth at the base of a young hazelnut tree must be removed two or three times each summer.

Figure 4-5. Suckers have been killed chemically by a registered contact herbicide.

Without attentive de-suckering each year, hazelnut trees will grow naturally as very dense, multi-stem shrubs that are difficult to manage. At harvest, fallen nuts can become lodged within the dense shrubs, becoming a haven for vertebrate pests including mice, voles, chipmunks and squirrels (Figure 4-6). Moulds that infect nuts and kernels can carry over from previous seasons' nuts if not removed each fall.

Figure 4-6. Mice have built a nest among the dense stems of this poorly pruned hazelnut tree to feed on fallen nuts. Mice in this nest were observed climbing the tree to feed on ripening nuts. Source: L. Weber, University of Guelph.

Irrigation

Hazelnut trees should be irrigated every growing season during periods of low rainfall, using enough water to wet the entire rooting zone. Ideally irrigation systems should be in place at planting, however it is still beneficial to add them later in the life of the orchard. For information on ensuring an adequate water supply and selecting irrigation equipment, refer to section Planning for Irrigation in Chapter 3: Site Selection and Orchard Establishment.

Irrigation is most important during orchard establishment to promote adequate root development and earlier nut production. Research in Europe and Oregon has shown moisture stress leads to reduced productivity.

During crop-bearing years, critical periods to avoid moisture stress extend from flower fertilization to kernel shell fill. There is generally enough moisture

Table 4-1. Daily irrigation requirements of hazelnut trees

Canopy Size	Water Demand per Tree on Hottest Days of Summer (5 mm Potential Evapotranspiration)	Approximate Planting Year
0.3 m x 0.3 m (1 ft x 1 ft)	0.8 L/day[1]	Planting year[2]
0.6 m x 0.6 m (2 ft x 2 ft)	1.6 L/day	Year 2[2]
1.5 m x 1.5 m (5 ft x 5 ft)	10 L/day	Year 3
2.1 m x 2.1 m (7 ft x 7 ft)	20 L/day	Year 4
2.6 m x 2.6 m (8.5 ft x 8.5 ft)	30 L/day	Year 5
3.0 m x 3.0 m (10 ft x 10 ft)	40 L/day	Full canopy

[1] Use caution when irrigating new plantings. Although the tree will not be transpiring significantly (due to the small leaf area), the tree may be competing with a ground cover or cover crop for water. Apply sufficient water daily or every other day to ensure the full tree rooting area is wetted.
[2] Determine whether to run drip irrigation longer, as each tree will only be receiving water from one or two emitters.

in Ontario during April and May, however, moisture stress during summer can impact both the current crop as well as the bud and flower set for the following year. In Ontario, the most common time for drought to affect hazelnuts is during the critical nut fill period from mid-July to August.

When and How Much to Irrigate

The water requirement of hazelnut trees is directly related to the canopy size (the number of leaves). Keep in mind that grassed alleys will also be competing with the trees for water. Maintain a 2-m-wide, weed-free strip in the tree row. Organic mulch around each tree can help conserve soil moisture while the trees are young.

In the hottest weeks of the summer in southern Ontario, potential plant water use is typically 5 mm/day. Table 4-1 shows the daily irrigation requirements for hazelnut trees by canopy size.

Soil moisture instruments can be used to determine when to irrigate and how long to irrigate.

Different soil textures – sand, sandy loam and clay loam – will have different amounts of soil moisture. In Figure 4-7, the area closest to the bottom represents water that is in the soil but tightly bound to the soil particles and unavailable to the plant. The areas above that represent water that is available for the plant to use. Water in excess of the three shaded areas will drain out of the soil profile. The maximum water that the soil can hold is called the "field capacity." Grower experience suggests that overhead irrigation be triggered before 50% of available water is depleted and drip irrigation be triggered before 20% of available water is depleted, that is to say, at 80% available water.

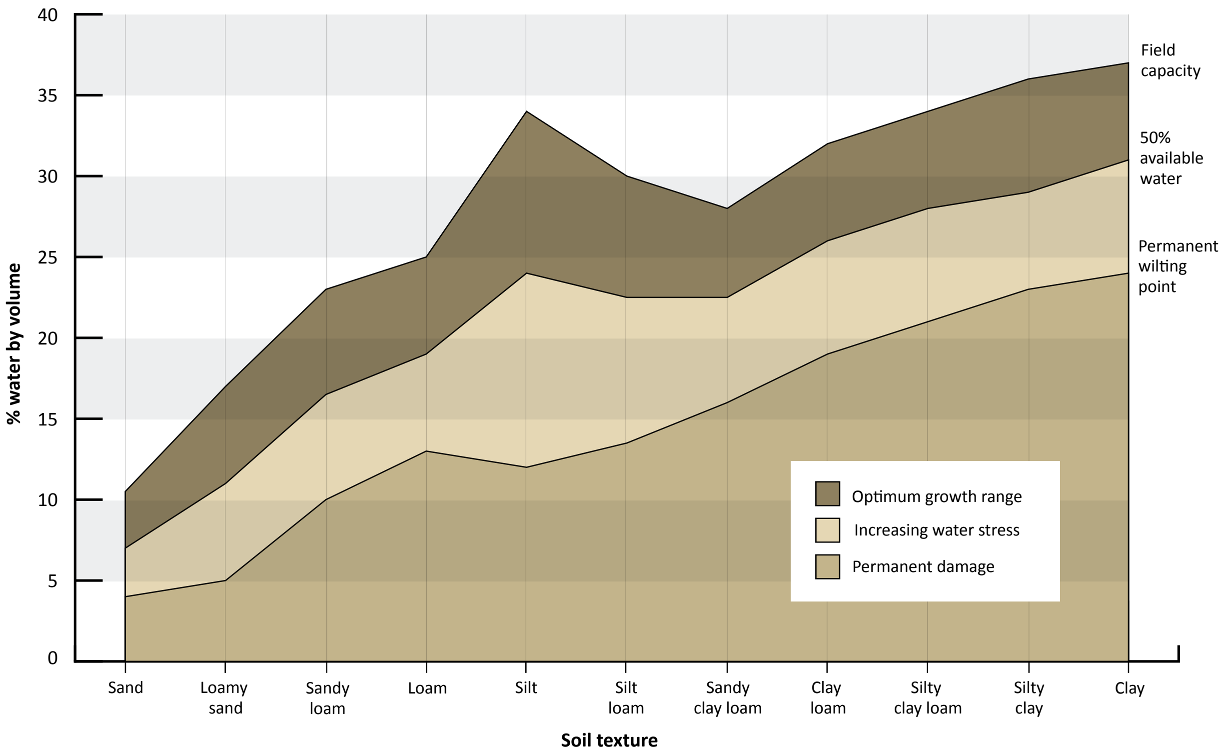

Figure 4-7. Available soil moisture by soil texture. Based on data from Ratliff, L.F., Ritchie, J.T., and Cassel, D.K. (1983). Soil Science Society of America Journal 47, 770(5).

Graphing the soil moisture data over time will help the irrigator see when to irrigate and whether an irrigation dose provided sufficient water, not enough or too much. An irrigation event or significant rainfall will cause the soil moisture to spike. Following this, the soil moisture can drop quickly, depending on the crop growth stage. As the soil dries out, the soil moisture will continue to drop, but more slowly. This is an indication that it is more difficult for the plant to take water out of the soil, and the soil moisture is approaching the permanent wilting point.

A second, deep-soil moisture instrument will permit the irrigator to see if the irrigation amount is too much and irrigation water is moving down below the active root zone.

For more information on irrigation, including videos on irrigation system monitoring and soil moisture monitoring, go to ontario.ca/omafra and search for “irrigation.”

Orchard Floor Management

Once hazelnut trees are planted, a permanent ground cover can be established in the alleyways within the first season, similar to other fruit orchard crops (Figure 4-8). Alternatively, the ground cover can be established the season before planting the trees. A weed-free strip can be maintained under the width of the tree canopy during establishment and during the cropping years, either through shallow tillage, by using registered herbicides or by using a combination of tillage and herbicide.

Figure 4-8. First-year hazelnuts are planted with a 2 m weed-free strip. The new permanent ground cover is establishing in alleyways.

A permanent sod ground cover will provide organic matter to improve soil health and support heavy orchard equipment (Figure 4-9). Grass mixtures, such as Kentucky blue grass, perennial rye grass and fescue, with a small percentage of white clover (5%), can provide a healthy ground cover that will out-compete many weeds. The ground cover can be mowed regularly to expose mice and voles to predators and to help maintain the flat surface required to harvest the nuts mechanically.

Figure 4-9. A permanent sod cover with effective weed suppression in the tree row.

In bearing orchards, a flat orchard floor is essential to allow mechanical harvesters to sweep up or vacuum the nuts off the ground. Roll the orchard floor as needed prior to nut drop. Flail mowing also helps maintain a flat surface and break up organic debris before harvest.

Intercropping in a New Orchard

It can be frustrating waiting several years for new orchards to begin generating income from an annual crop. Farmers have found ways to keep income flowing by growing other annual crops within an establishing orchard. During the first 3 or 4 years of orchard establishment, while the trees are small and non-bearing, annual crops can be planted in alleyways ("alley-cropping") instead of planting a permanent ground cover (Figure 4-10).

Figure 4-10. Pick-your-own crops, such as strawberries, can be productive and profitable for 3 or 4 years, ending as the hazelnut trees begin to bear a crop. Pest management requirements for hazelnut production and mechanized nut harvest ends alley-cropping opportunities in commercial orchards.

This will require extra care as well as knowledge and expertise with both crops to safely integrate management practices for the two different crops. Annual crops are planted outside of the weed-free tree row to minimize interference with tree roots and tree health (Figure 4-11). The health of the trees should always have priority over the annual crops.

Figure 4-11. In this first year hazelnut orchard, soybeans are planted as a crop or can be tilled in as a green manure to add organic matter to the soil. Care must be taken not to allow herbicides registered for soybean production to drift into the trees and cause damage. Harvesting the soybeans will also require a narrow harvester with an attentive driver to protect the trees.

Alley-cropping works as though the crops and new orchard are being grown in separate fields. Although the young trees and annual crops are integrated into the same field, the cost of establishment and production for hazelnuts remains a separate business identity for accounting, just as the cost of production for each alley-crop will have separate cost accounting (Figure 4-12). For accounting purposes, the alley crop must pay for itself, just as the hazelnut orchard must eventually pay for itself and be profitable.

Figure 4-12. Intensively managed, a first-year orchard is alley-cropped with three rows of green and yellow beans, while a mature bearing orchard with a permanent ground cover can be seen in the background. The grower will require expertise, the specialized equipment necessary for each crop, post-harvest handling and marketing knowledge.

Grazing livestock in nut orchards is no longer practiced due to concerns of food safety. Avoid situations that can result in human illness associated with livestock manure. Nuts fall onto the ground when ripe and must not mix with livestock manure, since sweep harvesters pick up nuts and other litter.

5. Nutrient Management

Fertility guidelines for most Ontario crops are based on Ontario-specific research. Because hazelnuts are a relatively new crop in the province, there is little Ontario-specific fertility research available. Fertility information presented in this section is adapted from guidelines developed for hazelnuts in Oregon as well as other tree fruit crops in Ontario. These general guidelines may change over time if Ontario-specific hazelnut fertility data becomes available.

For a complete guide to soil fertility, see OMAFRA Publication 611, *Soil Fertility Handbook* and other resources listed in Appendix B.

Crop nutrition is an important component in the production of high-yielding hazelnuts and the maintenance of healthy trees. The effectiveness of a soil fertility program will depend on the soil (fertility, management, organic matter and acidity), water management and other cultural practices, cultivar and crop pest status. Developing a sound soil fertility program involves assessing the crop and the soil's nutrient needs through soil and leaf analysis, coupled with visual observations of crop performance.

Fertility Guidelines for Hazelnuts in Ontario

The goal of any fertility program is to provide what the crop requires, while avoiding under- or over-application of nutrients. Under-application of nutrients can reduce an orchard's yield and quality. Over-application can also reduce yield or quality, increase costs and lead to environmental damage. Nutrient needs are generally determined by comparing test results to established guidelines for a given crop under Ontario conditions. In Ontario, these guidelines are generally based on Ontario-specific research trials. Like other emerging specialty crops in the province, there has been limited fertility research on hazelnuts in Ontario and therefore they do not have established guidelines, making it difficult for growers to determine how much fertilizer or manure to apply.

For specialty crops with no Ontario-specific fertility research, growers must generally rely on some combination of (1) approved Ontario fertility guidelines for crops that are related botanically or have similar production systems, and/or (2) established nutrient guidelines for the specialty crop in other growing regions. For hazelnuts, nutrient guidelines from Oregon are often used as a starting point in nutrient planning. However, crop nutrient requirements are dependent on a range of factors which include rainfall, temperature, soil type, soil organic matter, soil pH and the cultivar. These environmental factors may differ considerably between Ontario and other hazelnut growing regions. Consequently, guidelines from other areas should be used only as a starting point.

Ontario hazelnut growers may need to conduct their own research to determine the ideal fertilizer requirements for their growing conditions. For many plant nutrients, records of tissue analyses over time can be helpful in understanding an orchard's fertility requirements. This includes routine analyses of healthy leaves taken from the same cultivar, at the same growth stage, from one year to the next, but also samples from problem patches within orchards, or of trees with visual symptoms that indicate potential nutrient deficiencies. While analyses of symptomatic tissue can be difficult to interpret, if a nutrient concentration in symptomatic areas of an orchard is much lower than the same nutrient in unaffected trees, this may indicate that the nutrient is deficient. However, the nutrient deficiency could be a result of soil diseases or other factors, and not necessarily because the nutrient itself is deficient in the soil. It can also sometimes be helpful to take samples throughout the growing season, at different growth stages, for several years to help in understanding how the plants partition nutrients over time. Over time, a grower can establish their own estimated normal ranges by comparing crop observations and yields to plant analysis results.

For more information on nutrient management in specialty crops, refer to the nutrient management section of OMAFRA's Specialty Cropportunities resource (see Appendix B).

Assessing Fertility Requirements

There are three ways to assess soil and crop fertility:

- soil testing
- leaf analysis
- visual deficiency symptoms

Soil Testing

Soil testing is frequently used to develop fertilizer recommendations and help manage long-term soil fertility. It can also be used in-season to diagnose crop production problems. Soil testing in Ontario is conducted by commercial soil-testing laboratories, using tests accredited by OMAFRA (see Table 5-1. OMAFRA-Accredited Soil Tests). Soil nitrate tests are also available from most accredited laboratories. Soil organic matter tests can be useful for herbicide recommendations or for evaluating soil quality but are not accredited tests. For a list of accredited soil-testing laboratories, see Appendix D. Accredited Soil-Testing Laboratories in Ontario. OMAFRA-accredited soil tests are not available for boron, copper, iron or molybdenum. Plant analysis is generally a better indicator of deficiencies of these nutrients.

Table 5-1. OMAFRA-accredited soil tests

Materials	What is Analyzed[1]
Soils for field-grown crops, commercial, turf, etc.	Plant-available phosphorus, potassium, magnesium, zinc and manganese
	pH
	Lime requirement
Greenhouse media	Plant-available nitrogen, phosphorus, potassium, calcium, magnesium
	pH
	Total salts
Nutrient solutions, water	Plant-available nitrogen, phosphorus, potassium, calcium, magnesium
	pH
	Total salts
	Sulphates
	Chlorides

[1]Current as of 2020.

When to Sample

Prior to Planting Hazelnuts: If soil analysis has not been done previously for other crops on the site, take soil samples 1 or 2 years before planting a hazelnut orchard. Adjustments to soil pH and fertility are best done before planting the trees. Soil tests done too close to planting may not give adequate time for nutrient concentration and pH to be adjusted prior to orchard establishment. If adjustments to pH and/or fertility need to be made, it is best to test again after application of fertilizers and lime to determine if additional adjustments are necessary.

After Planting Hazelnuts: Conduct soil sampling and leaf tissue analysis at least every 2 years to monitor the fertility of the orchard and guide annual fertilizer decision-making. This is especially important where hazelnuts are a new crop on the field. More frequent testing may become necessary in the first few years of nut set, as the tree moves from a primarily vegetative state to a more productive phase, since nutrient demands will change with increasing tree and crop size.

Lab reports and detailed fertilizer records maintained over the life of the orchard can help refine nutrient management decisions. Visually monitor the appearance and overall health of the orchard each season and make note of these observations for the future.

Taking a Soil Sample

A soil-test report's accuracy and the resulting recommendations depend on properly taking, preparing and submitting a soil sample. To start soil sampling, you'll need:

- a soil probe or a shovel
- a clean plastic pail (avoid using galvanized metal pails; these will contaminate the sample for micronutrient analysis, particularly zinc)
- sample bags and boxes, usually available from the soil laboratory
- a pen or marker

Sample each orchard block separately. Separate large blocks and blocks with considerable variation into smaller sections. Each section should have relatively the same soil texture, topography, organic matter and cropping history.

Micronutrient deficiencies frequently occur in small patches in orchards or blocks. In these cases, analysis of soil or plants taken from the entire block is unlikely to identify the problem. Sample problem areas separately. When sampling a problem area, a comparison sample from an adjacent good area will help diagnose the problem.

For a basic test, take sample soil cores to a depth of 15 cm. Nitrate-nitrogen samples are taken to a depth of 30 cm. For both tests, take at least 20 soil cores for fields up to 5 ha in size. Take proportionately more cores for fields larger than 5 ha. The more cores you sample, the more reliable the measure of fertility in the field. One sample should not represent more than 10 ha.

Travel the area sampled in a zigzag pattern to provide a good variety of sampling sites. Avoid areas that may skew the results of the analysis, including recent fertilizer bands, dead furrows, areas adjacent to gravel roads or areas where lime, manure, compost or crop residues have been piled.

Break any lumps and mix the soil well before sending a sample for testing. Approximately 2 mL of each sample are used for the analysis. Fill a clean plastic bag with approximately 500 g of soil and place it into the sample box. Clearly mark the sample with all the necessary information (i.e., sample number, farm name, date, etc.). A submission form must accompany the sample.

Interpreting Soil Test Results

The OMAFRA-accredited soil-testing program provides results and guidelines for nitrogen, phosphate, potash, magnesium zinc and manganese fertilizer. It also gives guidelines for the amount and type of lime to be applied, if required. These guidelines can produce the highest economic yields when accompanied by good or above-average crop production management, and are specific to the crop, specified on the lab submission form.

Table 5-2. Soil test nutrient ratings

Response Category	Probability of Profitable Response to Applied Nutrients
High response (HR)	High (most of the cases)
Medium response (MR)	Medium (about half the cases)
Low response (LR)	Low (few of the cases)
Rare response (RR)	Rare (very few of the cases)
No or negative response (NR)*	Not profitable to apply nutrients*
*Adding nutrients to soils with these levels of nutrients may reduce crop yields or quality by interfering with the uptake of other nutrients.	

In a basic soil test, each nutrient is given a numerical value (usually recorded in ppm), a letter rating and a fertilizer guideline for the crop (usually in lb/acre). The letter rating of the nutrient is an indicator of the likelihood of crop response. The Ontario soil test ratings reflect the likelihood of having a large enough response to applied fertilizer in the year of application to pay for the fertilizer and allow additional profit for the grower. The rating system is explained in Table 5-2. Soil Test Nutrient Ratings.

There are currently no Ontario fertility guidelines for hazelnuts. Any response guidelines provided for hazelnuts will generally be based on information from other jurisdictions, or related crops in Ontario, and therefore may not be completely applicable to hazelnut orchards in Ontario. Where crop response values are indicated on lab reports for hazelnuts, it may be helpful to ask what crop or region these values are based on. Until Ontario-specific fertility guidelines are developed, growers may need to adapt fertility programs over time based on experience on their farm.

A soil test guideline is affected by manure application, plowing down of legume sod and the type of crop to be fertilized. Suggested fertilizer rates, especially for nitrogen and phosphorus, should be adjusted if manure and cover crops are used. This information is essential for a reliable fertilizer recommendation.

For more information on methods used in developing fertilizer guidelines from soil test results, refer to OMAFRA Publication 611, Soil Fertility Handbook.

Soil Tests From Other Laboratories

For labs that are not accredited, there is no assurance of the accuracy of the analysis. Only OMAFRA-accredited soil tests can be relied on to provide accurate fertilizer results and guidelines. To be accredited, a laboratory must use OMAFRA-approved testing procedures to demonstrate acceptable analytical precision and accuracy and must provide the OMAFRA fertilizer guidelines (where applicable).

A number of laboratories provide soil tests such as cation exchange capacity, aluminum, boron and copper. These tests are not accredited by OMAFRA because they have not been found to contribute to better fertilizer guidelines. Research has shown that on Ontario soils, use of cation exchange capacity to adjust potash requirements can lead to less reliable guidelines than are currently provided.

Soil Micronutrient Tests

OMAFRA-accredited tests are available for manganese and zinc. Zinc and manganese soil tests are best used in conjunction with visible deficiency symptoms. With manganese, plant analysis is also useful. OMAFRA-accredited soil tests are not available for boron, copper, iron or molybdenum. Plant analysis is generally a better indicator of deficiencies of these nutrients.

Great care is required to prevent contamination of soil samples with micronutrients, particularly zinc. Do not use galvanized (zinc-plated) soil sampling tubes or containers to take soil samples for micronutrient tests. Use a clean, plastic container in good condition. Take care to keep extraneous dust out of the samples.

Interpreting soil test and leaf tissue analysis reports can be challenging, particularly for an emerging crop such as hazelnuts. For information on how to interpret a soil analysis report, growers can contact the Soil Fertility Specialist (Horticulture) with the Ontario Ministry of Agriculture, Food and Rural Affairs, or an OMAFRA crop specialist.

Plant Analysis

Plant or leaf analysis measures the nutrient content of plant tissue. This can be a useful addition to soil testing. Comparing the results against the "normal" and "critical" values for the crop can indicate whether nutrient supply is adequate for optimum growth. If soil levels are known to be adequate, plant analysis may indicate other problems that are reducing nutrient uptake.

Plant analysis is the basis of fertilizer guidelines for perennial crops like tree fruits and grapes. It is also a useful supplement to soil testing for evaluating the fertility status of other perennial crops like hazelnut. It is quite independent of soil testing and can provide a valuable "second opinion", especially for phosphorus, potassium, magnesium and manganese. It is very useful in assessing the status of boron, copper, iron or molybdenum as these nutrients do not have reliable soil tests. It has not been very reliable for nitrogen and zinc.

See Appendix E for a list of laboratories that do leaf and petiole analysis.

Leaf Sampling

The timing of leaf sampling has a major effect on the results, since nutrient levels within a plant or leaf vary considerably with its age and physiological stage. Results are difficult to interpret if samples are taken at the wrong time. Results can also vary when comparing two different cultivars.

Despite this, plants suspected of being nutrient deficient should be sampled as soon as a problem appears. Samples are best taken from a problem area rather than from the entire field. Collect and submit a separate sample from an adjacent, non-affected part of the field, ideally from trees of the same cultivar, for comparison purposes.

When to Sample Hazelnuts: For hazelnut orchards, routine leaf tissue analysis should be done, in conjunction with soil testing, at least every 2 years to monitor the fertility of the orchard and guide annual fertilizer decision-making, especially where hazelnuts are a new crop on the field. In Oregon hazelnuts, leaf sampling is typically conducted in August to provide guidelines for future fertility programs. However, tissue samples can be taken any time (but preferably in June to early July, when the canopy is fully open), to help with in-season correction of some nutrient deficiencies in the orchard.

Take leaves from at least 20 plants distributed throughout the area chosen for sampling. Choose trees that are representative of the entire orchard, or the area with suspected deficiency symptoms. Each sample should consist of at least 100 g of fresh material. Sample problem areas separately. Very old and very young leaves often provide irregular test results. For hazelnuts, it is suggested that leaves be chosen from the middle of current-season shoots of average vigor around the edge of the tree, at approximately head height.

Collect tissue samples into labeled paper bags. Plant tissues will rot if they are stored in plastic bags. Avoid contaminating the sample with soil. Even a small amount of soil will cause the results to be invalid, especially for micronutrients.

Collect and submit a soil sample from both affected and non-affected areas to accompany the tissue sample. This soil sample can help address whether the nutrient deficiency is a result of limited soil availability or due to another contributing factor.

Fresh plant samples should be delivered directly to the laboratory. If they are not delivered immediately, they should be dried at a low temperature to prevent spoilage.

Interpretation

When nutrient levels are in the crop's sufficiency range, increasing the nutrient concentration in the leaf is unlikely to result in increased crop growth. The objective of a good fertility program is to maintain tissue concentrations on the lower end of the range. Attempting to bring the nutrient analysis up to the higher end could possibly result in over fertilization and may not be cost effective.

Plant analysis has limitations. Expert help in interpreting the results is often needed. Plant analysis does not necessarily indicate the cause of a deficiency or the amount of fertilizer required to correct it. The timing of plant analysis on many Ontario crops is difficult. Rapid growth and a relatively short growing season means that yield loss may have already occurred by the time sample results are available. However, it is a valuable tool for diagnosing nutrient-related problem areas for future corrective measures.

Visual Deficiency Symptoms

Leaf symptoms are helpful for evaluating some nutrient deficiencies. Unfortunately, by the time deficiency symptoms are visible, yield losses may have already occurred. Visual deficiency symptoms may also be easily confused with other production problems, such as pesticide injury, leaf and root diseases, insect damage, nematodes, compaction or air pollution. Suspected visual deficiencies should always be confirmed with leaf or plant analysis. Some visual deficiency symptoms of hazelnuts are described in the section *Nutrient Disorders*, Chapter 6: Insects, Diseases, Wildlife and Disorders.

Soil Acidity and Liming

The pH scale ranging from 0 to 14 is used to indicate acidity and alkalinity. A pH value of 7.0 is neutral, values below 7.0 are acid and those above 7.0 are alkaline. A soil pH of 6.5–7 is ideal for hazelnuts. If the soil pH is too low for hazelnut production, broadcast and incorporate lime into the soil at a rate prescribed by the lab results. Ground limestone is traditionally used to combat soil acidity and is easiest to apply prior to crop establishment.

The Buffer pH

Different soils with the same pH value will require different amounts of lime to bring the pH to a particular level, depending on the clay and organic matter content of each soil. The soil pH is used to determine whether soils should be limed but a separate soil test, the buffer pH, is done on soils needing lime to determine the amount of lime required. For soils needing lime (based on soil pH) use Table 5-3. Lime Requirements to Correct Soil Acidity Based on Soil pH and Soil Buffer pH to determine the amount of lime required to reach the target soil pH.

Table 5-3. Lime requirements to correct soil acidity based on soil pH and soil buffer pH

Buffer pH	Ground Limestone Required (tonne/ha)*			
	Target soil pH = 7.0[1]	Target soil pH = 6.5[2]	Target soil pH = 6.0[3]	Target soil pH = 5.5[4]
7.0	2	2	1	1
6.9	3	2	1	1
6.8	3	2	1	1
6.7	4	2	2	1
6.6	5	3	2	1
6.5	6	3	2	1
6.4	7	4	3	2
6.3	8	5	3	2
6.2	10	6	4	2
6.1	11	7	5	2
6.0	13	9	6	3
5.9	14	10	7	4
5.8	16	12	8	4
5.7	18	13	9	5
5.6	20	15	11	6
5.5	20	17	12	8
5.4	20	19	14	9
5.3	20	20	15	10
5.2	20	20	17	11
5.1	20	20	19	13
5.0	20	20	20	15
4.9	20	20	20	16
4.8	20	20	20	18
4.7	20	20	20	20
4.6	20	20	20	20

* Based on Agricultural Index of 75.
[1] Liming to pH 7.0 is recommended only for club-root control on cole crops.
[2] Add lime if soil pH is below 6.1.
[3] Add lime if soil pH is below 5.6.
[4] Add lime if soil pH is below 5.1.

Limestone Quality

Calcitic limestone consists largely of calcium carbonate, and dolomitic limestone is a mixture of both calcium and magnesium carbonates. Use dolomitic limestone on soils with a magnesium soil test of 100 or less, as it is an excellent and inexpensive source of management for acid soils. On soils with magnesium tests greater than 100, calcitic or dolomite limestone may be used.

Limestone varies in its effectiveness for raising soil pH depending on its neutralizing value and its particle size.

The **neutralizing value** is the amount of acid a given quantity of limestone will neutralize when it is totally dissolved. It is expressed as a percentage of the neutralizing value of pure calcium carbonate. Limestone that will neutralize 90% of what pure calcium carbonate could neutralize is said to have a neutralizing value of 90. In general, the higher the calcium and magnesium content of a limestone, the higher the neutralizing value.

Fineness rating, or **particle size**, also affects the neutralizing value of limestone. Limestone rock has much less surface area to react with soil than finely powdered limestone and, hence, neutralizes acidity much more slowly, to the point that it is of little value. The higher the fineness rating, the more rapidly the limestone raises the soil pH.

The Agricultural Index

The Agricultural Index combines the neutralizing value and the fineness rating of a limestone to compare different limestone sources. A limestone's Agricultural Index is determined by the following formula:

$$\text{The Agricultural Index} = \frac{\text{neutralizing value} \times \text{fineness rating}}{100}$$

The Agricultural Index can be used to compare the relative value of different limestones. Lime with a high Agricultural Index is worth more than lime with a low Index because it may be applied at a lower rate and still have the same impact.

For example, if two limestones, A and B, have Agricultural Indices of 50 and 80, respectively, the rate of application required for limestone A will be 80/50 x the rate required for limestone B.

Requirements for lime are based on limestone with an Agricultural Index of 75. For limestone with an unknown Agricultural Index, the rate of application can be calculated using the following equation:

$$\text{Limestone application rate from soil test} \times \frac{75}{\text{Agricultural Index of limestone source being used}} = \text{Rate of Application of limestone source being used}$$

For example, if a soil test recommends 9 t/ha of limestone and the limestone source has an Agricultural Index of 90, the application rate should be 7.5 t/ha (9 × 75/90 = 7.5 tonnes/ha).

The Agricultural Index does not provide information about magnesium content.

Effect of Tillage Depth

The lime application rates presented in Table 5-3. Lime Requirements to Correct Soil Acidity, should raise the pH of the top 15 cm of soil to the listed target pH. If the soil is tilled to a lesser or greater depth than 15 cm, proportionately less or more lime is required to reach the same target pH. Where reduced tillage depths are used, reduce the rates of application proportionately. More frequent liming will be needed in this case.

Lowering Soil pH

Lowering soil pH is only practical if the soil is already below a pH value of 6.5. This is accomplished by adding sulphur or ammonium sulphate. Since the desired pH for hazelnuts is 6.5 to 7, lowering pH below this value is not necessary. Soil pH cannot be manipulated from higher to lower pH from year to year. If the soil pH is above 6.5, it is usually quite impractical to lower the pH because of the very large amounts of sulphur or ammonium sulphate required.

Soil pH and Nutrient Availability

Plants generally take up nutrients only if they are dissolved in water. Soil pH influences the solubility of plant nutrients and other elements. Some nutrients are more soluble at high pH, others at low pH, and still others at ranges in between. This increase in solubility can also result in some elements, like aluminum and manganese, becoming toxic to the plant at low pH levels. Plant species differ in their requirements and tolerance of soil conditions that result from different pH regimes; however, they all generally have specific pH ranges at which they perform best. As such, monitoring and managing soil pH is one of the first steps in good soil management. For a pictoral guide of demonstrating the impact of soil pH on nutrient availability, refer to Table 3-2 on page 55 of Publication 611 *Soil Fertility Handbook* omafra.gov.on.ca/english/crops/pub611/pub611.pdf.

Macronutrients and Micronutrients

Macronutrients are required by the plant in large quantities for basic plant growth and development. The macronutrients include: nitrogen, phosphorous and potassium. Secondary macronutrients, including calcium, magnesium and sulphur, are required in moderate amounts. In general, macronutrients most frequently limit plant growth and development.

Nitrogen

Nitrogen is an essential element for growth and development of all crops. It is a component of chlorophyll, playing a vital role in photosynthesis, and is important to the formation of amino acids, proteins and enzymes. Nitrogen is naturally present in all soils. The nitrate form of nitrogen, while being readily available to plants, is very mobile in the soil, and consequently, any soil test measuring nitrogen only gives a snapshot of the nitrogen level present at the time of sampling. Nitrogen levels will constantly change due to the influence of soil temperature and moisture, cover crops, organic matter and other soil properties, as well as leaching or denitrification in waterlogged soils. Nitrogen rates must also be adjusted to account for incorporation of organic matter such as compost, manure, legume cover crops and crop debris into the field site prior to application of fertilizers.

Do not apply nitrogen prior to planting hazelnuts. Nitrogen should also not be applied during the first growing season, to encourage root growth away from the tree. Starting the second year, add nitrogen in small amounts and incrementally build up to the full rate over 10–12 years (Table 5-4). These applications can be made in early spring by hand as a banded ring around each tree under the drip line. Alternately, apply nitrogen mechanically in early spring, banded along both sides of each tree row, under the canopy dripline. Avoid nitrogen fertilizer contacting the trunks. In Oregon, nitrogen fertilizer is split into two half-rate applications during the spring as it is believed to improve utilization of nitrogen by the trees.

Phosphorous and Potassium

Phosphorous is important to photosynthesis, the development of enzymes and protein, cell division and the creation and transport of sugars and starches. It also impacts root growth and architecture as well as flowering in plants. Soil phosphorous levels across Ontario can be quite varied. However, many coarse sandy-loam soils often contain high levels of phosphorous. Fields with a history of regular manure applications often have high levels of phosphorous and may not respond to additional phosphorous fertilizer.

Potassium is an important component of plant cells, influencing the uptake of water by the roots and playing a role in respiration and photosynthesis. It helps develop the plant's ability to respond to biotic and abiotic stresses, and plays a role in flowering and fruiting. Most crops require equal amounts of potassium and nitrogen.

Prior to establishing a hazelnut orchard, if soil tests indicate a need, phosphorus (P) and potassium (K) can be broadcast and incorporated into the soil before tree planting. The rates of P and K should be adjusted based on soil sample test results. After the orchard is planted, adjust fertilizer rates based on the age of the trees from planting, and on the results of soil and leaf tissue analysis.

Table 5-4. Nutrient management guidelines for hazelnuts

The following fertilizer rates are based on soil sample analysis:
phosphorus — 12 ppm, potassium — 100 ppm
Tree planting density: 500 trees/ha (200 trees/acre)

Year	Nutrient/ha			
	Nitrogen/ha	Nitrogen/tree	Potassium/ha	Phosphorous/ha
Preplant	0	0	21 kg[1]	72 kg[1]
Year 2	23 kg	0.045 kg	—[2]	—[2]
Year 3–5	60 kg	0.12 kg	—[2]	—[2]
Year 6–7	97 kg	0.193 kg	—[2]	—[2]
Year 8–9	123 kg	0.245 kg	—[2]	—[2]
Year 10–12	155 kg	0.31 kg	—[2]	—[2]

[1] Preplant P and K rates will depend on results of soil tests.
[2] P and K rates should be based on soil test results and leaf tissue analysis.

Table 5-4 provides a preliminary guideline for calculating fertilizer amounts for hazelnut orchards in Ontario for the three macronutrients: nitrogen (N), phosphorus (P) and potassium (K), for an orchard with soil analyses that were deficient in P and K. These guidelines are based on suggested rates from hazelnuts in Oregon, as well as other tree fruit in Ontario.

Secondary Nutrients

Magnesium is a plant nutrient that is naturally plentiful in many Ontario soils. Very few soils in Ontario have OMAFRA-accredited soil magnesium tests below 20 ppm, which is the level at which magnesium is considered deficient. If soil pH is below 6.0, the most effective and inexpensive means of supplying magnesium is by the application of dolomitic lime. If the pH is above 6.0, and soil tests indicate magnesium is deficient, magnesium can be supplied through either magnesium sulphate or sulphate of potash magnesia, which is a mixture of sulphate of potash and magnesium sulphate. Potassium competes with magnesium for uptake by crops, and excessive potash applications can therefore induce or increase magnesium deficiency. For this reason, it is important to monitor soil potassium levels and to carefully control potash fertilizer applications on low magnesium soils.

Calcium is a vital component of cell walls and is involved in the movement of sugars and starches within the plant. Calcium moves through the plant almost exclusively with the transpiration stream. In other Ontario fruit crops, calcium deficiencies rarely occur on soil with a pH of 6.0–7.5. Calcium availability decreases as the soil pH drops below 6.5.

Sulphur is an important component of chlorophyll. Deficiencies occasionally occur on coarse, sandy-loam, low pH soils. Improving soil organic matter will help increase soil sulfur levels. Many livestock manures also contain significant amounts of sulphur. Historically, sulphur was a component of many synthetic fertilizers, but modern production methods have removed much of the sulphur found in fertilizer.

Secondary nutrient applications should be based on soil test and leaf tissue analyses.

Micronutrients

Micronutrients include boron, copper, iron, manganese, molybdenum, zinc and chlorine. Plants use these elements in smaller amounts than the major nutrients, but they are still very crucial to a plant's overall nutrition. Micronutrients are usually found in much lower levels in the soil than macronutrients. Soil pH, organic matter, clay content and mineralogy can influence the micronutrients soil test. This makes estimating micronutrient availability less reliable than macronutrient evaluation. Crops vary in their response to micronutrients.

Boron: For hazelnuts in Oregon, boron applications are sometimes made in the spring to increase nut set, even when boron levels are not deficient. It is not known if supplemental boron would be beneficial in Ontario. Avoid overapplying boron, as boron toxicity can occur in hazelnuts.

Micronutrient Fertilizers: Do not mix micronutrient elements with insecticide or fungicide sprays unless the manufacturer's directions indicate that this is permitted and experience has shown they are compatible. Mixing these could result in phytotoxicity of the micronutrient to hazelnut leaves.

Apply micronutrients based on competent advice or where experience has proven their application to be necessary. Micronutrients should generally only be applied when a deficiency is identified (see **Hazelnut Nutrient Requirements**, below), and only in sufficient quantities to correct the problem. The range between deficiency and toxicity with micronutrients can be narrow.

Soil applications are desirable, because roots are better designed to take up nutrients. However foliar applications can be used for some nutrients. Soil applications are generally made at soil-preparation time, and foliar applications are made during the growing season. A sticker-spreader may be required with some micronutrient sprays.

Hazelnut Nutrient Requirements in Leaf Tissue

In Oregon and BC, leaf tissue analyses are important in making fertilizer decisions for the coming year, by indicating which nutrients are present in trees in adequate, deficient or excessive amounts. Hazelnut tissue samples are typically taken in August to help plan future nutrient applications. However, if the goal is to correct significant nutrient deficiencies appearing in-season (e.g., when indicated by visual symptoms), leaf samples should be taken earlier in the growing season.

For information on how to take leaf samples, refer to the section *Plant Analysis* in this Chapter. Information on the ideal range for macro- and micronutrients for leaf tissue analysis has been developed by the Oregon hazelnut industry and can provide references for Ontario growers.

Table 5-5 summarizes the critical values for nutrients in hazelnut leaves as developed by Oregon State University, found in their publication EM 9080 *Growing Hazelnuts in the Pacific Northwest — Orchard Nutrition.* This complete factsheet on fertilizing hazelnut orchards is available for free download from the Oregon State University Extension Catalogue at catalog.extension.oregonstate.edu/em9080.

Information from Oregon can serve as a general guideline only. Since Oregon has different soils, environmental conditions and management practices, nutrient research from this region may not be directly applicable to Ontario conditions.

Table 5-5. Critical values for nutrients in hazelnut leaf tissue (Oregon)

Nutrient	Deficiency	Below Normal	Normal	Above Normal	Excess
Nitrogen (% dry weight)	<1.80	1.81–2.20	2.21–2.50	2.51–3.00	>3.00
Phosphorus (% dry weight)	<0.10	0.11–0.13	0.14–0.45	0.46–0.55	>0.55
Potassium (% dry weight)	<0.50	0.51–0.80	0.81–2.00	2.01–3.00	>3.00
Sulfur (% dry weight)	<0.08	0.90–0.12	0.13–0.20	0.21–0.50	>0.50
Calcium (% dry weight)	<0.60	0.61–1.00	1.01–2.50	2.51–3.00	>3.00
Magnesium (% dry weight)	<0.18	0.19–0.24	0.25–0.50	0.51–1.00	>1.00
Manganese (ppm dry weight)	<20	21–25	26–650	651–1,000	>1,000
Iron (ppm dry weight)	<40	41–50	51–400	401–500	>500
Copper (ppm dry weight)	<2	3–4	5–15	16–100	>100
Boron (ppm dry weight)	<25	26–30	31–75	76–100	>100
Zinc (ppm dry weight)	<10	11–15	16–60	61–100	>100

Source: Oregon State University, *Growing Hazelnuts in the Pacific Northwest — Orchard Nutrition*

Foliar Fertilizers

The application of foliar nutrient sprays, either routinely as part of a crop nutrition program, or to correct a deficiency, must be done properly to be effective. Nutrient management programs should always begin with proper attention to the fertility of the soil because the roots are the main way plants take up nutrients. Leaves are not optimized for taking up nutrients and supplemental foliar fertilization is only effective under certain conditions. If initial soil nutrition is inadequate, or other factors interfere with the movement of nutrients through the xylem from the roots to aboveground tissues, then supplemental foliar sprays may be beneficial for some nutrients.

When using foliar fertilizers, it is important to understand that unlike roots, foliar nutrient uptake is not selective. It is a passive process and depends on (1) the leaf surface and (2) the nutrient concentration gradient between the leaf surface and the leaf interior. The leaf surface serves as a natural barrier to nutrients. Nutrients in foliar fertilizers are dissolved in water, but the leaf surface is covered in a waxy cuticle that repels water, restricting nutrient movement into the leaf. Successful penetration of nutrients into the leaf will depend on:

- the crop species
- the nutrient, nutrient form and its phloem mobility
- coverage

- absorption by the leaf, which depends on leaf structure and conditions
- environmental conditions
- demand of the plant and nutrient status in the soil

Relative humidity (RH) is particularly important because it affects the permeability of the leaf cuticle to mineral nutrients. It also affects the rate of evaporation of the spray solution. For optimal uptake of foliar nutrients into leaves or other aboveground tissue, relative humidity should be between 60%–80%. Another important consideration is the phloem mobility of the nutrient. Once nutrients have penetrated the leaf, the only way they can leave that leaf and be carried to other plant tissues is through the phloem. Some nutrients have limited mobility to move into the phloem, in particular calcium, manganese and boron (depending on the plant species). Foliar applications of these nutrients will only be beneficial to the plant tissues they are in contact with – they will not travel to other parts of the plant.

The quantity of nutrients that can be applied as a foliar fertilizer is also limited, because of the danger of injuring the leaves. Combine nutrients with care, in low concentrations to minimize fertilizer burn. Check pesticide labels before mixing foliar nutrients with any pesticide spray.

More information on foliar nutrient applications can be found by in the resources listed in Appendix B.

6. Insects, Diseases, Wildlife and Disorders

Pests are one of the biggest challenges to hazelnut cultivation worldwide, although the specific pests and degree of damage vary considerably between production regions. In Ontario, hazelnuts are susceptible to a number of insect, mite, vertebrate and disease pests, with eastern filbert blight posing the biggest threat to the industry. Management of hazelnut pests requires proper identification and knowledge of pest biology, as well as frequent monitoring of the crop throughout the season to identify issues before they cause economic damage. Figure 6-1 provides a general guide to the main pests of hazelnuts and when they are active throughout the season.

This chapter will focus on the biology and cultural management of current and potential pests of hazelnuts in Ontario. However commercial hazelnut production is expanding in the province, and, as acreage and experience with the crop in Ontario increases, our understanding of the pest complex may change.

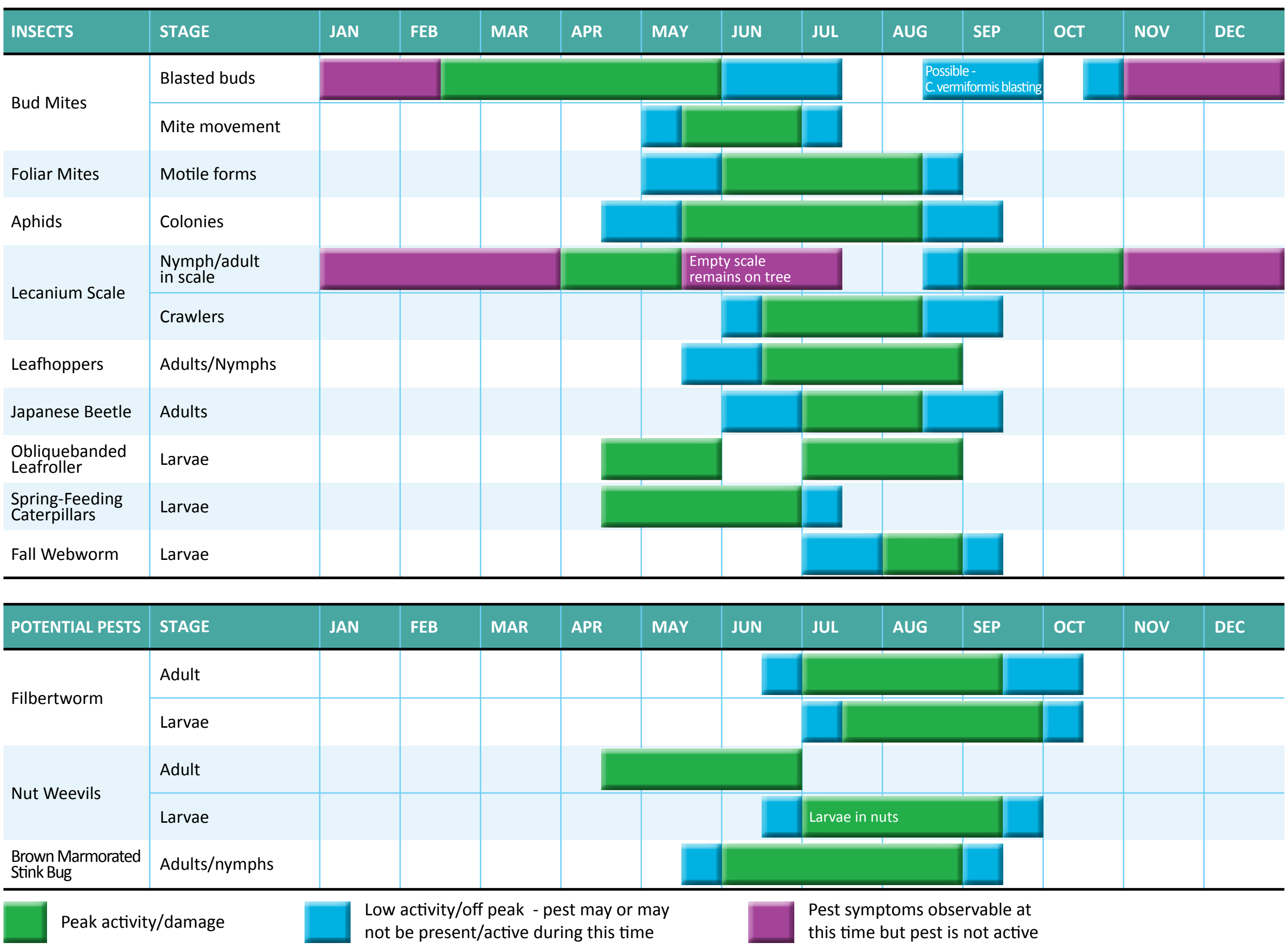

Figure 6-1. (A) Calendar of insect activity for hazelnuts in Ontario. Timings are guidelines based on observations of insect activity in Ontario hazelnut orchards, and knowledge from related crops in Ontario and Oregon. These may vary considerably from year to year, depending on winter and in-season temperature and precipitation, crop management and other factors.

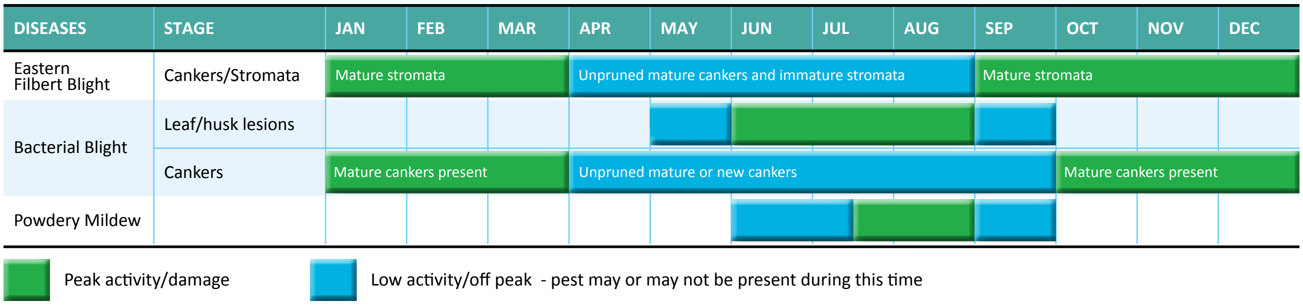

Figure 6-1. (B) Calendar of disease activity for hazelnuts in Ontario. Timings are guidelines based on observations of disease activity in Ontario hazelnut orchards, and knowledge from related crops in Ontario and Oregon. These may vary considerably from year to year, depending on winter and in-season temperature and precipitation, crop management and other factors.

Because pest control products change frequently, specific chemical controls are not mentioned in this publication. In order to legally use pest control products in this province, all products must be registered by Health Canada's Pest Management Regulatory Agency (PMRA) for use on hazelnuts in Ontario. Pest control projects registered on hazelnuts in other growing regions (e.g., Oregon) are not always registered in Canada, or their rates or other label parameters may differ. Any use that does not match the Canadian label is not permitted on Ontario hazelnuts, and is illegal here. It is the grower and applicator's responsibility to ensure that they are applying a pest control product according to the Canadian label. For information on pest control products registered on hazelnuts in Ontario, pesticide applicator certification and other integrated pest management strategies, refer to the resources listed in Appendix B.

Diseases

Eastern Filbert Blight

Eastern filbert blight (EFB) is the most devastating disease of hazelnut and a major factor limiting commercial production in Eastern North America. It is caused by the fungus *Anisogramma anomala*, which develops underneath the bark and can cause cankers, dieback and death of susceptible hazelnut trees. EFB is native to Eastern North America and causes only minor symptoms on native American hazelnuts, which are a wild host for the fungus. However, it is lethal to the European hazelnut species often used by confectionary companies and is the main reason early attempts at commercial production of hazelnuts in Eastern North America were not successful.

Eastern filbert blight does not occur in Europe and was not present in northwestern North America until the 1960s, when the fungus was accidentally introduced. By the 1980s, EFB was causing significant losses in hazelnut orchards in Washington and Oregon. This spurred considerable research in these regions, focusing on the development of resistant varieties and other control practices for the disease. Consequently, most of the information on EFB control comes from the Pacific Northwest, which has different environmental conditions than Ontario. Additionally, research suggests that there are more strains of the fungus present in Northeastern North America than on the west coast. The differences between the two growing regions mean that management practices developed in the Pacific Northwest may not always be applicable to Ontario growing conditions.

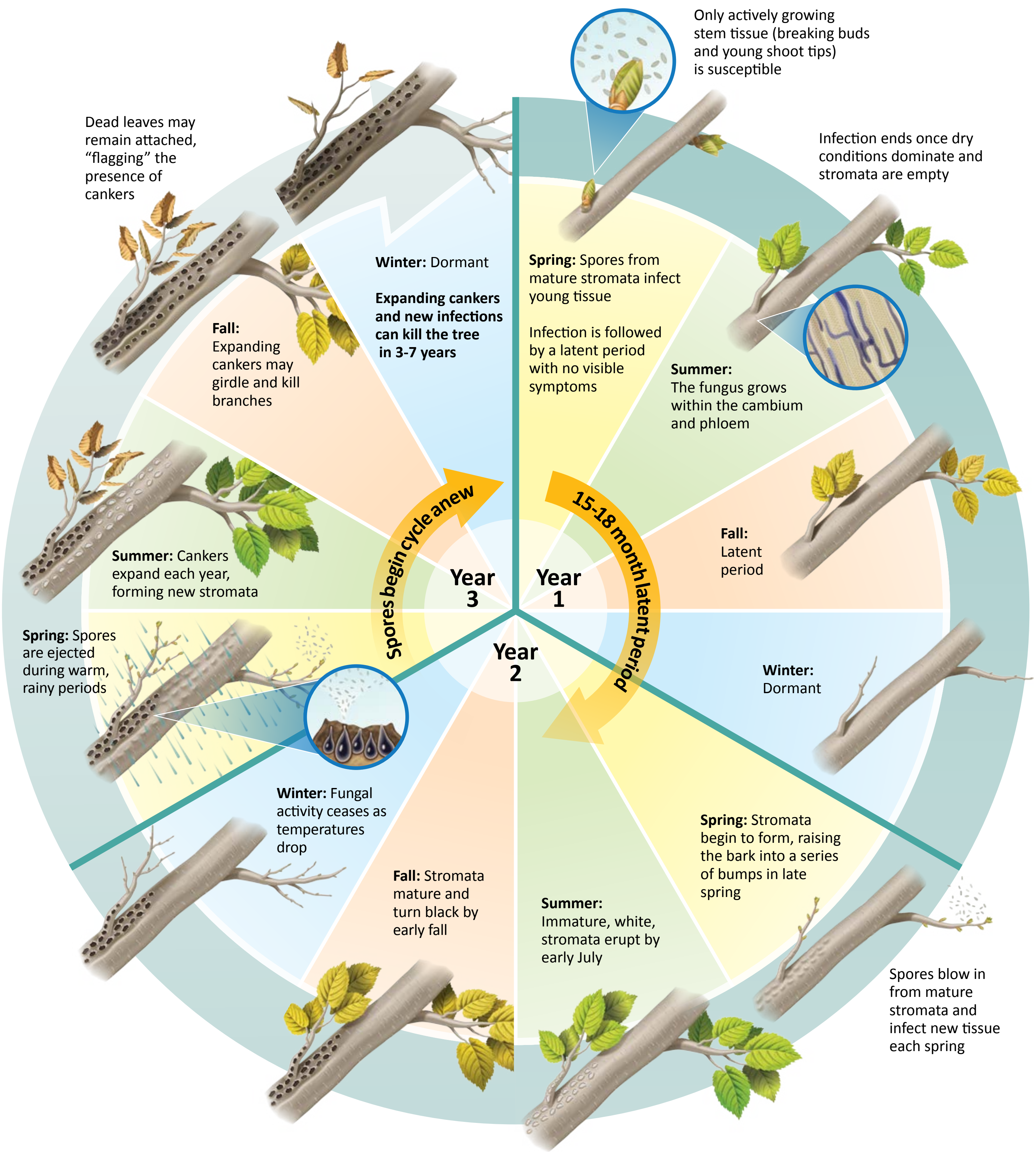

Figure 6-2. Life cycle of eastern filbert blight.

In Ontario, EFB has been observed at low levels in hazelnut orchards for more than 15 years, but disease incidence has increased as hazelnut acreage has increased. In a 2018 survey, eastern filbert blight was found in all commercial orchards visited, although disease severity varied considerably among orchards. Additionally, EFB cankers were observed in cultivars that had previously been reported to be resistant. Many of these cultivars were older ones developed in west coast breeding programs, where fewer strains of the fungus are present, so it is possible that these cultivars are more susceptible to EFB strains present in Ontario.

Biology and Life Cycle

A. anomala has a multi-year life cycle that begins in early spring, when spores are discharged from reproductive structures during wet weather, usually after several hours of continuous rain (Figure 6-2). Spores are spread by wind and rain. EFB spores germinate and invade trees through the epidermis of young, actively growing buds. Spores do not infect trees through wounds, natural openings, nuts or mature stems.

After infection of young shoots by the EFB fungus, there is a prolonged latent period during which the fungus colonizes the xylem, cambium and phloem, growing within the tree without any external symptoms (Figure 6-2). During this time, the fungus can be unknowingly spread to new orchards through propagation of infected trees. The latent period generally lasts from 12–18 months, although it can persist for as long as 2 years and ends with the production of cankers in the bark.

Spore-producing structures, called stromata, develop within cankers during the second summer after infection (Figure 6-2). Cankers on trunks, large scaffold limbs or certain resistant cultivars may not produce these stromata. The stromata contain thousands of tiny spores, called ascospores, which mature by the fall. Stromata can release spores over the fall and winter, however hazelnut trees are only susceptible to infection once vegetative buds break dormancy in the spring.

Vegetative shoots remain susceptible to infection until the apical buds stop growing, however risk of infection decreases as conditions become dry (since spores are only released during prolonged wet weather) and as stromata are emptied of viable spores. In Oregon, this is thought to occur by late spring. It is not known if this is the same under Ontario's environmental conditions.

The cankers formed by the fungus enlarge and expand around branches and twigs over time, producing new stromata each year. Eventually, branches can become girdled and die, however, the dead leaves often remain attached to the tree. This is referred to as flagging. As more branches die, plant vigour and productivity decline, and susceptible varieties die within 5–15 years, although they may continue to produce suckers for several years after the death of the main tree.

Identification and Damage

Cankers are sunken with raised edges, and range in size from a few centimetres to almost 1 m long, with the cambium tissue underneath the bark a medium brown colour. Initially, cankers often appear on young branches in the upper canopy, however they can occur on any above-ground part of the tree. Tree cells within these cankers are dead and do not continue to grow. In late June or early July, the first signs of stromata (spore-bearing structures) are raised bumps under the bark (Figure 6-3). The stromata enlarge until they erupt through the bark sometime during the summer as straight rows of raised, oval, round or oblong structures that are initially white but become black as they mature (Figure 6-4).

Eastern filbert blight cankers can occur in hazelnut cultivars that are tolerant of the disease, however they often look different than they do in susceptible cultivars. They may present as cracks or flat/sunken areas and have smaller or no stromata, and over time may become calloused or healed over (Figure 6-5). Symptoms of EFB can be difficult to detect in its early stages, and the disease is often only detected in orchards 4–5 years after the fungus initially invaded it.

Figure 6-3. The first symptoms of eastern filbert blight include rows of raised bumps appearing on branches in late spring or early summer.

Figure 6-4. Rows of mature black stromata running along the length of branches.

Figure 6-5. Cankers may still form on tolerant cultivars, but these may look more like cracks or flat sunken areas indicating where the infection has healed over. Source: C. Bakker, University of Guelph.

Monitoring

Mark diseased branches, twigs or other tree parts with flagging tape whenever they are observed during regular orchard activities, and scout specifically for EFB at least 2–3 times/year. In June and July, look for flagging branches (dead branches with the leaves still attached) (Figure 6-6A). Inspect flagging branches below the point where symptoms first appear for presence of cankers (Figure 6-6B). During the summer, stromata may appear as raised bumps prior to eruption or may be white immediately after, rather than their typical black colour. The best time to look for cankers is in late fall or winter, after leaves have fallen.

Figure 6-6. (A) Dead leaves often remain attached to branches killed by eastern filbert blight. (B) These leaves can "flag" the presence of the disease in mid-to-late summer, helping detect cankers during scouting.

Management

A multi-faceted approach is needed to manage this disease effectively, including resistant/tolerant cultivars, clean planting material, regular scouting, removal of infected material and preventive fungicides. This should begin prior to planting with the selection of resistant or tolerant cultivars.

It is important to remember that resistance characteristics occur along a spectrum, which does not always mean that the tree will never be infected. This is often referred to as disease tolerance instead of resistance. In Oregon, some cultivars (e.g., 'Lewis', 'Clark') have resistance but can be infected if they are repeatedly exposed to the fungus, while others (e.g., 'Yamhill', 'Jefferson') get cankers, but they are smaller, there are fewer of them, they may not have spores and they may eventually heal. Furthermore, varieties that are resistant to fungal strains present in the Pacific Northwest may be more susceptible to some of the additional strains present in the Northeast. For example, 'Hall's Giant' is reported to have intermediate resistance in Oregon but may be killed by the fungus in Ontario. 'Jefferson' and 'Yamhill' also have more spore-producing cankers in Ontario than in Oregon, although they still appear more disease-tolerant than highly susceptible varieties.

In Ontario, trials conducted by the University of Guelph from 2008 through 2016 identified some cultivars that did not show symptoms of EFB (e.g., 'Geneva', 'Chelsea', 'Norfolk', 'Alex'). As of 2020, these cultivars are more suitable for the fresh market than for sale to confectioners. Newer cultivars are being developed in breeding programs in Oregon and New Jersey that show greater tolerance to multiple strains of the EFB fungus, however these still must be tested under Ontario conditions. In the meantime, selection of less susceptible varieties in combination with use of other management strategies can help keep the disease under control.

In addition to variety selection, use clean planting material wherever possible. A clean plant certification program does not currently exist for hazelnuts in Ontario. Purchase from reliable propagators who have rigorous disease management protocols in place. Plants started with micropropagation are more likely to be free of pathogens, including *A. anomala*, although these can be re-introduced in the nursery. Even with a high degree of confidence in planting material, it is important to conduct detailed scouting for EFB and other pests for the first few years after planting, to detect any trees that were infected but may have been asymptomatic when they were delivered.

Scout orchards 2–3 times a year to look for cankers. Ideally, prune out infected branches immediately. If this is not possible, be sure to remove them prior to budbreak in the spring. The fungus grows ahead of the area in which it produces spores, so it is important to remove infected plant material at least 60–90 cm below the edge of the canker, or even further if practical, as recent Ontario research suggests that the fungus can sometimes spread more than 150 cm from the canker's edge. Removal of the entire tree may be required if trees are severely infected, or if pruning cankers involves cutting into the main trunk. Ensure cutting tools are sanitized between trees to avoid spread of disease (EFB and others) to healthy tissue. Fungal structures in pruned branches can continue to produce spores after removal, so burn or bury all pruned material. Symptomless infections will still be present in the orchard after pruning and will have to be removed the following season.

Refer to the resources listed in Appendix B for products registered for control of eastern filbert blight on hazelnuts. These fungicides are effective only when used preventively, protecting susceptible tissue from being infected by spores. They have no effect once the fungus has invaded the tree. Fungicides should be applied to young trees beginning at bud break and continue as long as spore release continues due to wet weather. In Oregon, this typically consists of four applications to susceptible hazelnut cultivars, applied at 14-day intervals and ending in May. However, in Ontario, heavy rains often continue into late spring, and with limited local research it is not yet known if trees require a longer period of protection. When prolonged wet weather progresses through late June, consider additional applications at that time.

The EFB fungus can develop resistance to fungicides with repeated use of the same product, so it is important to alternate between products with different modes of action. EFB-tolerant cultivars may require fewer or even no sprays, or in some cases they may require protective fungicides for only the first few years after planting.

Bacterial Blight

Bacterial blight, the second most important disease of hazelnut, is caused by the bacterium *Xanthomonas arboricola pv. corylina* (also called *Xanthomonas campestris pv. corylina*). It occurs on buds, leaves, husks, branches and trunks, and is common in most hazelnut-growing regions worldwide. Losses due to this disease are most frequently seen in young, establishing trees less than 6 years of age or in very stressed trees.

Biology and Life Cycle

The bacteria overwinters in cankers or infected buds, which can then ooze during the growing season under humid or wet conditions. The ooze contains bacterial spores, which are spread naturally throughout the growing season by rain, but can also be spread mechanically through infected nursery stock or contaminated tools. The bacteria then invade trees through natural openings, like stromata, or wounds on buds, leaves, branches or trunks. Buds may be completely killed or partially damaged. On leaves and stems, infections cause water-soaked lesions. The most serious symptoms occur when cankers develop in the bark, as these can completely girdle branches and trunks, which can kill the tree. Death tends to occur mainly in young trees (<6 years old), especially when they are stressed due to other factors such as moisture imbalances or infection by other pests.

Wet and warm weather (>20°C) favours infection. Bacterial blight may be more severe in years that follow heavy fall rains, where the bacteria is more readily transmitted, and after a winter where freezing injury has occurred, which both weakens the tree and creates wounds that the bacteria can enter. Some research suggests that an increased risk of bacterial blight can be associated with freeze events that have a greater difference between the high and low temperature.

Identification and Damage

On leaves, bacterial infections cause small, angular, reddish-brown spots that may be surrounded by a yellow-green halo (Figure 6-7A). Leaf lesions initially appear in late spring and become very common by mid-to-late summer. Lesions may eventually coalesce at the tip or sides of the leaf, causing blighting (Figure 6-7B).

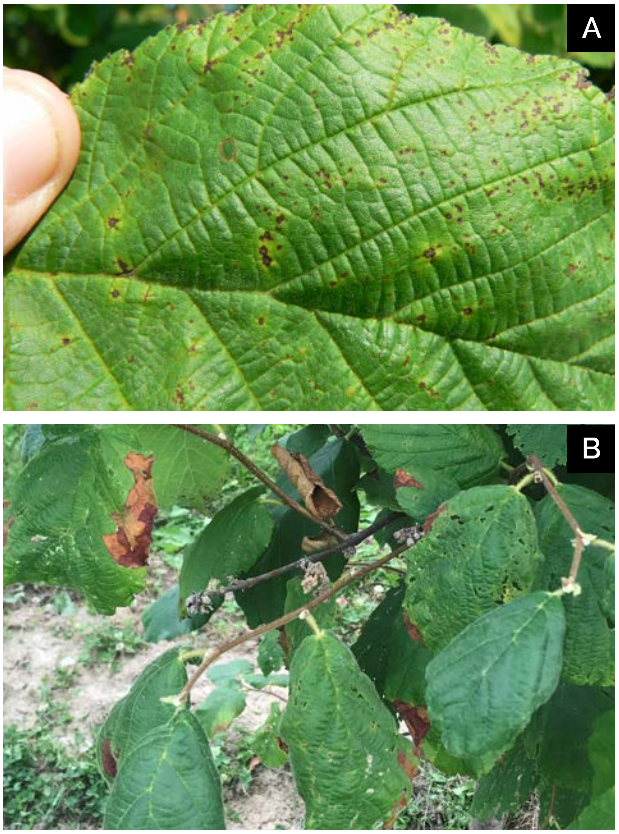

Figure 6-7. Bacterial blight lesions on hazelnut leaf initially begin as (A) water-soaked necrotic spots. (B) These can merge, resulting in large areas of browning.

Lesions on developing nut husks look like dark brown or black spots (Figure 6-8). Husk infections typically do not spread to the nuts in Ontario, although this has been observed in some other growing regions. Water-soaked lesions may also appear on current-season stems. Infected buds may turn brown and fail to leaf out.

Figure 6-8. Bacterial blight on husk.

Cankers on branches and other woody parts are more difficult to detect but may appear slightly sunken or cracked, and reddish-purple with darkened underlying tissue (Figure 6-9A and B). These cankers may ooze a sticky liquid under moist or humid conditions (Figure 6-9C). Leaves on dead twigs turn brown and cling to the branches, known as flagging, which is also a symptom of eastern filbert blight (Figure 6-10).

Figure 6-9. Bacterial blight cankers on (A) twig and (B) trunk. (C) Tissues underneath the lesion are generally discoloured.

Additionally, in Ontario bacterial blight cankers often have other pathogens present, such as *Botryosphaeria*, *Phomopsis*, or *Fusarium*. It is difficult to distinguish a canker with additional pathogens from one with just bacterial blight without laboratory confirmation. These pathogens are thought to be secondary, infecting the tree after it has been weakened by bacterial blight. However, some of these species are known pathogens to various tree species, and the dual infection may increase the decline of the tree.

Figure 6-10. Leaves on twigs and branches killed by bacterial blight often stay attached, flagging the presence of disease in a similar fashion to eastern filbert blight.

Monitoring

Scout young orchards regularly. Leaf lesions are fairly easy to identify and become more numerous from late spring through early summer. Lesions on husks may appear once nut clusters begin to develop. Examine these trees more closely to determine if cankers are present. Bacterial blight cankers on trunks and branches can be very difficult to detect or distinguish from winter injury and other abiotic damage to the tree. The bark may be sunken or reddish-purple, or may just appear cracked. Removing the bark will reveal discoloured, brownish tissue that may ooze. Flagging, or dead branches with leaves attached, indicates the presence of bacterial or eastern filbert blight. Follow these branches to the base (below where symptoms first appear) and look for signs of cankers. EFB cankers can be distinguished from bacterial blight by the presence of black stromata. It is possible to have both EFB and bacterial blight cankers on the same tree.

Management

Remove and destroy (burn or bury) infected cankers on branches and twigs, cutting 60–90 cm below symptomatic tissue. The bacteria can be spread on pruning equipment, so these tools should be sanitized before pruning the next tree. Some products are registered for protecting tissue from invasion by bacterial blight during high-risk periods with wet weather. See the resources listed in Appendix B, for products and rates. These can be applied to young orchards in the fall (late August to early September) before heavy rains begin, and again after 75% leaf drop if conditions are particularly wet.

Other strategies to manage this disease include planting only nursery stock known to be free of the pathogen, reducing stress from moisture and heat, and optimizing nutrients. To reduce moisture stress, do not let roots of nursery stock dry out, and irrigate trees for at least the first three growing seasons, even when it is not exceptionally dry. Mulch around the base of young trees can help retain moisture. Ensure other pests are managed properly to reduce additional stress on the tree. Vigorous growth can be an entry point for the bacteria, so avoid over-application of nitrogen. Closely watch plants with freeze injury from the previous winter and use white paint or other means to reduce sunscald during the summer, as these can serve as a point of entry for bacterial blight spores.

Powdery Mildew

Hazelnut powdery mildew, caused by the fungus *Phyllactinia guttata*, is characterized by a white powdery growth on the lower surface of hazelnut leaves (Figure 6-11). The fungus overwinters on fallen leaves and other tree debris under various hardwood trees, including hazelnuts, and spores are spread through the orchard by wind currents. Occasionally, black fruiting bodies may be produced within the white fungal growth in older infections. Unlike related species of powdery mildew that can cause season-long defoliation in other fruit crops starting in the spring, hazelnut powdery mildew does not typically appear until August. By the end of August, up to 40%–60% of hazelnuts in an orchard may have some leaves with powdery mildew, however symptoms are not typically severe and do not usually spread to the nut. Economic damage has not been observed in Ontario hazelnuts. Look for a fuzzy white growth on the leaves, initially in circular patches (Figure 6-11A) that may coalesce to completely cover the underside of the leaf (Figure 6-11B). Control is not generally required.

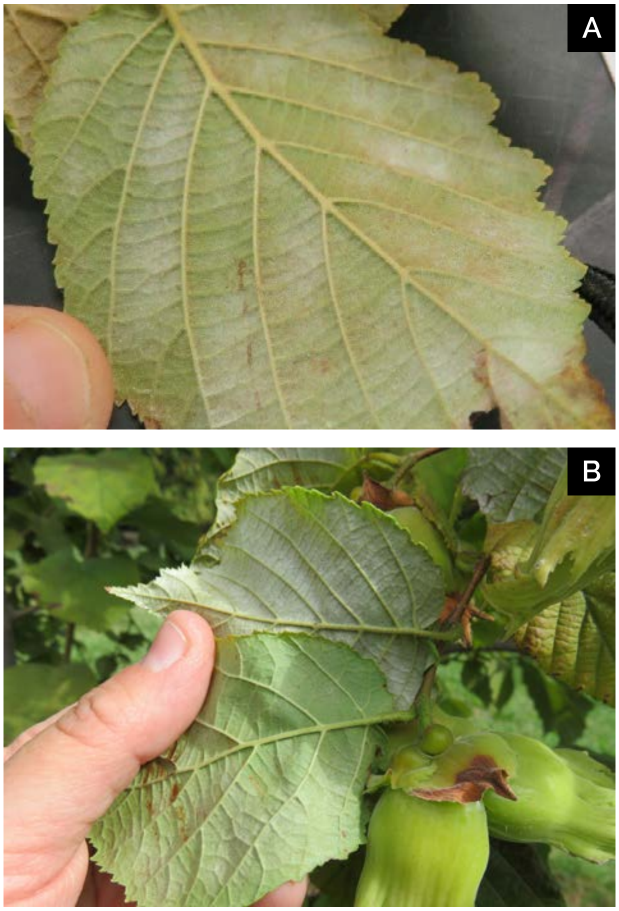

Figure 6-11. (A) Powdery mildew on hazelnut leaves presents initially as white fuzzy patches predominantly found on the leaf underside. (B) These can coalesce to completely cover the leaf in a white powdery growth — compare the upper leaf in the photo to the healthy leaf below it.

Root Conditions (Root Rots and Wet Feet)

As with many other crops, hazelnuts are susceptible to a number of root issues. These may be root rots caused by soilborne pathogens or simply “wet feet,” which occurs when trees are grown in saturated soil. With wet feet, roots growing in saturated soil are deprived of oxygen and they will consequently grow slowly and be stunted relative to trees grown in better-drained areas (Figure 6-12). These trees will have reduced yield and are more susceptible to both primary and secondary pathogens. This phenomenon is observed in trees growing in low areas of the orchard, especially in orchards where hazelnuts are planted in heavier soil. These trees may survive for years, but with stunted growth, reduced yields and twig and branch death, until they ultimately die.

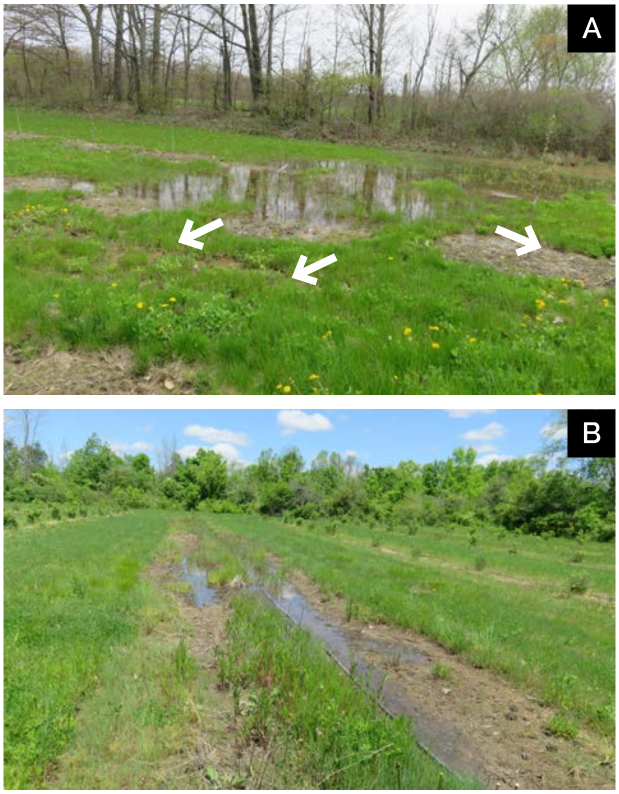

Figure 6-12. (A) Heavily stunted hazelnut trees due to poor soil drainage. (B) Young trees planted in the low area in the centre are much smaller than trees in the left and right rows, which have better drainage.

In addition to poor physiological survival in wet soils, hazelnuts can occasionally be infected with soilborne pathogens. *Phytophthora* species are common soilborne pathogens that infect the roots of many plant species. *Phytophthora* spp. are oomycetes, or fungus-like organisms, that are not always controlled by the same management methods as fungal pathogens.

Phytophthora root rot is favoured by wet conditions and tends to cause more problems on trees growing in heavy, wet soils, in areas that tend to retain water or when extended wet weather results in prolonged periods with wet soil. Waterlogged soils lead to the production of infective spores by *Phytophthora* species that are naturally present in the soil, which can swim through water-filled soil pores to enter roots or crowns of susceptible plant species.

In Oregon, phytophthora root rot has been found in hazelnut roots, however it is generally considered rare. In British Columbia, phytophthora root rot was detected in several young hazelnut orchards planted with newer, EFB-resistant cultivars. Phytophthora root rot has not yet been detected in Ontario hazelnuts, however *Phytophthora* species are very common in Ontario soils and do affect other tree fruit such as apples.

Phytophthora root rot symptoms will depend on the level of infection and whether the pathogen has affected the crown or roots. Symptoms include poorly developed foliage, yellowed leaves, leaf dieback and reduced plant vigour. Leaves may drop prematurely. These symptoms are similar to that of nutrient deficiencies and result from reduced ability of the roots to take up nutrients. Affected trees may suddenly die during hot weather because of an inability to take up water to replace losses through transpiration. Crowns may be discoloured, as well as the cambium of the tree, but discolouration from root rots will extend down towards the roots rather than up to the branches. When infection is severe, bark may become brown-black, water-soaked and ooze a dark fluid in the spring (Figure 6-13A). Infected root systems may also be darkened, with black feeder roots (Figure 6-13B). Affected trees may be weak and yield poorly for several years, before succumbing to the disease. Young trees will die more readily and rapidly because of their smaller crown and root systems.

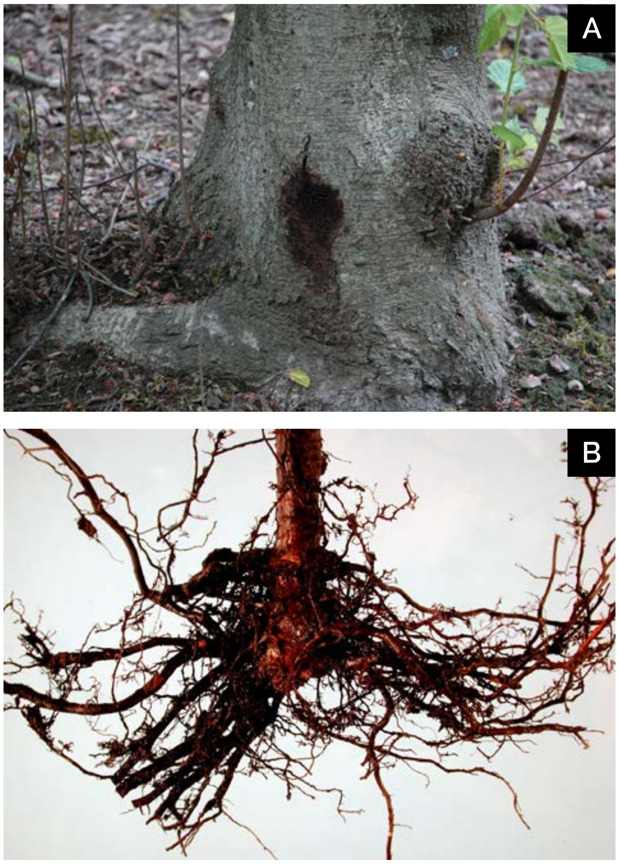

Figure 6-13. Phytophthora root rot can damage the cambium from the bottom up, leading to (A) dark, wet spots in the bark, where brown liquid oozes from the wound. Source: Dr. Jay Pscheidt, Oregon State University, (B) Affected root systems may be darkened with black feeder roots, Source: Oregon State University Plant Clinic.

This disease is very difficult to deal with once it has entered the tree, so the best management tactic is prevention. Soil fumigation is not an effective strategy for *Phytophthora* species, because these pathogens are easily reintroduced to the orchard. Locate new orchards in sites with good drainage and light soils wherever possible.
If soil is heavy, retains water for prolonged periods or is in low areas of the orchard, install sub-surface drainage tiles. Manage irrigation to avoid overwatering (see the section *Irrigation* in Chapter 4. *Orchard Management*). Avoid reusing pots for propagation because dormant spores can survive in contaminated pots. Carefully inspect roots and crowns of young trees to ensure they are healthy before planting them in the orchard.

In the Pacific Northwest, the fungus *Armillaria mellea* can cause root rots in hazelnut trees planted on newly cleared land. This fungus is a native forest pest with a wide host range and can infect hazelnuts if roots come into contact with partially decayed roots of previous trees that are infected. Armillaria root rot has not been detected in Ontario hazelnut and is not a commonly reported pathogen in other tree fruit crops in the province. However, this fungus is present in Ontario forests where it can be quite destructive. Reported symptoms of this disease in hazelnut include poor shoot growth and early leaf drop, often starting on only one side of the tree. White fungal growth appears on main roots and root crowns when the bark is removed (Figure 6-14). There may also be dark, branching, shoe-string-like fungal structures (fans). To avoid this disease, when clearing a forested site for an orchard, take precautions to remove and destroy all vegetation, stumps and roots larger than 2.5 cm and leave the site fallow for at least a year.

Figure 6-14. Armillaria root rot can produce white mycelial fans on the roots or crowns, which are observable when the bark is removed. Source: Steve Renquest, Oregon State University.

Canker Fungi (*Phomopsis* spp., *Botryosphaeria* spp.)

In young hazelnut orchards in British Columbia, surveys done in 2017 showed signs of phomopsis canker (*Phomopsis* spp.) and phytophthora root rot (see previous section) in sick or dying EFB-resistant trees. Symptoms of *Phomopsis* included brown to dark brown cankers or lesions (Figure 6-15) sometimes with light brown margins on stems, and reproductive structures called pycnidia that look like dark spots on trunks. Occasionally, decay of tree tissue under cankers resulted in sunken lesions with cracked margins. Enlargement of cankers caused dieback and defoliation of infected branches and a reduction in tree vigour.

In Oregon, pathologists have also recently noted cankers and other symptoms from previously unrecognized fungi, including species of *Phomopsis* and *Botryosphaeria*, on new, EFB-resistant hazelnut cultivars. Symptoms were variable, including branch dieback, reduced growth, slow bud break, leaf stunting and cankers, as well as reduced nut production.

Researchers do not yet know whether these pathogens will become a significant problem for hazelnuts. Possible reasons for the emergence of these pathogens include climate change–induced impacts on pest complexes, a reduction in fungicide use associated with shifts to EFB-resistant varieties, or increased, intensive production of hazelnuts on suboptimal sites, increasing stress and wounding on trees and making them more susceptible to invasion by these pathogens.

Figure 6-15. *Phomopsis* stem canker on Jefferson hazelnut. Source: Oregon State University Plant Clinic.

In Ontario, species of *Phomopsis* and *Botryosphaeria* have both been isolated from cankers on hazelnut, including young trees exhibiting symptoms of early dying, but these mainly occur in conjunction with bacterial blight lesions (Figure 6-16). It has been assumed that these were secondary invaders of tissue already weakened by bacteria, however, a thorough survey of cankers for pathogens has not been done in Ontario orchards.

Although early death has been observed in young Ontario hazelnut orchards between 2018 and 2020, these fungi do not appear to be the primary cause, as they are not consistently reported from infected orchards. When these fungi are detected, they are typically associated with bacterial blight. In this case, early death is more likely to be due to abiotic causes or insufficient management practices that may also make young trees more susceptible to these pathogens.

As EFB-tolerant varieties are found and fungicide requirements are reduced, other canker fungi may appear in Ontario orchards. Growers should be on the lookout for symptoms of dieback, reduced vigour and unusual cankers, and consider submitting those for laboratory diagnosis.

Figure 6-16. Hazelnut lesions co-infected with *Botryosphaeria* and bacterial blight.

Decay Fungi, Moss and Lichens

Decay fungi enter trees through wounds from pruning, winter injury, lightning or damage from cultivation equipment. They may also be secondary invaders colonizing trees already damaged by other pests. Spores of these fungi are carried by wind and enter trees through exposed sapwood, using the wood as a food source to develop and produce spore-bearing structures such as mushrooms or conks. In established hazelnut-growing regions such as Oregon, wood decay is often observed on older trees and takes two forms: a white rot that causes a moist, soft, lighter-coloured wood whose strength is only reduced after significant colonization, or a brown rot, which is brown, dry, crumbly and cracked, and rapidly weakens the rotted wood. This can predispose trees to limb loss, uprooted or broken trees during storms or reduced tree vigour.

In Ontario hazelnut orchards, which are still relatively young, decay fungi are observed mainly in trees already significantly weakened by EFB, bacterial disease or abiotic stress (e.g., when growth tubes are left on for too long). Two species are often observed. One is the fungus *Encoelia furfuracea* (Figure 6-17A), also known as the spring hazelcup, which is a colonizer of newly dying or dead hazelnut and is often found in association with bacterial blight lesions. Spore-bearing structures emerge through the bark as clusters of cups with a rough surface that are initially brown but can become white with age and have a vaguely brain-like appearance.

Nectria fungi invade trees that are stressed by other causes and initially produce a nondescript canker that looks like a slightly sunken, discoloured area of bark. The fruiting structures of this fungus are much more noticeable, with red-to-orange rows of rounded fungal growth (Figure 6-17B). In hazelnuts, it is found in association with EFB, bacterial blight or in grow tubes. *Nectria* can become a weak pathogen if the plant is weakened or stressed. Tree limbs with these fungi are weakened and should be pruned out. To avoid wood decay, ensure trees are healthy and vigorous, minimize injuries from pruning or cultivation and keep irrigation water from wetting tree trunks.

Lichens are mould-like structures growing on the surface of bark that are a drab white, grey, green or yellow (Figure 6-18), but become more colourful when wet. They are actually two organisms living as one – a fungi and an algae. Mosses are a type of non-vascular plant that produces spores instead of seeds to reproduce. Mosses and lichens have not been extensively observed on Ontario hazelnuts but are reported in other growing regions with more mature trees. These organisms can make their own food and are therefore not harmful to the tree. They do absorb moisture, however, and with extensive growth they can increase limb weight, making them more prone to breakage during winter. They do not typically become a significant problem in orchards that are regularly pruned and sprayed with copper products for control of bacterial blight.

Figure 6-17. (A) The fungi *Encoelia furfuracea* and (B) *Nectria* have been found colonizing dying hazelnut tissue.

Figure 6-18. Lichen/moss growing on tree trunk.

Insects

Bud Mites

Mites are very small relatives of spiders and ticks that feed on the leaves, flower buds and other parts of a wide variety of plants, including hazelnut. While a number of mite species may feed on hazelnut, bud mites are the most common and do the most damage. Bud mites are actually two different species from the gall mite family (Eriophyidae) — *Phytoptus avellanae* (the filbert bud mite), which is the more harmful, and *Cecidophyopsis vermiformis* (which does not have a common name), that may be found in the same bud. Bud mites are the most important arthropod pest of hazelnuts in Ontario, and damage has been increasing in Ontario.

Biology and Life Cycle

P. avellanae has been confirmed as being present in Ontario, while *C. vermiformis* has not yet been formally identified here, however both mites are thought to occur wherever hazelnuts are grown. The life cycle of these species has not been well studied in Ontario, but is likely to be similar to what has been observed in other regions.

Bud mites spend the winter inside dormant buds, with blasting (bud swellling) beginning in mid-winter (Figure 6-19). In the spring, healthy buds form shoots with tiny, new axillary buds, and mites of both species exit swollen (blasted) buds to migrate close to the axillary buds, invading the interior of the buds once they become larger. The timing of this migration depends on temperature, with emergence from old buds thought to occur when daytime temperatures are around 15°C.

From May to September, immature stages of *P. avellenae* feed and reproduce within the buds, but the buds remain small. Older, empty blasted buds dry out and fall off the tree by late spring. During the summer, other growing regions report that buds infested with *C. vermiformis* adults begin to enlarge from June to July and are fully blasted in August. This has not yet been confirmed to occur in Ontario. From August through early fall, *C. vermiformis* (if present in the orchard) will exit those blasted buds and migrate to new buds, often infesting the outer portion of buds already infested with *P. avellenae*. However, *C. vermiformis* is not as damaging, and the main period of mite migration relevant to management of this pest is the migration of *P. avellenae* in the spring. In the fall, *P. avellenae* adults appear and increase in number, and buds begin to enlarge, becoming fully blasted by late winter or early spring.

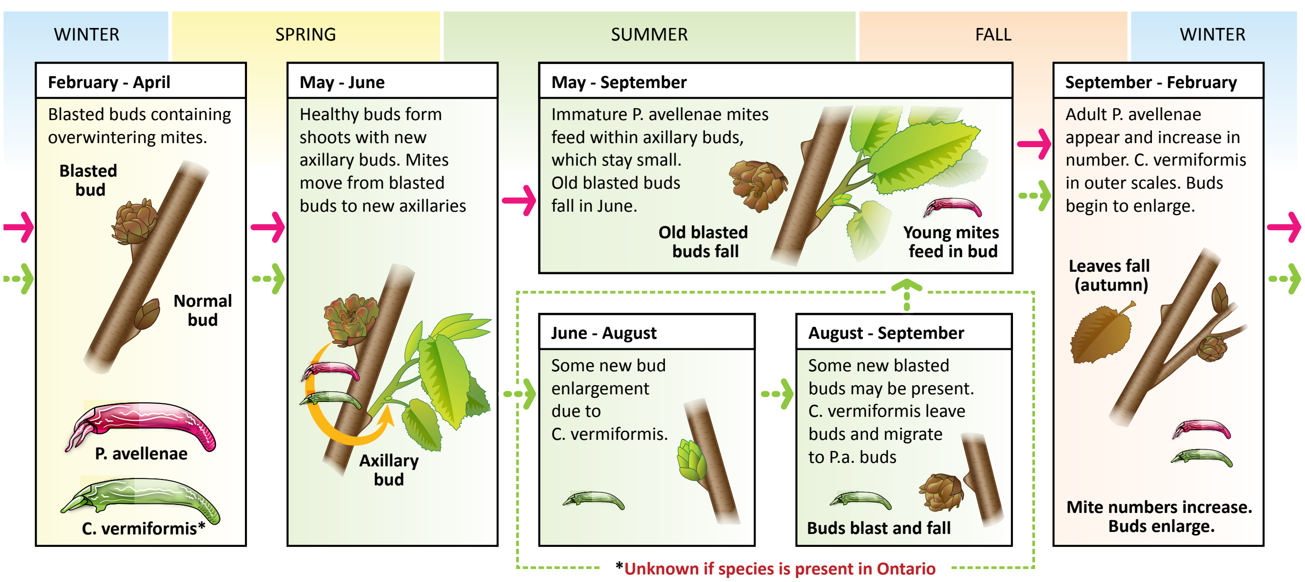

Figure 6-19. Life cycle of bud mites on hazelnuts (adapted from Oregon and New Zealand information for Ontario conditions).

P. avellanae may have a second form that also feeds on vegetative buds, leaves and male catkins, but most bud mites spend the majority of their life cycle protected within the buds, complicating control efforts (Figure 6-19). Mite damage to hazelnut varies from year to year, ranging from mild injury to complete crop loss.

Identification and Damage

Bud mites are microscopic, cigar-shaped and have a translucent-white colour and very small appendages (antennae and mouthparts) at the front of their body (Figure 6-20). The two mite species are not easily distinguished from one another and are differentiated mainly by the timing of bud blasting. *C. vermiformis* has not yet been confirmed as being present in Ontario hazelnuts.

With a length of 0.18–0.255 mm, they are difficult to detect with the naked eye and are most easily recognized by their damage. Bud mite feeding on buds causes them to become swollen, fleshy, deformed (Figure 6-21A) and often a pinkish-brownish colour (Figure 6-21B). These enlarged buds, often called blasted buds or big buds, can be checked for mites by splitting them open — they generally have at least some tissue that appears swollen or decayed and examination with a hand lens often reveals large numbers of rice-like mites that may move from side to side. Damaged buds may fail to leaf out, become dry and hard and eventually fall from the tree. They can also cause weak, unhealthy shoots (for vegetative buds); brittle catkins with limited pollen (in the case of a male bud) or no nuts (in the case of a fertilized flower).

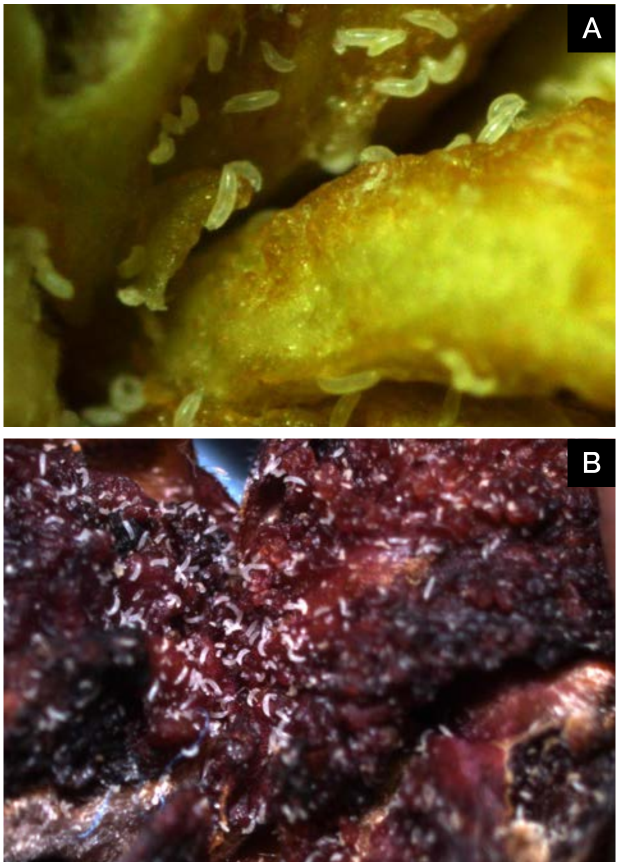

Figure 6-20. (A) Mites within a hazelnut bud are difficult to see with the naked eye. Note the softened, decayed interior bud tissue. (B) Close-up of bud mites. Bud mites are cigar-shaped with microscopic appendages located at the front of their body.

Figure 6-21. Hazelnut buds infested with bud mites. (A) Infested buds are typically much larger (lower left) than a normal sized bud (upper right) and (B) may contain softer, more decayed tissue.

Monitoring

Blasted buds are most easily observed in late winter or early spring, and this is the ideal time to assess overall levels of infestation in an orchard. Confirm the presence of adults by opening enlarged buds and checking for mites with a hand lens. Mite emergence from infested buds in the spring can be monitored by placing double-sided tape or other sticky substance and wrapping it tightly around twigs on both sides of blasted buds beginning in early spring. This will trap mites as they emerge from the buds, and they can be monitored using a 20x or higher hand lens, at least weekly, or more frequently at peak movement. According to research in Oregon, movement occurs with daily maximum temperatures above 15°C, or average temperatures above 9°C, particularly during long-term warming trends.

There are no established thresholds for bud mites in Ontario. In Eastern Europe, a threshold of 15% or more buds showing signs of blasting is used after visually inspecting all buds on four branches per tree on 10% of plants/ha. In Oregon, treatments are found to be most effective when about 50% of mites have exited blasted buds. These thresholds will likely vary with variety and environmental conditions, and should be used only as a general guide as growers gain experience with these pests.

Management

There are no products currently registered for the control of bud mites on hazelnut in Ontario. Should products become available in the future, sprays will only be effective if applied in the spring, when mites are migrating from damaged buds to newly forming buds. Once inside the buds, the mites are protected from the chemicals.

Hazelnut susceptibility to bud mite varies with cultivar, with those having small, tighter buds resisting penetration by mites. Most of the cultivars originating out of Oregon's breeding programs have been bred to resist bud mites. However, some of the Ontario varieties selected for filbert blight and cold tolerance seem susceptible to bud mites, including the cultivars 'Linda', 'Marion' and 'Norfolk'. For susceptible varieties, manually removing and destroying infested, enlarged buds during the winter can reduce populations but may not be practical for very large orchards or trees. Predatory mites and other natural enemies will feed on bud mites, either in the buds or as mites emerge from buds. Practices that preserve populations of beneficial insects, such as minimizing the use of miticides and insecticides, can promote biological control by these beneficial organisms.

Foliar Mites

A wide variety of mite species, both plant-feeding and beneficial, are commonly found on the leaves of hazelnut in most growing regions, although none are as economically damaging as bud mites. Mite feeding on leaves can cause leaf discolouration and drop. In Ontario hazelnuts, populations can build to sufficiently high levels to cause noticeable damage, however this is uncommon. To date, feeding damage by foliar mites has not caused economic losses in Ontario hazelnut orchards, however in other growing regions, late-season outbreaks of spider mites have been reported to cause significant damage. The large numbers of predatory mites present on hazelnut leaves in Ontario may be keeping foliar mite populations low.

Foliar mite species diversity appears to be greater in hazelnuts than in many other fruit crops grown in Ontario. The most common foliar mite pest found on hazelnuts in Ontario is the hazelnut mite, *Tetranycopsis horridus*. This species is also reported from Europe, China, Australia and Oregon. Other pest mite species found on hazelnut include the European red mite, *Panonychus ulmi*, and the rust mite *Aculus comatus*.

Less common species include *Coptophylla lamimani* and *Eotetranychus* spp. The two-spotted spider mite, *Tetranychus urticae*, a common pest of other fruit crops, is observed on Ontario hazelnuts but is less common than *T. horridus*. Many beneficial species are also active on hazelnut leaves, including the predatory mite *Typhlodromus pyri*, which is a common natural enemy in apples and tender fruit orchards in Ontario. Other predatory mites found in Ontario hazelnuts include the phytoseid mites *Kampimodromus corylosus*, *Paraseiulus triporus*, *Phytoseius delicatus* and *Phytoseius macropilus*.

Biology and Life Cycle

The hazelnut mite, *T. horridus*, is a member of the spider mite family (Tetranychidae) that also contains two-spotted spider mite and European red mite, common pests of many crops in Ontario. Hazelnut mites overwinter as eggs in tree crevices, then hatch in early spring. Populations of this species consist mainly of females that can reproduce asexually. Colonies of mites develop on both the upper and lower surfaces of hazelnut leaves. There are up to five generations per year. Spider mites can spread between plants by walking short distances or on wind currents. They can be spread longer distances by movement of infested plant material, equipment or on worker clothing. *T. horridus* feeds mainly on hazelnut but has also been reported on walnut, spruce, pine, yarrow, oak, alder and beans. It has been reported to be more damaging to certain hazelnut varieties, although this has not been studied in varieties grown in Ontario. Research suggests that hazelnut mite can develop at temperatures as low as 6°C, however development and reproduction are maximized at high temperatures (around 25°C), with peak spider mite populations often observed in hazelnuts late in the growing season.

Two-spotted spider mites can also be found on hazelnuts. This species overwinters as adults under bark or on weeds. Mite populations often initially build up on weeds and other vegetation beneath or adjacent to trees and then migrate into the tree canopy in mid-summer when this vegetation dries up. There are 3–5 generations per year.

European red mites overwinter as eggs in roughened bark around the base of buds, twigs and in inner parts of the tree close to the main trunk and branches. Eggs hatch in the spring and immature mites move to developing foliage and feed near the veins and midrib of developing foliage. They develop to adulthood and lay the first generation of summer eggs. Adults feed on both the upper and lower surfaces of the leaf. There are 6–8 generations per year. Hot, dry conditions are conducive to severe mite infestations, while cool or very hot (>30°C) temperatures and heavy rain can impede population development.

There is limited information on the biology of other mite species present on hazelnut.

Identification and Damage

Hazelnut mites are difficult to see with the naked eye. Adults are brownish-black, less than 0.5 mm in length and appear spiky due to the presence of numerous distinctive fine hairs protruding from the body (Figure 6-22). Hazelnut mites are initially found on leaf undersides but may move to upper surfaces as populations increase. Hazelnut mite colonies do not produce as much webbing as the related two-spotted spider mite. Hazelnut mite eggs are red and very small.

Figure 6-22. Hazelnut mite, *Tetranycopsis horridus*.

Two-spotted spider mite adults and nymphs are pale green or straw-coloured with two dark spots on the back, except for newly hatched mites, which are colourless. Adults are 0.5–1 mm long (Figure 6-23). This species produces dense webbing on leaf surfaces. Overwintering females are reddish orange, while eggs are clear and spherical, becoming milky white.

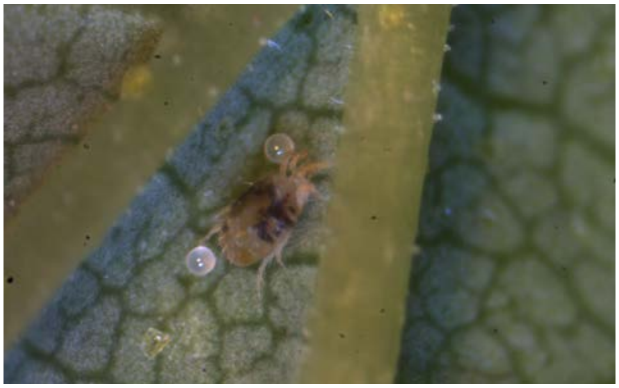

Figure 6-23. Two-spotted spider mite.

Adult European red mites are 0.3–0.4 mm long. Females are deep brown-red, with rows of spots along the back with raised spines (Figure 6-24). Males are lighter in colour with a pointed abdomen and longer legs. Eggs are red, slightly flattened and have a hair-like stalk protruding from the top. This species is similar in appearance to the hazelnut mite, however hazelnut mites are slightly rounder and hairier, and are generally present in greater numbers on hazelnut leaves.

Figure 6-24. European red mite.

Rust mites in the genus *Aculus* are sometimes observed on hazelnut (Figure 6-25). These tiny mites belong to the same family (Eriophyidae) as bud mites. Adults have only two pairs of legs (other species have eight) and are extremely small (0.07 mm), making them easy to miss. They are cream to light brown to orangish in colour and have a carrot or wedge-shaped appearance.

Figure 6-25. Rust mites on hazelnut.

Beneficial mites are variable in appearance. They may be distinguished from pest species because they are often (but not always) larger than their prey and are generally faster moving, often found moving rapidly among colonies of their prey. When you gently blow or touch them, predatory mites are more likely to rapidly move away.

Mites have piercing mouthparts to puncture plant cells and feed on the fluids, leading to a white to yellow stippling on the upper leaf surface. As feeding increases, leaves can appear bronze and burnt and may die (Figure 6-26). Severe defoliation can deplete energy from the tree, potentially reducing nut yield and quality or increasing susceptibility to other pests, however significant defoliation due to foliar mites is rare in Ontario. Injury from rust mites is very rare on hazelnuts but can cause yellowed, distorted foliage, leaf browning and edge curling.

Figure 6-26. Foliar mites on hazelnuts are usually kept in check by natural enemies, but when a rare population outbreak occurs, feeding damage can lead to bronzing on the upper surface of hazelnut leaves.

Monitoring

Check upper and lower surfaces of leaves for presence of mites as part of weekly scouting activities beginning in mid-to-late spring. Many mites are difficult to see with the naked eye and require a hand lens or dissecting microscope with a magnification of 25X–40X. There are no established monitoring protocols for foliar mites on hazelnuts, however record numbers of pests and beneficial mites when examining leaf clusters and husks for other pests such as caterpillars and aphids. This should be done weekly, especially during hot summer months when numbers can increase rapidly. Make sure to examine trees throughout the orchard block to get an average assessment of population levels, as mite populations may be locally higher in patches near sheltered areas and dusty roadways. There are no thresholds for foliar mites on hazelnuts.

Management

Hazelnut trees can tolerate considerable populations of foliar mites as long as predatory mite populations are high and defoliation is not significant. Control is rarely required in Ontario. Natural enemies, including predatory mites, are thought to be important in keeping populations in check. Use a selective pesticide program when controlling mites or other insect pests to preserve mite predators. Using well-managed cover crops to limit dusty conditions that favour build-up of certain pest mites and avoiding excess levels of nitrogen in the leaves (which increases mite fecundity) can also be helpful. Heavy rain can physically remove and kill many mites and can remove dust that collects on foliage and interferes with mite predators.

Aphids

Aphids are small, soft-bodied, sucking insects that drain fluids and nutrients from plant tissue. They are commonly observed in colonies on the underside of hazelnut leaves. The two main species of concern in North American hazelnuts are the filbert aphid, *Myzocallis coryli*, and the hazelnut aphid, *Corylobium avellanae*. Filbert aphid is most commonly observed in Ontario, however, other species may also be present in smaller numbers.

Biology and Life Cycle

The filbert aphid overwinters as an egg in crevices on bark and around bud scales. Eggs hatch in early spring over a period of several weeks, and the young aphids feed on the underside of expanding leaves, initially often near the leaf veins. Aphids feed by inserting their piercing-sucking mouthparts into leaves and husks, removing plant fluids and excreting large quantities of a sugary residue called honeydew, which can promote the growth of mould.

Young aphids mature rapidly, going through several moults, and within a few weeks become wingless adults that can immediately produce large numbers of offspring without mating or laying eggs. Adults and young aphids live together in colonies on the undersides of leaves, with several generations per growing season. Aphid populations can increase quickly under the right environmental conditions, but typically decline in late summer due to high heat and increased activity by natural enemies. Aphid populations tend to increase more quickly when feeding on succulent new growth, with numbers of young decreasing when they feed on older leaves. In late summer and fall, winged aphids are produced. These adults mate and lay overwintering eggs.

Identification and Damage

Aphids are small, soft-bodied, pear-shaped insects with straw-like mouthparts (Figure 6-27A). They are typically found in colonies on the underside of leaves (Figure 6-27B). They may be winged or wingless. All aphids have two characteristic “tail-pipes,” called cornicles, near the end of their body. Filbert aphid, the most common species on Ontario hazelnuts, is small and has shorter cornicles than many other aphid species, which can be difficult to see with the naked eye. It is pale green to yellow and its antenna and legs are the same colour as the rest of the body.

Hazelnut aphid was introduced to the West Coast in the early 2000s and has not been formally reported in Ontario. It is larger and darker green, making it difficult to distinguish from the leaf. The cornicles are longer, and the antenna and legs are darker than the body. Hazelnut aphid is mainly found on husks while filbert aphid is found on both leaves and husk.

Aphid feeding drains fluid and nutrients from leaves, distorting and wilting plants. They also produce a sticky substance, called honeydew, which can promote development of a black sooty mould. With very high populations, honeydew can be visible on the leaves and may drip off the side. This can also occur with high populations of scale. Large populations can decrease yield.

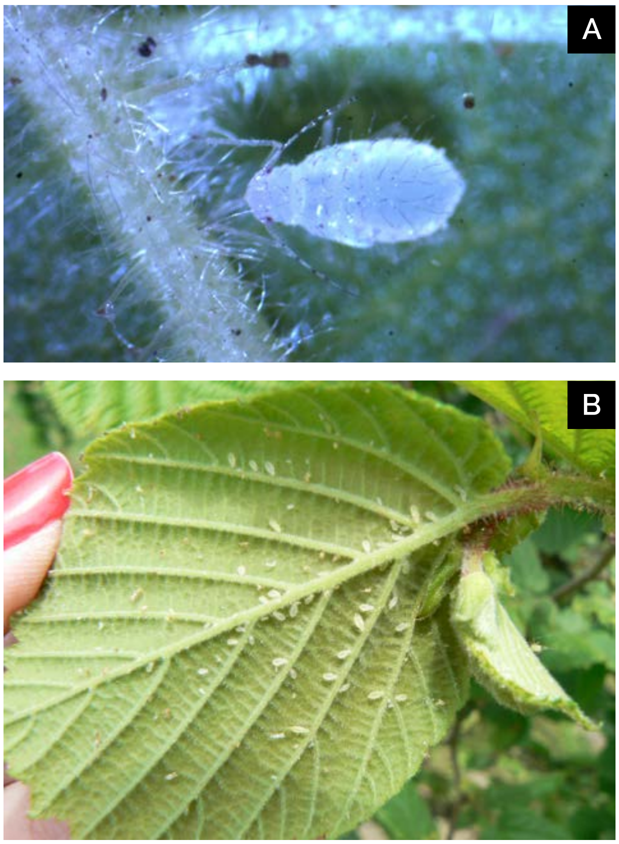

Figure 6-27. (A) Filbert aphid close-up. (B) Filbert aphid colony on underside of hazelnut leaf.

Monitoring

Monitor for aphids beginning in mid-spring as temperatures warm, particularly on the undersides of young, tender leaves. Check leaves and developing nut clusters on several terminals per tree and include all species of aphid in the total count. As aphids molt, they leave cast skins, which may still be visible on leaves — do not include these in counts. No threshold has been established for aphids on Ontario hazelnut, however thresholds established in Oregon can serve as a starting point. In Oregon, intervention is suggested with an average of 20 aphids/leaf in April, 30 aphids/leaf in May, 40 aphids/leaf in June and 40 aphids/leaf with increasing populations as of July.

It is very important to record presence and numbers of predators and natural enemies when assessing aphid populations in orchards, as these can be very important in keeping aphids in check naturally. Ladybeetle adults and larvae, hoverfly larvae, lacewing larvae and minute pirate bugs are all common in Ontario hazelnuts. Parasitic wasps are also common. Adults are difficult to see, so in general, signs of parasitism are noted. Parasitized aphids, or mummies, are swollen, round, tan to bronze-coloured and have a thin, papery skin that may have a circular exit hole. If large numbers of natural enemies are present, resample orchards again in a week to see if aphid numbers are decreasing naturally.

Management

Small-to-medium populations of aphids can often be controlled by beneficial predators and parasitoids before they can damage the crop; insecticide applications are often not needed. Predators, parasitism and various aphid diseases are very common in Ontario hazelnut orchards. Aphid predators and pathogens can be harmed by many fungicides and insecticides. Use as little pesticide as possible so that populations of these beneficial organisms can develop in hazelnut orchards. Some chemicals are registered for control of aphid populations. Select products with minimal impacts on natural enemies. Harsher insecticides can lead to secondary outbreaks of other pests that are normally kept in check by natural enemies. Do not use more nitrogen than needed, as nitrogen stimulates young growth that is attractive to aphids. Numerous natural enemies prey on aphids and can significantly reduce populations.

Lecanium Scale

Scales are tiny, sucking insects that are immobile for most of their lives. They often lack wings or legs and are typically covered by a hard or waxy coating that makes it difficult to distinguish them from the leaves, twigs, branches or trunks on which they live. Like aphids, scales remove fluids and nutrients from plant tissue and excrete large quantities of honeydew. Severe infestations can cause twig dieback and weaken trees, however scale only occasionally reaches high populations in some hazelnut orchards.

Numerous species damage tree fruit crops, but the most common scale found on Ontario hazelnuts is the European fruit lecanium scale (*Parthenolecanium corni*). The San Jose scale, *Quadraspidotus perniciosus*, has been observed on hazelnut and other tree nuts but rarely causes damage. For biology and identification of San Jose scale, see Ontario Apple IPM at ontario.ca/cropIPM.

Biology and Life Cycle

Lecanium scale feeds on a number of species of fruit and landscape trees. They overwinter as second instar nymphs on twigs or branches underneath their waxy protective shell. They resume feeding in the spring, maturing to adulthood by late spring. Males are winged and leave the covering to seek out females to mate. Females are immobile, remaining under the protective covering to lay eggs, then die soon after. The eggs typically hatch in late June, producing immature nymphs, often referred to as crawlers because they have legs and are mobile. These crawlers leave the protective shell to migrate to the underside of leaf veins to feed, where they will remain until late summer or early fall, when they move back to twigs or new shoots, settle, secreting a waxy protective cover to overwinter. As the scale molts underneath these covers, the legs and antenna of the crawler become smaller, until the older insect is completely immobile.

Identification and Damage

Mature females are the most conspicuous life stage, producing a reddish brown to brown, hardened, convex bump-like covering on twigs and branches that is about 3–5 mm in diameter (Figure 6-28). After egg-laying in the spring, scales are filled with masses of hundreds of white to pinkish, oval eggs. After crawlers emerge, empty scales may remain on the plant for some time. Crawlers, the mobile stage, are oval and flat, pinkish-brown, with well-developed legs and antennae (Figure 6-29). They are typically found on the undersides of leaves, often along leaf veins.

Figure 6-28. Adult Lecanium scales on a hazelnut twig. Note the hard, convex, reddish-brown waxy covering that makes them difficult to recognize as insects. Source: D.K.B. Cheung.

Figure 6-29. Close up of immature crawler stage on hazelnut leaf. Crawlers are flat and somewhat transparent, and can be difficult to distinguish.

Because the insect is generally immobile and blends well with the host plant, it is often the signs of feeding that are observed. Affected leaves may turn yellow and drop, and twigs or branches can die with severe infestations. This can lead to reduced tree growth and fruit size, and weakening of trees, making them more susceptible to disease. As scales feed, they excrete large quantities of sticky, sugary fluids, called honeydew, which can promote the growth of a black, fungus (sooty mould) that can also stunt tree growth. Honeydew production is greatest in late spring when nymphs feed heavily on young wood.

Monitoring

Where there is a history of damage from scale, monitor throughout the growing season. In early spring, look for overwintering nymphs under the protective scale on the previous year's growth. These scales can be turned over to check for female development and egg hatch. By early summer, check leaf undersides for presence of crawlers (Figure 6-29). It may be possible to detect movement of crawlers in late spring or early summer by placing sticky substances such as Tanglefoot or electrical tape in bands on trees. Honeydew (sticky fluids) on leaves, and leaf and twig dieback would also be a sign to check the tree for presence of scale. There are no established thresholds for scale on hazelnut in Ontario, but scale populations rarely build to high enough levels on hazelnut to cause significant damage.

Management

Scales rarely warrant control on hazelnut, because naturally occurring predators and parasites keep populations in check. Predators often wait near shells to feed on crawlers as they emerge. Minimize the use of broad-spectrum insecticides in orchards to help preserve populations of these beneficial natural enemies. However, if pesticide sprays or other factors disrupt this natural biological control, some scale control products are registered for Ontario hazelnut. See the resources listed in Appendix B for products and rates. Timing is very important to the efficacy of scale insecticides, as chemicals will not readily penetrate the protective waxy covering of the immobile stage. Time sprays for late spring, when most eggs have hatched and crawlers are starting to emerge and settle on the leaves.

Leafhoppers

Leafhoppers are small, wedge-shaped insects that rapidly run, hop or fly away when they are disturbed. The most common species of leafhopper found on hazelnut in Ontario is the potato leafhopper (*Empoasca fabae)*. While they can be problematic in new orchards, they generally do not reach damaging levels in Ontario hazelnuts.

Biology and Life Cycle

Potato leafhoppers do not overwinter in Ontario but are blown in on wind currents from the southern U.S. from mid-May through mid-June. This insect is common in alfalfa and often moves into other crops after hay is cut. In most fruit crops, adults are often first seen after the first hay cut in early to mid-June. Adults mate and lay eggs on leaves and stems, hatching approximately 10 days later. Leafhopper nymphs develop to adulthood in approximately 25 days.

There are multiple generations per year, with activity continuing until the insect is killed by a hard frost. Like aphids, both adults and nymphs are sucking insects that feed on plant juices within leaves. As they feed, a toxin is injected that blocks the flow of fluids within the plant, causing a characteristic pattern of damage. Under hot, dry weather, leafhopper populations can build very rapidly.

Identification and Damage

Potato leafhopper adults are about 3 mm long, light green and wedge-shaped, with a broad head and body tapering to the tips of the wings, which fold tent-like across the back (Figure 6-30A). They often have six small, pale dots directly behind their head. The nymphs are similar to the adults but are smaller, yellowish-green and lack wings (Figure 6-30B). As the nymphs mature, they develop wingpads. Both adults and nymphs move rapidly away when disturbed, the adults by hopping or flying and the nymphs by running in a distinct sideways fashion. Leaf damage typically begins as yellowing and browning at the leaf margin, a phenomenon known as "hopperburn," and leaves often curl under. Leafhopper feeding can also cause stippling or bleaching of leaves.

Monitoring

Check for leafhoppers weekly, beginning in early June. Look for symptoms such as curled leaves or yellowing/browning at the leaf edge. Nymphs and adults will be found mostly on the leaf underside (Figure 6-30), but they will rapidly move off the leaf during scouting, so turn leaves over carefully when checking for their presence. There are no established thresholds for potato leafhopper in Ontario hazelnuts.

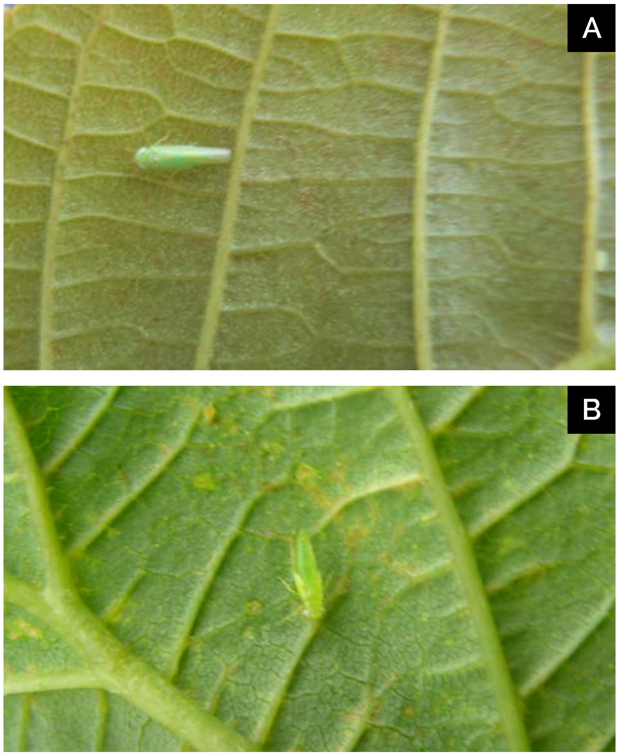

Figure 6-30. Leafhopper (A) adults and (B) nymphs.

Management

There are no insecticides currently registered for control of leafhoppers on hazelnut in Ontario. On hazelnut, leafhoppers are generally problematic only on newly planted trees, and control is not often required. In some crops, a naturally occurring fungal pathogen can reduce leafhopper populations under cool, moist conditions. Predators and parasitoids are thought to provide only limited control of this insect. If possible, avoid planting hay fields near hazelnut orchards, as leafhoppers commonly move to alternate crops when hay fields are cut.

Japanese Beetle

The Japanese beetle (*Popillia japonica)* is native to Asia and was first found in Canada in 1939. It is currently found only in Eastern North America. The Japanese beetle has an extremely wide host range, and adult beetles have done significant damage to foliage in Ontario hazelnut orchards in recent years.

Hazelnut growers who sell and ship hazelnut trees should be aware that Japanese beetles are a quarantine pest regulated by the Canadian Food Inspection Agency (CFIA). This means that the movement of the insect and infested plants or soil is regulated to prevent further spread into uninfested areas. For more information, see the CFIA Directive D-96-15, *Phytosanitary Requirements to Prevent the Spread of Japanese Beetle, Popilla Japonica, in Canada and the United States* (inspection.gc.ca).

Biology and Life Cycle

Japanese beetles spend the winter as larvae, or grubs, deep in the soil. As temperatures warm in the spring, grubs move closer to the soil surface where they feed briefly on the roots of turf or other plants and then pupate in late spring. Adults begin to emerge from the soil in late June, with peak emergence in early July. Adults remain active for 6–8 weeks, during which they spend extended periods aggregating, feeding and mating repeatedly. This species is known for its aggregation behaviour, which makes them fairly easy to spot on plants and trees. They are most active on warm, sunny days and are capable of flying long distances of 1.6 km or more. Beetles usually feed and mate during the morning and return to the soil in the late afternoon.

Females lay eggs in the soil of grassy areas from July to August. Eggs hatch in about 2 weeks, and larvae feed on fine plant roots in the upper soil until temperatures cool in September, after which they move deep into the soil to overwinter. Egg hatch and larval survival are reduced when there is inadequate soil moisture, and during cold winters with inadequate snow cover.

Japanese beetles have a host range in excess of 300 plant species. Preferred plants for adult feeding include grape, early apples, cherry, peach, plum, raspberry, woody ornamentals, rose, zinnia, linden and corn. Adults are attracted to hazelnuts, but damage is sporadic across Ontario, with feeding damage most commonly reported from known Japanese beetle "hot spots," such as where hazelnut is located close to vineyards or grassy areas. Feeding damage is most severe on young hazelnuts.

Identification and Damage

The adults of this species are easily identified. They are approximately 10–12 mm long with a metallic green head, bronze wing covers and white tufts on the tip of the abdomen (Figure 6-31). The larvae are 2 cm long, C-shaped grubs. They are milky white with a brown head and three pairs of legs. Larvae are found in the soil in early spring and again in late summer, however they may not overwinter in hazelnut orchards but may be present in surrounding grassy areas or turf.

Adult beetles feed on the upper surface of young, succulent foliage. They chew tissue between veins and leave skeletonized foliage with a lace-like appearance (Figure 6-32). They often begin feeding at the top of the canopy and progress downwards. On young trees with severe infestations, it is possible to almost completely defoliate trees. Damage may be less significant on mature trees, especially in years with fewer insects.

Figure 6-31. Japanese beetles infesting hazelnuts.

Figure 6-32. Severe Japanese beetle defoliation of young hazelnut tree.

Monitoring

Begin scouting for adults in mid-to-late June. It has been noted that after emergence adults will feed on shorter plants such as weeds first, then move to taller plants. Beetles often begin feeding at the top of plants, so make sure to look for signs of beetles or feeding damage in the upper canopy, especially at the start of the feeding period. Monitoring traps for Japanese beetle are commercially available and are highly efficient at attracting beetles, however they are not necessary because Japanese beetles are easy to distinguish during routine scouting due to their conspicuous daytime feeding habits. There are no established thresholds for Japanese beetles on hazelnut.

Management

Mature, healthy hazelnut trees can tolerate some defoliation without a significant impact on yield or tree growth, however very young trees or those stressed by damage from other pests may be more vulnerable. There are currently no insecticides registered for control of adult Japanese beetles. With young trees and small orchards, it is possible to hand-pick adult beetles into buckets of soapy water. It is suggested that this occur early in the morning, prior to feeding damage, as it has been noted that damage to foliage releases chemicals that may attract more beetles.

If possible, do not locate new orchards near vineyards, turf, grassy areas or other desirable host plants. Clean cultivation or beneficial nematodes may help reduce populations of grubs overwintering within orchards, however, will not stop new adults from invading the orchard from other areas. Since many Japanese beetles are thought to fly into hazelnut orchards from the surrounding area and the grubs themselves do not damage trees, control of the grub stage is not thought to be a cost-effective way of controlling this insect.

Commercial monitoring traps are highly effective at attracting adults, and there has been some research looking at using these as a management tool. However, these traps actually attract many more beetles to the area than are caught by the trap and it is not uncommon to see beetles overflowing from traps in heavily infested areas, resulting in higher levels of localized damage. As a result, susceptible plants may suffer more damage than if the traps were not used. Due to the prolonged period of activity and multiple sources of adults from other areas of the landscape, re-infestation may occur following any management intervention.

Obliquebanded Leafroller

The obliquebanded leafroller (OBLR), *Choristoneura roseceana*, is native to North America and a common pest of apples and other fruit crops in Ontario. OBLR is part of the spring-feeding caterpillar complex but has a second generation that feeds on leaves and fruit later in the summer. In Oregon, OBLR can be a significant pest of hazelnut, however significant nut damage by this insect has not yet been reported in Ontario hazelnuts (Figure 6-33).

Biology and Life Cycle

OBLR overwinters as larvae under bark or in limb crotches that become active once temperatures rise above 10°C in early spring. Larvae move to buds and new leaves, where they web and roll up developing leaves, feeding mainly on foliage until they pupate in early June. Moths emerge from late June through July to mate and lay eggs in the upper portions of trees. Summer generation larvae hatch in 2 weeks and disperse to new trees on wind currents using silken threads. Larvae feed on leaves in and around terminals but may also feed on developing nut clusters. Larvae pupate and adults emerge from early August through early September, mate and lay eggs. Larvae from this generation overwinter.

Identification and Damage

Adult moths are light tan to dark brown with darker bands on the forewings (Figure 6-33A). Female wingspans are 24–30 mm and are generally darker than males. Male wingspans are 16–22 mm. Larvae are light green to yellowish green to dark green, with a dark brown or black head and a similar coloured segment just behind the head (prothoracic shield) (Figure 6-33B). The edge between the head and prothoracic shield is often white or cream. Eggs are light green to greenish yellow, turning black prior to hatching, and are laid in patches of several hundred eggs that look like small, overlapping scales.

Larvae feed on leaves on or near their rolled shelters (Figure 6-34). Feeding damage may appear as windowpane-type feeding holes or general chewing on leaf margins. Leaves can be unrolled to reveal webbing, excrement and the caterpillars themselves. Summer generation larvae can feed on the shell underneath the husk, causing scarring and staining of young nuts, which may cause premature nut drop, however this is not common in Ontario.

Figure 6-33. OBLR (A) adult and (B) larvae.

Figure 6-34. OBLR most commonly feed on hazelnut leaves in mid to late spring. Damage to developing nuts has not been widely observed in Ontario.

Monitoring

Check for damage by leafrollers and other caterpillars weekly, beginning in early spring. Check three leaf clusters per terminal on three terminals per tree on 10–20 trees across the orchard for presence of larvae or feeding damage. Each terminal is considered a sampling unit. Pheromone traps are commercially available to monitor adult flight. Place 1 trap/2 ha of orchard, approximately 1.8 m high, and check nut clusters for signs of larval feeding. There are no established thresholds for this insect in Ontario, but an action threshold of 20%–25% infestation for larvae and trap catches of 40 moths per week with larvae feeding on the nuts is used for hazelnuts in Oregon. This may need to be modified for Ontario.

Management

Pheromone trapping in Ontario hazelnut orchards over several years suggests that OBLR rarely reaches threshold levels and nut feeding is not extensive. It is likely that natural enemies are keeping larval populations below damaging levels after the spring generation, suggesting that insecticides may not be required every season. Conserve these natural enemies by applying pesticides only when necessary and selecting narrow-spectrum products. A list of products registered on OBLR on hazelnuts in Ontario, and their relative impacts on beneficial insects, can be found in the resources mentioned in Appendix B.

Spring-Feeding Caterpillars

The spring-feeding caterpillar complex consists of several species of moths (family Lepidoptera) that feed on fruit trees early in the season, typically from budbreak through the end of June. This includes fruitworms, tent caterpillars, gypsy moths, leafrollers, cankerworms and budmoths. They generally feed on foliage and cause varying degrees of damage. Obliquebanded leafroller is part of this complex but is treated separately because it can also damage nuts. Of the remaining species, the gypsy moth (*Lymantria dispar*) has caused the most significant damage to Ontario hazelnuts to date, with severe defoliation observed in young trees during population outbreaks of this species.

Biology and Life Cycle

Life cycles of the different species vary, but most species overwinter as larvae or eggs, hatching and/or becoming active very early in the spring, when green tissue first appears. The larvae feed on leaves and buds. Leaf-rolling caterpillars will roll leaves up as they expand, using silken webbing, where they hide during the day. Other species, such as tent caterpillars, form silken tents or mats on trees, which they use as shelters. Most spring-feeding caterpillars pupate in late spring and emerge later as non-feeding adults to mate and lay eggs. There is generally only one generation per year, so once larvae have pupated, defoliation ceases.

The gypsy moth, the most damaging of the spring-feeding complex so far, is known as a forest pest but has a very wide host range. It overwinters as egg masses on tree trunks and the undersides of branches that hatch between late April and mid-May. Young larvae may remain on the tree to feed but also spin short lengths of silk, which allows them to be blown to new hosts on the wind. Larvae pass through five to six larval instars before they pupate in early-to-mid-summer. First-to-third instar larvae feed from dawn to mid-morning, then seek shelter during the day under bark or ground cover. Later instars are more likely to feed at night from sunset to sunrise. Larvae feed voraciously and can completely defoliate young trees, but adults do not feed, so defoliation ceases once pupation occurs in July. Gypsy moths have "boom and bust" population cycles, where seasons with severe damage are followed by seasons with very few caterpillars or damage. The forest and eastern tent caterpillar are spring-feeding caterpillars and have similar fluctuations in their populations and a similar life cycle to gypsy moth, although pupation occurs earlier, in late June.

Identification and Damage

Caterpillars of each species are quite variable in appearance:

Gypsy moth (*Lymantria dispar*):
Egg masses of 300–1,000 eggs are buff-coloured, covered with fibrous hairs and located on the bark of tree trunks and branches (Figure 6-35A). Young larvae are 6–7 mm long and initially black and hairy, but as they grow they become grey with distinctive, double rows of five blue followed by six red spots running down the back and long, wispy hairs (Figure 6-35B). Mature larvae are 30–65 mm long. Adult moths are black and white (Figure 6-35A). Young larvae chew small holes in leaves, referred to as shothole feeding, starting on upper branches. Feeding by older larvae is more significant, often beginning from the outer leaf edge and moving into the center. Feeding by large numbers of older larvae can significantly defoliate young hazelnut trees.

Figure 6-35. Gypsy moth. (A) Adult female on egg mass. (B) Larvae and feeding damage.

Green fruitworm (*Orthosia hibisci*):
Eggs are whitish grey and 0.8 mm in diameter by 0.5 mm tall. Fully grown larvae are large (up to 40 mm long), lime to dark green, with small white spots and several white, longitudinal stripes running along the length of the body (Figure 6-36). Adults have dark forewings and lighter hindwings with wingspans of 25–40 mm.

Figure 6-36. Green fruitworm.

Eastern tent caterpillar (*Malacosoma americanum*) **and forest tent caterpillar** (*Malacosoma disstria*):

Egg masses of both species are brown and laid in cylindrical masses around twigs. Larvae are up to 40–50 mm in length and hairy. Eastern tent caterpillars are brownish with blue spots along the body and a white stripe running the length of the back and live in a single large tent that they leave to feed on foliage in mornings and evenings (Figure 6-37). Forest tent caterpillars are blue and black with a row of white, keyhole-shaped spots running along the back. Instead of a tent, they spin a silken mat on leaves or branches where they aggregate (Figure 6-38). Larvae initially chew sections from the edge or centre of the leaf, but colonies can completely defoliate leaves and branches.

Figure 6-37. Eastern tent caterpillar.

Figure 6-38. Forest tent caterpillar.

Leafrollers:

In addition to obliquebanded leafroller, several other species are also found in Ontario fruit orchards during the spring (Figure 6-39). Eggs are found on the upper leaf surface as flattened, overlapping clusters of 20–200 yellow to brownish eggs. The redbanded leafroller (*Argyrotaenia velutinana*) is a pale-headed, greenish, active caterpillar that measures 16 mm at maturity. Variegated leafroller (*Platynota flavedana*) larvae are green with a light brown or amber head; the sides of the body are a lighter green than the top. The fruit tree leafroller (*Archips argyrospila*) is light to dark green with a black head and wriggles backward when disturbed. The European/filbert leafroller (*Archips rosana*) has not been identified in Ontario but is a common defoliator of hazelnut in British Columbia and Oregon. It is typically green with many pale hairs on the body, a dark brown head, and the beginning of its thorax is also covered by a dark-brown plate. Leafrollers feed on leaves and buds, rolling up expanding leaves using a silken webbing, which they use as shelter during the day.

Figure 6-39. Several species of leafroller can be found feeding on the leaves of tree nuts.

Monitoring

Monitor young trees for caterpillars or rolled leaves beginning early in the spring as soon as foliage emerges. Some leafroller species can be monitored with commercially available traps to detect adult flight and egg-laying. No thresholds have been established for leafrollers or other caterpillars in Ontario hazelnuts, however thresholds established for leafrollers on Oregon hazelnuts or Ontario apples may be useful as a guide. For thresholds and monitoring methods, see the resources listed in Appendix B.

Management

In many cases, control of spring-feeding caterpillars on hazelnut is not required, because feeding activity is restricted to the early spring, giving trees time to recover. However, outbreak years of gypsy moth have resulted in significant defoliation of young hazelnuts in Ontario that required intervention to avoid stunting and weakening of trees. In smaller orchards or with young trees, small numbers of caterpillars can be handpicked and crushed. Gypsy moths can be attracted to the base of trees by installing burlap skirts at the base. These need to be inspected daily and the larvae removed and destroyed. In the winter, egg masses of some species, including gypsy moth and tent caterpillars, become visible and can be removed and destroyed. In larger orchards, these cultural practices may be impractical.

Some products are registered for leafroller control in Ontario hazelnut. See the resources listed in Appendix B, for products and rates. Many predatory and parasitic insects and diseases attack caterpillars and may help reduce populations. To conserve populations of these beneficial organisms, apply chemical pest control products only when necessary, and select the most narrow-spectrum products possible.

Fall Webworm

The fall webworm (*Hyphantria cunea*) is a common tent-making caterpillar found throughout North America on a wide variety of deciduous trees and shrubs, with nut trees being one of its preferred hosts. Unlike the forest and eastern tent caterpillars, which are part of the early spring caterpillar complex, the fall webworm is active later in the summer through the fall. Although the webs are highly noticeable and unsightly, it is generally not thought to be a problem for mature, healthy trees. However, in Ontario incidental damage to hazelnuts has been observed where tents are formed around developing nut clusters.

Biology and Life Cycle

Fall webworm overwinters as pupae in cocoons within leaf litter or soil, emerging as adult moths in late June to early July. Mated females deposit several hundred eggs on the underside of leaves. Egg hatch occurs in early-to-mid-summer, and newly emerged larvae immediately begin to feed and form large webs near the ends of branches that they use for shelter and protection from predators. Unlike tent caterpillar, they generally remain inside the tent to feed, which they enlarge over time to accommodate new leaves. After 6–8 weeks, mature larvae drop to the soil in September to pupate and overwinter.

Identification and Damage

Eggs are round, white to golden-yellow and laid in groups of 200–300 on leaf undersides. Larvae are a pale yellowish brown with a black head, dark stripes running along the side and long, whitish hairs protruding from red or black tubercles (Figure 6-40). When disturbed, they often rear back or make coordinated jerky movements. Their webs are distinctive and generally formed at ends of branches (Figure 6-41A). Their webs are sometimes confused with those of tent caterpillars, however they appear later in the season (mid-summer versus only in spring for tent caterpillars), are larger and messier and tend to be concentrated at branch tips (as opposed to branch unions for tent caterpillars). Adult moths are mainly white and hairy, with bright yellow to orange patches on the front legs and a wingspan of 35–42 mm.

Young larvae feed on the upper surfaces of leaves, causing them to become necrotic and die. Older caterpillars consume the entire leaf, leaving only the veins and mid-ribs. Where tents encompass developing nuts, larvae may feed on sections of the nut, leaving cavities and holes (Figure 6-41B). This damage is only seen on nut clusters contained within a tent.

Figure 6-40. Fall webworms generally remain within their tent, expanding it over time.

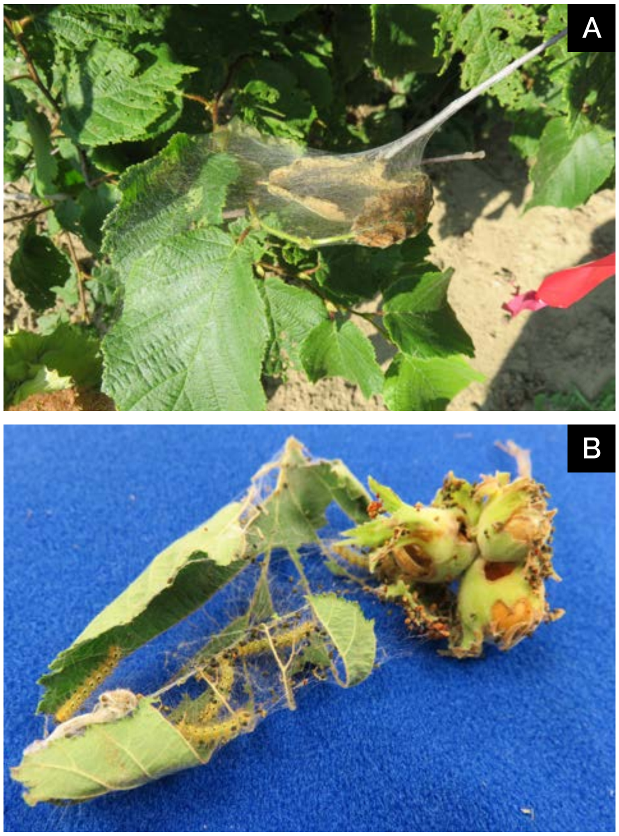

Figure 6-41. (A) Webworm feeding is mainly on the leaves within their tent. (B) When the tent encloses young, developing nuts, larvae will feed on the nuts.

Monitoring

Webs of this insect are quite noticeable even at an early stage. Check for presence of fall webworm tents at the end of branches beginning in mid-to-late July. Webs are often more common on trees growing in open areas such as roadsides or yards, or along the edges of wooded areas.

Management

Because feeding occurs mainly in late summer when photosynthesis is nearing completion, feeding rarely causes serious damage unless trees are very young or stressed by other pests or abiotic conditions. Fall webworm has not traditionally been reported to attack fruit, however damage to developing hazelnuts has been observed in hazelnuts when tents happen to enclose nut clusters while they are still young and soft. There are no insecticides registered for fall webworm, however so far control has not been required. Nests can be pruned out, particularly when they are forming near or around developing nut clusters. Fall webworm is also attacked by a large number of parasites, predators and diseases and is thought to serve as a late-season food source for these natural enemies, helping them survive and remain in the orchard to control early-season caterpillars such as gypsy moth the following season.

Filbertworm

The filbertworm, *Cydia latiferreana*, is one of the most important insect pests of hazelnut in many regions of the world, including Oregon and Washington. Larvae of this moth species have been observed in wild acorns from Ontario and Quebec, and adults have been detected in pheromone traps in several orchards in Southwestern Ontario (Niagara to Essex), but, as of 2020, significant nut damage by filbertworm has not been observed in commercial orchards in Ontario. Damage from this pest may increase as nut acreage increases.

Biology and Life Cycle

Filbertworms overwinter as larvae in the soil, which pupate in spring and emerge as adults from late June through October. Eggs are laid near developing nut clusters and hatch in 8–10 days. Young larvae feed on husks attached to nuts until they identify a softened area that allows them to enter the nut. Larvae then feed within the nut for several weeks before mature larvae exit the nut by enlarging their initial entrance hole or chewing a new hole in the shell. Larvae then drop to the ground and overwinter in a silken cocoon in soil to a depth of up to 5 cm, in organic debris on the ground or in cracks on trees. On the West Coast, there may be two generations per year. The number of generations has not been documented in Ontario. Filbertworm larvae favour hazelnuts but have been reported to feed on acorns and nuts of oak, beech and chestnut.

Identification and Damage

The forewing of adult moths varies considerably in colour from tan to dark brown to rusty, however, typically there are two to three metallic bands running horizontally across the wings, which measure 1.4–1.9 cm across (Figure 6-42). Larvae are about 1.5 cm long and white to pinkish with a dark, yellowish-brown head (Figure 6-43). The prothoracic shield (region just behind the head) is brown with dark mottling. They can be distinguished from weevil larvae by the presence of three pairs of legs and several pairs of prolegs on their abdomen.

Figure 6-42. Filbertworm adult. Source: Larry R. Barber, USDA Forest Service, Bugwood.org.

Kernels within damaged nuts may be completely destroyed or partially decayed, and nuts may also contain larval excrement. Entry holes into the nuts by young larvae are generally not visible, while exit holes are much larger, but may be mistaken for those of weevils. Damaged nuts may drop early.

Figure 6-43. Filbertworm larvae in hazelnut. Source: Todd M. Gilligan and Marc E. Epstein, TortAl: Tortricids of Agricultural Importance, APHIS PPQ, Bugwood.org.

Monitoring

Filbertworm adults may be monitored with commercially available pheromone traps, which should be placed in the upper third of the canopy by early June. Four traps are suggested for the first 4 ha, adding one trap for each additional 1.6 hectares. Traps are commonly used in most regions where this insect is a known pest. In Ontario, pheromone traps should be considered at a minimum in orchards with holes in nuts the previous season, concentrating on orchard perimeters. There is no established threshold for filbertworm in Ontario but in Oregon, control is suggested with an average catch of 2–3 moths per trap, or 5 moths in any one trap.

Management

Filbertworm control has not traditionally been required in Ontario hazelnuts, but this may change as acreage increases in the province. At present there are no insecticides registered for control of filbertworm in Canada, but in Oregon, insecticides are typically applied 8–12 days after moths first emerge. Commercial mating disruption products for filbertworm are also not currently registered for use on hazelnuts in Canada. Predators, parasitoids and bats may prey on hatching larvae before they move into nuts. Infested nuts often drop early. Destroying the first nuts to drop, which may contain a higher percentage of filbertworm, may reduce levels of overwintering larvae. Similarly, flail mowing infested acorns from nearby oaks may also reduce pest populations.

Hazelnut Weevil

Hazelnut or filbert weevils are snout beetles in the genus *Curculio* whose immature stages infest wild and commercial hazelnuts. Different species are problematic in different geographic regions. In Europe, *Curculio nucum* can be a major pest of commercial hazelnuts often requiring control. *C. occidentis* is the species reported in hazelnuts in western North America, however damage in these areas is reported to be sporadic and does not often require control. In Eastern North America, *C. obtusus* is the most common native species infesting wild hazelnuts, its relatives and oak. While *C. obtusus* is commonly reported from wild hosts, as of 2020, weevil species have not been a significant issue in commercial orchards in Ontario. However, growers should be familiar with, and monitoring for, hazelnut weevils since end-of-season damage at harvest is difficult to distinguish from that of filbertworm.

Biology and Life Cycle

Weevils overwinter as adults in soil, emerging in spring and flying to nearby hosts where they feed and mate on immature nuts or acorns. Females excavate chambers in nut shells to lay eggs beginning in late June. Larvae hatch approximately 2 weeks later, burrow into nuts to feed and develop on the kernel. The kernel is destroyed, filled with decayed material and excrement. Mature larvae chew an exit hole in the shell (Figure 6-44) between late August and mid-September, drop to the ground and burrow 7–15 cm into the soil, where they enter a state of diapause (dormancy). Diapausing larvae may remain in soil for up to 3 years, depending on the species, before emerging as adults in the spring (Figure 6-45).

Identification and Damage

Adults are brown to orangish snout beetles with long, curved, thin mouthparts. Adult weevils have bent antennae that arise from their elongated, beak-like snout (Figure 6-45A). Larvae are grublike and cream-coloured with a brown head and lack the legs and prolegs typical of filbertworm larvae and other caterpillars (Figure 6-45B). They are relatively slow-moving and curl into a C-shape when disturbed.

Figure 6-44. Hazelnut weevil exit hole.

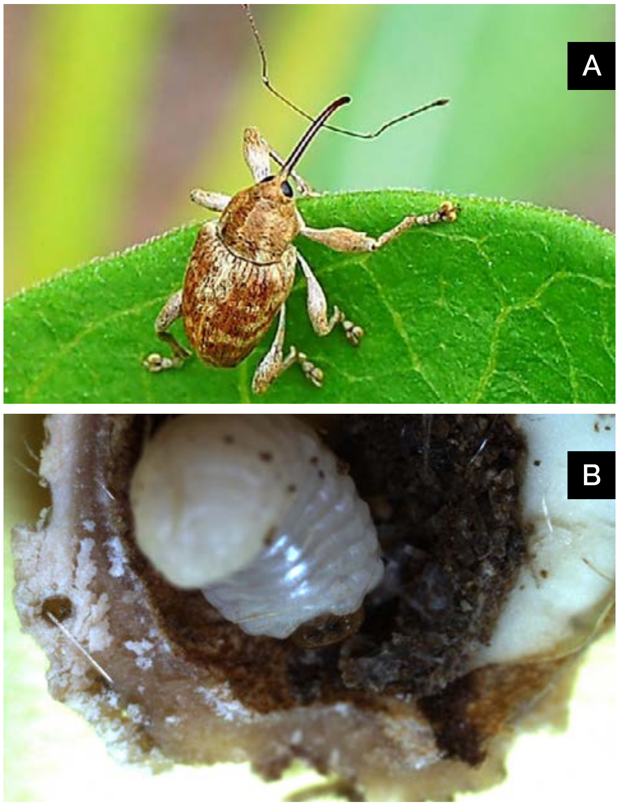

Figure 6-45. (A) Adult weevil (*Corylus* spp.). Source: Jon Yuschock, Bugwood.org. (B) Larvae in nut.

Eggs are small, white and elliptical and deposited in layers in the nut shell. They are approximately 60 mm long. Larval feeding destroys hazelnut kernels, and nut interiors may be filled with decayed tissue and larval excrement. When larvae have emerged from nuts, they leave a clean, circular hole in the side of the shell. Holes and nut damage are similar to that caused by filbertworm.

Monitoring

There is no formal scouting methodology for hazelnut weevil. Scouting is indicated where large numbers of nuts with holes were observed the previous season, and hazelnut weevil should be considered if there are holes in nuts and pheromone traps are not detecting the presence of filbertworm. Scout orchards to look for adult weevils on leaves and developing nut clusters in late spring through early July, concentrating on orchard edges especially near wild hosts. Tapping trees with a padded pole to dislodge insects onto a tapping tray can be useful in detecting the presence of adults. Cracking a subset of developing nuts in July and early August, particularly those with signs of visible damage and/or nuts near orchard perimeters, can help detect the presence of immature larvae, which can be helpful in distinguishing whether later damage is due to weevils or filbertworm.

Management

As of 2020, hazelnut weevil has not been observed at high levels in commercial hazelnut orchards in Ontario, and control has not been required. Some products are registered for this insect, however there is no established threshold. If significant levels of weevil damage have been observed the previous season, control may be required once adults appear in May and June. In these cases, border sprays may be sufficient if insects seem to be invading from wild hosts. In Europe, some work has been done investigating the use of entomopathogenic nematodes to control diapausing larvae in soil. It is not known if this would be cost effective in Ontario, if required.

Brown Marmorated Stink Bug

The brown marmorated stink bug (BMSB), *Halyomorpha halys* (Stal), is an invasive insect native to Asia that was accidentally introduced to North America in the mid-1990s. It was first identified in Pennsylvania in 2001 and has since been detected in most states and several Canadian provinces. BMSB is capable of extended flight and is an excellent hitchhiker, allowing it to be moved over large distances in shipping containers, cargo and vehicles. Large populations exist in several mid-Atlantic states, where it is a significant agricultural and nuisance pest. In Canada, it was first detected in Hamilton, Ontario, in 2012, and is now confirmed across southern Ontario.

BMSB is well adapted to a diversity of landscapes and has an extremely wide host range that includes ornamental trees and shrubs, field crops, vegetables, grapes, berries and fruit and nut trees, including hazelnut. Unlike most native stink bug pests, the piercing-sucking mouthparts of BMSB are capable of penetrating hazelnut shells at all stages of development, and hazelnuts are on the list of crops considered to be at highest risk of damage from this pest. BMSB has caused extensive damage to hazelnuts in some European countries, including Turkey and Georgia. In the U.S., there has been significant but sporadic damage in hazelnut plantings in New Jersey and growers are seeing increasing damage in Oregon. In Ontario, BMSB has been trapped in hazelnut orchards in the Niagara region, but as of 2020, no breeding populations or damage have been seen in Ontario hazelnuts. It is important for Ontario hazelnut growers to be aware of this pest and the types of damage it can cause.

Biology and Life Cycle

BMSB has a single generation per year in northern latitudes, though more are possible in warmer climates. Adults emerge from May to June as temperatures and day length increase and feed for several weeks on early-season hosts before mating. Adults are long-lived and egg-laying occurs over an extended time period from May through August. Emergence from overwintering sites is also staggered, resulting in the presence of multiple life stages (eggs, nymphs and adults) throughout the growing season. Both adults and nymphs cause feeding damage to crops. A single female may lay several hundred eggs. Decreasing day length in August and September triggers movement of new adults to overwintering sites (protected areas in woodlots, rocky outcroppings and human-built structures). Where populations are well-established, overwintering adults can become a major nuisance pest due to large aggregations of insects that often move into buildings in the fall.

Populations tend to become established in urban areas first, then spread out to nearby agricultural areas. Due to its broad host range, BMSB can readily switch hosts, and adults move long distances throughout the growing season. Populations may build up on unmanaged woody hosts before it moves into crops. Crops are at greatest risk for injury when fruit or seeds are present.

Identification and Damage

Adult brown marmorated stink bugs are 12–17 mm long and shield-shaped, with a mottled, brown-grey body (Figure 6-46A). The pronotum or "shoulder" is smooth and rounded, lacking spines except one beside each eye. They have two white bands on each antenna, which are diagnostic for the species, and a poorly defined white band on the legs. The tip of the abdomen has white, inward pointing triangles alternating with dark areas, similar to some other stink bug species. BMSB adults may be distinguished from other predatory and pest stink bugs that may be present in hazelnut orchards by the two white bands on the antennae and the lack of toothed edges on the pronotum or shoulders.

BMSB eggs are barrel-shaped and deposited in clusters of 20–30 on the underside of leaves. They are initially pale green, becoming yellow with red eye spots close to hatch, and have minute spines that form a fine halo around the top of the egg. Nymphs are 2.4–12 mm long, lack wings, and go through five instars before becoming adults. First instars can be confused with other species. They have a dark orange abdomen with black banding, and black legs and head, remaining clustered on the egg mass before moulting into second instars (Figure 6-46B). Newly moulted second instars are generally dark and have a tick-like appearance. Third-to-fifth instar nymphs become progressively darker and more like adults, developing an alternating light-dark pattern on the edge of the abdomen and white bands on the antennae and legs (Figure 6-46C).

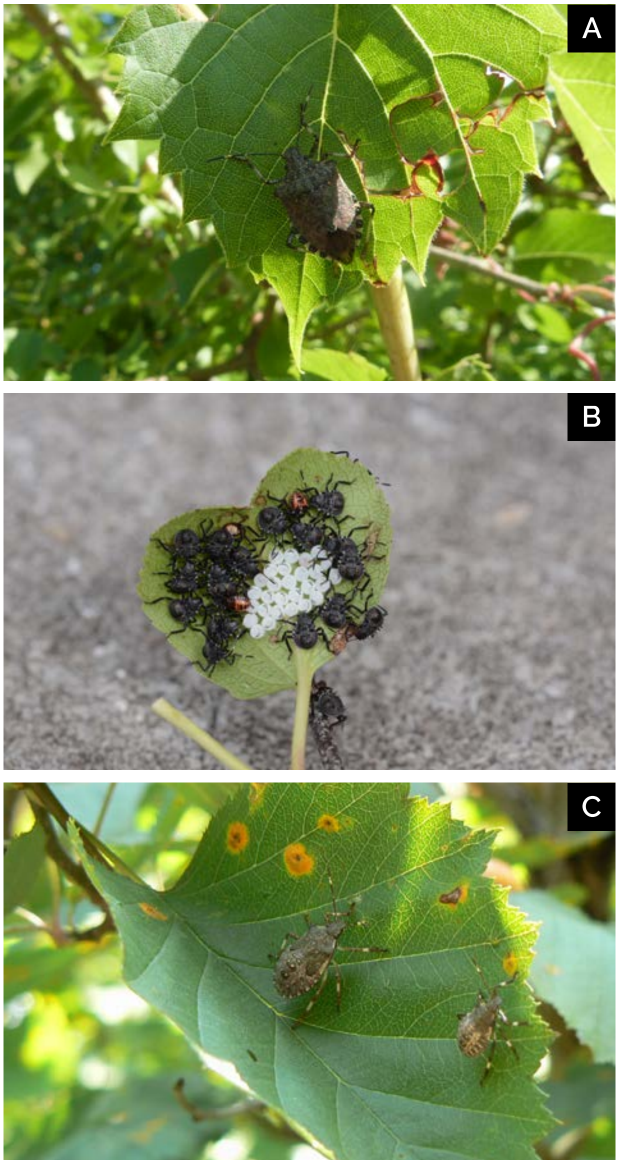

Figure 6-46. Brown marmorated stink bug. (A) Adult. (B) First (reddish) and second (darker) instar nymphs. (C) Later instar nymphs.

BMSB damage results when nymphs and adults insert their piercing-sucking mouthparts into fruit, buds, leaves, stems or nuts, removing fluids and nutrients and injecting digestive enzymes into the plant, which results in the formation of small necrotic areas at the feeding site. Hazelnut shell thickness and hardness do not protect hazelnuts from feeding damage by BMSB, and in Oregon all life stages except the first have been observed to feed on nuts and leaves. Damage to hazelnuts varies with the developmental stage of the nut, can be difficult to detect externally and may only be noticeable when the nut is cracked after harvest (Figure 6-47A-D). Feeding during shell expansion can disrupt kernel development, leading to blanks (which can also be caused by pollination issues or lack of irrigation) (Figure 6-47B). Feeding during kernel expansion results in shrivelled, deformed kernels) (Figure 6-47C), and feeding on nuts that are close to maturity causes corking (Figure 6-47D). This corking and scarring can be confused with generalized decay after harvest, which is why in-season monitoring for the pest is important.

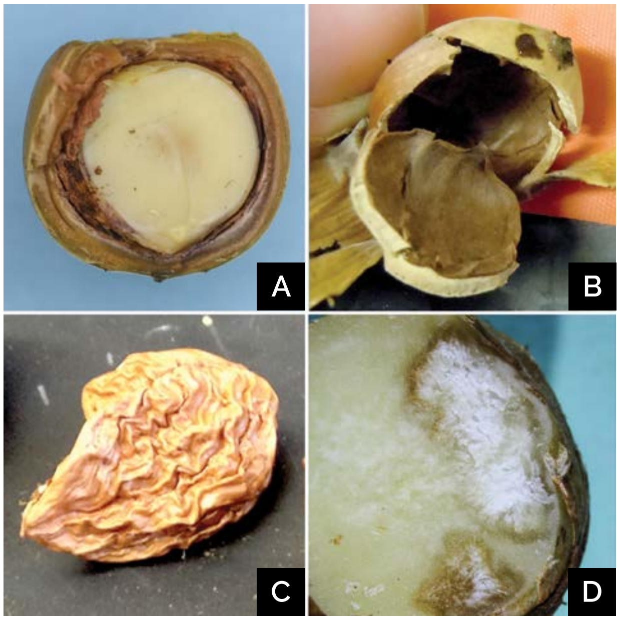

Figure 6-47. Main damage symptoms associated with BMSB feeding on hazelnuts. (A) Healthy kernel (in shell). (B) blank nut (empty shell). (C) Shriveled kernel. (D) Corking damage. Source: Chris Hedstrom, Oregon State University.

Monitoring

There are no established monitoring techniques for BMSB in Ontario. Note the presence of stink bugs during regular scouting, both through visual observation of trees and tapping. Tree tapping involves striking branches 2–3 times with a padded stick to dislodge insects onto a tapping tray for observation and counting. Tapping trays can be handmade or purchased commercially. This method can also be useful for monitoring other insects such as caterpillars, weevils and natural enemies. However, it is important to take note of the diagnostic characteristics of BMSB described above so you can distinguish them from the predatory stink bugs naturally present in hazelnut orchards that play an important role in feeding on other hazelnut pests and should not be controlled. In the spring, with the onset of warm, sunny days, it can be helpful to examine trees bordering woodlots, as well as tall plants and trees near overwintering sites, including landscape plants that are potential hosts (e.g., tree of heaven, catalpa, buckthorn, eastern redbud, English holly, ash, maple and dogwood) for emerging adults that may be basking in the sun. BMSB are fast movers, so it can be easier to spot insects in trees when temperatures are below 10°C.

Finally, pheromone traps baited with aggregation hormones to attract nymphs and adults are commercially available. Most BMSB traps consist of a pyramid with a collection container on top or clear sticky panels to trap the insects. These should be placed along the orchard perimeter, especially near woodlots. However, a positive detection in a trap does not necessarily mean crop damage is occurring, so trapping should not replace visual monitoring in the orchard.

Management

There are currently no established thresholds or insecticides registered for control of brown marmorated stink bug on hazelnut in Ontario. On other crops where products are registered, insecticide chemistries are not very effective at keeping this pest under control. At present in Ontario, BMSB appears to be focused more in landscape plants than crops, so it is thought that crop damage will be more of a concern in hot, dry summers when alternative hosts are scarce. Orchards near monocultures, especially of other high-risk crops such as apples and tender fruit may be at greater risk of damage. There are a number of predators and parasitoids that will attack various life stages of BMSB. Several research programs in North America are investigating classical biological control solutions using natural enemies from Asia and are seeing early success. The egg parasitoid *Trissolcus japonicus* (Samurai wasp), an important biological control agent found in BMSB's native range, has recently been identified in Ontario. Its distribution and impact on local BMSB populations is still being evaluated.

Kernel Disorders

Blanks, Poor Nut Fill and Deformed Kernels

Blanks are hazelnut shells that either have no kernel or a very small kernel filling less than a quarter of the interior of the shell (Figure 6-48). Blanks are often attributed to a lack of pollination, however with a complete failure of pollination, the shell would not have developed at all since pollination stimulates the formation of the shell. Improper kernel development in blanks is more likely due either to fertilization not occurring or embryo development aborting at an early stage. Poor nut fill occurs when kernels fill only 25%–50% of the shell (Figure 6-49), while deformed kernels may have sunken areas, or wrinkling over a large portion of the surface (Figure 6-50).

Figure 6-48. Blank hazelnut shell with no kernel.

Figure 6-49. Poor nut fill is characterized by the kernel filling over 25% but less than 50% of the shell.

Figure 6-50. Shriveled kernels.

In many cases the exact cause of blanks or poor fill is unknown but is generally attributed to various environmental stresses to trees occurring between pollination and fertilization (for blanks) or during kernel development (for poorly filled or shrunken/shriveled kernels). Possible stresses include poor soil moisture, low light levels in poorly pruned orchards or deficiencies in certain nutrients (e.g., nitrogen, boron and potassium). Cool temperatures during fertilization have been hypothesized as a potential cause of blanks, while rapid kernel growth under very high temperatures has been suggested as a cause of shrunken kernels. Some cultivars, such as 'Barcelona', tend to produce more blanks. Damage to hazelnuts by brown marmorated stink bug early in nut development can also cause blank nuts or shriveled kernels.

Blank shells are easier to crack open and tend to fall from the tree earlier than fully developed nuts. Flailing the orchard floor when these first, blank nuts drop, prior to initial harvest, can help reduce the proportion of blanks in the harvested crop. There are no established practices known to reduce blank production, beyond avoiding cultivars with a greater tendency to produce them.

Brown Stain

Brown stain is a disorder of unknown cause, which is associated with a brownish liquid that soaks the sides or end of the nut, typically beginning part way through nut development. The condition typically begins as water-soaked, soft spots on the shell that become brown, streaked, sometimes sunken stains during the summer months (Figure 6-51A). In severe cases, the interior of the shell and kernel may become completely soft and brown (Figure 6-51B). In other growing regions, affected nut clusters may drop prematurely or contain only partially filled nuts. While the cause of brown stain is unknown, it is presumed to be physiological because it has not been found in association with any pests.

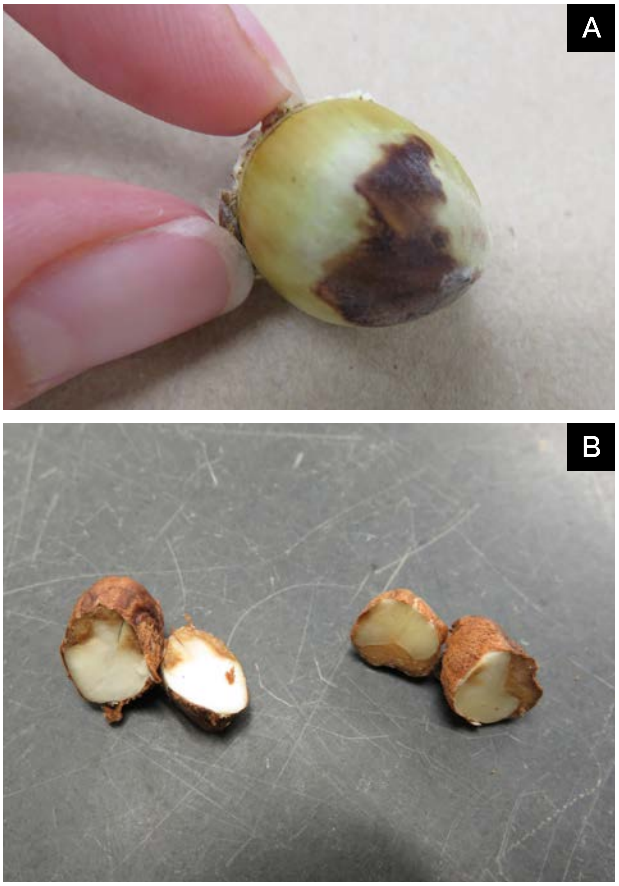

Figure 6-51. Brown staining on hazelnuts. (A) Brown, streaked stains on the shell appear during the summer months. (B) In severe cases, the interior kernel may become soft and brown.

Kernel Mould

Kernel mould is the development of any fuzzy, fungal growth on the inner or outer portion of the kernel (Figure 6-52). Mould can reduce both kernel quality and marketable yield, since processors will not accept nuts as U.S. No. 1 if the percentage of defects (including mould, decay and insect damage) exceeds 5%. Kernel mould fungi have not been well studied in Ontario, but in a recent survey in Oregon hazelnuts, common fungi associated with kernel mould included *Penicillium spp., Cladosporium spp.*, *Diaporthe rudis* and *Aspergillus spp*. The fungus *Ramularia spp.* has been associated with tip mould and the yeast *Eremothecium coryli* has been associated with kernel spot, but these are reported to be rare in Oregon.

Figure 6-52. Nuts on the left became mouldy after being stored in nut totes in wet weather. Nuts on the right are healthy. Source: Dr. Jay Pscheidt, Oregon State University.

Many of these species are also found in symptomless kernels, but their growth is favoured by moist conditions. Studies suggest that if nuts fall onto wet soil at harvest time, the moisture promotes growth of the fungi on kernels. Higher incidence of moulds has been associated with large amounts of rainfall during the spring or at harvest, when bins of harvested nuts are left out in the rain, and with certain cultivars (e.g., 'Lewis' and 'Santiam' have higher incidence of mould than 'Barcelona' and 'Jefferson'). To help reduce the incidence of kernel mould, ensure prompt harvest, drying and shelling of kernels, ideally before heavy fall rains saturate the soil. In studies done in Oregon, use of wire screens to prevent nuts from contacting wet soil reduced the incidence of mould by giving nuts more opportunity to dry out between rainstorms. Delaying mechanical flailing of orchard floors until later in the spring and selecting cultivars with lower incidences of kernel mould can also help reduce levels of mould in harvested nuts.

Vertebrate Pests

Several vertebrate pest species can cause economic damage to hazelnuts. Chief among these are several species of birds (including jays and crows) and squirrels, which may remove much of the crop before it is mature. Deer, voles (field mice) and rabbits can also damage trees.

Birds

Blue jays, crows, magpies and other bird species feed on ripening nuts. Flocks will congregate in hazelnut orchards and can have a substantial impact on yield (Figure 6-53). Some species flock together and pass through orchards near or at harvest. Wild turkeys will also feed on nuts in the fall and buds during the winter months. Bird damage is not always obvious. Physical damage such as bird pecks are easy to spot but crops completely removed by birds can only be estimated.

Figure 6-53. (A) Hazelnut tree in early August surrounded by discarded nuts fed on by birds. (B) Birds and other vertebrates will split open young shells to feed on kernels.

Possible methods of controlling birds in orchards include physical exclusion, visual repellants and acoustic repellants. To be effective, bird control generally requires multiple strategies, some of which can bother neighbours living near the orchard. No single approach to bird control is 100% effective. Even netting may benefit from integration with other bird control tactics. Bird control strategies will vary with the farm, location and bird species causing problems.

Begin by understanding which birds are causing damage, where they are coming from, how they behave and where the highest-risk areas are located. Observe birds in the crop and identify their key behaviours. Look for ways to disrupt these behaviours to make feeding more difficult. Note bird flight paths, areas of high bird activity, past history of bird damage in orchard blocks, surrounding vegetation, power lines, locations of watering points, alternative food sources that may be nearby, etc.

Physical exclusion uses netting or other barriers to physically prevent birds from feeding on the crop (Figure 6-54). It is the best way to ensure crop protection but is usually the most costly and impractical and does not guarantee 100% protection as birds can still find ways into the crop. There are various types and colours of nets that may be installed directly onto the crop or fastened to an overhead structure.

Figure 6-54. Netting over trees will prevent birds from feeding on nuts, but is too expensive to be cost effective in most orchards.

Visual deterrents use movement and things resembling predators to frighten birds, but usually need to be combined with other methods, such as acoustic deterrents, to be effective. They include scare-eye balloons which are coloured balloons that move in the wind and resemble the mouth of a hawk. Tapes and streamers move in the wind and reflect sunlight, making it appear as if the field is in motion from above (Figure 6-55). Kites shaped like birds of prey and tethered to high poles appear like predators hunting in the orchard. Streamers, flashtape, artificial predators and scarecrows can be used but must be moved constantly, as birds quickly realize the threat is not real. Air dancers are large, inflatable, "dancing men" that wave randomly in the air. These require a power source and should also be moved regularly. Bird lasers produce beams of light that birds associate with predator-like behavior. Some jurisdictions may have regulations prohibiting high powered lasers so check acceptability of the laser before use. Radio-controlled model aircraft and unmanned aerial vehicles (UAVs) can also be used but are costly, require skilled operators, and operators must follow all aviation regulations and may require a certificate from Transport Canada.

Figure 6-55. Streamers in an apple orchard make it appear as if the field is in motion to birds travelling above.

Acoustic deterrents use various types of sounds to frighten birds away. Propane-fired bird-scaring cannons (bird bangers), which produce loud, gunfire-like sounds, are probably the most familiar, but can lead to frequent noise complaints from neighbours. They must be used in compliance with best management practices. Additionally, in hazelnut, propane cannons have not been effective against blue jays. Electronic sound devices (squawkers) use electronic noises to irritate birds and disrupt their senses, distress calls of specific bird species or attack calls of predators (Figure 6-56). These are usually more acceptable to neighbours than bird bangers. Cannons and squawkers may be used together. Other sound-producing devices include pyrotechnic pistol cartridges, air horns, clanging metal and Mylar humming lines. These may work for only a few days before birds start to ignore them and may provide the most benefit when used only just before harvest, when bird pressure is highest.

Figure 6-56. Electronic sound device sending out predatory attack calls in hazelnut orchard.

Encouraging predation through falconry or kestrel nesting boxes is another option but may be cost-prohibitive. This includes use of trained hawks and falcons over the orchard, which is very expensive. Predators must also be airborne to be effective. When birds of prey are tethered to a post, birds quickly realize predators are unable to attack. American kestrels are small birds of prey native to Ontario that will feed on smaller birds. Kestrels can be attracted to a farm by building nest boxes mounted on poles 5–6 m high, away from wooded areas with the entrance facing the southeast. This may reduce bird feeding, however effectiveness is limited in later-ripening crops, as they tend to leave the area by early August.

Many growers ask whether they can hunt to control bird and other vertebrate pests. Although sometimes possible, hunting is generally not as effective as the previously listed techniques. Growers should also be aware there may be legislation governing hunting and the use of firearms on their property. Laws protect many bird species, so always check with the Ministry of Natural Resources and Forestry (MNRF) before you allow anyone to hunt on your property.

As a rule, multiple methods will be required to manage problem bird populations in orchards, and these should be initiated early. If birds have already fed on the crop, controls will not be as effective. Birds are also intelligent and will quickly get used to regular, repeated or consistent control measures. Varying the timing, placement and type of device throughout the season will help prevent birds from acclimating to the repellant. Observe bird behaviour while controls are being used. If something is not working, change it immediately. Be cognizant of the impact of bird control strategies on neighbours. For more information on bird control in horticultural crops, see the resources listed in Appendix B.

Squirrels

Squirrels are particularly fond of hazelnuts and can be a very significant pest in some orchards. They eat ripening nuts and carry mature nuts away, in some cases removing a large percentage of the crop before harvest even begins. Squirrels, along with mice and voles, may also feed on the roots and bark at the base of the tree. As with birds, squirrels can be difficult to manage due to their ability to climb, jump and fit through small openings, as well as their tendency to learn and adapt to pest control strategies employed against them.

Squirrels are susceptible to predation by birds of prey, coyotes, cats and other natural predators. Predation on squirrels generally is not sufficient to keep populations in check but may prevent some damage.

Squirrels are often much more problematic in hazelnut orchards located close to wooded areas that provide them with habitat and shelter from predators. Locate new orchards as far as possible from woodlots and fencerows, although this must also be balanced with the loss of potential benefits from having fencerows along orchards (see *Windbreaks and Wind Protection* in Chapter 3, *Site Selection and Orchard Establishment*). This will not eliminate the entry of squirrels into orchards, but will reduce numbers and make other intervention techniques, such as hunting, more effective.

Electric fences to exclude squirrels from orchards (Figure 6-57) should generally only be considered if the primary problem is ground squirrels. Ground squirrels are not generally a problem in most Ontario hazelnut orchards as their range does not extend into much of the province. Grey and red squirrels are far more common, but less likely to be affected by electric fences.

Figure 6-57. Electric fencing surrounding a hazelnut orchard. Fences may deter grey and red squirrels from feeding, especially if there are some alternative food sources (e.g., other nut trees) outside the fence, but do not completely prevent squirrels from getting into the orchard.

In order to receive a shock, squirrels need to be in contact with both the fence and the ground (or a ground wire) at the same time to close the circuit. Grey and red squirrels are extremely adept jumpers and tend to jump from the ground directly to the top of an electric fence, so an electric fence is unlikely to be effective against them. Ground squirrels may be affected by the fence, however fencing would need to extend at least 0.9 m below the ground and 0.6 m above it and be made of durable materials such as roofing iron and fence posts. It must have no holes or other breaches and be well away from surrounding landscape or forest trees that are close to the orchard.

Fencing for squirrels would need to be at least 1.8 m in height, with 3 m between the top of the fence and adjacent trees, and consequently is likely to be cost-prohibitive.

Netting of trees would provide more protection than fencing and would also help reduce bird damage (Figure 6-54). Netting would have to be of a sufficiently small mesh, and have no holes or loose areas at the base of the tree for squirrels to enter. However, netting is likely cost-prohibitive for large trees and orchards and would interfere with other orchard management practices, such as pesticide sprays.

Squirrels may be managed with traps or through hunting, however, growers and landowners are responsible for ensuring all relevant legislation is followed. Contact the Ministry of Natural Resources and Forestry (MNRF) for more information. Trapping and shooting also generally do not remove all squirrels from an orchard, especially when orchards are located close to woodlots or dense fencerows.

Where cultural practices are insufficient, toxic baits may be registered for use against some rodent species in orchards and crop areas. Search the Pest Management Regulatory Agency (PMRA) website www.pr-rp.hc-sc.gc.ca/ls-re/index-eng.php for toxic baits registered for use in commercial orchards. Always check the label to ensure the product can be legally used in hazelnuts and against squirrels and follow all label instructions for use. Do not use poison-coated corn baits or broadcast baits on the orchard floor, as these are poisonous to farm pets and non-target wildlife. Bait stations have less impact on non-target organisms.

Mice and Voles

Mice and voles will feed on nuts, roots and tree bark near the ground. Voles feed on tree bark, particularly in winter when cover is present (Figure 6-58). This feeding can girdle the tree, which may increase tree stress or even kill very young trees. Occasionally, mice will build nests at the base of multi-stemmed hazelnut trees close to harvest and feed on ripening nuts (Figure 6-59). They are generally only a problem when populations are very high, as populations are often kept in check by their many natural predators. A variety of natural predators such as hawks, owls, crows, ravens, weasels, foxes, coyotes, racoons, skunks, cats and snakes feed on voles and squirrels and generally keep low-to-moderate populations under control. In years with high populations, other management methods may be required.

Figure 6-58. Vole feeding damage to hazelnut bark.

Figure 6-59. Mice will occasionally build nests at the base of multi-stemmed trees and feed on ripening nuts.

Voles require green, growing vegetation for protection from predators, access to food and breeding. Reduce long grass and cover by regularly mowing grasses in and around orchards to 8–15 cm. Avoid waiting long intervals between mowing or using mowing techniques such as sickle-bar mowers that produce a thatch layer which provides cover for voles. Remove all mulch, sod, nuts and other debris at least 60 cm from the base of trunks or tree rows.

Mouse guards can be used to protect the bark of newly planted trees from vole damage (Figure 6-60). These should be buried 5 cm deep in the soil and require regular monitoring to ensure they are working and not interfering with root or bark development. There are different types of tree guards. Mesh mouse guards (Figure 6-60A) prevent feeding on bark while promoting air circulation. Solid tree guards prevent mouse feeding and may also provide some additional protection, for example from herbicides, but may lead to accumulation of debris. Tree guards should not be left on trees for subsequent years. Cover crop management and tree guards are less effective against squirrels, due to their ability to jump large distances.

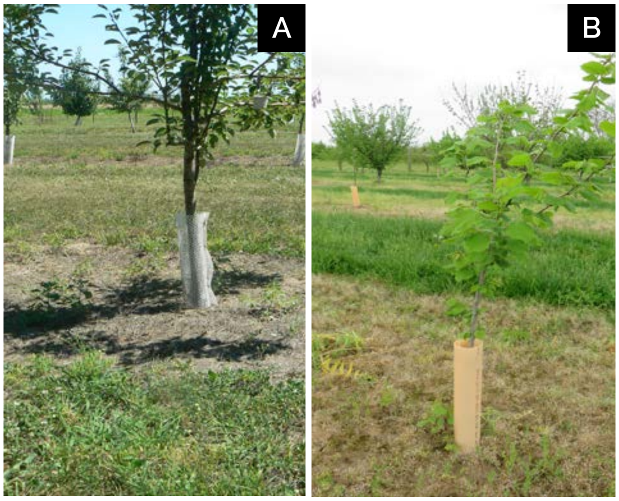

Figure 6-60. (A) Mesh mouse guards. (B) Solid tree guards.

Toxic baits are registered for use against some rodent species in orchards and crop areas. For more information, see the section on toxic baits in *Squirrels*.

Deer

White-tailed deer will feed on the foliage, buds, twigs or nuts of many commercially cultivated trees, including hazelnut, and this can impact growth and yield. In winter and early spring, deer may feed on soft tender tips and terminal growth. This "nipping" results in loss of fruit buds and, more importantly, tree shape. Bucks will also rub antlers against tree trunks, damaging bark. Reducing deer damage in orchards works best where an integrated approach is used, which includes fencing, repellents, scare devices and hunting (where permitted).

Several types of fences are available for use around orchards, including permanent woven wire, mesh and electrical fences. These may be most economical for orchards in areas with large populations of deer where the likelihood of damage is high. Permanent woven wire fence provides a barrier that requires little maintenance but can be expensive to install. The costs often limit their use around orchards. The fence is constructed from sections of 15 cm x 30 cm wire mesh joined with hog rings, reaching a height of 2–3 m. Barbed wire at the top of the fence is no longer considered appropriate for deer fencing, because barbs above the height of the animal do not act as a deterrent, pose an entanglement hazard and are less visible. Poly mesh fencing is another type of fence considered strong, long-lasting and easy to install. The fence is made of a series of 10.16 cm2 UV-resistant polyethylene mesh that are stretched 6 m between supporting poles. This type of fencing is considered very effective, provided the entire area is enclosed, because deer have relatively poor vision and depth perception. Because the fence and accessories are black, deer cannot judge where it starts and stops. They become scared of the fence and run around its perimeter but usually do not try to jump it. The third type of fencing, electrical, is easy to erect, repair and maintain. Check local bylaws to determine what type of electric fences can be used on a property.

As electric fences have low visibility, deer need to be lured into contacting them with their noses through regular baiting, and the shock trains the deer to avoid the fenced area. Tape and braided electric fences are preferred over tensile fences due to increased visibility and decreased entanglement hazard. Electrical fences can be temporary or permanent. Permanent fences provide year-round protection from deer and are best suited to orchard crops. They are best used under light deer pressure or for relatively small areas. Low-profile fences are an entanglement hazard for deer and may not provide adequate protection, especially in the winter when snow restricts deer from using alternative food sources.

Auditory and visual repellants (propane cannons, cap exploders, strobe lights, sirens, fireworks and gunfire) can be effective in scaring deer off when they first appear. However, deer often become accustomed to them, even when the devices are occasionally moved, so scare devices are usually only a short-term solution. Dogs contained in the orchard using invisible electric fencing are sometimes used to chase deer away. Large, aggressive dogs work best for this — a family pet may not provide adequate protection. Techniques that involve direct harassment of deer such as dogs or pyrotechnics require prior authorization from the MNRF.

Odour or taste repellents are also available to manage deer in orchards. Contact repellents are applied directly to plants and repel deer by imparting an unpleasant taste. Area repellents, which are more commonly used in orchards, are applied near the plants and rely on odour to repel deer. Area repellents include suspending bars of hand soaps, dryer sheets or bags of human hair, from trees around orchards.

Finally, problem deer can be hunted by licensed hunters during hunting season. Agricultural deer removal authorization can be obtained outside of the hunting season by applying for a permit for agricultural deer removal from the MNRF. Growers are responsible for obtaining all necessary permits and ensuring compliance with all relevant regulations.

Raccoons

Raccoons can also be a significant problem in hazelnut orchards and can remove maturing nuts from several hectares of trees before harvest. They may also break the branches when climbing trees to feed on nuts. There are no poisonous bait formulations registered against raccoons. Some growers of vegetables and other crops have found electric fences to be effective in deterring raccoons. These should be at least two-wire fences, with wires spaced 15 and 30 cm above the ground, although a three-wire fence, with wires spaced 10, 20 and 33 cm above the ground, may provide better protection. Raccoons may also be hunted with an appropriate permit. Contact MNRF for more information on hunting requirements for raccoons in Ontario.

Rabbits

Rabbits feed low on tender terminal growth and fruit buds during the winter, which can girdle trees. European hare (jackrabbit) can also damage limbs as high as 1 m from the ground, due to their ability to stand on their hind legs. Rabbits and hares have many natural predators such as foxes, owls and hawks, which may help reduce populations. Plant orchards away from natural meadows or brush to reduce rabbit pressure. Eliminate brush piles, weed patches, junk dumps and stone piles in or adjacent to the orchard, where rabbits can live and hide. Paint trunks and lower scaffolds with white exterior latex paint to repel rabbits. Plastic tree guards on newly planted trees may repel rabbits the first year after planting but should not be left on trees for prolonged periods. Hunting and live traps may help with small rabbit populations but are less effective on large populations because time and labour costs are prohibitive. Check with MNRF for rules and regulations regarding hunting or live trapping rabbits.

Abiotic Disorders

Abiotic disorders are conditions that are not caused by a living organism but by soil and weather conditions, or man-made physical and chemical disturbances. Abiotic injury can also weaken the plant and predispose it to attack by pests. Abiotic disorders are often confused with damage caused by pests. Some characteristics that can be helpful in distinguishing between the two include:

- Abiotic damage will often impact multiple plant species while biotic pest issues are often specific to the crop or related species. If weeds or adjacent crops and landscape plants are exhibiting similar symptoms, this may indicate an abiotic disorder such as environmental stress or chemical injury.
- Abiotic disorders often result from a single stress (e.g., a frost) and therefore typically do not spread between plants over time. Pests typically spread to neighbouring plants or plant

parts over time. Check to see if symptoms remain the same or spread. For example, plant diseases and herbicide injury can both cause yellow spots on plant tissue. However, the disease lesions will typically spread and coalesce, while herbicide injury droplet patterns remain the same.

- Because abiotic disorders are often related to environmental factors or cultural practices, the pattern of damage is often regular or uniform within the field. Biotic damage may initially appear random or patchy.
- Pest damage often (but not always) occurs in conjunction with the presence of the pathogen or insect. If no pests are present, consider an abiotic disorder. This can be confounded by the fact that some abiotic disorders promote the development of secondary pests.

Abiotic disorders are not always avoidable but are managed by improving overall growing conditions, avoiding the damaging factors and, when possible, selecting plants that are resistant to abiotic damage (for example, cold-tolerant hazelnut varieties).

Herbicide Damage

Trees can be harmed by accidental exposure to herbicides (Figure 6-61 and Figure 6-62). Careless application, spray drift or leaching into the root zone are common culprits. The severity and type of damage depends on the amount and type of herbicide applied. Slight exposure may have no long-term effects at all. Exposure to soil-borne herbicides that are active over a period of months or even years, however, is far more damaging. Common symptoms of herbicide injury include stunting, yellowing, twisting, bleaching, spotting and burning of leaves and shoots. On hazelnuts, herbicide damage to bark can facilitate invasion by secondary pathogens such as bacterial blight or decay fungi, and the appearance of these pathogens may be the main symptom of injury.

Figure 6-61. Three-year-old hazelnut orchard with stunting and dieback due to application of glyphosate near trees the year of planting.

Figure 6-62. Examples of glyphosate damage to tree fruit. (A) Young apple tree with shortened internodes due to glyphosate drift. (B) Apple tissue with narrow leaves due to glyphosate drift.

It is important for growers to be aware that, unlike with an annual crop, symptoms of herbicide injury to hazelnut trees may not be observed for 1 or more years after it occurred. These symptoms can be magnified if the tree experienced additional stresses in the years following the application, such as winter damage or insufficient moisture. When dealing with unexplained stunting or unusual patterns or incidence of secondary diseases in hazelnuts, do not forget to consider previous years' herbicide applications as a potential cause. Injury from some herbicides, such as glyphosate, can sometimes delay the onset of dormancy and hence cold hardiness of the tree, thus increasing the potential for freeze injury.

Once accidental exposure has occurred, there is little you can do to correct the damage beyond watering, fertilizing and controlling major pests to relieve additional stress to the plant. Prevention is the better practice. Read herbicide labels carefully before use and follow all instructions. To avoid problems caused by spray drift, do not make pesticide applications to hazelnuts (or neighbouring crops) on windy days.

Young hazelnut trees are much more sensitive to herbicide injury than established ones. Some herbicides registered on hazelnuts specify that they can only be applied to established orchards. Follow these instructions carefully. Plastic tree guards are often used on newly planted hazelnuts to help protect them from herbicide damage, among other things, and there can be a tendency for an applicator to be less careful when applying herbicides near them. However, these do not necessarily prevent herbicides from either moving down to the root zone, or drifting up and into the tree guard. When applying herbicides around tree guards, remain cautious about avoiding drift and only use herbicides whose labels specify that they can be applied to young hazelnuts with tree guards. Plastic tree guards can also slow bark development, leading to increased herbicide injury when they are removed. Observations from Oregon also suggest that removing tree guards during times of environmental stress (low moisture, high wind, high sun) can also increase southwest injury to the bark, which can in turn provide an entry point for herbicides. For this reason, spring removal of tree guards is suggested over fall removal.

Take care when applying herbicides, where registered, for sucker control. Do not allow these products to contact green or immature bark. This can damage or kill the bark, creating points of entry for pests or even other herbicides. Note that immature bark can appear brownish at the surface — if green tissue appears after gently scraping the bark with a knife, consider it immature. It is also important to be aware that some hazelnut cultivars (e.g., 'Jefferson') seem to be more easily injured by herbicides than others receiving the same treatment. In Oregon, greater herbicide damage has been reported on micro-propagated trees than on tie-off or conventionally layered trees, possibly due to a slower maturing of the bark.

Use of adjuvants or surfactants with herbicides can make it easier for them to move into immature bark or be taken up by suckers. Always follow label instructions on the use of adjuvants carefully and note that different formulations of the same active ingredient may contain different amounts of surfactant.

One of the most common herbicides used in agriculture is glyphosate, which is sold under numerous trade names. Glyphosate is absorbed by the green tissues of plants and is then transferred to the root system. Symptoms of damage on orchard trees include interveinal chlorosis (whitening) of the new leaves at the growing points, leaf crinkling/cupping/curling or distortion. Leaves may be closer together and cup due to the stunted growth of the shoots. Younger leaves may yellow. Glyphosate can enter a tree and remain internally for several years at sub-lethal levels, making them unhealthy and more susceptible to other pests, which can enter and further weaken the tree.

Many other herbicides, both those registered on hazelnuts or those that drift in from other crops, have the potential to cause injury to hazelnuts. Symptoms of injury are often specific to the particular active ingredient or its mode of action, so a familiarity with the different types of injury can be helpful in identifying the cause. For a gallery of symptoms of injury caused by commonly used herbicides in Ontario, see the Ontario Crop IPM resource at ontario.ca/cropIPM.

Winter Injury and Southwest Injury

Winter injury refers to various types of damage to wood and bud tissues caused when cold temperatures drop to a critical level. Fruit tree cells have complex mechanisms that help them "harden off" or acclimatize for the winter. Short days and colder temperatures in the fall and early winter cause fruit trees to move water from within their cells to the spaces between them. Upon freezing, ice crystals form outside the cells where they do not damage them. Continued exposure to cold temperatures moves trees into deeper dormancy and greater tolerance of very cold temperatures. Winter injury occurs when temperatures drop below the critical level that each species can tolerate. Usually wood is more cold tolerant than flower buds. However, tree trunks near ground level and branch crotches are the slowest to harden off and are the most vulnerable to cold temperatures, as are unhealthy or stressed trees.

Winter injury can be caused by a number of factors, including excessive winds (which desiccate trees), bright sun or high mid-winter temperatures when ground is frozen, alternate freezing and thawing of ground in late winter, heavy snow and ice causing bending and snapping roots, and ice damage to trunks and branches. Many tree species are at risk of winter injury, especially when they are only marginally hardy to the area where they are planted. If winters are particularly harsh, or if there are rapid temperature fluctuations during the late fall or winter, leaf and flower buds can be killed. The effects are often not evident until late spring, when new growth collapses and inner wood appears black to the core. To guard against this, avoid excess fertilization and do not fertilize late in the summer or fall. This will prevent late fall growth and ensure adequate hardening off.

Symptoms of winter injury vary with the crop. For young, thin-barked trees, winter injury takes the form of frost cracks, called "southwest injury" (Figure 6-63). These are long splits in the bark mainly on the south or west side of the trunk due to greater daily temperature fluctuations as a result of sun exposure. Wrapping the trunk with burlap or painting it with a white latex can reduce this problem.

Figure 6-63. Southwest injury.

Nutrient Disorders

Plants require optimal nutrition for growth and development. Too much or too little of a given nutrient can cause a range of symptoms in plants. Many nutrient deficiencies take some time for symptoms to occur, typically appearing at times of very high nutrient demand, such as periods of maximum growth or during nut development. Symptoms can be confusing to distinguish, especially for new growers, and are often mistaken for pest damage. In general, the two can be distinguished by the pattern of damage: nutrient deficiencies are more likely to be uniform and crop-wide while pest issues are more likely to be localized or random.

A nutrient's distinctive deficiency symptoms are related to its function, characteristics and mobility within the plant. Additionally, the location where symptoms first appear is a function of the mobility of the nutrient in the plant. Mobile nutrients (nitrogen, phosphorous, potassium and magnesium) can be moved by the tree to other locations in the plant. When they are deficient, the plant tends to move remaining supplies of that nutrient to new growth, where it is most needed. This causes nutrient deficiency symptoms in older leaves. Immobile nutrients (sulfur, calcium, boron, zinc, copper and iron) cannot be moved by the plant and tend to remain trapped in older leaves. Deficiencies of these nutrients tend to appear first in new growth and hazelnut shoots.

Nutrient toxicity can also occur, when plant tissues receive excess levels of a given nutrient. Nutrient toxicity symptoms are also variable and difficult to distinguish, but can include slower growth or maturity, deeper green colour to leaves, scorching or chlorosis of leaves and downward curling leaves. Additionally, excess levels of one nutrient may interfere with the tree's ability to take up others, thereby causing a deficiency in another nutrient.

Deficiency symptoms of various nutrients are listed below. Once identified, however, rectifying a nutrient deficiency is not necessarily as simple as adding more of that nutrient. If symptoms are delayed or have occurred late in the season after the crop and its growth have already been affected, it may be too late. More importantly, nutrient deficiencies are often not due to a lack of the nutrient in the soil. Many nutrient deficiencies occur because of an antagonistic interaction between nutrients, where they compete for uptake.

This interaction can occur in one of two ways. In one, an excess of one nutrient can block other nutrients from uptake sites on the plant root, making it deficient because the nutrient cannot get to an uptake site. In the second, the excess nutrient is present in high enough amounts that it changes the pH of the growing media, making the other nutrient unavailable to the plant. In many cases, an excess of one nutrient can knock many others out of balance. For example, excess potassium can cause increased availability of iron and manganese while decreasing availability of nitrogen, phosphorous, magnesium, calcium and boron.

Soil pH is also critical to the availability of nutrients to plants. If the pH is too far from the target range for your crop, nutrients will be converted to forms that are not available to the plant. Other factors that limit the ability of plants to take up nutrients include insufficient moisture, restricted root development or the activities of certain pests. **Soil or tissue analysis should be used to confirm what is indicated by deficiency symptoms.**

Common symptoms caused by deficiencies in mobile nutrients (appearing first in older leaves) include:

- **Nitrogen** deficiency will cause leaves to turn light green or yellow (Figure 6-64). This can occur with insufficient nitrogen application but also if heavy spring rain washes nitrogen away and if you use high carbon organic mulches such as fresh wood shavings, which can remove nitrogen from the soil. Decomposed wood shavings will not have this result. In Oregon, when sawdust mulch is used, nitrogen deficiency can occur, so new trees are often planted with a small quantity of slow-release fertilizer to counteract this.

Figure 6-64. Nitrogen deficiency in hops. The plants on the right received adequate fertility while the four plants on the left received no nitrogen.

- **Phosphorous** deficiency symptoms present typically as a purplish-red colour that may be more noticeable on the leaf underside. In severe cases, tips may die back. Excess phosphorous can reduce the crop's ability to take up zinc and iron, leading to deficiencies, yellowing and burning.
- **Potassium** deficiency causes a yellowing and burning of the leaf margins, or an interveinal purpling also beginning at the margin (Figure 6-65), and may cause misshapen fruit or fruit abortion. The leaf margins can then become necrotic (die). Excess potash reduces the plant's ability to remove calcium and magnesium from the soil, causing deficiencies in those nutrients.

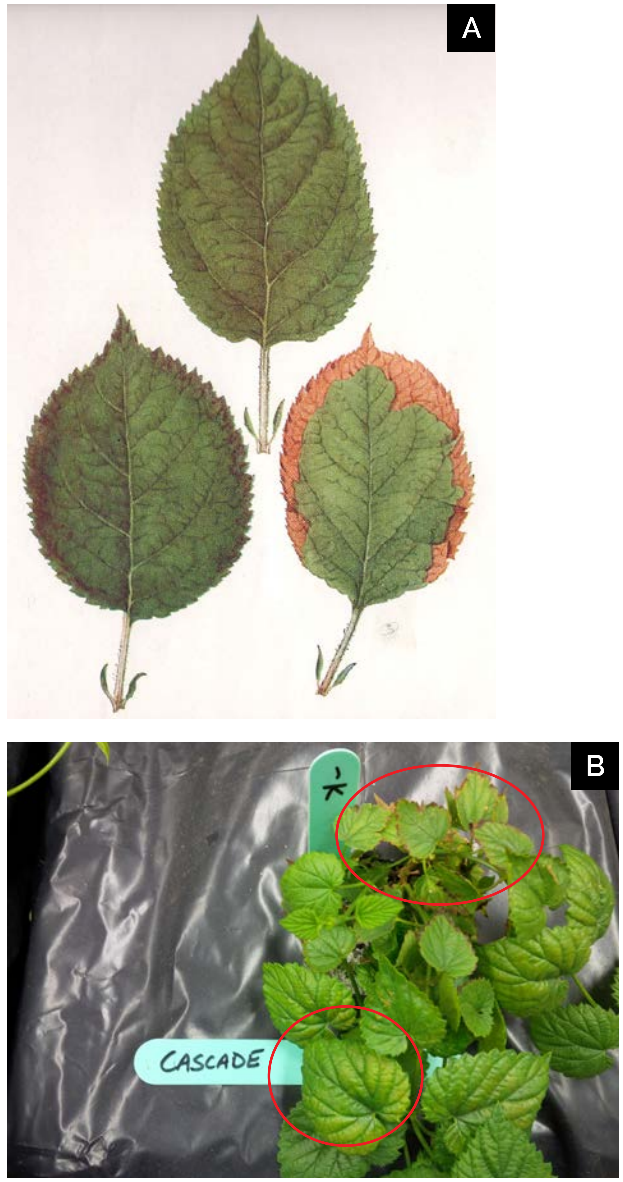

Figure 6-65. Potassium deficiency. (A) apples (note interveinal purpling and scorching/browning of leaf margin) and (B) hops (note the yellowing of the lower leaves and scorching of the leaf margins on the upper leaves).

- **Magnesium** deficiency causes leaf tissue between veins to turn yellow, while the veins remain green (Figure 6-66). Severe deficiencies cause leaf margins to curl. Magnesium deficiencies are common in young hazelnuts in Oregon.

Figure 6-66. Magnesium deficiency in hops.

Common symptoms caused by deficiencies in immobile nutrients (appearing first in younger leaves):

- **Boron** plays an important role in the structure of plant cell walls, fruit set and seed development, and deficiency symptoms vary widely between crops. In fruit and nut trees, boron deficiency can cause leaf chlorosis and necrosis, branch dieback, premature fruit drop, poor nut development or misshapen fruit. In Oregon, foliar applications of boron in mid-May are used to increase nut cluster set. It is not known if this would be required under Ontario conditions. Excess boron can cause leaf burn, so it is important not to over-apply.
- **Manganese** deficiency causes yellowing between veins of young leaves. Leaves gradually turn pale green with darker green patches next to the veins. Manganese toxicity can occur on soils with a low pH. It causes brown spots or yellow mottled areas near leaf tips and along the leaf margins (Figure 6-67). Brown spots may also develop on veins, petioles and stems.

Figure 6-67. Manganese deficiency in grapes.

- **Zinc** deficiencies cause young leaves to become mottled or have interveinal chlorosis (whitish or yellow discolouration between the veins) as a striping or banding. Necrotic spots may appear at the leaf margins or tips. New leaves may be small and cupped upward or distorted. The internodes (length of stem between the leaves) may also be shorter, causing a stunting of the canopy. Zinc deficiencies are most often seen on sandy soils with high pH levels.
- **Calcium** deficiencies can result in the death of a plant's growing point and may cause premature drop of blossoms and bud. Yellow to brown spots may occur on leaves, often at the margins, which may be surrounded by a brown outline. Tip burn or cupping occurs on some plant species (Figure 6-68).

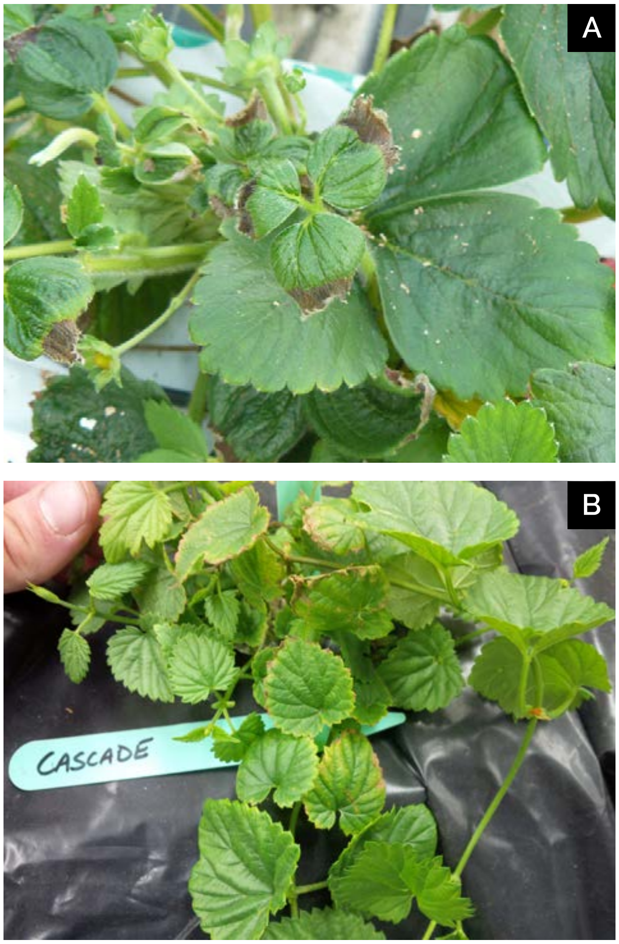

Figure 6-68. Calcium deficiency in (A) strawberry and (B) hops.

- **Sulfur** deficiency is similar to nitrogen deficiency, except that it affects the whole plant. Nitrogen deficiency usually appears on the older leaves first. Affected plants are often stunted and have pale foliage. Maturity may be delayed. Sulfur deficiency is common in young hazelnut orchards in Oregon.
- **Iron** deficiency causes leaves to yellow or whiten between the veins, while the veins themselves remain green except in extreme cases (Figure 6-69). Iron deficiencies are rare in Ontario.

Figure 6-69. Iron deficiency in grape leaves.

7. Weed Management

Weeds are plants growing in an undesirable location. For hazelnut orchards, this usually means plants growing directly under or between trees. Weeds compete with trees for moisture and nutrients. They may also serve as alternate hosts of diseases or insects, provide habitat and protective cover for rodent pests, and, in the case of noxious or poisonous weeds, be harmful to workers. In hazelnuts, high weed pressure late in the season can also interfere with harvest.

Weed Types and Identification

Although weeds are present in every orchard, there can be wide variations between orchards in the weed species present and the density of each population. Scouting and accurate identification of weeds is an important part of integrated pest management in hazelnuts.

It is easy to distinguish between the two main types of weeds: broadleaf (weeds with two cotyledons and broad leaves with variable sizes and shapes) and grassy (weeds with long, narrow leaves with parallel veins). Beyond this, it is important to learn the growth habit of the weed, and target management strategies at susceptible stages.

Weeds have one (or more) of the following life cycles: annual, biennial or perennial.

Annual weeds grow and flower in 1 year. Some weeds in orchards are winter annuals, i.e., they begin their growth in the fall, forming a rosette, and flower the following spring or summer. Annual weeds compete for nutrients and water as they grow near crops. After they flower, they die, however, their seeds may cause recurring problems for several years by forming a soil seed bank.

Common types of annual weeds include barnyard grass, common chickweed, crabgrass, downy brome (grass), lamb's quarters, pigweed species, ragweed species and smartweed species.

Biennial weeds have a 2-year life cycle, producing leaves in the first year and flowering in the second year. As with annual weeds, they compete with crops they grow near, die after flowering and leave seeds that may cause recurring problems by forming a soil seed bank.

Common types of biennial weeds include burdock, buttercup, pepper grass, wild carrot, wild parsnip and yellow rocket.

Perennial weeds live for many years, and generally establish from various types of root systems, although many will also spread by seeds. They usually flower every year as well as expand their root system, which allows them to spread by both methods through fields. Perennial weeds can be very competitive, especially if they grow in thick patches.

Common types of perennial weeds include Canada thistle, creeping Charlie, dandelion, field bindweed, hedge bine, milkweed, plantain, poison ivy, quackgrass, wild grape and yellow nutsedge.

For information on identification of weeds, see the following resources:

- OMAFRA Crop IPM, Weeds and Weed Management at ontario.ca/crops
- Ontario Weed Gallery (ontario.ca/omafra search for Ontario Weed Gallery)
- www.weedinfo.ca
- *Weed ID Guide for Ontario Crops*: To download or order this field guide, type the term "Weed ID Guide for Ontario Crops" into your search engine browser.
- *Problem Weed Guide for Ontario Crops*: To download or order this field guide, type the term "Problem Weed Guide for Ontario Crops" into your search engine browser.

Weed Management

Weeds tend to be a more significant problem in younger hazelnut orchards, where high light penetration through small trees promotes the growth of weeds. Mature orchards, where shading inhibits weed establishment, have fewer weed problems, provided good weed control practices have been in place since the orchard was established. Additionally, in hazelnut orchards, very dense weed cover towards the end of the summer (for example, in seasons with very wet conditions) can interfere with nut harvest. Weed management in hazelnuts generally involves application of registered herbicides along the tree row and flail-mowing in between the rows.

Cultural Management Practices

Establishment of a mowed, grassed area in between the rows is used in many orchards to help suppress weeds (Figure 7-1).

Figure 7-1. A combination of a mowed, grassed area between rows and a weed-free strip along the tree row is commonly used in hazelnuts to manage weeds.

Mulching along the tree rows can also be used to reduce weeds, while also providing other benefits such as improving soil structure and reducing moisture loss. This can be especially useful in young orchards, which have fewer herbicide options registered (Figure 7-2). Mulches such as sawdust, wood chips, straw or compost should be placed in a layer 7.5–10-cm thick along tree rows, leaving a gap 60–90 cm away from the tree trunk. Note that organic mulches can promote rodents. Mulches also tie up soil-applied herbicides and reduce their effectiveness. Avoid weed seeds in mulch. Monitor nutrient levels in trees as the mulch breaks down. Any excess mulch remaining on the trees when they begin bearing nuts could interfere with harvest and would need to be removed by flailing (mowing) or other means.

Figure 7-2. Mulch is sometimes used in young hazelnut orchards to help suppress weeds.

Flail mowers chop vegetation close to ground level, while also helping to mulch debris remaining around the trees. Repeatedly mowing the orchard floor between tree rows to no more than 0.6 cm of the soil level generally provides good weed control between the rows. Begin mowing in early spring once the ground dries out, and repeat 4–6 times per season (Figure 7-3), finishing with a final run prior to harvest to prepare the orchard floor for harvest (see Chapter 8: Harvest and Postharvest Handling, for more information).

Figure 7-3. Flail mower in hazelnut orchard. For hazelnuts, mowing vegetation between the tree rows to within 0.6 cm of the soil 4–6 times per season, beginning in early spring, generally provides good weed control.

Irrigation management can also influence weed populations (Figure 7-4). When soil moisture is abundant, the impact of weeds on crop yield loss and plant growth is reduced. Drip irrigation is preferable over overhead irrigation because water is targeted at crop roots rather than at the shallower weed roots. Excess overhead water or rainfall, however, can promote the growth of weeds.

Figure 7-4. Early weed escapes in the planting year compete with young trees for moisture and nutrients. The addition of water through irrigation (note irrigation tubing) allows trees to tolerate more weed competition.

Herbicides

How Herbicides Work

Herbicides registered for orchards kill weeds in several ways, but there are three broad categories of control methods:

- Burndown (contact) — The herbicide is applied to existing vegetation and kills the top growth. The herbicide is directed under the trees to create a weed-free strip and/or applied to the row alleyways. Some burndown herbicides are systemic — they are absorbed into the weed and move to the growing point and/or the roots, and give longer-term control for perennial weeds. Other burndown herbicides are not systemic and target only above-ground green tissue. These do not give long-term control of perennial weeds.
- Soil residual (pre-emergent) — The herbicide is applied to the soil surface before weed seedlings germinate. The chemical remains in the soil for several weeks to months, killing germinating seedlings. Generally, a rainfall of at least 12 mm is required to activate the herbicide, resulting in a longer period of control.
- Post-emergent (selective) — These herbicides kill only certain weeds of existing vegetation (e.g., grasses only or broadleaves only). These are usually targeted for weed escapes or for problem weeds such as thistles or annual grasses.

Advantages and disadvantages of using each type of herbicide are summarized in Table 7-1.

Table 7-1. Advantages and disadvantages of herbicide control categories

Herbicide	Advantages	Disadvantages
Burndown	• controls all emerged weeds • inexpensive • widely available	• may damage trees if absorbed (systemic) • early weeds compete with trees • perennial weeds not killed • new seedlings germinate after application
Soil residual	• reliable control • effective for longer periods • cost effective • broad spectrum • longer window to apply	• may cause tree injury • not safe on low organic matter soil • may have tree-age restriction • may leave residues after orchard removal • may require incorporation • applied before weed problems are known • may affect soil microbes
Selective	• targets specific weeds • minimizes herbicide use • generally safe for trees	• does not control a broad spectrum of weeds • often requires an extra application • is an additional expense • requires critical timing

Herbicides for Ontario Hazelnuts

When selecting herbicides for use on hazelnuts, select only products that are labelled for use on hazelnuts in Ontario, and ensure you closely follow the label for any restrictions on use such as tree age or soil type. For example, some herbicide labels specify that they should not be used on young trees. It is important to follow these instructions to avoid risking crop injury.

Application of products that are not registered on hazelnuts is not only illegal, but also puts a grower at risk of damaging the crop. While many Ontario growers look to the U.S. for information on production and weed management, it is important to be aware that some herbicides registered on hazelnuts in the U.S. or other countries are not registered on hazelnuts in Canada and therefore are not legal to use here. Additionally, even when herbicides are registered in both countries, U.S. labels can have different rates or use patterns. Ontario hazelnut growers must always follow the Canadian label instructions.

Herbicide registrations change frequently and consequently are not listed in this publication. For a current list of herbicides registered on hazelnuts in Ontario, refer to the resources listed in Appendix B.

Herbicide Resistance

Herbicide-resistant weeds are an increasing problem for Ontario growers. Herbicide resistance refers to the ability of a plant to survive a herbicide treatment that previously killed it. Resistance occurs when the same herbicide is applied in the same field, year after year. The resistant weeds set seed and may eventually dominate the population, which is then not effectively controlled by the herbicide.

Herbicide resistance has been documented in numerous locations across Ontario. Resistance has been reported in over 20 weed species to one or more of the following herbicide groups: 1, 2, 4, 5, 6, 7, 9 and 14. A major concern is the increase in glyphosate-resistant weeds in Ontario, including giant ragweed, Canada fleabane, common ragweed and waterhemp. For more information on areas with herbicide resistance, search for “herbicide resistance” on the OMAFRA website at ontario.ca/crops.

To delay the development of herbicide resistance, use the following strategies:

- alternate between herbicides with different modes of action (indicated by the herbicide group number on the product label)
- only use herbicides when necessary, and use labelled rates
- employ other non-chemical tactics such as cover crops and mulches to reduce weed seeds in soil

Strategies for Integrated Weed Management in Hazelnuts

Pre-plant Year

Managing weeds the year prior to planting reduces weed problems later in an orchard's life. Application of general burndown herbicides after weed growth has begun in the pre-plant year can help reduce the weed load, however, ensure these herbicides will not carry over and damage young trees. Hard-to-control perennial weeds such as dandelion and thistle are often best controlled at this stage.

Using the pre-plant year to build organic matter with a green manure crop can also give opportunities to reduce weed pressure. Choose a crop that grows thickly and suppresses annual weeds, and plant it after application of the general burndown herbicide. With grassy covers, selective herbicides may be required to control broadleaf perennial weeds.

Planting Year

Weed competition in the planting year can drastically reduce the growth of tree fruit (Figure 7-5). Figure 7-6 shows the impact of weed competition on growth of newly planted apple trees during the first 3 months from planting in May until July. The herbicide treatment maintained a complete weed-free strip from May until July and resulted in the most tree growth. Trees in the hand-weeded control treatment had less growth, because of some weed growth between hoeings, emphasizing the need to maintain a weed-free area. Other research shows this effect remains with the tree for many years.

Figure 7-5. Severe stunting in a 1-year-old hazelnut orchard that had no mechanical or chemical weed control the season after planting. Weed pressure is so high that the trees can barely be seen (arrows).

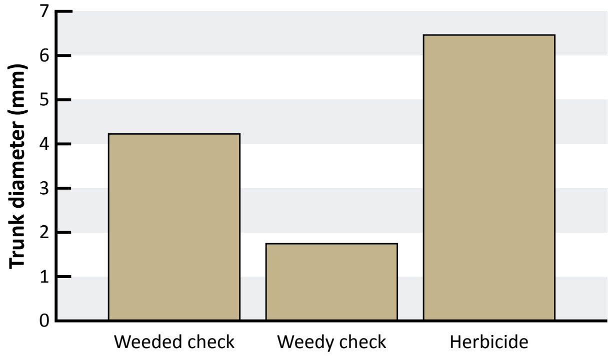

Figure 7-6. Weed competition effects on new apple trees. Weeds competing with newly planted apple trees caused severe growth reduction in only 3 months. (*Unpublished, Harrow 1990*)

After tree planting, it can be very challenging to maintain a weed-free strip under small trees, however weed control efforts in the early years of an orchard will pay off in increased establishment, tree vigour and early yields.

Establish a weed-free band in the tree row that extends beyond the drip line of the tree and maintain this weed free for at least the first 3 months after planting. Apply mulch, if you are using it, and plan on spot-treating any weeds that break through the mulch. Herbicides applied during the pre-plant year may provide some weed control during the first few weeks after planting, however, due to limited shading by young trees, weed escapes are likely to begin by early summer. Use a selective herbicide, where registered, and cultivate or hand hoe to keep the tree rows clean until later in the summer. Ensure young orchards are receiving adequate moisture through irrigation or rainfall to reduce both competition with weeds and stress on establishing trees.

Herbicides and Young Trees

Use extreme caution when applying herbicides to very young hazelnut trees. Several products labelled for use on established trees can be quite damaging to very young trees. Closely follow label instructions regarding use on young trees. Herbicide damage to young trees may not be immediately obvious. In some cases, symptoms may not show up for 1 or more years. In others, the tree is only weakened by the herbicide, making it more susceptible to damage by disease or insect pests, which may ultimately kill the tree several years later. In several Ontario orchards, deaths, dieback stunting and distortion of leaves of 2–3-year-old trees have been linked to herbicide damage in the year of planting (Figure 7-7). Even when herbicides are permitted for use on young trees, exercise caution to ensure herbicides do not come into contact with leaves or tender green tissue through direct application or drift. For information on avoiding herbicide drift, search for “herbicide drift” at www.sprayers101.com.

Figure 7-7. Two and three-year-old hazelnut trees with stunting and dieback due to glyphosate drift in the year of planting. In this case symptoms took 1 to 2 years after application to appear.

Tree Guards

Many growers use tree guards on freshly planted hazelnuts to protect them from herbicide drift, as well as sunscald and rodent damage (Figure 7-8A). Some herbicides require that tree guards be used if they are to be applied to newly planted trees. However, it is important to remember that tree guards will not provide 100% protection from drift, nor will they prevent systemic herbicides from entering the tree through the roots, so herbicides whose labels specify they are not to be used on young trees should be avoided even when using tree guards. Tree guards also create a warm, moist environment that can provide habitat for rodents and promote the growth of disease or decay fungi and can make sucker control within the guards more challenging (Figure 7-8B). Tree guards should be removed within 1–2 years of planting to avoid these negative effects.

Figure 7-8. (A) Plastic tree guard on young hazelnut tree. (B) The warm, moist environment within a tree guard can promote the development of decay fungi or hazelnut diseases such as bacterial blight. Photo 7-8B Source: Barb Yates, Ferrero Canada.

Established Orchards

Weed control will continue to be important for several years after planting. As trees mature, more herbicides can be used in hazelnut orchards. Herbicides are typically applied early season and again mid-season. Once trees begin to bear nuts, flail-mowing is often required 30 days before harvest to ensure weeds do not interfere with harvest. See Chapter 8: Harvest and Postharvest Handling, for more information. A registered soil residual herbicide can also be applied in the late fall after harvest.

8. Harvest and Post-Harvest Handling

Once nuts reach full size and shells have hardened, the ripening process occurs. Nuts change colour from the base upwards and the nut begins to separate from the husk. Husks mature and dry, gradually opening to release the nut (Figure 8-1). Ripe nuts usually fall for 2-4 weeks, with the timing varying by cultivar. In Ontario, hazelnut harvest usually begins in late August or early September and lasts up to 6–10 weeks, depending on the varieties being grown and environmental conditions of the orchard, with final harvest sometimes extending to late October.

Figure 8-1. Hazelnuts are beginning to ripen and husks are drying back.

Preparing for Harvest

Orchard floor preparation is necessary, particularly prior to mechanized harvest, to ensure an efficient harvest and minimize contamination of harvest bins with extraneous debris. Just prior to nut drop, flail or mow the orchard ground cover low to the soil so the fallen, ripe nuts can be easily harvested. Blank nuts often fall prior to healthy nuts and a final flailing after blanks have fallen but before good nuts begin to fall can help prevent blanks from mixing with good nuts.

After flailing, a weighted roller can flatten the orchard floor firmly to remove small ruts and bumps and create a smooth surface. Having flat ground allows the sweeper paddles or brushes on the harvester to efficiently pick the hazelnuts off the ground as it passes. Ensure there are no bumps or depressions in the orchard floor and remove any mounds of soil immediately around trees.

Squirrels and other vertebrate pests will eat ripening nuts before they fall to the ground. In orchards with high vertebrate pressure, control these pests well in advance of harvest to avoid losing nuts prior to them falling to the ground. For more information, see the section *Vertebrate Pests* in Chapter 6: Insects, Diseases, Wildlife and Disorders.

Service and inspect all equipment and machinery used for harvesting, storage and transportation of hazelnuts before the start of harvest to prevent contamination and to avoid potential working hazards. Clean the harvester frequently during the harvest season to prevent or reduce the spread of insect pests, diseases and weed seeds between orchards and orchard blocks.

Harvesting

Hazelnuts are harvested once they are ripe. Growers typically wait for the ripe nuts to fall naturally without shaking them from branches. Fully ripened nuts can be encouraged to fall with a gentle shaking of branches in small orchards. Harvest nuts as soon as possible — don't leave them on the ground for more than a few days. Quick and efficient harvests will help prevent spoilage moulds in kernels and reduce feeding loss by rodents, birds and other wild animals. Rainy, wet weather can hamper harvest operations and increase the incidence of mould in kernels. Try to avoid nuts remaining on wet soil, and to complete harvest before the onset of heavy rains.

Hazelnuts can be harvested by hand or mechanically. Harvest type depends on the size of the orchard, available equipment and marketing objectives.

Hand Harvest

In smaller orchards, nuts can be collected by hand into small portable containers or bags, such as in a pick-your-own operation or by a small harvest crew. For workers who prefer to remain standing, hand-operated "Bag-a-Nut" harvest aids can collect nuts of various sizes into rotating wire baskets. Several growers are testing netting spread under the canopy to collect nuts as they fall (Figure 8-2). Ripe hazelnuts that fall into the netting can be collected by hand or vacuumed up into containers. Netting can be raised off the ground to keep nuts clean of soil or rain-splashed mud and allowing them to dry more quickly.

Figure 8-2. A small-scale net harvest test. (A) Ripe hazelnuts fall into netting spread out under the tree. (B) Netting is raised off the ground to keep nuts clean.

Mechanized Harvesting

For medium and large commercial orchards, the most efficient method of harvest is to use machine harvesters (Figure 8-3). Mechanized harvesters operate using sweep collection or vacuum collection. In Oregon, specialized equipment first separates fallen hazelnuts from leaves and twigs using powerful fans and directional brushes that collect the nuts into long windrows. A sweep harvester then follows to collect the nuts from the windrows into bins for transport to post-harvest handling facilities. Mechanical sweep harvesters make three or more passes through each orchard block as the ripened nuts fall over a 2–3-week period, within each crop variety.

Figure 8-3. A compact harvester picking up ripe hazelnuts under trees. The rotating sweep paddles extend underneath the large canopy.

Nuts should be moved to a post-harvest processing area or facility as soon as possible after harvest. Avoid leaving harvested nuts in the rain, as this can increase the incidence of kernel mold. Store hazelnuts in clean, open and drained plastic containers that are dedicated strictly to tree nuts. To prevent cross-contamination of allergenic proteins to non-nut foods, do not store other foods in nut containers.

Post-Harvest Field Management

After harvest is completed, flail-mow the orchard to clear or pulverize any remaining nuts, twigs and branches that can carry over wood diseases and kernel moulds and attract mice and voles into the orchard. Keep the ground cover mowed short until late fall to encourage natural predators and discourage mice and voles from inhabiting the orchard during winter.

After hazelnut trees are fully dormant and leaves have fallen, a registered herbicide can be carefully applied in tree rows to manage overwintering perennial and biennial weeds. If required, fall applications of fungicides or bactericides can be made to manage tree diseases that may be active at this time. For a list of registered products, refer to the resources listed in Appendix B. Always use products according to label directions.

Before snowfall, install an adequate number of rodent bait stations per hectare and fill with fresh bait (if registered for use on hazelnuts) to control mice and voles under the snow during winter. See Chapter 6: Insects, Diseases, Wildlife and Disorders, for details on rodent control.

General Post-Harvest Practices for Hazelnuts

After harvest, nuts must be washed, sanitized, dehydrated and placed in storage until they are ready for marketing (Figure 8-4). Post-harvest operations are separated into three groups:

1. Operations that clean, sanitize and dehydrate the in-shell nuts before they are stored.
2. Operations that keep in-shell product for long-term storage.
3. Operations that shell (crack open), package and ship the nuts to market and supply secondary manufacturers/processors.

These operations and other value-added processing steps, such as roasting, coating or seasoning, may take place on-farm or at a central processing facility.

Growers in regions with larger hazelnut industry, such as Oregon and British Columbia, often do not clean and dry their crops, as there are numerous processors available to do that for them. These facilities are not as widely available to Ontario hazelnut growers, since the industry is still small.

All post-harvest operations should follow food safety and traceability guidelines. For information on these guidelines, refer to Chapter 9: Food Safety.

Figure 8-4. Hazelnuts ready for fresh market or value-added products.

Cleaning

At each stage of post-harvest handling, the nuts become progressively cleaner, so it is important to separate each stage of the process in a linear flow to prevent cross-contamination. Much of the dirty work can be completed outside to help keep the processing facility and the final product-handling processes cleaner. For traceability and marketing purposes, hazelnuts are handled in batches to maintain separation of cultivars and the precise location or orchard block where each batch was grown. A batch system and traceability program is also ideal for small growers.

Harvested inshell nuts are transported to and unloaded at the primary handling or processing facility. First, soil, leaves, twigs and other debris are removed from the nuts. Nuts that do not fall free from the husk must be de-husked. This is achieved by passing the harvested crop through a specialized de-husking machine. Bulk bins or containers with grated bottoms help remove debris, and washwater can drain out freely. These types of bins allow air to circulate between the nuts, which helps with drying. A rotating grated cylinder is commonly used to remove loose soil and debris and provide an initial wash of hazelnuts as they arrive from the orchard.

Hazelnuts are thoroughly washed in open-top tanks, using washwater practices similar to fresh produce. It is necessary to wash and clean inshell hazelnuts in advance of the sanitizing procedure, otherwise the sanitizer will not be able to sanitize the hazelnuts properly. Sanitizing inshell nuts is important to reduce contamination on the surface of the shells. Consult with OMAFRA food inspection specialists for advice on cleaning and sanitation practices.

Drying

Inshell hazelnuts are dried to 5%–8% kernel moisture content, which allows for proper storage in a dried state, while also preventing the nuts from becoming rancid or mouldy. The harvested nuts should be dried within 24 hr of harvest to prevent mould. Optimal drying temperatures are 32.2°C–38°C. At this temperature, it takes 2–3 days to reduce the moisture level from field condition down to the required 5%–8%. During the drying process, the internal colour of kernels gradually changes from white to cream, starting from the outside. Meters can be used to precisely measure the moisture content.

Nuts are usually dried in permanent bulk dryers or portable bin-type dryers. Recently, wood-fired driers have become available to dehydrate nuts; they can also be used to burn waste nut shells from cracking operations. The amount of heat necessary to dry hazelnuts to 5%–8% moisture content is relatively small. There is no need to purchase expensive equipment. For a small farm operation, a homemade fan-powered box dryer can work. Many inexpensive, efficient dryers have been made by remodelling a modern tobacco kiln, a grain dryer or an old building already on the farm. If the crop is small, dry hazelnuts by spreading them out in a thin layer in a dehumidified room, protected from rodent pests.

As soon as the nuts are dried to an inshell moisture content of 5%–8%, or a cracked-out kernel moisture content of 3.5%–4.5% grade, seal them in plastic-lined, airtight boxes, bags or bins and move them into long-term storage. The plastic liners will stabilize the moisture content, prevent the absorption of flavours and odours from other products, and protect the kernels from oxidative rancidity and self-heating. Kernels can be vacuum-packaged and sealed into plastic bags of various sizes to prevent oxidized off-flavours of nut oils, then placed into cold storage to extend shelf life (Figure 8-5).

Figure 8-5. A commercial vacuum packaging unit is used to maintain kernel quality and prevent oxidation of nut oils during cold storage.

Storage

The long-term storage facility can be a large part of the primary processing facility. This is where the nuts will be held until they are shelled (cracked) or shipped to other manufacturers. One tonne of inshell hazelnuts or one tonne of kernels (no shells) will occupy 2.5–3.0 m^3 of storage.

Since nut storage is the interface between the field cleaning operations and the clean cracking and packaging operations, it is important to implement steps to minimize cross-contamination. Ensure storage facilities are clean and dry, well-ventilated, and able to maintain temperature and humidity at levels appropriate for hazelnuts. Storage areas must also be protected from rain and kept free of insects, rodents and birds.

Keep the nuts away from light, such as ultraviolet light, which causes the kernels to become rancid faster and to heat up. This leads to unpleasant off-tastes and odours that reduce the shelf life and value significantly. UV light can also reduce oil yield and change the composition of the oil. More free fatty acids are produced in affected kernels, which makes it harder to decolour and blanch the kernels.

The storage life of hazelnuts depends largely upon the temperature. Nuts can be stored for longer periods at cooler temperatures. Store hazelnuts below 10°C, with 60-65% relative humidity. Hazelnuts stored at room temperature and exposed to air can turn rancid within a few weeks. For food safety purposes, the aflatoxin-producing species, *Aspergillus flavus*, cannot grow or produce aflatoxin at relative humidities below 70% and temperatures less than 10°C. While stored at 0°C–1.7°C, with 60%–65% relative humidity, hazelnuts will keep for up to 2 years.

Since dehydrated hazelnuts have a very low water content, they can be frozen in the shell or as kernels. When stored at -3.9°C to -2.8°C, with 60%–65% relative humidity, hazelnuts may be kept in bulk for up to 4 years.

The use of controlled atmosphere (CA) storage will provide superior long-term storage of hazelnuts. A low oxygen concentration (example 2%) in storage air will prevent oxidation of fats and oils (rancidity), minimize respiration of nuts and prevent infestation by all storage pests. High carbon dioxide (e.g., 20%) will reduce hazelnut respiration to maintain quality and prevent storage pests. The remaining atmosphere in a CA storage is inert nitrogen gas.

Cracking, Sizing and Packaging

Once the nuts are removed from storage, they can be either packed and immediately shipped, or the kernels can be cracked out of the shells and then packed and shipped. It is a best practice to remove the shells or process the kernels immediately before being sold, because the kernels degrade faster once they are removed from the shells.

Consider adopting size-grading standards that are currently recognized by other countries, such as the U.S. standard grades for minimum and maximum nut diameter, as shown in Table 8-1.

Table 8-1. U.S. Standards for Grades of Filberts in the Shell - size classifications.

Size Classification	Maximum Size (mm)	Minimum Size (mm)
Round type varieties		
Jumbo	No maximum	22.2
Large	22.2	19.4
Medium	19.4	19.0
Small	19.0	No minimum
Long type varieties		
Jumbo	No maximum	18.6
Large	18.6	17.5
Medium	17.5	13.5
Small	13.5	No minimum

Adapted from *United States Department of Agriculture Filbert/hazelnut Kernels and Filberts in the Shell. Inspection Instructions. August 2016.*

To reduce the number of broken kernels, separate the nuts by size through a size-grading machine before they are cracked. The cracking rollers can be adjusted to receive the various sizes of nuts in batches so that nuts are lightly cracked and fewer kernels are damaged. Following cracking, a winnower machine separates kernels from shell fragments using a blower fan, where shell fragments are blown upwards and the kernels fall by gravity into collection bins. Once the kernels are separated from the shells, inspect samples of nuts visually to remove kernels with defects and broken kernels, and to determine and record the quality of each batch.

After the final inspection, pack and ship the kernels. The packaging will vary according to the specifications of the buyer. This can be from small packages for immediate retail sales, large boxes for loose retail sales to large 1-tonne tote bags for further manufacturing.

As there is no established Canadian grade for hazelnuts, in North America the U.S. grading system can be used as a guide. These specifications can be found on the United States Department of Agriculture website www.ams.usda.gov/grades-standards/filberts-shell-grades-and-standards. As of the time of writing, the most recent standards were published in 2016. The standard "U.S. No. 1" grade consists of hazelnuts inshell that are:

- at least medium size (19.0–19.4 mm)
- less than 20% of a different type (round nuts versus long oval nuts)
- less than 10% defective nuts, provided that less than 5% are poorly filled or blanks and not more than 5% of rancid, decayed, mouldy or insect injured, including not more than 3% with insect damage
- less than 15% of nuts off size, with less than 10% undersized

U.S. No. 1 grade kernels (no shells) includes:

- not more than 0.0002% of foreign materials
- not more than 5% kernels below grade, including not more than 2% mouldy, rancid, decayed or insect damaged

Note: It is possible that a Canadian grade may be established in the future if the Ontario hazelnut industry expands sufficiently.

Shipping

Hazelnuts can be shipped in ventilated shipping containers, providing that water content, packaging and transport conditions (temperature, relative humidity and protection from storage pests, including insects, rodents or other contaminants) of nuts comply with federal and provincial regulations. Protect the cargo against solar radiation to prevent nuts from becoming rancid or self-heating. In damp weather, protect the cargo from moisture, since it may lead to mould, spoilage and self-heating as a result of respiratory activity.

To ensure safe transport, secure the bags in such a way that they cannot slip or shift during transport. Pay attention to the packing pattern of the bags to allow proper cargo ventilation and reduce stack pressure.

Nuts intended for import or interprovincial trade are regulated by the Canadian Food Inspection Agency under the Safe Food for Canadians Regulations. Inshell nuts that are packaged, labelled, transported, advertised or sold by non-federally licensed establishments in Ontario are regulated by Ontario Regulation 119/11 under the *Food Safety and Quality Act*. For more details, consult the OMAFRA Food Safety Inspection Branch at 1-877-424-1300.

9. Food Safety

Regardless of the crop-related activity (production, harvest or post-harvest), follow safe food handling practices. Food safety can be viewed as a partnership among all players involved in production, from input suppliers, farmers, post-harvest handlers, manufacturers, distributors, retail and government agencies. Consumers, both domestic and international, have an expectation that their food is safe.

Prevention, reduction or elimination of potential biological, chemical and physical food safety hazards must be a priority during hazelnut production and processing. The most common human health risks associated with hazelnuts include *Salmonella* and *E. coli*, which usually originate from animal waste and aflatoxins caused by fungal contaminants, primarily from mould in kernels (Figure 9-1).

Figure 9-1. Mould on harvested hazelnuts. (A) Mould forming on shells of nuts that were wet at harvest. (B) Mould on kernels may persist even after blanching. Source: Dr. Jay Pscheidt, Oregon State University.

Injury to a kernel caused by an insect pest or other source during the growing season can lead to secondary decay by fungal contaminants after harvest. Moulds can produce mycotoxins, which are closely monitored by provincial food safety programs. Consequently, effective pest management programs in orchards can be directly related to food quality and safety. Take proactive steps to prevent and manage these and other potential risks during all stages of the production and processing of hazelnuts.

Hazelnuts and other tree nuts contain allergenic proteins, which are a hazard to people who have sensitivities or allergies to tree nuts. Tree nuts must be kept separate from other non-nut foods that may be produced at a farm. All equipment that contacts hazelnuts (e.g., used for harvest, storage, processing, etc.) should be dedicated as "nut use only." Facilities that receive, handle, process, package or store hazelnuts, should dedicate an area to "nut only" and maintain physical separation and/or segregation between this and other non-nut handling or farm produce areas of the facility (if applicable).

Good Agricultural Practices (GAPs)

Food safety begins in the orchard with the implementation of good agricultural practices (GAP). GAPs consider all aspects of production, including selecting the most appropriate site for the orchard. When selecting a new orchard site, consider previous land use, nearby industrial sites and adjacent land uses (e.g., livestock yards or manure storage sites). The surrounding environment can be a significant contributor for potential cross-contamination. If irrigation water is used, assess the risks for potential contaminants prior to use, such as those introduced by manure runoff or animal access. Irrigation water testing can also be used as an assessment tool. It is a best practice to exclude animals from water sources and from the hazelnut orchard. Do not permit livestock to graze in an orchard during the production and harvest periods due to the added risk of contaminating fallen ripe nuts with manure. Ensure pest control and other crop protection are registered for use in Ontario on the problem and the crop you are targeting, and always use them as directed on the product label. It is very important to ensure that harvesting equipment is clean and sanitary, and personnel maintain appropriate hygienic practices, especially during harvest.

Good Manufacturing Practices (GMPs)

Food safety hazard management at the processing facility includes all aspects of the process, from the design and construction of the building, to how the processes are controlled within the building. Prevention, reduction or elimination of potential food safety hazards must be a priority during hazelnut processing.

To create a safe food-processing environment, establish practices that reduce or prevent contamination introduced by the surrounding environment, people and/or their activities. Collectively, these practices are commonly called good manufacturing practices (GMPs). They can also be referred to as prerequisite programs (PRPs), preventive control programs (PCPs) or best management practices (BMPs). GMPs include personnel practices, receiving, shipping, handling, storage, packaging, cleaning and sanitation, preventive maintenance, calibration, pest control, waste management and other activities within the processing facility.

The Consumer Brands Association (formerly Grocery Manufacturers Association) in the U.S. has developed two food safety resources for nut processors — *Industry Handbook for Safe Processing of Nuts* and *Control of Salmonella in Low Moisture Foods Guidance Document*. Both are available on their website www.consumerbrandsassociation.org. This is a U.S. website. Always ensure that any regulations or regulated products mentioned here are permitted in Canada.

For additional detailed food safety information, email OMAFRA food safety staff at foodinspection@ontario.ca.

Consideration must be made for all federal and provincial regulations and acts that are applicable to the process, including post-harvest activities. For additional information, consult:

- *Food and Drugs Act* and Food and Drug Regulations (www.laws-lois.justice.gc.ca/eng/regulations/C.R.C.,_c._870)
- Safe Food for Canadian Regs (www.laws-lois.justice.gc.ca/eng/regulations/SOR-2018-108)
- O. Reg. 493/17 Food Premises under the *Health Protection and Promotion Act* (ontario.ca/laws/regulation/170493)

Whether these regulations apply depends on the activity being carried out and where it is being carried out. Contact the federal government and local public health units directly for specific information.

Building and Water Regulations

All buildings and equipment must conform to all pertinent regulations and safety standards. Consult your municipal Planning Department and the Ontario Ministry of Labour before you design your processing plant.

Facility design and construction should discourage pests and external contaminants from entering or remaining inside the buildings. Internal building surfaces must be cleanable (Figure 9-2).

Equipment should be constructed of materials that are compatible with the product, and the design should accommodate easy cleaning and sanitation, in addition to regular maintenance.

Figure 9-2. An on-farm nut cracking and processing facility.

The ceiling, walls, floor and all equipment should be constructed of materials that can be cleaned and sanitized (Figure 9-2). All food-handling equipment that directly contacts food should be made of food grade material. Ensure staff receive food-handling training.

Process flow through the facility for the nuts and any nut byproducts should move from receiving raw/dirty product through to finished/cleaned product and shipping. Process ingredients, packaging materials, personnel and waste material should move in the same direction as the product. This maintains a clean, sanitary environment and reduces the risk of cross-contamination within the facility and of the final product. Operationally different or incompatible activities should be segregated or kept separate to reduce the risk of cross-contamination. For example, product grading/sorting (raw/dirty) and final packaging materials (clean) must be kept separate.

Processing facilities must plan for a water supply and a water disposal method. Facilities in or near urban areas can choose to access (and pay for) municipal drinking water supplies and municipal sewer services. In rural areas, processing facilities access water by developing on-site supplies such as wells. Facilities that draw more than 50,000 L on any day will require a Permit to Take Water from the Ontario Ministry of the Environment, Conservation and Parks (MECP). Waste processing water must be managed, and most methods require approval from MECP through an Environmental Compliance Approval (ECA). Some municipalities will approve food processing plant septic systems if the daily wastewater volumes are under 10,000 L per day. Consult your local office of the Ontario Ministry of the Environment, Conservation and Parks for more information about water regulations.

Food Traceability

What Is Food Traceability?

Food traceability is the ability to track a given food or ingredient from its point of production (e.g., the farm) through processing, manufacturing and transportation to retail and sale to consumers. It is a common expectation that an operator can complete full traceability. Effective, full traceability requires the operator to have the capacity to trace products and product-related items "one-step forward and one-step backwards." Primary food producers are encouraged to have a traceability program in place for foods produced on the farm, consisting of lot codes and recordkeeping.

Commercial nut orchards are well suited for effective traceability. Each orchard can be identified by the varieties that are grown in detailed block maps of the property. Many orchard operators have established a map and coding system for their orchards to enable detailed records to be kept of all activities. These activities should include agricultural inputs such as fertilizer, pest and weed control products (including their purpose, dates, rates and weather conditions), harvest activities and other important factors that may impact the crop.

A food traceability program can be added to existing orchard maps and block identifiers that will enable the coding of each block (or batch) of hazelnuts as they are harvested. The identifying code will follow each batch of hazelnuts from post-harvest handling through to storage, to shipping. A code affixed onto each bulk storage container will tell the farm operator the variety and the block location where it was grown.

In addition to the container labels, detailed records are kept (hard copy or computer) that will allow growers to track the hazelnuts after leaving the farm (**one step forward**). If a food safety or quality issue arises after leaving the farm, an effective traceability system can help the grower quickly determine the location of each batch and where products have been marketed, by accessing their records.

Growers can add other information to their recordkeeping and traceability program that will help them manage the business, increase efficiency and reduce risk. Tracing products or product-related items such as inputs (**one step back**) means keeping information that identifies where inputs have been sourced from, the quantity and when they were received. Examples of input items include nursery stock or seedlings, new storage containers, sanitizing products, pest control and fertilizer products. Information about the supplier, such as complete contact information, is important in the event there is ever an issue with the supplied item or recall of the product.

What Are the Benefits of Food Traceability?

Food traceability is becoming a must-have in the industry to mitigate and manage risk around food safety incidents and recalls. As it becomes more widespread, industry leaders are discovering the additional benefits to traceability:

- operational and supply chain efficiency
- gaining and keeping consumer trust through transparency
- reducing food loss and waste
- market differentiation
- enabling sustainability initiatives (such as tracking fuel consumption or verifying legality)
- mitigating food fraud, e.g., verifying cultivar identity by DNA barcoding

Recordkeeping Forms

Figures 9-3 and 9-4 are examples of records that can be used as part of a traceability program for a hazelnut farm.

Farm operator name: Jones / Hazelnut Farm						
Orchard identifier: East sideroad orchard						
Harvest Year: 2020						
Variety/ orchard block	Date harvested	Container type and number	Container code	Post harvest treatment	Date into storage	Storage room #
Yamhill/7B	Oct 14/20	1 tonne totes/14	Yam7B20	Inshell, dried to 6% moisture	Oct. 18/20	3
Jefferson/3C	Oct 18/20	20 kg boxes/37	Jeff3C20	Inshell, dried to 8% moisture	Oct. 22/20	2

Figure 9-3. Example of a record form for harvested hazelnuts.

Harvest Year:					
Variety/ orchard block	Container code	Date removed from storage or purchased	Buyer name and/or contact info	Quantity of containers purchased	Other notes
Yamhill/7B	Yam7B20	Feb. 2/21	Sarah's Healthy Food Market	2 totes	pick up, Greg W/ 9:30 am Feb. 3/21

Figure 9-4. Example of a record form for hazelnut sales.

For additional detailed food safety information, email OMAFRA food safety staff at foodinspection@ontario.ca.

Glossary

Abdomen: The posterior of the three main body segments of an insect's body, located just behind the thorax.

Abiotic: Not derived from living organisms.

Abiotic plant disorders: Non-pathological disorders such as poor light, weather damage, water-logging or a lack of nutrients, that affect the functioning of the plant system. An abiotic, or physiological disorder, is distinguished from plant diseases caused by pathogens (although the symptoms may appear disease-like), in that they can usually be prevented by altering environmental conditions. However, once a plant shows symptoms it is likely that the season's yields will be reduced.

Allele: One of multiple forms of a gene, found at the same place on a chromosome in all members of a species.

Alley-cropping: A system where multiple rows of trees or shrubs are planted with a companion crop cultivated in the alley ways between them to diversify farm income or provide other potential benefits.

Annual life cycle: A plant that completes its life cycle within a one year period. Summer annuals complete their life cycle between spring and fall. Winter annuals germinate in fall, overwinter and then flower and complete their life cycle the following spring or summer.

Apical bud: The primary growing point located at the tip of the main stem. Also referred to as a terminal bud.

Apical dominance: A phenomenon where a main shoot dominates and inhibits the growing lateral buds, so that it remains the only shoot at the terminal. Typically, the apical bud at the end of the shoot produces a hormone to inhibit growth of the lateral buds.

Ascospore: A type of fungal spore, specific to certain fungi (e.g., the eastern filbert blight fungus).

Axil: The upper angle between a leaf stalk and the branch it is growing from, or between a branch and the trunk it is growing from.

Axillary bud: A bud that grows at a leaf node, which may develop into a branch or flower.

Bark: The outermost protective layer on the stems and roots of woody plants, comprised of all the tissues outside the vascular cambium.

Biennial life cycle: Completes its life cycle within a two-year period. Germinates in the spring, overwinters, flowers the following spring or summer and dies back the following fall.

Blank nut: Hazelnut shells that have either no kernel or a very small kernel filling less than a quarter of the shell interior.

Blasted bud (hazelnuts): A damaged, swollen bud, due to damage from mite feeding on the interior.

Blind wood: A growth characteristic of some fruit trees in which buds at the base of a shoot or branch remain dormant or "blind" and lateral shoots do not develop.

Bract: A modified or specialized leaf or scale, typically small, and often associated with reproductive structures such as a flower or flower cluster in its axil.

Bud: An undeveloped or embryonic shoot appearing as a small protuberance in the leaf axil or at the tip of a plant stem that will develop into a flower, leaf or shoot.

Bud break: The opening of a dormant bud, when the shoot begins to grow.

Cambium: A thin layer of cells that lie between the bark and the wood that phloem and xylem grow from.

Canker: Dead, collapsed areas of plant tissue or bark caused by infection or injury. With eastern filbert blight in hazelnuts, cankers are the sunken, dead areas of the branch or trunk where rows of stromata form.

Catkin: A thin, cylindrical flower cluster (a spike) with few petals, that are largely wind-pollinated. Clusters consist of many unisexual (male in hazelnut) flowers arranged along a central stem. Found on trees such as willow and hazel.

Chlorophyll: The pigment which gives plants its green color and is responsible for absorption of light, allowing photosynthesis to occur.

Chlorosis: Failure of chlorophyll development caused by disease or a nutritional disturbance; fading of green plant color to light green, yellow, or white.

Clay: (a) A soil particle <0.002 mm in equivalent diameter. (b) A soil that has properties dominated by clay-size particles.

Cold-hardiness: A plant's resistance to cold, typically measured by the lowest temperature it can withstand.

Cold sensitive: Plant/tissue damage or death due to exposure to cold temperatures.

Cold tolerant: A plant that can survive prolonged exposure to cold temperatures.

Compost: Organic residues, usually with soil added, that have been piled, mixed, moistened, and allowed to decompose; used as a soil amendment.

Cotyledon: The seed leaves. Often visible when large seeds are opened. These are the first leaves visible in the germinated seedling. Broad-leaved crops or weeds have two cotyledons (dicots). Grasses (monocots) have one.

Cornicle: One of the pair of small tubular outgrowths on the hind end of the aphid abdomen.

Cross-pollination: The transfer of pollen from one variety to a different variety of the same species of tree.

Cultural pest control: Refers to the manipulation of crop production systems to manage pest populations, such as sanitation, cultivar resistance and environmental management.

Cuticle: A continuous layer of waxy substances covering the outer surfaces of the epidermis of plants. It contains cutin and protects against water loss/water gain and other damage.

Cuttings: The taking of green shoots or dormant hardwood from parent plants to propagate nursery stock.

Diapause: A period of suspended animation in the lives of many insects, especially in the young stages.

Disease resistance: Any inherited characteristic in a plant that reduces the impact of a disease. A plant with disease resistance has reduced pathogen growth on or in it relative to a susceptible plant, which is different than disease tolerance.

Disease tolerance: Plant which shows little disease-related damage despite the presence of the pathogen on or in the plant.

Dormancy: The state in which a plant slows or ceases growth or metabolic activity for a period of time, often to survive adverse environmental conditions.

Drainage: The frequency and length of time when the soil is free of excessive water. For example, water is removed quickly in well drained soils. In poorly drained soils, the root zone is water-logged for long periods unless some form of artificial drainage is installed.

Drip line: The area located under the outer circumference of a tree's canopy, from which water drips to the ground.

Epidermis: The outer layer of cells covering plant tissue.

Feeder root: Small, thin, hair like roots in plants that absorb water and nutrients from the soil. Found in the upper inches of the soil, they grow outward and typically upward from the large roots near the soil surface.

Fertigation: The application of fertilizers through irrigation systems.

Fertilization: The union of male and female reproductive cells to produce a zygote (fertilized egg). In plants, this involves production of a pollen tube which grows towards the ovaries. The sperm in the pollen travel down the pollen tube to penetrate the egg. Hazelnut flowers have an unusual biology in which there is a prolonged time lapse between initial growth of the pollen tube and fertilization of the egg.

Field capacity: The maximum amount of water that soil can hold without it draining out.

Flagging: Occurs when branches in the tree's canopy turn brown and die, but remain attached, often due to insect feeding, disease, water stress or root damage. Flagging can begin spring or summer and becomes very obvious by fall.

Flail mower: A type of powered mowing equipment that is used to cut heavy grass/scrub that a normal lawn mower could not cope with.

Forewing: The front pair of wings, nearest to the head of the insect.

Good Agricultural Practices (GAP) – A collection of principles to apply for on-farm production and post-production processes to allow for safe and healthy agricultural products

Good Manufacturing Processes (GMP) – The basic, universal conditions and procedures within a processing establishment that create conditions favourable for production of safe food. They are the sum of all the programs/policies, practices and procedures that must be applied to reduce contamination risk during food processing.

Girdling: The loss of the bark from around the entire circumference of a branch or trunk of a woody plant, which results in the eventual death of the area above the girdle.

Grafting: A horticultural technique in which two plants are joined into one. It generally involves a shoot or twig being inserted into a wound made in the trunk or stem of another plant (rootstock), so that each plant's tissues can grow together.

Green manure: Cover crops that are planted in order to be plowed back into the soil to add nutrients or organic matter.

Grub: An insect larva, especially a beetle.

Hardiness: Describes a plant's ability to survive adverse growing conditions (e.g., cold, heat, dryness or wind).

Honeydew: The sweet liquid secreted from the anus of aphids and some other sap sucking bugs.

Host: An organism, plant or animal, that is being attacked by a predator, parasite or a parasitoid insect.

Host range: The range or number of host species that a pathogen or parasite is able to infect or parasitize.

Husk: The protective outer fibrous coating surrounding some fruits or seeds.

Instar: The stage in an insect's life history between any two moults. A newly-hatched insect which has not yet moulted is said to be a first-instar nymph or larva.

Intercropping: The simultaneous cultivation of two or more crops in the same field for much of their growing period. The goal is to increase yield on a piece of land by using areas that would not otherwise be used if growing a single crop.

Internode: The part of a stem between any two nodes.

Interveinal: Tissue between the leaf veins.

Kernel: The soft, typically edible part of a nut contained within the shell.

Larva: Name given to an immature insect which is markedly different from the adult. The life stage in between egg and pupa. Examples include caterpillars, fly maggots and grubs.

Latent period: The time delay between when a plant is infected and when it begins to show symptoms.

Lateral branch: Secondary branches that arise as side shoots from scaffold or other branches

Lateral bud: Buds along the sides of branches. Growth comes from these and terminal buds.

Layering: A method of propagating trees and shrubs from stems still attached to the parent plant.

Lesion: A localized, defined area of damaged tissue, usually caused by disease or trauma. Can take the form of a spot, canker, blister, or scab.

Lignify: To transition into wood or woody tissue, due to the deposition of lignin in cell walls. Apparent as the development of brown tissue on the outside of a shoot or shell.

Loam: A soil having properties approximately equally influenced by sand, silt, and clay components. A medium-textured soil; one with good properties for growing plants.

Macronutients: Nutrients required by plants in large quantities for basic plant growth and development (e.g., nitrogen, phosphorous, potassium).

Mating disruption: A pest management technique involving the release of synthetically produced sex pheromones in large amounts to confuse males and limit their ability to locate calling females, thereby reducing mating of the target pest.

Meristem: A region of plant tissue consisting of undifferentiated cells capable of cell division. The actively growing tissue of a plant. Found mainly at growing tips of roots and shoots and in the cambium.

Micronutrients: Nutrients which are needed in small quanitites by the plant and are often less prevalent in the soil, but are as important as macronutrients (e.g., iron, manganese, boron, etc.).

Micropropagation: An artificial method of producing plants vegetatively by growing them in cell or tissue culture and then planting them out.

Midrib: The central, thick vein running from a leaf's base to its tip.

Molt: The process of shedding the old cuticle and producing a larger replacement. Used by immature insects to increase in size.

Mycelium: The vegetative body of a fungus, consisting of a mass of fine filaments called hyphae.

Natural enemies: Predators, parasitoids or pathogens that help to reduce pest numbers, sometimes keeping populations from reaching economic injury levels.

Necrosis: Death of cells or tissue, usually accompanied by black or brown darkening.

Node: The "joint" of a stem or rhizome. Where the leaf or twig is attached to the stem, and where auxiliary buds and branches are produced.

Nymph: Name given to the young stages of those insects that do not pupate. The nymph is usually quite similar to the adult except that its wings are not fully developed.

One-year old wood: Shoots that were produced by the previous season's growth. Typically used during dormant pruning.

Organic matter: The portion of the soil that contains plant or animal tissue in varying stages of decomposition. It helps maintain soil structure, enhances soil moisture-holding capacity, increases the ability of the soil to hold nutrients and improves drainage.

Ovate: Having an oval or egg-like shape.

Parasite: An organism that spends all or part of its life in close association with another species, taking food from it but giving nothing in return. Ectoparasites live on the outside of their hosts, while endoparasites live inside the host's body.

Parasitoid: An insect whose larvae live as parasites that eventually kill their hosts.

Pathogen: Any organism that causes disease.

Perennial plant: Lives for more than 2 years. Compare with annual, winter annual or biennial. These plants often establish from various types of root systems in addition to seeds.

Permanent wilting point: The minimum amount of water in the soil that a plant requires not to wilt.

Petiole: The stalk of a leaf, attaching the blade to the stem.

Pheromone: A chemical produced by some species of insects to communicate with members of the same species (e.g., 'sex pheromones' which a female produces to attract a mate). Some are used with traps to monitor for insects.

Phloem: The tissue in plants responsible for the transport of nutrients from the leaves to throughout the plant.

Photosynthesis: The process by which green plants and some other organisms use sunlight to produce energy from carbon dioxide and water. Photosynthesis in plants generally involves the green pigment chlorophyll and generates oxygen as a byproduct.

Pistil: Female organs of a flower, containing a stigma, style, and ovary.

Pollination: The transfer of pollen from male flower parts to female flower parts (stigma).

Pollinizer: A plant that provides pollen for the cross-pollination of another plant or cultivar. A desirable pollinizer supplies abundant, compatible and viable pollen at a flowering time that matches the plant to be pollinated.

Predator: An insect that attacks and feeds on other insects, usually smaller and weaker than itself.

Proleg: Fleshy, stubby, leg-like structures that appear under the abdomen of most caterpillars and certain other insects.

Pronotum: The dorsal exoskeleton that covers the first segment of an insect's thorax, immediately behind the head. For some insects (e.g., stink bugs) it may have distinctive features that aid in identification.

Propagated cultivar: Genetic duplicates of a parent tree with identical growth habits and cropping characteristics to the parent plant.

Protandrous: Plants or plant varieties where male reproductive structures mature and appear before the female structures.

Prothoracic shield: For some insects, a hardened plate in the area right behind the head.

Pruning: The removal of a portion of a tree to eliminate dead or damaged wood, increase light in the canopy, maintain or correct tree structure, give new vigor for growth and reduce the tendency for biennial bearing.

Pupa: A stage in the life history of some insects (e.g., butterflies, beetles and flies), during which the larval body is rebuilt into that of the adult insect. Typically, a non-feeding and inactive stage.

Pupate: To become a pupa.

Pycnidia: For certain types of fungi, a flask- or pear-shaped fruiting body which contains the spores. For the eastern filbert blight fungus, pycnidia produce ascospores and are contained within the stroma.

Rancid: An unpleasant smell or taste caused by the decomposition of fats and oils when exposed to light, air, moisture or bacterial action.

Rootstock: A plant onto which another variety or closely related plant is grafted. Forms the base and root of the grafted plant and controls the new plant's growth rate, size, yield potential, response to nutrition and other factors.

Runoff: Excess water that cannot be absorbed into the soil or is trapped on the soil surface that flows out of the field.

Sand: (a) A soil particle between 0.05 and 2.0 mm in diameter. (b) A soil composed of a large fraction of sand-size particles.

Scaffold limb: Large, primary branches or limbs that form the framework of a tree or shrub

Secondary pathogen: Can only cause disease in a plant that is already weakened or compromised by other factors such as infection by a pre-existing disease or other stress. Also called opportunistic pathogens.

Seedling tree: Trees that are produced from germinated hazelnut seeds, which usually do not share the same characteristics as the parent tree.

Serrated: Having a jagged, sawlike edge.

Shell: The hard external covering which encloses the nut kernel.

Shoot: The length of new branch growth in a season. Shoots consist of the stems including leaves, lateral buds, flowering stems and flower buds.

Shrub: A woody plant which is smaller than a tree and has several main stems arising at or near the ground.

Soil structure: Physical property of a soil relating to the arrangement and stability of soil particles and pores.

Spore: Reproductive structure of fungi and some other organisms, containing one or more cells; a bacterial cell modified to survive an adverse environment.

Sporulation: The production of spores.

Stamen: The male fertilizing organ of a flower, typically consisting of pollen structures.

Stigma: In a flower, the part of a pistil that receives the pollen during pollination.

Stromata: Plural form of stroma. A mass of fungal tissue in which reproductive structures develop. For the eastern filbert blight fungus, stromata are the round-oval, black structures that form in rows within tree cankers, with each stroma containing 50-100 spore-producing pycnidia.

Stunting: Reduced plant growth due to a pest or a lack of water, nutrients or other necessity for plant development.

Style: In a flower, a narrow, elongated extension that holds the stigma.

Suckers: New shoot growth pushing from the roots or base of a plant (sometimes called root suckers, or watersprouts).

Systemic: A compound or organism that enters the plant and moves throughout all plant parts via the xylem and phloem.

Tensile: Capable of being stretched.

Temperate: A climate zone with average summer temperatures above 10°C and average winter temperatures at or below 0°C. Crop production in this growing zone can be limited by cold temperatures in the winter or insufficient heat units in the summer.

Terminal bud: Bud located at the tip of stems, branches or shoots, marking the end of the current season's growth.

Thresholds: Control guidelines that indicate when pesticides should be applied to prevent economic losses. Timing of control measures is critical. Spray guidelines for insect pests are based on an economic threshold where the lost income from not applying a control will be higher than the cost of applying a control. In other words, some damage to the crop is tolerated, as long as this damage does not exceed the cost of the control. Thresholds for disease, weeds, nematodes and vertebrates may be based on weather, site history, stage of crop development and field observations.

Thorax: The middle section of the body of an insect, between the head and the abdomen, bearing the legs and wings.

Tolerant: A plant that is able to survive infection/ feeding or be able to grow and produce yield in response to a pest attack.

Traceability: The ability to track a food or ingredient from its point of production (e.g., the farm) through processing, manufacturing and transportation to retail and sale to customers.

Training: The pruning of a young tree during the first 5 years of growth to establish the trees structure and form. Requires properly timed cuts over the course of a season.

Transpiration: Loss of water vapour from the plant.

Vascular: Relating to plant tissues (xylem and phloem) which conduct water, sap, and nutrients in flowering plants and ferns.

Vegetative: Plant tissues that are only used for photosynthesis and growth (leaves).

Vertebrate: Species that have a backbone/ vertebral column

Windbreak: A planting of trees or shrubs which shelters an area from wind.

Xylem: The vascular tissue in plants responsible for transport of water and nutrients upward from the root throughout the plant, and which also helps form the woody element in the stem.

ontario.ca/crops

Appendices

Appendix A. Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) Tree Nut Advisory Staff

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A complete list of Ontario Ministry of Agriculture, Food and Rural Affairs advisory staff is available at infogo.gov.on.ca/infogo/

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1 Stone Rd. W.
Guelph, ON N1G 4Y2
Toll-free: 1-877-424-1300
TTY: 1-855-696-2811
Email: ag.info.omafra@ontario.ca

Appendix B. Additional Resources

Many factsheets, publications and other resources are available from the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA).

These can be ordered from ServiceOntario:

- Online at ServiceOntario Publications at ontario.ca/publications
- Many can also be found online at ontario.ca/crops
- For a complete list of publications from OMAFRA go to ontario.ca/omafra

Below is a list of OMAFRA and other resources relevant to producers of hazelnuts and other tree fruit.

Crop Protection for Hazelnuts in Ontario
Information on crop protection products registered for use on commercial tree nut crops in Ontario through 2021, as well as related information, can be found in the following publications:

- Publication 360E – Crop Protection Guide for Tree Nuts 2021
- Publication 75B – Guide to Weed Control: Hort Crops 2021

After 2021, information on tree nut crop protection products in Ontario can be found by visiting the OMAFRA website at ontario.ca/crops and searching for "crop protection information for tree nuts" or "weed control information for horticultural crops".

Websites:
The following websites and blogs offer timely, technical information on production and pests on Ontario tree nut crops:

- **Hazelnut budgeting tool** (ontario.ca/crops, search for "budget tools") – Excel based budgeting tool for hazelnuts in Ontario.
- **Establishment and Production Costs for Hazelnuts in Ontario** (ontario.ca/crops, search for "hazelnut production costs") – Cost of production report for hazelnuts in Ontario (2018).
- **ONSpecialtycrops blog** (onspecialtycrops.ca) – Timely information on crop production, pest management and events of interest to hazelnuts and other specialty fruit growers in Ontario.
- **ONFruit blog** (onfruit.ca) – Timely information on crop protection, pest management and events affecting fruit production in Ontario.
- **Specialty Cropportunities** (ontario.ca/crops, search for "cropportunities") – Information on production, marketing and pest management of specialty crops in Ontario, including tree nuts.
- **Soil management, fertilizer use, crop nutrition and cover crops for fruit production** (ontario.ca/crops)
- **Irrigation information and videos** (ontario.ca/crops, search for "irrigation")
- **Health Canada's Pest Management Regulatory Agency Label Search Tool** to find labels for pesticides and products registered for use in Canada https://pr-rp.hc-sc.gc.ca/ls-re/index-eng.php
- **Information on pesticide application technology** (www.sprayers101.ca)
- **Training and certification required to buy, use, sell or transfer certain pesticides in Ontario** (www.opep.ca)
- **Ontario Crop IPM modules** (ontario.ca/cropIPM) – Pest identification, biology, scouting and management information for several Ontario fruit crops.
- **Starting a farm in Ontario business information** (ontario.ca/agbusiness, search for "starting a farm in Ontario") – Resources to assist new growers in planning to start a farm.
- **Direct Farm Marketing Resources** (ontario.ca/agbusiness, search for "direct farm marketing"). Various resources providing information on direct farm marketing of crops in Ontario.

OMAFRA Publications

- Publication 310 - *Integrated Pest Management for Ontario Apples*
- Publication 208 - *Predatory Insects in Fruit Orchards*
- Publication 611 - *Soil Fertility Handbook*
- Publication 841 - *Guide to Nursery and Landscape Plant Production*
- Publication 854 – *Vegetable and Fruit Washwater Treatment Manual*

OMAFRA Factsheets

- *Provisional Descriptions of Hazelnut Varieties for Ontario.* To see a provisional list of hazelnut crop varieties and pollenizer varieties for Ontario, refer to the OMAFRA website at ontario.ca/crops (search for hazelnut varieties).
- *Growing Non-Traditional Crops in Ontario*
- *Irrigation Scheduling for Fruit Crops*
- *Design, Construction and Maintenance of Irrigation Reservoirs in Ontario*
- *Water Efficiency and Conservation Practices for Irrigation*
- *Common Disorders of Broad-Leaved Trees*
- *Forced-Air Cooling Systems for Fresh Ontario Fruits and Vegetables*
- *Using Propane-Fired Cannons to Keep Birds Away from Vineyards*
- *Bird Control in Horticultural Crops*
- *Troubleshooting Cold Storage Problems*
- *Mating Disruption for Management of Insect Pests*
- *How Weather Conditions Affect Spray Applications*
- *Six Elements of Effective Spraying in Orchards and Vineyards*
- *Calibrating Airblast Sprayers*
- *Adjusting, Maintaining and Cleaning Airblast Sprayers*
- *Pesticide Drift from Ground Applications*

Best Management Practices

The Best Management Practices series of publications presents a practical, affordable approach to conserving a farm's soil and water resources without sacrificing productivity. A sampling of titles appears below. For a complete list of books in the BMP series visit ontario.ca/omafra.

- BMP01E Farm Forestry and Habitat Management
- BMP06E Soil Management
- BMP07E Water Management
- BMP08E Irrigation Management
- BMP09E Integrated Pest Management
- BMP13E Pesticide Storage, Handling and Application
- BMP15E Buffer Strips
- BMP16E Manure Management
- BMP20E Managing Crop Nutrients

Appendix C. Diagnostic Services

Samples for disease diagnosis, insect or weed identification, nematode counts and Verticillium testing can be sent to:

Pest Diagnostic Clinic
Laboratory Services Division
University of Guelph
95 Stone Rd. W.
Guelph, Ontario, N1H 8J7
Tel: 519-767-6299
Toll Free: 1-877-UofG-AFL (1-877-863-4235)
Email: aflinfo@uoguelph.ca
Website: www.afl.uoguelph.ca

Payment must accompany samples at the time of submission. Submission forms are available at www.afl.uoguelph.ca/submitting-samples.

How to Sample for Nematodes

Soil

When to Sample

Soil and root samples can be taken at any time of the year that the soil is not frozen. In Ontario, nematode soil population levels are generally at their highest in May and June and again in September and October.

How to Sample Soil

Use a soil sampling tube, trowel or narrow-bladed shovel to take samples. Sample soil to a depth of 20–25 cm. If the soil is bare, remove the top 2 cm prior to sampling. A sample should consist of 10 or more subsamples combined. Mix well. Then take a sample of 0.5–1 L from this. No one sample should represent more than 2.5 ha. Mix subsamples in a clean pail or plastic bag.

Sampling Pattern

If living crop plants are present in the sample area, take samples within the row and from the area of the feeder root zone (with trees, this is the drip line).

Number of Subsamples

Based on the total area sampled:

<500 m^2	10 subsamples
500 m^2–0.5 ha	25 subsamples
0.5 ha–2.5 ha	50 subsamples

Roots

From small plants, sample the entire root system plus adhering soil. For large plants, 10–20 g, dig fresh weight from the feeder root zone and submit.

Problem Areas

Take soil and root samples from the margins of the problem area where the plants are still living. If possible, also take samples from healthy areas in the same field. If possible, take both soil and root samples from problem and healthy areas in the same field.

Sample Handling

Soil Samples

Place in plastic bags as soon as possible after collecting.

Root Samples

Place in plastic bags and cover with moist soil from the sample area.

Storage

Store samples at 5°C–10°C and do not expose them to direct sunlight or extreme heat or cold (freezing). Only living nematodes can be counted. Accurate counts depend on proper handling of samples.

Submitting Plant for Disease Diagnosis or Identification

Sample Submission Forms

Sample submission forms can be found online at the University of Guelph Agriculture & Food Laboratory at: www.afl.uoguelph.ca/submitting-samples. Carefully fill in all the categories on the form. In the space provided, draw the most obvious symptom and the pattern of the disease in the field. It is important to include the cropping history of the area for the past 3 years and this year's pesticide use records.

Choose a complete, representative sample showing early symptoms. Submit as much of the plant as is practical, including the root system, or several plants showing a range of symptoms. If symptoms are general, collect the sample from an area where they are of intermediate severity. Completely dead material is usually inadequate for diagnosis.

With plant specimens submitted for identification, include at least a 20–25-cm sample of the top portion of the stem with lateral buds, leaves, flowers or fruits in identifiable condition. Wrap plants in newspaper and put in a plastic bag. Tie the root system off in a separate plastic bag to avoid drying out and contamination of the leaves by soil. Do NOT add moisture, as this encourages decay in transit. Cushion specimens and pack in a sturdy box to avoid damage during shipping. Avoid leaving specimens to bake or freeze in a vehicle or in a location where they could deteriorate.

Delivery

Deliver to the Pest Diagnostic Clinic as soon as possible by first class mail or by courier at the beginning of the week.

Submitting Insect Specimens for Identification

Collecting Samples

Place dead, hard-bodied insects in vials or boxes and cushion with tissues or cotton. Place soft-bodied insects and caterpillars in vials containing alcohol. Do not use water, as this results in rot. Do not tape insects to paper or send them loose in an envelope.

Place live insects in a container with enough plant "food" to support them during transit. Be sure to write "live" on the outside of the container.

Appendix D. Accredited Soil-Testing Laboratories in Ontario

The following labs are accredited to perform soil tests for pH, buffer pH, P, K, Mg and Nitrate-N on Ontario soils. To find a current list of accredited soil-testing laboratories, check the OMAFRA website at ontario.ca/crops or consult an OMAFRA fertility specialist.

Laboratory Name	Contact Information	Contact Names
A & L Canada Laboratories Inc.	2136 Jetstream Rd. London, ON N5V 3P5 Tel: 519-457-2575 Toll Free: 855-837-8347 Email: alcanadalabs@alcanada.com	Dave Stallard Greg Patterson Ian McLachlin
Eurofins Environment Testing Canada Inc.	8-146 Colonnade Rd. Ottawa, ON K2E 7Y1 Tel: 613-727-5692 Email: infocanada@eurofins.com	Amy Walpole-James Rebecca Koshy
SGS Agrifood Laboratories	Unit #1, 503 Imperial Rd. North Guelph, ON N1H 6T9 Tel: 519-837-1600 Toll Free: 800-265-7175 Email: ca.agri.guelph.lab@sgs.com	Tim Wright Jack Legg
Brookside Laboratories, Inc.	200 White Mountain Dr. New Bremen, OH 45869 Tel: 419-977-2766 Email: info@blinc.com	Spencer Gelhaus Jackie Brackman
University of Guelph, Laboratory Services	University of Guelph P.O. Box 3650 95 Stone Rd. West Guelph, ON N1H 8J7 Tel: 519-767-6299 Toll Free: 877-863-4235 Email: aflinfo@uoguelph.ca	Nick Schrier
Stratford Agri-Analysis	1131 Erie St. PO Box 760 Stratford, ON N5A 6W1 Tel: 519-273-4411 Toll Free: 800-323-9089 Email: info@stratfordagri.ca	Barbara Spaniers Keith Lemp
Activation Laboratories Ltd.	41 Bittern St. Ancaster, ON L9G 4V5 Tel: 905-648-9611 Toll Free: 888-228-5227 Email: victoriapechorina@actlabs.com	Carolyn Fraser Rob Deakin
Honeyland Ag Services	3918 West Corner Dr. Ailsa Craig, ON N0M 1A0 Tel: 226-377-8485 Email: croelands@honeylandag.com	Chris Roelands

Appendix E. Leaf and Petiole Tissue Analysis

There is no official accreditation in Ontario for tissue analysis, but accredited soil-testing labs are monitored for proficiency on tissue analysis. To find a current list of accredited soil-testing laboratories that conduct tissue analysis, check the OMAFRA website at ontario.ca/crops or consult an OMAFRA fertility specialist.

Lab	Contact Information	Contact Names	Type of Analysis	Nutrients Tested
A & L Canada Laboratories	2136 Jetstream Rd. London, ON N5V 3P5 Tel: 519-457-2575 Email: aginfo@alcanada.com	Dave Stallard Greg Patterson	Basic	N, P, K, Mg, Ca
			Complete	N, P, K, Mg, Ca, Na, S, Fe, Al, Mn, B, Cu, Zn
SGS Agrifood Laboratories	Unit #1, 503 Imperial Rd. North Guelph, ON N1H 6T9 Tel: 519-837-1600 Email: ca.agri.guelph.lab@sgs.com	Tim Wright Jack Legg	Basic	N, P, K, Mg, Ca
			Complete	Basic + Zn, Mn, Cu, Fe, B
Soil and Nutrient Laboratory	University of Guelph P.O. Box 3650 95 Stone Rd. West Guelph, ON N1H 8J7 Tel: 519-767-6299 Email: aflinfo@uoguelph.ca	Nick Schrier	Plant Pkg I	N, P, K, Ca, Mg
			Plant Pkg II	N, P, K, Ca, Mg, Zn, Cu, Mn, B, Na, Al and Mo
Stratford Agri-Analysis	1131 Erie St. PO Box 760 Stratford, ON N5A 6W1 Tel: 519-273-4411 Email: info@stratfordagri.ca	Barbara Spanjers Keith Lemp	Complete	N, P, K, Mg, Ca, Na, B, Cu, Zn, Fe, Mn
Brookside Laboratories, Inc.	200 White Mountain Dr. New Bremen, OH 45869 Tel: 419-977-2766 Email: info@blinc.com	Spencer Gelhaus Jackie Brackman	Complete	N, P, K, Mg, Ca, Na, B, Cu, Zn, Fe, Mn
Activation Laboratories Ltd.	41 Bittern St. Ancaster, ON L9G 4V5 Tel: 905-648-9611 Email: victoriapechorina@actlabs.com	Carolyn Fraser Rob Deakin	Complete	N, P, K, Mg, Ca, Na, B, Cu, Zn, Fe, Mn

Appendix F. Pest Monitoring Equipment Suppliers

This list includes sources of weather monitoring equipment, pest monitoring supplies and biological control agents. This is a partial list and does not imply any endorsement or recommendation by the Ontario Ministry of Agriculture, Food and Rural Affairs of the companies listed. For more extensive, up-to-date lists of these suppliers, see the OMAFRA website at ontario.ca/crops.

Company	Contact Information	Products
Anatis Bioprotection	278 rang Saint-André Saint-Jacques-le-Mineur, QC J0J 1Z0 Tel: 800-305-7714 Email: info@anatisbioprotection.com www.anatisbioprotection.com	• beneficial insects and mites
Biobest Canada Ltd.	2020 Foxrun Rd. R.R. #4 Leamington, ON N8H 3V7 Tel: 519-322-2178 Email: info@biobest.ca www.biobestgroup.com	• beneficial insects, mites, nematodes • pheromone lures and traps
BioQuip Products Inc.	2321 Gladwick St. Rancho Dominguez, CA 90220 Tel: 310-667-8800 Email: bqinfo@bioquip.com www.bioquip.com	• hand lens magnifiers • vials, storage netting • insect nets and collection equipment
Cooper Mill Ltd.	31 Hastings Rd. R.R. #3 Madoc, ON K0K 2K0 Tel: 613-473-4847 Email: ipm@coopermill.com www.coopermill.com	• pheromone lures and traps
Distributions Solida Inc.	480 rang St-Antoine St. Ferreol-les-Neiges, QC G0A 3R0 Tel: 418-826-0900 Email: info.solida.ca www.solida.ca	• pheromone lures and traps • tangle traps, insect trap coating • hand lens magnifiers • tally counters
Gempler's	P.O. Box 44996, Madison, WI 53744 Tel: 800-382-8473 Email: customerservice@gempler.com www.gemplers.com	• weather monitoring equipment • pheromone lures and traps • tangle traps • hand lens magnifiers • tally counters
Great Lakes IPM	7563 N Crystal Rd. Vestaburg, MI 48891 Tel: 989-268-5693 Email: glipm@greatlakesipm.com www.greatlakesipm.com	• pheromone lures and traps • tangle traps • hand lens magnifiers • tally counters • insect sweep nets • field diagnostic equipment

Koppert Canada Ltd.	40 Ironside Cres. #3 Scarborough, ON M1X 1G4 Tel: 800-567-4195 Email: info@koppert.ca www.koppert.ca	• beneficial insects, mites • pheromone traps and lures • BioWorks products
Natural Insect Control	3737 Netherby Rd. Stevensville, ON L0S 1S0 Tel: 905-382-2904 Email: nic@niagara.com www.naturalinsectcontrol.com	• beneficial insects, mites and nematodes • pheromone lures and traps • mating disruption devices • bird houses
N.M. Bartlett Inc.	4509 Bartlett Rd. Beamsville, ON L0R 1B1 Tel: 905-563-8261 Toll free: 800-767-8658 Email: info@bartlett.ca www.bartlett.ca	• pheromone lures and traps • mating disruption devices
Plant Products Inc.	50 Hazelton St. Leamington, ON N8H 3W1 Tel: 519-326-9037 www.plantproducts.com	• pheromone lures and traps • mating disruption devices • rodent traps • sticky tape and cards • tangle traps • beneficial insects

Appendix G. Other Contacts

University of Guelph

Main Campus
50 Stone Rd. East
Guelph, ON N1G 2W1
Tel: 519-824-4120
www.uoguelph.ca

Ridgetown College
120 Main St. East
Ridgetown, ON N0P 2C0
Tel: 519-674-1500
www.ridgetownc.com

Department of Plant Agriculture
www.plant.uoguelph.ca

Department of Plant Agriculture, Guelph
50 Stone Rd. West
Guelph, ON N1G 2WI
Tel: 519-824-4120, ext. 56086

Department of Plant Agriculture, Simcoe
1283 Blueline Rd., Box 587
Simcoe, ON N3Y 4N5
Tel: 519-426-7127 ext. 344

Department of Plant Agriculture, Vineland
Box 7000, 4890 Victoria Ave. North
Vineland Station, L0R 2E0
Tel: 905-562-4141

Lab Services Division
P.O. Box 3650, 95 Stone Rd. West
Guelph, ON N1H 8J7
Tel: 519-767-6299
www.guelphlabservices.com

Pest Diagnostic Clinic
Tel: 877-863-4235 or 519-823-1268 ext 57256

Agriculture & Agri-Food Canada Research Centres

www.agr.gc.ca

Ottawa Research and Development Centre
960 Carling Ave.
Ottawa, ON K1A 0C6
Tel: 613-759-1858

Harrow Research and Development Centre
2585 County Road 20
Harrow, ON N0R 1G0
Tel: 519-738-2251

London Research and Development Centre
1391 Sandford St.
London, ON N5V 4T3
Tel: 519-457-1470

Vineland Research Farm
4902 Victoria Ave. North
Vineland, ON L0R 2E0
Tel: 905-562-4113

Guelph Research and Development Centre
93 Stone Rd. West
Guelph, ON N1G 5C9
Tel: 519-829-2400

Canadian Food Inspection Agency Regional Offices (Plant Protection)

www.inspection.gc.ca

Belleville
345 College St. East
Belleville, ON K8N 5S7
Tel: 613-969-3333

Brantford
625 Park Rd. North, Ste. 6
Brantford, ON N3T 5P9
Tel: 519-753-3478

Hamilton
709 Main St. West, Ste. 101
Hamilton, ON L8S 1A2
Tel: 905-572-2201

London
19-1200 Commissioners Rd. East
London, ON N5Z 4R3
Tel: 519-691-1300

St. Catharines
395 Ontario St., Box 19
St. Catharines, ON L2N 7N6
Tel: 905-937-7434

Toronto
1124 Finch Ave. West, Unit 2
Downsview, ON M3J 2E2
Tel: 647-790-1100

Guelph
174 Stone Rd. West
Guelph, ON N1G 4T1
Tel: 519-837-9400

Vineland Research and Innovation Centre

www.vinelandresearch.com
4890 Victoria Ave. North
Vineland Station, ON L0R 2E0
Tel: 905-562-0320

Appendix H. The Metric System and Abbreviations

Metric units

Linear measures (length)
10 millimetres (mm) = 1 centimetre (cm)
100 centimetres (cm) = 1 metre (m)
1,000 metres = 1 kilometre (km)

Square measures (area)
100 m × 100 m = 10,000 m^2 = 1 hectare (ha)
100 ha = 1 square kilometre (km^2)

Cubic measures (volume)
Dry measure
1,000 cubic millimetres (mm^3) = 1 cubic centimetre (cm^3)
1,000,000 cm^3 = 1 cubic metre (m^3)
Liquid measure
1,000 millilitres (mL) = 1 litre (L)
100 L = 1 hectolitre (hL)

Weight-volume equivalents (for water)
(1.00 kg) 1,000 grams = litre (1.00 L)
(0.50 kg) 500 g = 500 mL (0.50 L)
(0.10 kg) 100 g = 100 mL (0.10 L)
(0.01 kg) 10 g = 10 mL (0.01 L)
(0.001 kg) 1 g = 1 mL (0.001 L)

Weight measures
1,000 milligrams (mg) = 1 gram (g)
1,000 g = 1 kilogram (kg)
1,000 kg = 1 tonne (t)
1 mg/kg = 1 part per million (ppm)

Dry–liquid equivalents
1 cm^3 = 1 mL
1 m^3 = 1,000 L

Metric conversions (approximate)
5 mL = 1 tsp
15 mL = 1 tbsp
28.5 mL = 1 fl. oz.

Handy metric conversion factor (approximate)
litres per hectare × 0.4 = litres per acre
kilograms per hectare × 0.4 = kilograms per acre

Application rate conversions

Metric to Imperial or U.S. (approximate)
litres per hectare × 0.09 = Imp. gallons per acre
litres per hectare × 0.11 = U.S. gallons per acre
litres per hectare × 0.36 = Imp. quarts per acre
litres per hectare × 0.43 = U.S. quarts per acre
litres per hectare × 0.71 = Imp. pints per acre
litres per hectare × 0.86 = U.S. pints per acre
millilitres per hectare × 0.014 = U.S. fluid ounces per acre
grams per hectare × 0.015 = ounces per acre
kilograms per hectare × 0.89 = pounds per acre
tonnes per hectare × 0.45 = tons per acre
Imperial or U.S. to metric (approximate)
Imp. gallons per acre × 11.23 = litres per hectare (L/ha)
U.S. gallons per acre × 9.35 = litres per hectare (L/ha)
Imp. quarts per acre × 2.8 = litres per hectare (L/ha)
U.S. quarts per acre × 2.34 = litres per hectare (L/ha)
Imp. pints per acre × 1.4 = litres per hectare (L/ha)
U.S. pints per acre × 1.17 = litres per hectare (L/ha)
Imp. fluid ounces per acre × 70 = millilitres per hectare (mL/ha)
U.S. fluid ounces per acre × 73 = millilitres per hectare (mL/ha)
tons per acre × 2.24 = tonnes per hectare (t/ha)
pounds per acre × 1.12 = kilograms per hectare (kg/ha)
pounds per acre × 0.45 = kilograms per acre (kg/acre)
ounces per acre × 70=grams per hectare (g/ha)

Dry weight conversions (approximate)

Metric Imperial
grams or kilograms/hectare ounces or pounds/acre
100 g/ha = 1½ oz/acre
200 g/ha = 3 oz/acre
300 g/ha = 4¼ oz/acre
500 g/ha = 7 oz/acre
700 g/ha = 10 oz/acre
1.10 kg/ha = 1 lb/acre
1.50 kg/ha = 1¼ lb/acre
2.00 kg/ha = 1¾ lb/acre
2.50 kg/ha = 2¼ lb/acre
3.25 kg/ha = 3 lb/acre
4.00 kg/ha = 3½ lb/acre
5.00 kg/ha = 4½ lb/acre
6.00 kg/ha = 5¼ lb/acre
7.50 kg/ha = 6¾ lb/acre
9.00 kg/ha = 8 lb/acre
11.00 kg/ha = 10 lb/acre
13.00 kg/ha = 11½ lb/acre
15.00 kg/ha = 13½ lb/acre

Conversion tables – metric to imperial (approximate)

Length
1 millimetre (mm) = 0.04 inches
1 centimetre (cm) = 0.40 inches
1 metre (m) = 39.40 inches
1 metre (m) = 3.28 feet
1 metre (m) = 1.09 yards
1 kilometre (km) = 0.62 miles

Area
1 square centimetre (cm^2) = 0.16 square inches
1 square metre (m^2) = 10.77 square feet
1 square metre (m^2) = 1.20 square yards
1 square kilometre (km^2) = 0.39 square miles
1 hectare (ha) = 107,636 square feet
1 hectare (ha) = 2.5 acres

Volume (dry)
1 cubic centimetre (cm^3) = 0.061 cubic inches
1 cubic metre (m^3) = 1.31 cubic yards
1 cubic metre (m^3) = 35.31 cubic feet
1,000 cubic metres (m^3) = 0.81 acre-feet
1 hectolitre (hL) = 2.8 bushels

Volume (liquid)
1 millilitre (mL) = 0.035 fluid ounces (Imp.)
1 litre (L) = 1.76 pints (Imp.)
1 litre (L) = 0.88 quarts (Imp.)
1 litre (L) = 0.22 gallons (Imp.)
1 litre (L) = 0.26 gallons (U.S.)

Weight
1 gram (g) = 0.035 ounces
1 kilogram (kg) = 2.21 pounds
1 tonne (t) = 1.10 short tons
1 tonne (t) = 2,205 pounds

Pressure
1 kilopascal (kPa) = 0.15 pounds/in.^{2}

Speed
1 metre per second = 3.28 feet per second
1 metre per second = 2.24 miles per hour
1 kilometre per hour = 0.62 miles per hour

Temperature
°F = (°C × $\frac{9}{5}$) + 32

Conversion tables – imperial to metric (approximate)

Length
1 inch = 2.54 cm
1 foot = 0.30 m
1 yard = 0.91 m
1 mile = 1.61 km

Area
1 square foot = 0.09 m^2
1 square yard = 0.84 m^2
1 acre = 0.40 ha

Volume (dry)
1 cubic yard = 0.76 m^3
1 bushel = 36.37 L

Volume (liquid)
1 fluid ounce (Imp.) = 28.41 mL
1 pint (Imp.) = 0.57 L
1 gallon (Imp.) = 4.55 L
1 gallon (U.S.) = 3.79 L

Weight
1 ounce = 28.35 g
1 pound = 453.6 g
1 ton = 0.91 tonne

Pressure
1 pound per square inch = 6.90 kPa

Temperature
°C = (°F – 32) × 5⁄9

Abbreviations

% = per cent
ai = active ingredient
AP = agricultural powder
cm = centimetre
cm^2 = square centimetre
CS = capsule suspension
DF = dry flowable
DG = dispersible granular
DP = dispersible powder
E = emulsifiable
EC = electrical conductivity
e.g. = for example
F = flowable
g = gram
Gr = granules, granular
ha = hectare
kg = kilogram
km/h = kilometres per hour
kPa = kilopascal
L = litre
m = metre
m^2 = square metre
mL = millilitre
mm = millimetre
m/s = metres per second
SC = sprayable concentrate
SP = soluble powder
t = tonne
W = wettable (powder)
WDG = water dispersible granular
WG = wettable granule
WP = wettable powder