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Guide to Ginseng Production

Ministry of Agriculture, Food and Agribusiness

Ontario

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Contents

CHAPTER 1

Introduction to Ginseng

Before growing ginseng, consider the unique history of North American ginseng (also known as Canadian ginseng) in Canada. This history helps explain the production practices used for ginseng cultivation in the field and some of the regulations that impact ginseng production and trade. This chapter covers:

- the history of ginseng trade with China
- the history of wild harvest and wild population decline
- ginseng production economics and market trends
- production systems and regulations that may impact ginseng production
- the unique structure and life cycle of ginseng
- the typical timeline of ginseng production

History

As early as 1643, the Portuguese explorer Luthmin described ginseng after his travels to China. The plant he found was *Panax ginseng* C.A. Meyer. It had been regarded for thousands of years as the most significant herb in Asia where it was used as a wonder drug, cure-all and aphrodisiac. In fact, the root word for "panacea" (cure-all) and *Panax* are the same. Records from China dating back 5,000 years identify the plant and discuss its importance in traditional Chinese medicine. Jesuit Father Jartoux, who was stationed in China, wrote of Asian ginseng in 1702.

In 1716, the Jesuit priest Father Joseph François Lafitau in Quebec took diagrams from Father Jartoux to the Haudenosaunee living near Montreal. They identified a similar plant, *Panax quinquefolius* L., growing in the hardwood forests near Montreal. Father Lafitau encouraged the Haudenosaunee to dig the root for trade with the French fur traders.

Over the next 150 years, ginseng harvest across eastern North America increased to more than 68,000 kg per year and the plant became scarce in the wild. By the late 19th century, the destruction of forests and continued harvesting of ginseng warranted the first regulations by the Ontario government to limit the harvest of wild ginseng to protect wild populations.

In 1896, Clarence Hellyer established the first known ginseng garden under artificial shade in Canada near Waterford, Ontario. Over the next few decades, a few growers from Ontario and Wisconsin established the market for field-cultivated North American ginseng in Hong Kong. Eventually, North American ginseng became the preferred ginseng of the Chinese and China remains the primary market for Ontario-grown root to this day.

The Ontario ginseng acreage expanded rapidly in the 1980s and 1990s to become one of the most important field-grown horticultural crops in the province. Acreage has remained fairly steady since the early 1990s, with yearly fluctuations often driven by price.

The relatively short history of ginseng production in the field, the lack of improvements through breeding and the minimal research conducted on the crop compared to other horticultural crops cause some unique challenges for ginseng production. The most serious challenge is ginseng replant disease (GRD), an issue that often prevents successful ginseng production on the same land, even decades after the first crop.

For more information, see *Ginseng Replant Disease (GRD)*, Chapter 6. Other challenges are covered in *Ginseng Plant Structure and Development* in this chapter.

Economics

Ginseng is very difficult to grow. It takes considerable financial investment to establish and maintain, followed by several years of production before a grower sees any income from their first crop. Ginseng prices vary considerably in cycles of approximately 8–10 years, fluctuating from periods of high profit to equivalent periods where prices fall well below the cost of production. When the crop is planted, it is impossible to predict prices at harvest. There is no crop insurance for ginseng growers, so crop losses from pests or environmental damage are borne entirely by the grower. Ginseng can reap relatively high profits at times, but there is also significant financial risk.

The difficulty of growing ginseng and economies of scale mean new growers should expect lower yields and higher costs per acre than established growers. What may be profitable for an established grower with high yield and quality may not be profitable for new growers. Growers interested in ginseng should do research before getting started. Talk to existing growers, learn about the production system and associated costs and research export market conditions. Consider starting small to ensure a high-quality crop can be grown before growing on a large scale. Growers can also manage the risk by growing other crops or livestock that provide more stable income.

For more information on the costs associated with growing ginseng, see the OMAFA factsheet *Cost of Production of Ginseng in Ontario*.

Production Systems

There are several traditional production systems for growing ginseng in Ontario:

- field-cultivated under artificial shade

- woods-grown, using the forest as a natural canopy but using soil preparation, fertility and pest control measures
- wild-simulated, where seeds are planted in a natural setting — sometimes called wild-cultivated

This guide discusses the field-cultivated system for growing ginseng under artificial shade (see *Ginseng Shading Systems*, Chapter 2).

Regulations Impacting Production of North American Ginseng in Ontario

There are very few stands of wild American ginseng remaining in Ontario forests (Figure 1, Figure 2). The decline in populations has been attributed to the harvest of wild populations and the loss of habitat from logging. As a result, American ginseng is listed as a threatened species by the Committee on the Status of Species at Risk in Ontario (COSSARO).

Threatened species are protected through regulations that prevent most activities in the wild in Ontario, including both woods-grown and wild-simulated production systems. At the time of this publication, those regulations are being rewritten. For the current status of production systems outside of a field environment, contact:

Ontario Ministry of the Environment, Conservation and Parks

Telephone: 1-800-565-4923

Website: ontario.ca/page/ministry-environment-conservation-parks

Members of the Ontario Ginseng Growers Association (OGGA) are generally exempt by regulation from species at risk regulations if they meet these requirements:

- roots are produced under artificial shade on lands licensed under Ontario Regulation 340/01 (Designation — Ontario Ginseng Growers Association)
- growers do not use seeds or other plant material collected from the wild in Ontario

Export of ginseng roots is also impacted by the Convention on International Trade of Endangered Species of Wild Fauna and Flora (CITES). For more information, see *CITES Requirements for Exporting Ginseng*, Chapter 8.

Ontario Ginseng Growers Association

The OGGA is the representative association for ginseng under the *Farm Products Marketing Act* and has the authority to collect a mandatory acreage fee to support research, education and promotion.

Figure 1. A stand of wild ginseng in Ontario.

Figure 2. A collection of wild ginseng roots. Note the elongated rhizome at the top of each root. Many of these roots are 10–20 years old.

All producers who grow 1/4 acre or more of ginseng in Ontario are required to register with the OGGA. Growers pay an acreage fee for each year the crop is growing and should contact OGGA in the year of planting.

Find out more at ginsengontario.com.

Ginseng Plant Structure and Development

At maturity, American ginseng (*Panax quinquefolius* L.) is a fleshy-rooted, perennial herbaceous plant with above-ground portions 45–60 cm in height (Figure 3).

New plants emerge each spring from buds on a rhizome at the neck of the root. The rhizome remains in place for the life of the plant and root age can be estimated by the number of bud scars present.

Ginseng is a member of the *Araliaceae* family of plants. There are no other cultivated members of this family in Ontario, but several members are common in Ontario forests.

The *Araliaceae* family is closely related to the carrot family (*Apiaceae*).

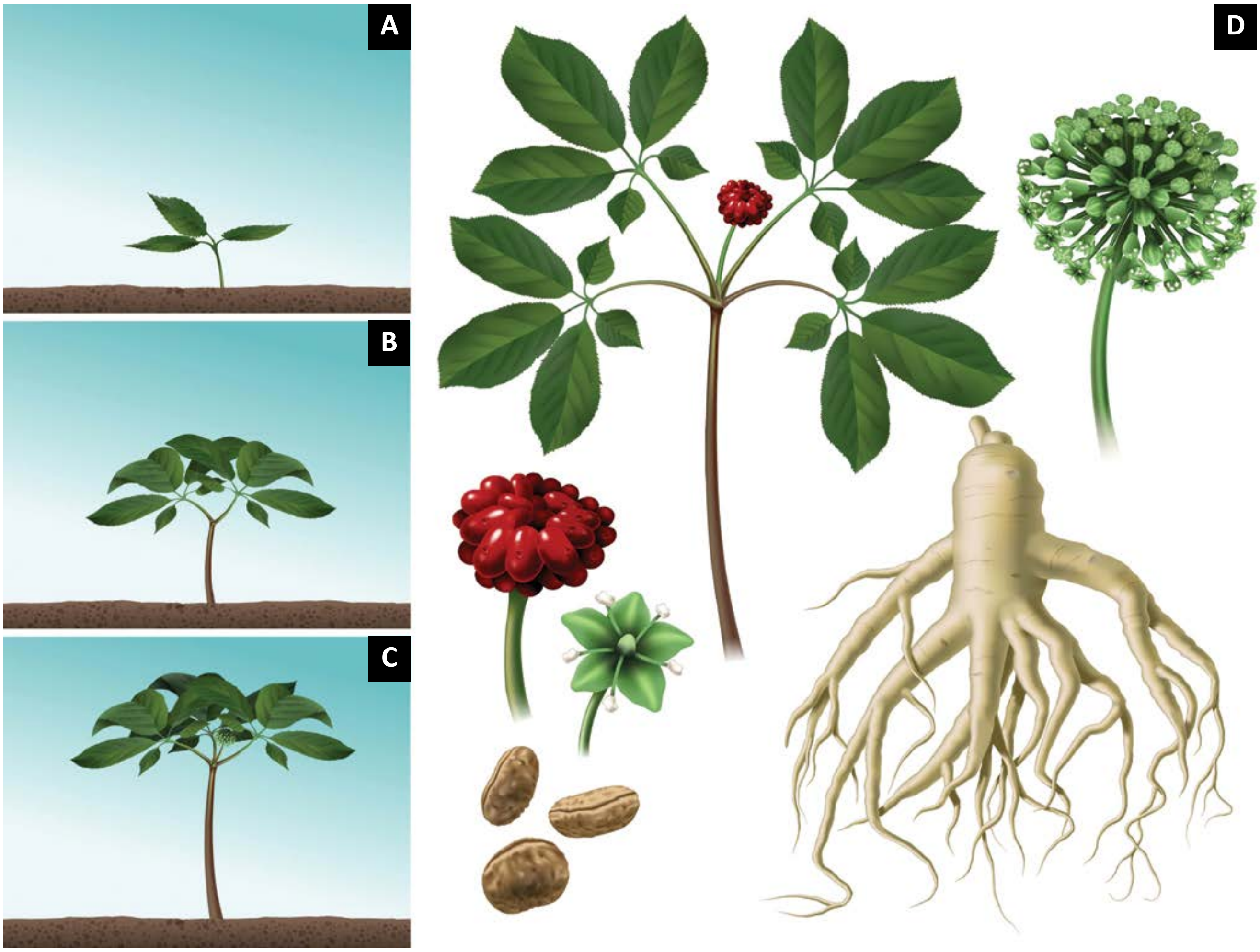


Figure 3. Diagram of a typical *Panax quinquefolius* plant and its parts. A) Typical mature seedling with a single 3-leaflet leaf, B) Typical 2-year old plant with two 5-leaflet leaves, C) Typical 3-year old plant with three 5-leaflet leaves, D) Mature 4-year old plant and its parts, including flower cluster, flower closeup, berry cluster, mature seeds and marketable taproot.

Several features of ginseng distinguish it from other horticultural crops.

- Ginseng seed requires a lengthy period of stratification (after-ripening) after the seed is harvested before it will germinate. If stratification is interrupted, germination is delayed. For more information, see *Seed Stratification*, Chapter 4.
- Ginseng must be grown in an environment that mimics its natural forest setting.
- Ginseng has no aerial growing point. This is different than most plants that develop progressively after emergence, with new leaves forming and flowers developing from growing points above ground. In ginseng, all plant parts are present at emergence, including the flower head. The leaves unfold and expand as time passes. The flower head elongates and enlarges during berry formation and seed set. Further development does not occur after this initial expansion.
- Damaged plant parts are not replaced by new growth. Leaf damage has a direct effect on the photosynthetic capacity of the plant for the remainder of that season. This feature of plant development means it is very important to protect the leaves from damage due to disease and mechanical injury. Early defoliation of the ginseng plant due to diseases or frost may result in the loss of a full season of growth.
- The tops of some plants may not emerge for a year. This is probably related to bud damage before emergence.
- Ginseng roots only reach a marketable size after a minimum of 3 years of production (preferably four), after which a one-time harvest occurs. Yield potential does increase with age, but disease pressures build up in ginseng gardens and harvesting beyond 4 or 5 years is very rare. Other than medicinal root crops, there are very few commercial crops that are both perennial and have a one-time harvest. In the wild, roots often do not reach the same size until at least 10 years after seeding and the oldest plants can be more than 100 years old.

The Principal Growth Stages of Ginseng

Germination and Bud Development

Ginseng is propagated by seed. Seeds typically do not germinate for 18–20 months after seed harvest under the Ontario production system and require a specific stratification period (maturation process). See *Seed Stratification*, Chapter 4 for more information. As the embryo matures, the seed coat splits. The new root emerges first, followed rapidly by the new shoot.

Older stems emerge each spring from a bud on an underground rhizome following a cold period that is necessary to satisfy dormancy. There is usually one stem per root, but occasionally two stems emerge from the same root. Buds swell and shoots begin to emerge when soil temperatures warm in early spring. The hooked stem emerges through the soil in late April or early May (Figure 4). As the leaves unfold, an immature flower head is exposed.

Figure 4. A 2-year-old ginseng top emerging through the straw in spring.

Leaf Development

In seedlings, food reserves for the developing leaf come from the seed. Development of the canopy in seedlings and mature plants takes about 4 weeks. The seedling shoot is a single trifoliate leaf (three small leaflets atop a single stem) with no flower head (Figure 5). Leaves begin to unfold when the seedling shoot reaches about 50% of its expected height and development continues until the leaflets are horizontal.

Figure 5. Fully expanded ginseng seedlings.

In older plants, the food reserves for the developing leaves come from the root. During emergence, older roots can lose as much as 30%–50% dry matter content. This loss is recovered and surpassed through photosynthesis after the canopy is established. As shoots emerge from older roots, the leaves are folded. Leaves on plants 2 years and older have 3–5 leaflets situated at the end of the petioles (prongs). It is common for 2-year-old plants to have two prongs, 3-year-old plants to have three prongs and 4-year-old plants to have four prongs. Plants rarely have more than four prongs, no matter their age.

Root and Bud Formation

The horizontal wrinkles on ginseng roots happen when the roots expand and contract in response to temperature changes, ensuring the root and rhizome remain below the soil surface. These wrinkles are much more pronounced in roots from the wild.

Ginseng seedlings have a dry-weight gain of about 0.2 g, 2-year-old roots gain about 2 g and 3-year-old roots gain about 3.5 g. A mature ginseng root is usually about 28% dry matter. The fresh weight of a 3-year-old harvestable root is about 10–15 g, but can be higher under ideal conditions. Root weight gain starts in seedlings when the canopy has unfolded. In older plants, root weight begins to increase about mid-June, continuing until mid-September.

In seedlings, a bud for the following year's growth gradually develops over the growing season. Bud length increases at the same time as root weight. If the top is killed early in the seedling year, this bud will not be developed enough to sprout the following year and the plant dies. In addition to the primary bud, a secondary bud begins to develop by the end of the seedling year next to the primary bud. This bud normally sprouts 2 years later. From this point on, the root always has multiple buds, including a primary and a secondary bud.

Additional buds are often located at the base of the rhizome or along the rhizome (Figure 6). These buds rarely develop unless there is physical damage to the primary and secondary buds at the top of the rhizome. A secondary bud does not usually develop in the same year if the primary bud is damaged. In some cases, secondary shoots can develop if the primary bud is killed by frost very early in the season before emergence. If the primary bud and the resulting shoot are killed early in one year, the extra root reserves required for secondary bud development the following year often results in a weaker plant. Plus, the plant has lost a year's growth compared to surrounding plants. This plant would often be hidden within the canopy once it re-emerges and is not likely to produce a marketable root unless all of the roots in a bed were damaged in the same manner.

Flower Head Development

Flower heads begin to develop on 20%–50% of 2-year-old plants and the vast majority of older plants. The flower buds will be present at the time of emergence, arising from the top where the prongs meet the main stem.

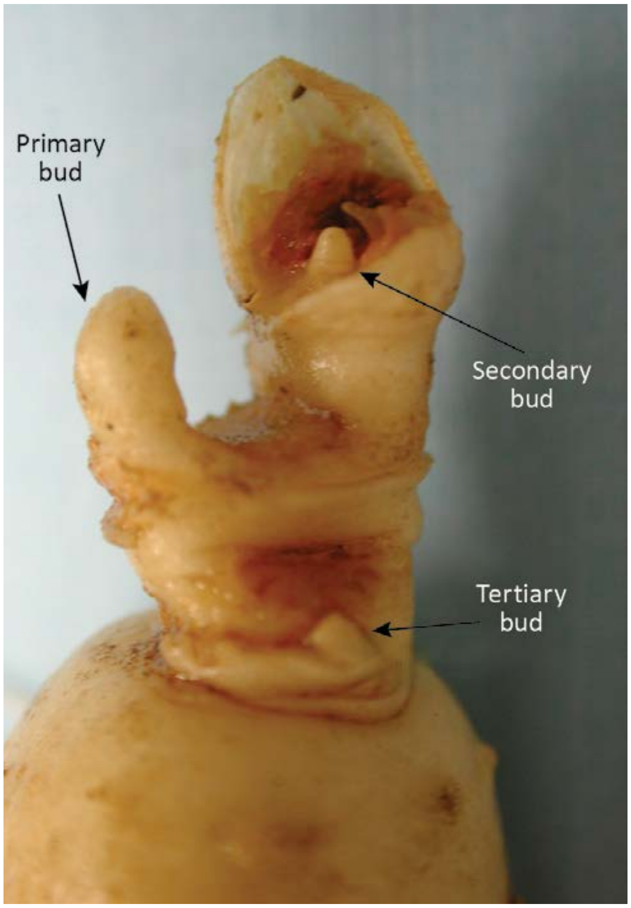


Figure 6. Buds on a 4-year-old ginseng root. Note the secondary buds that are smaller than the primary bud. The secondary bud on the right often develops in the year after the primary bud.

About mid-June, 50% of growth is reached and the maximum elongation is reached by the end of June.

Ginseng flowers are borne on an umbel. All the peduncles (small stems holding the flowers or berries) originate at the same point on the stem holding the flower head, which is also a peduncle (Figure 7). Ginseng flowers form between mid-June and late-July. Over the 6-week flowering period, about 35% of flowers are open at any given time. Flowering occurs in about three flushes and begins at the outside of the umbel, proceeding toward the centre. Berries ripen in the same order.

During the flowering period, there are seed heads that contain flower buds, flowers and berries at the same time. Ginseng flowers are small and inconspicuous. The flowers have five greenish-white petals that are 2–3 mm across.

Given the energy requirements of the plant for flower, berry and seed development, ginseng growers manually remove the flower bud in late spring to encourage more root growth, except for acreage destined for seed production. This process is called debudding and is covered in *Debudding Ginseng*, Chapter 5.

Pollination

Ginseng is self-fertile and can be pollinated even when no pollinators are present. However, greater genetic diversity and potentially improved pollination can occur when pollinators are present. Hover flies and sweat bees are the primary pollinators in ginseng and can transport pollen between plants. Pollen tube formation can be interrupted during periods of high temperatures and/or moisture stress, causing the seed to abort. Seed abortion close to berry maturity may result in seeds that appear intact after harvest but decay in storage or fail to fully develop and germinate.

Figure 7. Ginseng flower head with the first flush of flowers open.

Ginseng Berries and Seeds

Once fertilized, ginseng seeds develop in the green berry (Figure 8). As the berries mature, they gradually change colour from green to dark red. The berries are ready to pick at the red stage (Figure 9) and fall off the umbel when they are dark red. Berry development usually lasts about 4–6 weeks and the seed head doubles in size during this time. Berries are usually ready to harvest by mid- to late-August. Since berries do not all ripen at the same time, growers choose a time to harvest them when most berries are mature but before too many older berries begin falling off the plant.

Figure 9. Ripe ginseng berries ready for harvest.

Each berry usually contains two seeds, although one and three seeds can occasionally be found. Each umbel may contain 30–40 berries and 60–80 seeds. The developing embryo in the seed is not yet mature when the berries are harvested.

Seeds usually set on 80%–90% of flowering plants in gardens that are 3 years and older. Under hot, dry conditions, seed set may drop to less than 50%. Weather conditions, especially heat, may cause abortion due to poor pollination or interference with seed development (see *Heat Stress*, Chapter 6).

Figure 8. Seeds developing inside a green ginseng berry.

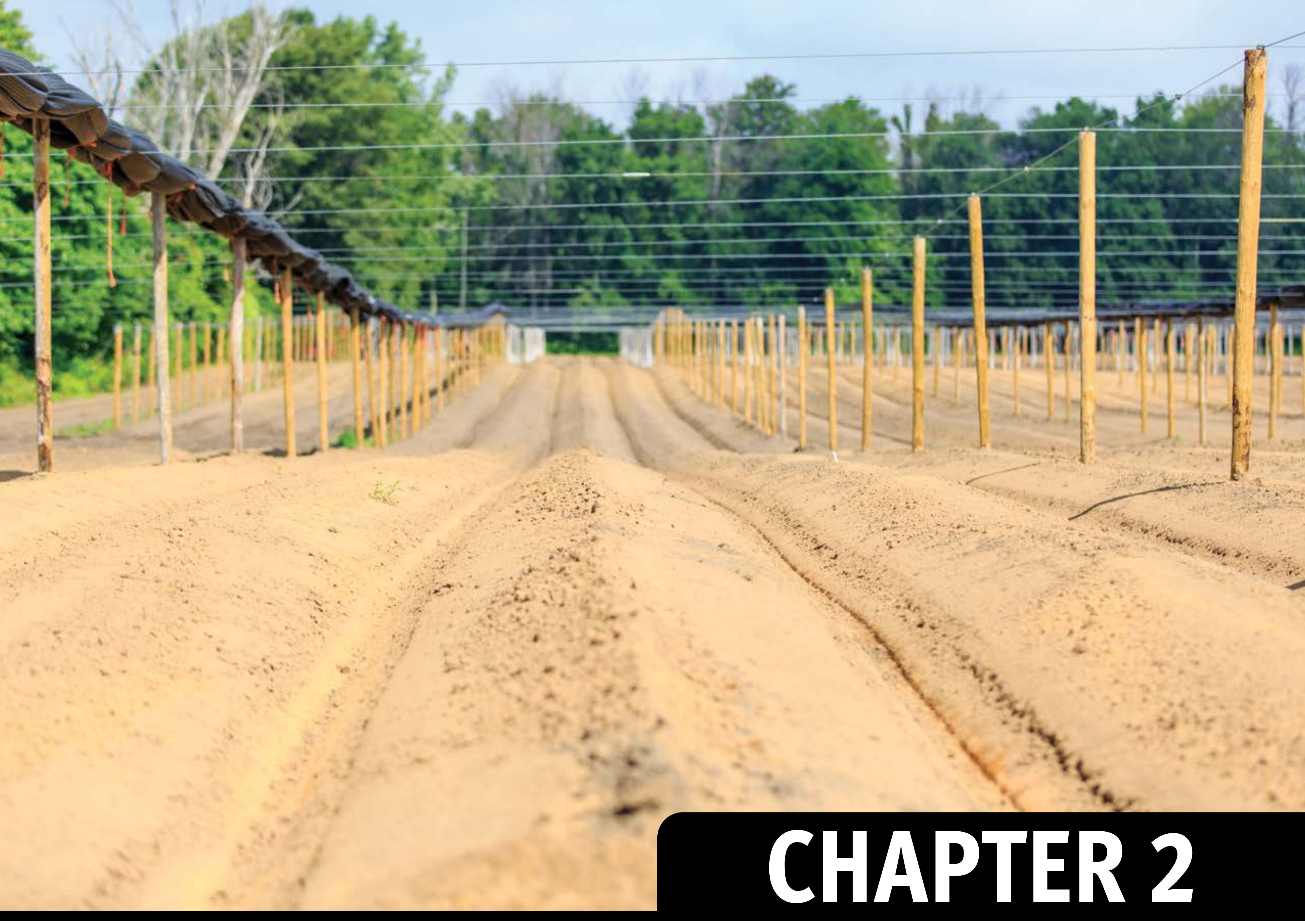
Senescence

Following berry harvest, the leaves remain green for 3–4 weeks. Seedlings without a flower head start to show leaf yellowing during this period. The leaves of ginseng plants generally remain green for 100–120 days after emergence and can stay green for up to 180 days under perfect conditions. Once senescence is complete, the leaves turn yellow and drop and the stems become yellow and dry. At this point in a harvestable garden, the tops are necrotic and can be safely removed by scraping and the roots dug. The timing of senescence and eventual necrosis of the leaves can be manipulated partially by grower fertility practices. In gardens that are not harvested, the leaves drop onto the straw mulch and the dry stems remain erect.

Timeline of Ginseng Production

Ginseng's unique biology requires a unique production system. While systems may vary between growers, there is a consistent timeline of ginseng production that most growers follow (Figure 10). Understanding this timeline helps growers navigate through this publication. Growers typically plant new fields and harvest old ones every year. This requires growers to coordinate labour to ensure tasks for all ages of gardens are conducted on time.

Figure 10. Timeline of ginseng production. (A) Fumigation occurs in the spring of the seeding year (Year 0), sealed with a plastic tarp for some fumigants. (B) The shade structure is erected over the summer and beds are formed just before seeding. (C) Ginseng is seeded using air-assist seeders. (D) The beds are covered in a thick layer of straw mulch to insulate the seeds and eventual roots. (E) A seedling crop with a sparse canopy (Year 1) covered with plastic shade cloth. (F) A 2-year-old garden (Year 2) with canopy closed. (G) A 3-year-old garden (Year 3) with a dense canopy. (H) The shade structure is removed at the end of three or more years to kill the canopy and the roots are dug with variations of modified potato diggers combined with hand labour.



CHAPTER 2

Site Selection and Preparation

Commercial ginseng production is designed to reproduce the environmental conditions of the forest in a field setting. In the forest, ginseng grows on the forest floor in a shaded environment, covered in decomposing leaf mulch with well-drained soil that is high in organic matter. Many of the practices involved in field site selection and preparation are designed to mimic these forest conditions.

There are important differences between field and forest production, particularly, the density of production. Plants in the forest are widely spaced, while plants in the field are placed significantly closer together to maximize yield. Soils in most ginseng production areas are also very low in organic matter and the balance of soil microorganisms that can outcompete ginseng pathogens is disrupted. Some field practices are necessary that are not as important in the forest — pest control, fertilization and airflow modification. While ginseng in the forest can tolerate moist soils, the combination of wet conditions and higher plant density in the field increases the risk of diseases. As a result, drainage is a very important consideration in commercial field production.

Site Selection

Site selection is the most important step to a successful crop. Planting on an inappropriate site can result in higher disease pressures and potential crop loss. Establishing any part of a garden in an area with poor drainage or heavy soil can increase the risk to the entire garden, since diseases that develop in one area can quickly spread to the remainder of the garden.

The basic requirements of site selection are:

- ✓ sites with no history of ginseng production — except under certain conditions and management practices (see *Ginseng Replant Disease (GRD)*, Chapter 6)
- ✓ soil textures ranging from sand to sandy loam
- ✓ good drainage
- ✓ higher than average organic matter content — or improvements to organic matter content before seeding
- ✓ availability of sufficient calcium

Site History

Ginseng is generally not grown on the same land twice because of ginseng replant disease (GRD). GRD is a complex issue that can lead to significant reductions in yield and plant survival and can occur decades after the first ginseng crop. Research led by Ontario Ginseng Growers Association (OGGA) and OMAFA has improved the understanding and management of GRD. It is now possible to replant ginseng under certain conditions, but the risk of disease is still much higher in replanted gardens. Not all factors in GRD development are understood, but ilyonectria (cylindrocarpon) root rot — caused by the fungal pathogen *Ilyonectria mors-panacis* (formerly *Cylindrocarpon destructans*) — is the disease most prevalent in replanted gardens. See *Ginseng Replant Disease (GRD)*, Chapter 6 for more information.

As a result of replant disease, ginseng growers continually lease new land and often travel farther from their home farms to their fields. Knowing a site's cropping history is essential to production success, but it can be difficult to find information going back decades. Sources of cropping history include the landowner, farmers in the area and the OGGA. Suitable land for ginseng production is becoming scarce in some areas of Ontario.

Ginseng is also prone to diseases of some other crops, particularly perennial horticultural crops. For example, *Phytophthora cactorum* — the most damaging disease of ginseng — is a pathogen on many other horticultural crops including apples, strawberries and cucurbits. Ginseng can also be susceptible to verticillium wilt if planted after potatoes or certain other crops (see *Verticillium Wilt*, Chapter 6). Planting ginseng soon after one of these crops may increase the risk of root diseases on ginseng. Recent research, however, indicates that growing ginseng after perennial crops like apples does not result in increased ilyonectria (cylindrocarpon) root rot because the species of *Ilyonectria* (formerly *Cylindrocarpon* that affects ginseng (*I. mors-panacis*) is not a main pathogen of other horticultural crops in Ontario.

Soil Type

Several types of soil are suitable for ginseng production in sites that meet basic requirements described in this chapter.

- Sandy soils often produce the highest yields and the lowest risk of disease.
- Sandy loam soils may have reasonable yields if drainage is good, but the risk of root disease is much higher than in sandy soil.
- Clay and clay loam soils are not appropriate for growing ginseng on a commercial scale.

Soil type can also affect root shape. Very sandy soils with low organic matter tend to produce long, pencil-like roots. Some markets value this type of root, but most markets prefer a stubbier, chunkier root. Soils with gravel or stones allow water to percolate too quickly and may be prone to temperature fluctuations that can also affect root shape.

Good drainage is essential for any soil where ginseng is grown. Do not plant ginseng in poorly drained areas of a field where diseases can develop and spread to the rest of the field. Subsoil drainage is also important to ensure adequate drainage out of the root zone. Always examine the soil profile in the prospective field to help identify subsurface layers that have an impact on drainage. If subsoil drainage is not sufficient, soil in the beds remains near saturation, encouraging the development of phytophthora root rot.

Soil Sampling

Before choosing land, consider doing soil tests. Collect soil samples before site preparation to help identify issues that might develop in the ginseng garden, so you know how to prepare soil ahead of seeding. Soil samples can be used to determine:

- the soil type and organic matter content of the soil
- the nutrient concentrations and pH in the soil so they can be adjusted through fertilizer, lime and manure application (see Chapter 3)
- the populations of plant parasitic nematodes (see *Nematodes*, Chapter 6)

Soil can be tested for some soil pathogens that may affect the ginseng crop, but there is limited understanding of how to sample properly or how test results relate to the severity of root diseases. Many pathogens affecting ginseng (*Fusarium* and *Pythium*) are present in most agricultural soils, but may not be an issue if the field is prepared and managed properly. Alternatively, the presence of *Phytophthora cactorum* at seeding will increase the risk of disease in the garden.

Growers often want to know the concentration of pesticide residues in the soil ahead of ginseng production so sites with higher risks of exceeding maximum residue limits (MRLs) can be avoided. However, recent research suggests pesticide concentrations in the soil are highly variable and may not correlate with the eventual root concentrations. Excessive testing is typically required to accurately determine the risk and may be cost-prohibitive.

Water Management

Ginseng does not thrive in wet areas. Avoid low spots in fields and areas of surface water runoff. Grade fields to facilitate the removal of surface water. Drainage problems are best diagnosed after heavy rains or snow melt events in the year or two prior to garden establishment.

Grading a field

Grading a field before planting is always the best option. When laying out a garden, design beds so that water flows freely down the trenches and out of the garden. In areas where water tends to flow during the early spring and after periods of rainfall, maintain a grassed waterway to help water movement and avoid soil erosion.

Several design factors help with water management.

- ✓ Dig a perimeter trench that is slightly lower than the ends of the garden trenches.
- ✓ Drain the perimeter trench into a collection pool.
- ✓ Extend trenches at the end of a downward slope to keep water moving during periods of heavy rain.
- ✓ Dig a trench that follows the natural water flow. This trench may cut through beds in low areas.

✓ Insert Hickenbottom drains, which are vertical pipes that channel surface water into underground drainage systems.

For more information on drainage systems and regulations that may impact the installation of drainage systems consult Agricultural Drainage on Ontario.ca

Ginseng planted over an entire field without considering waterways will have areas of *Phytophthora* infections where the water flows regularly or pools in the trenches (Figure 11). Movement of machinery through these areas spread disease throughout the entire garden. With a shortage of suitable land, growers may have to use marginal land for ginseng production, which is more prone to drainage issues.

Figure 11. Phytophthora root rot developing in a low area of a ginseng garden where water pools after heavy rains.

Dealing With Excess Water

Wet areas in a garden can be hot spots for phytophthora root rot. Dig collection pools to contain water runoff from ginseng gardens in a low area deep enough to hold water runoff after heavy rains.

When water stands in a trench, it saturates the adjacent bed. Ginseng roots can reach well down into the soil in beds and root tips adjacent to a flooded trench are in danger of

Figure 12. A diseased area of a ginseng garden recently subsoiled to improve drainage.

infection by *Phytophthora cactorum* (see *Phytophthora Root Rot and Blight of Ginseng*, Chapter 6). When the water subsides, trenches will be muddy and more likely to stick to machinery and boots, allowing soil-borne pathogens to spread throughout the garden.

Add wood chips or other absorbent material (thick layer of straw) to areas of a garden to prevent splashing where water tends to pool in the trenches. Splashing from wet trenches in diseased areas is a leading cause of phytophthora leaf blight.

Water management cannot be stressed enough. Do not plant seed in low, wet areas.

Reducing Soil Compaction

Beds in a ginseng garden are formed along and between rows of posts that support the shade material. Application of fertilizer and pest control products requires repeatedly driving on the same trenches because the equipment must fit between the post rows.
The extensive maintenance required in ginseng gardens often leads to soil compaction and poor drainage in these trenches. Compaction can be alleviated to some extent by subsoiling the trench (Figure 12). Subsoil trenches before heavy rains to improve drainage from the trenches. Use a knife-style subsoiler or a coulter disc that does not disturb the soil profile but allows water to drain.

Ginseng Shading Systems

In commercial ginseng production, shade structures affect the garden temperature and light intensity. In a new garden, the posts are usually set before seeding, but the shade material is not pulled over the beds until the following spring when the new plants emerge. If shading structures are up in the winter or pulled over the crop too early in the spring, they can collapse with just a few centimetres of snow.

Commercial ginseng growers historically used wooden-lath shade structures (Figure 13). The industry has now moved to either low-polypropylene cloth or high-polypropylene cloth because of higher material and labour costs required to erect and maintain wooden structures, especially for larger acreages.

Figure 13. A ginseng garden with wooden lath shade.

Low-Cloth Shade

Low-cloth shade is about 1.8–2.5 m in height (Figure 14). Woven polypropylene strips that are 7.3 m (24 ft) wide are strung using grommets and “S” hooks along tensile wires the length of the garden. Shade cloth may vary in the amount of light penetration and can create weave patterns that block 74%–82% of the light. There are two half beds and three full beds between post rows in low-cloth gardens.

Figure 14. A ginseng garden with low-cloth shade.

High-Cloth Shade

High-cloth shade is about 3.0–3.7 m in height (Figure 15). The polypropylene cloth used for high-cloth shade is 10.9 m (36 ft) wide. The difference between the high-cloth and low-cloth systems is the height and spacing of the posts and metal posts are more often used in high-cloth shade. There are two half beds and five full beds between post rows in high-cloth shade gardens.

Figure 15. A ginseng garden with high-cloth shade.

Shade cloth suppliers can custom install the structure or assist with the design, supplies and equipment necessary for erecting a shade structure. Posts are often marked out in a grid using GPS technologies and custom suppliers of this service are available.

Different brands of shade cloth can be used in either system, these differ in the amount and pattern of light transmission. Black cloth is currently the only colour used. There are other colours available that may help reduce heat accumulation under the shade, but these must be tested before adopting them widely.

Shading System Considerations

The choice of high- or low-cloth shade systems is mostly an economic decision, based on the price of materials and availability and cost of equipment that fits within that system. High-cloth shade systems are a newer technology than low-cloth systems and require taller and stronger posts, more or stronger anchors and taller platforms for workers to handle the shade cloth. Given the distance between posts, larger spray booms are required in high-cloth systems — increasing the area that can be sprayed at one time and lowering labour and fuel costs. Once a shading system is chosen, it is difficult to switch because of the investments made in equipment and posts that fit the current system. New growers should examine the long-term costs associated with each system before choosing one and purchasing equipment.

Temperature

The temperature between the plant canopy and the shade material in a ginseng garden depends on the type of shade used and the topography of the field. Hot air can build up at the top of hills under the shade.

- Wooden-lath shades have the advantage of being cooler in the summer and providing more frost protection than the newer cloth systems.
- High-cloth shades are cooler in summer than low-cloth shades.
- Temperature and humidity under low-cloth shade can remain high all day unless vents are provided for hot air to rise out of the garden.
- Air temperatures just above the ginseng canopy are up to 6˚C higher on a sunny, calm day than the air above the shade structure.

On hot days, the additional heat in the plant canopy can restrict growth of the plant and cause symptoms of heat stress, including leaf damage and berry abortion.

Frost

Black shade cloth can affect the risk of frost damage in the spring. As a native plant, ginseng is tolerant of mild freezes at its most sensitive point — between leaf expansion and early canopy closure for older plants and any time after the emergence of seedlings. Shade cloth can radiate heat quickly at night, causing cold air to pool under the shade and along the edges of the garden. This air can be a few degrees colder than the open areas nearby.

Black cloth also blocks airflow that could mix the cold air with warmer air around and above the garden. The radiation of heat along the edge of the garden can further reduce temperatures in these areas, leading to higher frost damage. All these factors make frost risk for ginseng similar to tender crops in open fields during the most sensitive period, especially if the garden is in a sheltered area. The risk can be reduced by erecting gardens in open areas with good air flow and a slope for cold air drainage out of the garden. For more information on the impacts of frost, see *Low-Temperature and Freeze Damage*, Chapter 6.

Rainfall

Shading structures can influence rainfall patterns under the shade and rainfall is highly variable under a cloth shade. Much of the rain falls through shade cloth, but a portion remains on top of the shade and travels downhill along the shade until it reaches a low point. Considerably more rain can fall at these low points, causing nutritional and disease problems for the plants below. This issue is more pronounced when the garden is established on a slope, as the water travels along the shade until it reaches a cross cable under the shade and then falls in a straight and narrow band under the cable. The nutritional effect of this process is called drip-line chlorosis (see *Drip-Line Chlorosis*, Chapter 6). Keep cables tight and add extra posts in low areas to help mitigate this effect.

Airflow

Shading structures also affect airflow through the garden. Good airflow is necessary for drying the leaves and reducing foliar disease pressures. Avoid situating gardens in locations with restricted airflow. Gardens in protected corners of fields surrounded by woods usually have a higher incidence of both foliar and root disease. In addition, low-cloth shade can restrict airflow more than high-cloth shade. Wind speeds under the shade can be up to one-sixth of the wind speed above the shade structure. Provide vents for hot and humid air to escape the shade structure and establish gardens in open sites to facilitate air movement and improve airflow.

Land Preparation and Fumigation

Land preparation a year or two ahead of seeding is beneficial to help build soil organic matter and fertility. However, not all growers have access to the land before the seeding year. Growers who prepare land the year before seeding often plant a cover crop to improve the organic matter content of the soil and suppress parasitic nematode populations. Summer grasses such as pearl millet (for example, Canadian Forage Pearl Millet 101) are the most common cover crops used because they can suppress nematodes and increase organic matter content. Mustard cover crops can also be used as a biofumigant crop the year before seeding or early in the spring of the seeding year. To help choose a cover crop, visit the Ontario pages of the Midwest Cover Crop Council. For more information on mustard biofumigation, see *Alternatives and Improvements to Fumigation* in this chapter.

The main pre-plant activities in the seeding year are applying manure and fertilizer, fumigating and erecting the shade structure. Manure and fertilizer application are covered in more detail in later chapters. Between each of these activities, keep the soil free of weeds and ensure the breakdown of manure and previous crop residues. Soil cultivation is the best way to achieve this. Plant residues can reduce the success of fumigation and interfere with seeding. Weeds that grow after fumigation can also harbour diseases, insects and nematodes that can later spread to the crop.

Fumigation Timing

Fumigation is standard practice in ginseng production to manage soil-borne pathogens, nematodes and weeds. Most fumigation in ginseng is done by custom applicators from late May to July once the soil has been prepared and organic residues have been broken down. Application timing is flexible and often depends on the availability of custom applicators and farm labour scheduling.

Fumigation Methods

Fumigation in ginseng is normally a broadcast application that treats the entire field, not just banded under the beds. Despite the term broadcast, most of the fumigants used in ginseng are applied by soil injection to a specific depth. The soil surface is then sealed by plastic tarps (Figure 16), irrigation and/or rolling (Figure 17), depending on the fumigant. The seal keeps fumigants in the soil long enough to have activity on the target organisms. Fumigants do not penetrate organic residues or clumps of soil very well and the fumigation may not control the pathogens contained in these residues. Breakdown of residues is essential before fumigation, since they can also break through the soil surface, providing a chimney for the fumigant to escape from the soil before it can be effective. The soil seal must be kept in place for 7–14 days, depending on the fumigant, followed by a further period to allow any remaining fumigant to dissipate before seeding can occur. Shade structures are usually erected between fumigation and seeding, allowing time for the fumigants to dissipate before seeding. Consult fumigant labels for required re-entry periods and safety precautions.

Figure 16. Plastic tarps being applied at fumigation to seal the fumigant into the soil.

Figure 17. A fumigator using a power roller to seal the fumigant into the soil.

Fumigation is one of the most critical aspects of ginseng production, especially in replanted gardens or those with a history of pathogens that affect ginseng. Ensure soil moisture and temperature are within the required range listed on the label. Wet and cold soils limit the movement of the fumigant through the soil, preventing it from treating some areas of the soil profile. These soil conditions reduce timely escape of the fumigant after application and potentially cause worker exposure issues or damage to seeds planted while the fumigant is still in the ground. Hot and dry soils could accelerate the movement of fumigants through the soil causing them to escape too quickly. These conditions can prevent adequate control of soil pathogens and lead to fumigant drift that could be dangerous for nearby residences or businesses.

Fumigation Safety Precautions

Fumigant applicators must ensure they follow all safety precautions listed on the fumigant label. This includes, but is not limited to, ensuring proper soil and weather conditions during and post-application, posting all required signage, restricting entry to the field and buffer zone and monitoring the site during and after application. Failure to follow the label can cause premature fumigant escape and drift issues, potentially leading to serious health risks to farm workers, passers-by and nearby residents. If such incidents are caused by neglect, there could be significant legal or financial consequences for the applicator or others involved. Thoroughly read the most current version of the label before applying any fumigant. The label is the law.

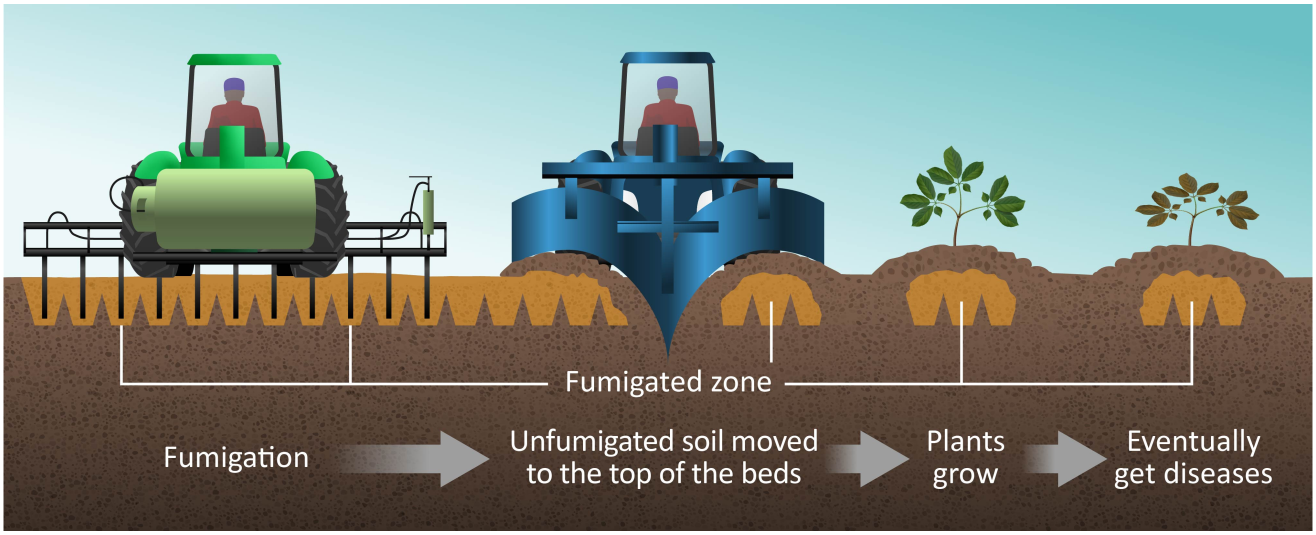


Figure 18. Distribution of fumigants in soil during broadcast fumigation and movement of treated soil during bed formation. Some unfumigated soil is often moved to the top of the newly formed bed.

Fumigant Patterns in the Soil

Consider the pattern of control provided by soil injection of fumigants. Fumigant injection involves liquid or gas being released from a shank 15–30 cm below the soil surface. After release, the fumigant generally moves outward and upward over time resulting in a "V" pattern of release that can leave untreated areas between shanks (Figure 18). In loose, hot and/or dry soils, these V patterns are narrower as the upward movement is faster than the lateral movement, increasing the size of the untreated areas between the shanks. As the fumigant rises through the soil profile, it can accelerate as it approaches the surface leaving a few centimetres of poorly treated soil near the surface if there is not an adequate seal. Some fumigants are applied using impermeable films to seal the fumigant in the soil. These films can slow the upward movement of the fumigant and prevent fumigant escape, improving coverage lower in the soil profile and near the soil surface.

Fumigation can be an expensive step for ginseng production, but the benefits for long-term reduction in soil pathogens far outweigh the costs. With these high costs, it is beneficial to fumigate correctly. This may involve irrigation to ensure adequate soil moisture and a good seal of the surface to prevent premature escape of the fumigant. For more information on fumigation practices and products registered for use on ginseng, consult the Ontario Crop Protection Hub.

Alternatives and Improvements to Fumigation

Research conducted by the OGGA and OMAFA on GRD over the past decade has shown that alternative disinfestation strategies can be effective to control soil-borne pathogens of ginseng when combined with other management techniques. These strategies could be applied during the land preparation years to improve the control by fumigation, improve the efficacy of fumigation and provide alternatives to fumigation in certain situations. Research on GRD has shown that, under replant conditions, alternative strategies, followed by fumigation, can improve disease control over fumigation alone, but do not provide sufficient disease control on their own. In non-replant conditions, these alternatives may be more viable as stand-alone strategies. Further research is required before recommending widespread adoption.

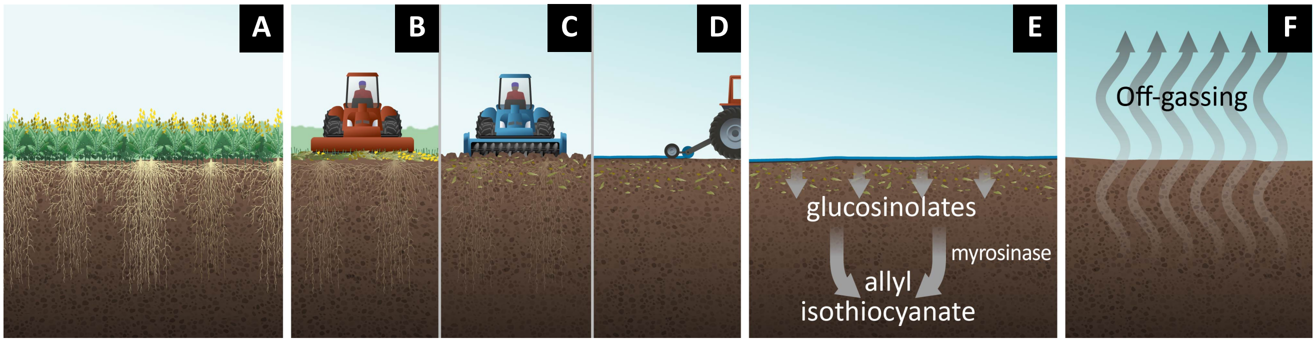


Figure 19. The process of mustard biofumigation. (A) Grow a thick stand of mustard. (B) Chop the mustard with a flail mower. (C) Incorporate the mustard into the soil using a rototiller. (D) Seal the soil. (E) Glucosinolates are converted to the biofumigant allyl isothiocyanate by the enzyme myrosinase. (F) Remove the seal after 10—14 days and allow the biofumigant gas to escape.

Solarization

Solarization involves covering the soil with clear or black plastic tarps to heat the soil and kill soil-borne pathogens. This technique is more successful in hot and dry climates, but the clear totally impermeable films (TIF) used as a seal for fumigation have shown some effect for controlling GRD in Ontario when fumigation occurs during the heat of summer. This technique is not an acceptable alternative to fumigation. When using TIF films for fumigation, leave tarps on the soil for an extended period during the summer for additional control by solarization. The heating effect could extend to areas where the fumigant does not reach.

Mustard Biofumigation

The glucosinolates naturally present in mustards break down to chemicals (allyl isothiocyanates) that are similar in structure and function to the same active ingredients found in several fumigants. Different mustard cover crops contain different forms of these chemicals that can control different soil pathogens. Research in apples has shown that a 50/50 mix of yellow and white mustard seed meals high in glucosinolates provide broad spectrum control of pathogens involved in apple replant disease, including *Ilyonectria, Phytophthora, Pythium* and nematode species. Related species of all these pathogens are also primary targets of fumigation in ginseng. The 50/50 blend of yellow and white mustard species was shown to be more effective than either type on its own because each mustard controlled a different spectrum of pathogens in the soil.

Research conducted by OGGA and OMAFA has shown that mustard cover crops are as effective as mustard seed meals in controlling GRD, at a fraction of the cost. But these crops must be selected, grown, incorporated and carefully sealed into the soil to have any effect.

The process of biofumigation using mustard cover crops is illustrated in Figure 19 and includes six steps.

The process of mustard biofumigation

1. Select mustard cover crops high in glucosinolates that are specifically intended for biofumigation and nematode control. Ontario research has proven the efficacy of a 50/50 combination of 'Pacific Gold' yellow mustard and 'White Gold' white mustard for this purpose. Other cultivars with similar or higher glucosinolate content should have similar efficacy. The research has only proven the efficacy of the 50/50 blend of yellow and white mustards. The efficacy of any changes to the ratio of these mustards or the use of different species of mustard is unknown and requires further research.
2. Plant the mustard cultivar mix to ensure a 50/50 blend of the eventual cover crop by planting the species at an equal weight of seed per area to counteract the different sizes of the seeds of the two species.
3. Fertilize and water the cover crops to ensure a thick stand. For pathogen control, the cover crop must be dense, which can only be achieved through fertilization, particularly nitrogen and ensuring adequate water throughout cover crop growth. Consider planting the cover crop early in the spring to avoid hot periods that could cause the cover crop to flower prematurely and limit biomass production.
4. Plow down the cover crop at around 25% flowering when some green seed pods have been formed, but no seeds have matured. Just like fumigation, ensure adequate moisture is available at the time of plow down and incorporation to ensure release of the isothiocyanates and slow their movement through and out of the soil. Plow down in the morning when it is cooler to slow down the release of the chemicals from the mustard.
5. At plow down, ensure everything is ready for rapid chopping, incorporation and sealing. Any delays cause premature release of the glucosinolates and greatly reduce pathogen control. The mustard should be finely chopped with a flail mower. This must be immediately followed by both deep and even incorporation into the soil using a rototiller and sealing the soil. TIF films used for fumigation offer the best soil seal. Power rolling of moist soil and/or 5–10 mm of irrigation following incorporation may also be effective, but plant debris can often prevent an adequate seal.
6. Do not disturb the soil for 10–14 days. Cultivate lightly to allow any remaining chemicals to escape. Wait a few more days before seeding to prevent damaging the seeds. This is usually not an issue due to the 4–6 week period required to erect the shade structure between soil treatment and seeding.

Failure to closely follow these steps greatly reduces disease control effectiveness.

Anaerobic Soil Disinfestation

Anaerobic Soil Disinfestation (ASD) is an alternative to fumigation that has received considerable attention in recent years, particularly for organic production. In Ontario, ASD has proven to be the most effective alternative disinfestation technique for the management of GRD. The principle of ASD is to incorporate a carbon source into moist soil, block oxygen flow into the soil using TIF plastic tarps and then let the microorganisms in the soil feed on the carbon source and use up the available oxygen in the process. The carbon source must be easily broken down so the reaction can occur quickly. This process creates anaerobic conditions, releasing volatile compounds that kill plant pathogens and shifting the entire soil microbial community. The result is a reduction in soil pathogens, but not a complete sterilization of the soil.

The procedures for anaerobic soil disinfestation (ASD) are illustrated in Figure 20 and include six steps.

1. Ensure the soil is warm at the time of carbon incorporation. Cool soils in spring and fall may not allow for optimal activity of microorganisms.
2. Choose a carbon source that breaks down easily like molasses, ethanol or fine seed meals. These products can be purchased from seed mills and should be applied at 5–10 t/ha. The addition of some nitrogen fertilizer (50 kg/ha or less) ahead of carbon incorporation may enhance the efficacy of the treatment by speeding up microbial activity in the soil.
3. Use a rototiller to evenly incorporate the carbon source to a depth of 15–20 cm.
4. Irrigate after incorporation to saturation to reduce the amount of air spaces and oxygen in the soil.
5. Seal the soil with a plastic tarp. Standard plastic tarps can be effective, but TIF is preferred because it is impermeable to oxygen. Repair any holes in the tarp immediately. Deter animals from walking on the tarps after application. The efficacy of ASD is improved if the soil can be drip-irrigated under the plastic regularly after incorporation to reduce air spaces in the soil, but this may not be practical or cost-effective for ginseng growers.
6. Wait 3–4 weeks or longer before removing the tarps. Experience in Ontario has shown that efficacy improves the longer the tarp remains on the soil. At tarp removal, cultivate to introduce oxygen back into the soil and allow volatile chemicals to escape. Wait at least 1 week after cultivation before seeding.

Bed Formation

Once the field has been adequately prepared and the fumigants or alternatives have dissipated from the soil, determine the direction of the beds. Beds are often formed from north to south to limit sun penetration into the ends of the garden. If they are formed east to west, the rising and setting sun can cause some light damage deeper into the garden. Erect side shades to block the sun along the sides of the garden (Figure 21). With the north-to-south orientation, the open end of the garden is to the south, where the angle of the midday sun is much higher. In contrast, the predominant airflow is from the southwest and west, so better airflow can be achieved with southwest to northwest or west to east oriented beds. Proper drainage down the trenches and out of the garden should take precedence over these considerations.

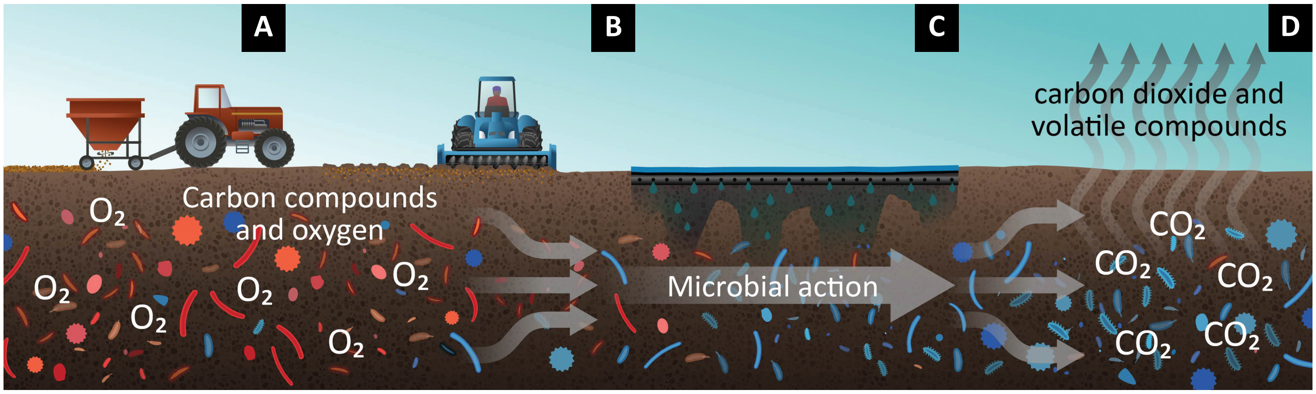


Figure 20. The process of anaerobic soil disinfestation. (A) Spread a carbon source that is easily broken down onto the field. (B) Evenly incorporate the carbon source and ensure high soil moisture. (C) Seal the soil with totally impermeable films (TIF). Drip irrigation under the tarp improves efficacy. (D) Keep the tarp in place for several weeks and allow soil microorganisms to use up the soil oxygen as they break down the carbon source.

Figure 21. Side shades on the edge of a ginseng garden.

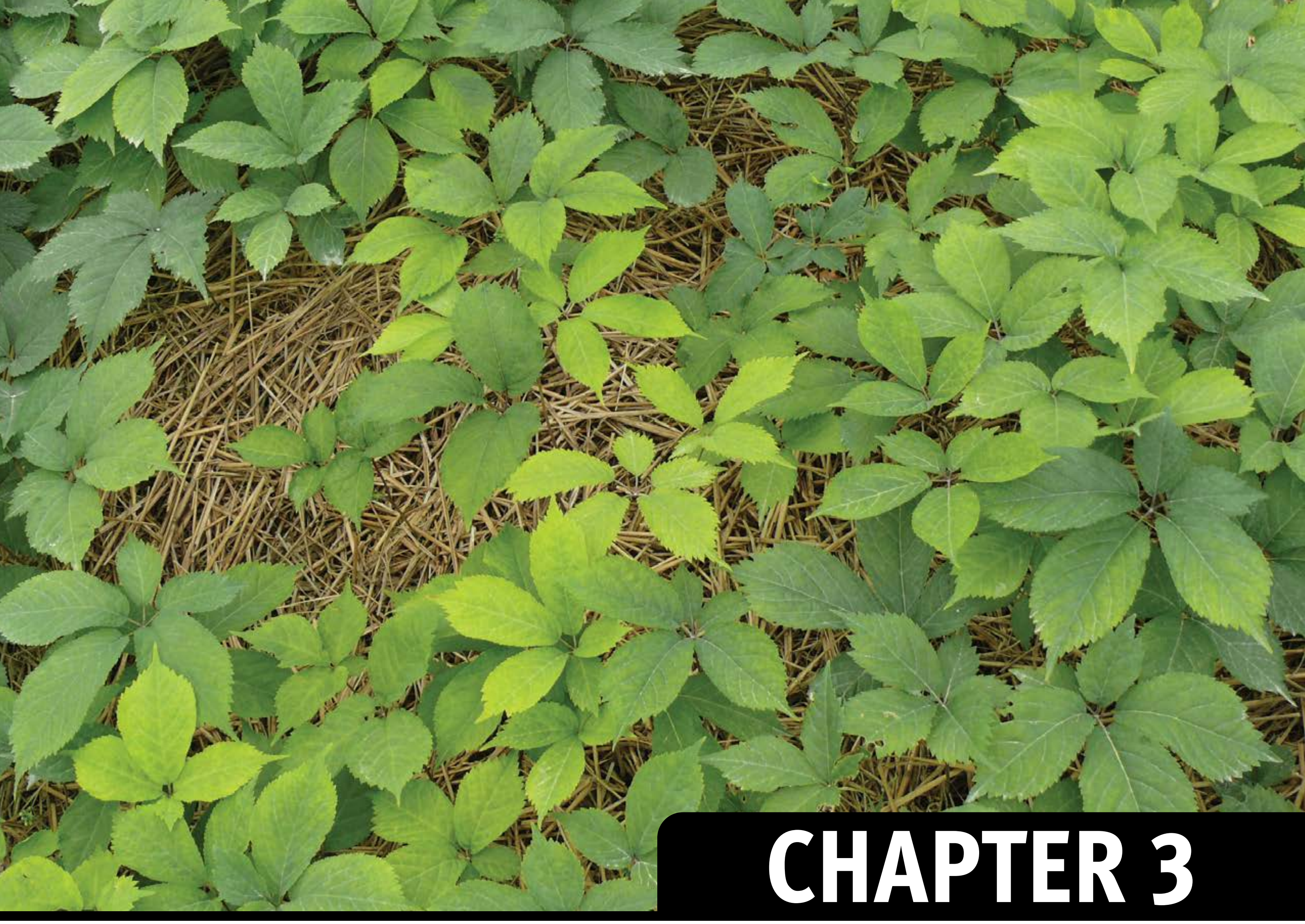
Figure 22. Raised beds created using a bed former.

Figure 23. A bed groomer used to smooth out the beds after bed forming.

Figure 24. Recently formed ginseng beds. Note the lighter-coloured soil at the top of the bed, which is deep subsoil pulled up by the bed former.

After the posts are set for the shade structure, form the beds using bed-forming equipment (Figure 22), followed by bed grooming equipment to smooth out the beds (Figure 23). Occasionally, growers prefer to form the beds before installing posts. Ginseng beds are usually 1.8 m wide, centre to centre and 20–30 cm high (Figure 22). When forming beds, avoid digging up unfumigated/untreated soil from deep in the soil profile (see Figure 18).

The deepest soil is often placed at the top of the bed during bed formation (Figure 24). If this soil is contaminated with soil-borne pathogens, they will quickly colonize the sterile soil in the bed and damage the ginseng crop the following year. Techniques that minimize the amount of unfumigated soil incorporated into the bed can greatly improve disease control, especially for GRD.



CHAPTER 3

Soil Management and Fertility

Soil fertility is an important component for producing high-yielding, top-quality ginseng and is one key part of a crop management program. The effectiveness of a soil fertility program depends on careful soil and water management and crop protection. Developing a sound soil fertility program begins with assessing the nutrient needs of the crop and the soil.

For a complete guide to soil fertility, see OMAFA Publication 611, Soil Fertility Handbook.

Assessing Nutrient Needs

There are three ways to assess soil and crop fertility:

1. visual deficiency symptoms
2. soil testing
3. plant analysis

Visual Deficiency Symptoms

Leaf symptoms are helpful for evaluating some nutrient deficiencies but yield losses may have already occurred by the time deficiency symptoms are visible. Visual deficiency symptoms may also be confused with other production problems — herbicide injury, leaf and root diseases, nematodes, insect damage, soil compaction or air pollution. While nutrient deficiency symptoms can be diagnosed in some crops based on the age of the leaf on which they appear, this is not possible for ginseng because plant leaves are all the same age. Suspected visual deficiencies can often be confirmed with leaf or plant analysis. Some visual deficiency symptoms are described later in this chapter.

Soil Testing

Soil testing in Ontario is conducted by commercial laboratories that use tests accredited by OMAFA. The laboratories are accredited for soil pH, buffer pH, nitrate-N, phosphorus, potassium, magnesium, manganese index and zinc index. OMAFA-accredited soil tests are not available for boron, copper, iron or molybdenum. Plant analysis is generally a better indicator of deficiencies of these nutrients.

For a list of accredited soil-testing laboratories in Ontario, see *Appendix C. Accredited Soil-Testing Laboratories in Ontario.* Soil organic matter tests can be useful for herbicide recommendations or for evaluating soil quality, but are not accredited tests.

When to Sample

Ideally, prepare ginseng land 1–2 years before the seeding year to adjust fertility and pH. Higher land lease prices have made it more common to avoid these preparation years and start land preparation the year of seeding, but this may not give adequate time for nutrient concentration and pH to be adjusted prior to seeding. Regardless of when you begin preparing the land, collect soil samples in the previous fall so fertilizer and lime can be applied the following spring. This is especially important for applications in the year of seeding, if they are necessary, because it provides the maximum length of time for pH to change prior to seeding. If adjustments to pH and/or fertility are made, test again after fertilizer and lime applications to see if additional adjustments are needed.

Potassium levels can change quickly on sandy soils where large amounts of nutrients are removed by the crop, especially if there is limited crop residue left on the soil. Soil sampling earlier than the fall of the year prior to seeding may not provide an accurate indication of soil potassium levels.

Taking a Soil Sample

The accuracy of a soil test report and the resulting suggested fertilizer application rates depends on properly taking, preparing and submitting a soil sample. The following are needed to sample soil:

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

Collect at least one sample from each garden — more in large gardens and gardens with considerable variation. Each sample should represent an area with relatively similar soil texture, topography, organic matter and cropping history.

Micronutrient deficiencies often occur in small patches in fields. In these cases, analysis of soil or plants taken from the entire garden is unlikely to identify the problem. A separate diagnostic soil or tissue sample is needed for these areas. When sampling a problem area, take a comparison sample from an adjacent, good area to help diagnose the problem.

A basic soil test consists of soil cores to 15 cm depth collected in a zigzag pattern throughout the field. Nitrate-nitrogen samples are taken to a depth of 30 cm. For both tests, collect at least 20 soil cores for fields up to 5 ha in size. Proportionately more cores are required for gardens larger than 5 ha. The more cores included in the sample, the more reliable the measure of the fertility in the garden. One sample should not represent more than 10 ha.

Avoid certain areas of the field 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.

Once the soil is collected, thoroughly mix the soil and break up lumps to ensure the sample represents the whole field. The lab only uses a small amount of the sample for each test, so a well-mixed sample provides greater accuracy. Labs need about 500 g of soil for testing and this can be placed into the soil sample boxes they provide. Mark samples clearly with all the necessary information, including sample number, farm name and date. A submission form must accompany the sample.

Interpreting the Results

The OMAFA-accredited soil-testing program provides guidelines for nitrogen, phosphate, potash, magnesium, zinc and manganese fertilizer. The program also provides 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.

In a soil test, each nutrient is given a numerical value (usually recorded in ppm or mg/kg), a letter rating and a fertilizer guideline for the crop specified on the soil test submission form. The Ontario soil test nutrient ratings were revised to 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 1.

A soil test guideline is affected by manure application, plowing down of legume sod and the type of crop to be fertilized. This information is essential for a reliable fertilizer guideline and should be indicated on the laboratory submission form. If manure and cover crops are used, adjust the fertilizer rate guidelines, especially for nitrogen and phosphorus.

There are several methods used in developing fertilizer guidelines from soil test results.

OMAFA-Accredited Guidelines

The OMAFA-accredited program uses a sufficiency approach, which applies nutrients up to the levels that yield greater economic returns (responsive range). This approach offers the least risk of profit loss from over-fertilization, minimizes nutrient loss and maximizes net returns to fertilization. Applying nutrients at the suggested rate maintains or gradually increases soil fertility. The soil test ratings of low response (LR), rare response (RR) or no response (NR) indicate that an economic response to adding more of that nutrient is unlikely. In rare cases, a specific nutrient may be suggested to enhance crop quality at these ratings. Adding nutrients to soils with a no response (NR) rating may reduce crop yields or quality by interfering with the uptake of other nutrients.

Table 1. 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

Soil Tests from Other Laboratories

Each year, some farmers ask how to interpret results from laboratories that are not accredited. If the unaccredited laboratory uses the identical test used by the OMAFA-accredited service and expresses results in the same units, the OMAFA fertilizer guidelines for phosphate and potash can be determined. There is no assurance of the accuracy of the analysis.

Only OMAFA-accredited soil tests can be relied on to provide accurate fertilizer guidelines. To be accredited, a laboratory must enrol in the external quality assurance program operated by the North American Proficiency Testing Program *(naptprogram.org)*, use OMAFA-approved testing protocols, report quarterly test results to OMAFA, demonstrate acceptable analytical precision and accuracy and provide the OMAFA fertilizer guidelines. Soil tests on farms that must complete a nutrient management plan must be carried out at OMAFA-accredited labs.

Soil Micronutrient Tests

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

Take great care 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 clean, plastic containers in good condition. Keep extraneous dust out of the samples.

Plant Analysis

Plant tissue analysis measures the nutrient content of plant tissue to identify if a specific nutrient is excessive, adequate or deficient during the growing season. If any nutrients are deficient, corrective action can be taken by the grower. Comparing the results against the normal and critical values for the crop can indicate whether nutrient supply is adequate for optimum growth.

Plant analysis is the basis of fertilizer guidelines for perennial crops like tree fruits and grapes and is a useful supplement to soil testing for evaluation of the fertility status of ginseng. Plant analysis is independent of soil testing and can provide a valuable second opinion, especially for phosphorus, potassium, magnesium and manganese. It has not proven reliable for nitrogen and zinc. There is no reliable soil test for boron or copper, so plant analysis and visual symptoms are used for diagnosing deficiencies. These visual symptoms are particularly important for ginseng growers to recognize. Ginseng is sensitive to excess boron. Leaf analysis is the only way to confirm if ginseng has a boron deficiency or toxicity.

There are limitations to plant analysis. Expert help in interpreting the results is often needed, since the analysis does not indicate the cause of a deficiency or the amount of fertilizer required to correct it. Adjusting some fertilizers after ginseng establishment can be very difficult. Plant analysis results in these cases may be more useful for correcting the problem in future gardens.

Taking a Plant Sample

Time of sampling has a major effect on the results, since nutrient levels within a plant vary considerably with its age. Results are difficult to interpret if samples are taken at times other than those suggested. Sample plants suspected of being nutrient deficient as soon as a problem appears and take samples from the problem area rather than the entire field.

A plant sample for nutrient analysis should include leaves from at least 20 plants distributed throughout the area chosen for sampling and at least 100 g of fresh material.

Sample problem areas separately. Do not contaminate samples with soil. Even a small amount of soil invalidates the results, especially for micronutrients.

In ginseng, the best time to collect samples is early to mid-July when the canopy is fully expanded. Sampling during leaf expansion produces variable and inaccurate results. Nutrient levels in ginseng leaves may be affected by flowering and seed development and by deflowering. If nutrient deficiencies or toxicities are suspected, sample from good and bad areas of the garden. Collect one leaf prong from each plant to ensure some leaves remain on the plant for further root development.

Sample Preparation

Deliver fresh plant material directly to the laboratory. If the material cannot be delivered immediately, dry it to prevent spoilage. Samples can be dried in an oven at 65˚C or less or dried in the sun if precautions are taken to prevent contamination with dust or soil. Samples should not contact galvanized (zinc-coated) metal, brass or copper.

Fertilizer Requirements

Soil Acidity

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 acidic and those above 7.0 are alkaline. Most ginseng gardens are adjusted to a pH of 6.5 before seeding. As the garden ages, the pH will drop slightly. When the pH is higher than 7.5 or lower than 5.5, roots may be predisposed to disease. Ginseng is found in the wild in Ontario in soils ranging from pH 4.5–7.1, but disease pressure is lower in the wild.

The Buffer pH and Liming

To correct soil acidity, broadcast ground limestone and work it into the soil at rates determined by a soil test. Different soils with one soil pH value (for example, 5.2), require different amounts of lime to bring the pH to a particular desired level (for example, 6.0), depending mainly on the clay and organic matter content of each soil. The soil pH is used to determine whether soils should be limed. A separate soil test, the buffer pH, is run on soils needing lime to determine the amount of lime required. For soils needing lime (based on soil pH), use Table 2 to determine the amount of lime required to reach different target soil pH values.

Limestone Quality

Calcitic limestone is mostly 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 an excellent and inexpensive source of magnesium for acid soils. On soils with magnesium tests greater than 100, use calcitic or dolomitic limestone.

Two main factors affect the value of limestone for soil application: neutralizing value and particle size.

The amount of acid a given quantity of limestone will neutralize when totally dissolved is called the neutralizing value, expressed as a percentage of the neutralizing value of pure calcium carbonate. Limestone that neutralizes 90% as much acid as pure calcium carbonate has a neutralizing value of 90. In general, the higher the calcium and magnesium content of a limestone, the higher the neutralizing value.

Particle size or fineness rating, is the second factor. Limestone rock has much less surface area to react with soil than finely powdered limestone and neutralizes acidity much more slowly to the point of being of little value. The calculation of a fineness rating for ground limestone is illustrated in Table 3.

Table 2. Lime Requirements to Correct Soil Acidity Based on Soil pH and Soil Buffer pH

Ground limestone required in t/ha (Based on an Agricultural Index of 75)			
Buffer pH	**Target Soil pH = 6.5 (Lime if soil pH below 6.1)**	**Target Soil pH = 6.0 (Lime if soil pH below 5.6)**	**Target Soil pH = 5.5 (Lime if soil pH below 5.1)**
7.0	2	1	1
6.9	2	1	1
6.8	2	1	1
6.7	2	2	1
6.6	3	2	1
6.5	3	2	1
6.4	4	3	2
6.3	5	3	2
6.2	6	4	2
6.1	7	5	2
6.0	9	6	3
5.9	10	7	4
5.8	12	8	4
5.7	13	8	5
5.6	15	11	6
5.5	17	12	8
5.4	19	14	9
5.3	20	15	10
5.2	20	17	11
5.1	20	19	13
5.0	20	20	15
4.9	20	20	16
4.8	20	20	18
4.7	20	20	20
4.6	20	20	20

Table 3. Example Calculation of the Fineness Rating of a Limestone

Particle Size	**% of Sample**	**×**	**Effectiveness Factor**	**=**	**Fineness Raiting**
Coarser than #10 sieve[1]	10	×	0	=	0
#10 to #60 sieve	40	×	0.4	=	16
Finer than #60 sieve	50	×	1.0	=	50
Fineness Rating of Whole Sample				=	66

[1] A #10 Tyler sieve has wires spaced 2.0 mm apart.

The Agricultural Index

The Agricultural Index combines the neutralizing value and the fineness rating to compare various limestones that are available.

The Agricultural Index is used to compare the relative value of different limestones for neutralization of soil acidity. Lime with a high Agricultural Index is worth proportionately more than lime with a low index because it can be applied at a lower rate and still have the same impact. Requirements for lime are based on limestone with an Agricultural Index of 75. If the Agricultural Index of the limestone to be used is known, a rate of application specifically for limestone of that quality can be calculated using the following example:

Agricultural Index = (neutralizing value × fineness rating)/100

If two ground limestones, A and B, have Agricultural Indices of 40 and 80, respectively, the value of limestone A for adjusting pH is half as much as limestone B. Therefore, you will need to apply twice as much of limestone A to have the same effect.

If the limestone requirement as determined by a soil test is 9 t/ha and the most suitable source of limestone from a quality and price standpoint has an Agricultural Index of 90, apply 75/90 × 9 = 7.5 t/ha.

The Agricultural Index does not provide information about magnesium content.

Tillage Depth

Lime requirements presented in this publication 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. Ginseng growers form large, raised beds after lime application and should consider treating deeper into the soil profile.

Lowering Soil pH

Lowering pH is only practical if the soil is already below a pH value of 6.5 and can be accomplished by adding sulphur or ammonium sulphate. The desired pH for ginseng is 6.5, so lowering pH below this value is not necessary. If the soil pH is above 6.5, it is usually impractical to lower it because of the large amounts of sulphur or ammonium sulphate required.

Nitrogen

The nitrogen (N) requirement for ginseng is 40 kg/ha, applied every year of production as a broadcast application in the spring prior to emergence. Nitrogen rates exceeding 50 kg/ha do not increase root yield and may lead to a reduction in yield. The rate of nitrogen applied has little effect on the root ginsenoside concentration (Refer to section *Ginsenosides* in Chapter 8). Nitrogen requirements for fertigation are similar to broadcast applications.

Adjust this guideline to account for nitrogen made available from any manure/compost applied to the field. Although manure application occurs up to a year before ginseng germination, organic nitrogen gives a nitrogen credit for several years after application — 10% in the second year, 5% in the third year and 2% in the fourth year.

Growers often apply much higher rates of nitrogen over the growing season, usually split across multiple applications. Research does not support these high nitrogen application rates. The nitrogen needs of the crop may have increased in proportion to the increase in yields since research was conducted in the 2000s. These increased nitrogen needs have not been proven and would only account for a maximum of a 50% increase in the rate.

Consider these four factors before applying excessive rates of nitrogen over the season.

1. At 40kg/ha, the nitrogen requirement of ginseng is similar to other root crops such as sweet potatoes (50 kg/ha), potatoes at 15 t/ha yield (50 kg/ha) and turnips (35 kg/ha) and only slightly lower than carrots and beets (110 kg/ha). Most of these crops yield a total dry weight that is two to five times that of a 4-year ginseng crop. The nitrogen requirements of ginseng should be much lower than most crops grown in full sun due to a much slower growth rate.
2. Excess nitrogen can make ginseng leaves dark green and healthy-looking at the expense of root growth. A healthy leaf canopy does not always translate to higher yields. Growers often fertilize to counteract the effects of drip-line chlorosis (yellowing), caused by excess water falling off the shade in strips through the garden. Consider what the added nitrogen is doing to the 80%–90% of the garden that is not affected by drip-line chlorosis. For more information, see *Drip-Line Chlorosis*, Chapter 6.
3. Excess nitrogen can have unintended consequences. High nitrogen can lead to larger roots with thinner cell walls, making ginseng more prone to invasion by soil pathogens. There is evidence to suggest that excess and variable fertilizer application may result in uneven growth that contributes to abiotic rusty root, the most common disorder affecting marketability of roots in Ontario (See *Abiotic Rusty Root*, Chapter 6).
4. Excess fertilizer is an unnecessary expense.

Phosphorus and Potassium

Ginseng responds positively to phosphorus (P). Phosphorus is usually measured in the form of phosphate (P_2O_5). Insufficient phosphorus results in smaller roots and low phosphorus levels contribute to "pencil root" in seedlings. This can occur because of low phosphorus concentrations in the soil or when there is sufficient phosphorus, but soil conditions are not suitable for uptake.

Uptake of phosphorus by ginseng may be limited in cool, wet or dry soils. Phosphorus deficiency caused by cool and wet conditions is most common in the spring. This problem usually diminishes when the soil warms up. Phosphorus deficiency due to dry conditions can be mitigated with irrigation. Phosphorus availability can also be affected by soil pH and is highest at pH 6.5.

Plants need potassium (often called potash: K) as much as they need nitrogen. Potassium is involved in the production of the plant's structural components and influences the process of photosynthesis and water uptake by roots. It also plays a role in starch and sugar conversion, overall quality and pest resistance.

Phosphorus and potassium requirements are based on OMAFA-accredited soil tests (Table 4, Table 5). Only use these tables with OMAFA-accredited soil tests. Adjust the listed requirements to account for any manure or compost applied to the field. Around 40% of the phosphorus and potassium is available to the plant in the first year after manure application and another 40% in the second year.

Where a soil test is not available, a rough estimate of requirements can be obtained from these tables using the following guidelines:

- Where the field has been fertilized regularly for several years or heavily in recent years, use one of the rates of phosphorus and potassium listed for the Medium Response (MR) soil test rating.
- If the field has received little fertilizer in the past, use one of the rates recommended for a High Response (HR) soil test rating.

Soils rated No Response (NR) for phosphorus contain much more plant-available phosphorus than required for most crops. Avoid applications of phosphorus fertilizers, compost, manure, sewage sludge or other sources of phosphorus to these soils because of the increased risk of water pollution.

Table 4. Phosphorus Requirements for Ginseng on Mineral Soils
HR = High Response, MR = Medium Response, LR = Low Response, RR = Rare Response, NR = No Response

Soil Test Phosphorus (P) mg P/L of soil (ppm P)[1]	Phosphate (P_2O_5) Required (kg/ha)	
	New Gardens	Established Gardens
0–3	270 HR	80 HR
4–5	260 HR	60 HR
6–7	250 HR	50 HR
8–9	240 HR	40 HR
10–12	230 HR	30 MR
13–15	220 HR	20 MR
16–20	200 HR	0 LR
21–25	170 HR	0 LR
26–30	140 MR	0 RR
31–40	110 MR	0 RR
41–50	80 MR	0 RR
51–60	50 LR	0 RR
61–80	0 RR	0 NR
80 +	0 RR	0 NR

[1] *Using the 0.5 M sodium bicarbonate method*

Table 5. Potassium Requirements for Ginseng on Mineral Soils
HR = High Response, MR = Medium Response, LR = Low Response, RR = Rare Response, NR = No Response

Soil Test Potassium (K) mg K/L of soil (ppm K)[1]	Potash (K_2O) Required (kg/ha)
0–15	230 HR
16–30	220 HR
31–45	200 HR
46–60	180 HR
61–80	140 HR
81–100	100 HR
101–120	70 MR
121–150	50 MR
151–180	40 MR
181–210	0 LR
211–250	0 RR
250 +	0 NR

[1] *Using the normal ammonium acetate method*

Magnesium

Magnesium (Mg) is a plant nutrient that is naturally plentiful in many Ontario soils. Soils with magnesium soil tests below 20 ppm (OMAFA-accredited soil test) require magnesium application for the production of most crops. Very few Ontario soils have magnesium tests below 20 ppm. If the soil pH is below 6.0, the most effective and inexpensive means of supplying magnesium is applying dolomitic lime. If the pH is above 6.0 and the soil test 20 ppm or below, magnesium can be supplied through either magnesium sulphate or sulphate of potash magnesia — a mixture of sulphate of potash and magnesium sulphate. Growers should apply 30 kg/ha of actual soluble magnesium. These latter sources of magnesium are usually much more expensive than magnesium from dolomitic limestone.

Potassium competes with magnesium for uptake by crops and excessive potassium applications can induce or increase magnesium deficiency. Monitor soil potassium levels and carefully control potassium fertilizer applications on low magnesium soils.

Calcium

Calcium (Ca) is essential for the growth of the ginseng plant and the health of the root. Most soils in the ginseng-growing areas of Ontario have moderate levels of calcium. Soil calcium can be made more available to plants by adjusting the soil pH. When pH is adjusted with the addition of lime, calcium may also be added. Calcium availability decreases as the pH drops below 6.5.

Calcium deficiency symptoms have been noted in ginseng. Once the canopy is established, calcium is not redistributed in the leaves. As a result, deficient leaves develop necrotic edges and the leaf tissue dries progressively toward the centre.

The availability of calcium is a function of the total calcium supply, soil pH, the exchange capacity of the soil and the soil type. Calcium uptake in plants is depressed by ammonium-based nitrogen and high levels of potassium, magnesium, manganese and aluminum.

Micronutrient Fertilizers

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

Apply micronutrient elements based on competent advice, such as a certified crop advisor or extension expert or where experience has proven their application to be necessary. Soil or foliar applications can be effective. Soil applications are generally made at soil-preparation time and foliar applications are applied during the growing season. Leaves are not designed to take up nutrients. Wherever possible, correct anticipated nutrient deficiencies using soil application ahead of planting. Foliar applications are only effective for specific elements (boron, iron, zinc, copper, molybdenum) applied under specific conditions, generally 60%–80% relative humidity. A sticker-spreader is usually required in micronutrient sprays.

Preventing and Correcting Manganese Deficiency

Manganese (Mn) is less available at high soil pH, so do not add more lime than needed to correct soil acidity. The OMAFA-accredited soil manganese test is reported as a Manganese Availability Index. This index reflects the effect of the soil's pH on manganese availability. Interpretation of the index is found in Table 6.

Preventing and Correcting Zinc Deficiency

High phosphorus in the soil and/or in the fertilizer can cause or increase the severity of

Table 6. Manganese Availability Index Interpretation

Manganese Index	Suggested Treatments
>30	soil manganese availability is adequate for field-grown crops
16–30	soil manganese availability is adequate for many crops, but is approaching deficiency levels for some crops — if deficiency symptoms appear, spray with manganese and consider a re-check for deficiency using plant analysis
<16	soil manganese availability is believed to be insufficient for many crops — spray with manganese if deficiency symptoms appear

Table 7. Zinc Availability Index Interpretation

Zinc Availability Index	Suggested Treatments
>200	suspect contamination of the sample or of the field
25–200	soil zinc availability is adequate for most field-grown crops
15–24	zinc availability is adequate for most crops, but is bordering on deficiency for some — if the field sampled is uneven in soil texture, pH or erosion, some areas may respond to zinc applications
<15	zinc is likely to be deficient for some crops and should be applied in the fertilizer

zinc (Zn) deficiency. Growers must not apply more phosphorus than needed. The use of animal manures can prevent or reduce zinc deficiency. Erosion control can prevent deficiency of zinc by maintaining the topsoil. The OMAFA-accredited soil zinc test is reported as a Zinc Availability Index. This index reflects the effect of the soil's pH on zinc availability. Interpretation of the index is found in Table 7.

Zinc deficiency can be prevented by the application of zinc fertilizer to the soil. Foliar sprays can help correct a deficiency after the symptoms have appeared if they are used early in the growing season.

Copper

Copper (Cu) soil tests are quite unreliable on Ontario soils, but plant analysis is useful. Copper is unlikely to be deficient in mineral soil, except in very sandy soils.

Boron

Boron (B) is required on some soils. Boron deficiency is usually associated with dry weather and no reliable soil test has been developed. Plant analysis and visible plant symptoms are useful predictors of boron requirements.

Ginseng requires very little boron. Growers are advised not to add boron to soils that test above 0.5 ppm. Boron toxicity in ginseng is expressed as reduced emergence, necrosis, chlorosis, premature seed drop and reduced root yield. Boron toxicity in ginseng is discussed further in *Abiotic Disorders of Ginseng*, Chapter 6.

Iron and Molybdenum

Iron (Fe) and molybdenum (Mo) deficiency have not been found in field crops in Ontario.

Adjustments to Fertilizer Requirements — Manure

Ginseng growers commonly apply manure ahead of ginseng production to increase the organic matter content and fertility of the soil to make it more closely match the conditions of the forest environment. Manure application is typically done in the spring before seeding but is occasionally split into two applications — one the year before seeding and one in the spring of the seeding year. Dry cattle manure is the most common source, but other sources, such as poultry manure or spent mushroom compost, are also used. Typical rates for cattle manure range from 20–45 t/ha. Apply manure no later than 4–6 weeks before fumigation, then work the manure thoroughly into the soil so organic matter can break down prior to fumigation.

The nutrient content of manure is highly variable and manure should be analysed before applying it to the field. OMAFA-accredited laboratories conduct manure analysis for an accurate assessment of nutrient content (*Appendix C. Accredited Soil-Testing Laboratories in Ontario*). To estimate the nutrient content, a listing of the average nutrient concentrations for different types of manure is available in OMAFA Factsheet 21-077, *Available Nutrients from Manure for Various Livestock Types*.

Long-Term Value of Manure

The long-term availability of phosphorus, potassium, magnesium, zinc or manganese from previous manure applications is best estimated by soil testing. Application of large quantities of manure over time can result in high levels of available phosphorus and potassium in soils. Manure also contributes other plant nutrients and organic matter to soil that may be of some long-term value.

Most of the available nitrogen in manures is used by crops or lost during the first growing season following application. In ginseng, there is no crop in the ground for a year after application, so the available nitrogen is not available to the crop. The remaining organic nitrogen becomes available in small, diminishing quantities in succeeding years. This availability is often assumed to be 10% of the organic nitrogen the year after application, 5% two years after application and 2% three years after application. Due to the large amounts of manure applied, ginseng growers should factor this organic nitrogen into the nitrogen needs of the seedling year and beyond and adjust nitrogen fertilizer rates accordingly. A soil test accounts for residual phosphorus and potassium in the soil from previous manure applications.

For more information on manures, including environmental impacts and how to mitigate them, calibrating application equipment and regulatory requirements, see OMAFA Publication 611 *Soil Fertility Handbook*.

Fertilizer Materials

Most nutrients needed for plant growth can be supplied by several fertilizer materials (Table 8, Table 9). The selection of a fertilizer depends on the availability, cost, solubility, salt index and the objective of the application (single or blend, ammonium NH_4^+, nitrate NO_3^-).

Soluble Salts in Farm Soils

High concentrations of water-soluble salts in soils can prevent or delay the germination of seeds, kill established plants and/or seriously retard their growth.

Ontario soils are naturally low in soluble salts. As a result, they rarely cause a problem in crop production and are not routinely measured in soil tests.

Soluble salts in soils can result from excessive applications of fertilizers and manures, runoff of salts applied to roads and chemical spills on farmland. High concentrations of soluble salts in or near a fertilizer band can cause serious early plant growth problems without significantly affecting the salt concentrations in the remainder of the soil.

A given amount of salt in a soil provides a higher salt concentration in soil water if the amount of water is small. Soluble salts also interfere with the uptake of water by plants and plant growth is most affected by soluble salts in periods of low moisture supply (drought).

Table 8. Fertilizer Materials — Primary and Secondary Nutrients (— = not applicable)

Nutrient	Material	Form	% Nutrient	% Sulphur	Salt Index[1]	Salt Index[2]
Nitrogen (N)	ammonium nitrate	dry	30–34	—	102	14.5
	calcium ammonium nitrate	dry	27	—	93	15.3
	urea	dry	45–46	—	73	7.8
	ammonium sulphate	dry	21	24	69	16.3
	urea-ammonium nitrate	liquid	28	—	63	11.3
	anhydrous ammonia	liquid[3]	82	—	47	2.9
Phosphate (P_2O_5)	monoammonium phosphate	dry	48–52	—	27	2.0
	diammonium phosphate (18-46-0)	dry	46	—	29	2.3
	ammonium polyphosphate (10-34-0)	liquid	34	—	20	2.3
Potash (K_2O)	muriate of potash	dry	60–62	—	115	9.7
	sulphate of potash	dry	50	18	46	4.3
	sulphate of potash magnesia (11% mg)	dry	22	20	43	9.9
	potassium nitrate (13-0-44)	dry	44	—	74	6.1

[1] Osmotic pressure increases from dissolution of the fertilizer relative to the same weight of sodium nitrate (100).
[2] Expressed per unit (100 lb) of nutrient ($N + P_2O_5 + K_2O$).
[3] Liquid under pressure.

Table 9. Fertilizer Materials — Secondary and Micronutrients

Nutrient	Material	% Nutrient
Magnesium (Mg)	dolomitic limestone	6%–13% Mg
	magnesium sulphate (epsom salts)	10.5% Mg, 14% S
	sulphate of potash magnesia	11% Mg, 20% S
Sulphur (S)	calcium sulphate (gypsum)	19% S
	elemental sulphur	90% S
	ammonium thiosulphate	12% N, 26% S
Boron (B)	sodium borate	12%–21% B
	solubor	20.5% B
Copper (Cu)	copper sulphate	13%–25% Cu
	copper chelates	5%–13% Cu
Manganese (Mn)	manganese sulphate	26%–28% Mn
	manganese chelates	5%–12% Mn
Molybdenum (Mo)	sodium molybdate	39% Mo
Zinc (Zn)	zinc sulphate	36% Zn
	zinc chelates	7%–14% Zn
	zinc oxysulphate	18%–36% Zn

Table 10. Soil Conductivity Reading Interpretation[1]

Conductivity "Salt" Reading millisiemens/cm	Rating	Plant Response
0–0.25	low	suitable for most plants if recommended amounts of fertilizer are used
0.26–0.45	medium	suitable for most plants with adequate amounts of fertilizer
0.46–0.70	high	may reduce emergence and cause slight-to-severe damage to salt-sensitive plants
0.71–1.00	excessive	may prevent emergence and cause slight-to-severe damage to most plants
1.00	excessive	expected to cause severe damage to most plants

[1] *Conductivity reading using a paste compound of two parts water and one part soil or saturated paste equivalent (multiply by 5).*

Soluble salts can be determined in the laboratory by measuring the electrical conductivity of a soil-water slurry. The higher the concentration of water-soluble salts, the higher the conductivity. Table 10 provides an interpretation of soil conductivity readings in Ontario field soils in a paste compound of two parts water and one part soil — the procedure used by the OMAFA-accredited soil testing program.

Crop Damage from Fertilizer Materials

All fertilizer salts can damage germinating seeds and plant roots if applied in sufficient concentrations near the seed. While fertilizers are not typically applied to ginseng at seeding, they have the potential to damage germinating seedlings if applied in April or May of the seedling year. Ginseng tops in older gardens can also be damaged by applications made in the spring during top emergence.

Fertilizers vary in crop safety per unit of plant nutrient due to:

- differences in the amount of salts contained in the fertilizer per unit of plant nutrient
- differences in solubility of the salts in the soil
- the higher potential for crop damage of a few specific materials or elements, such as ammonia and boron

Nitrogen Fertilizers

Ammonium nitrate, monoammonium phosphate and ammonium sulphate are similar in crop safety and are much safer than anhydrous ammonia, aqua ammonia or urea. Diammonium phosphate is less safe than monoammonium phosphate but safer than urea. Take care with products with more potential to damage the crop. Do not place anhydrous ammonia and aqua ammonia near seeds as they can damage the crop.

Phosphorus Fertilizers

Phosphorus fertilizers usually cause less crop damage because a large portion of the phosphorus is precipitated in the soil before it can reach the plant roots. The concentration of phosphorus in soil solution at any one time is very low. No limit is normally set for the safe rate that phosphorus fertilizers can be applied near the seed of ginseng.

Diammonium phosphate is less safe than other phosphorus fertilizers (see *Nitrogen Fertilizers*, on previous page).

Potassium Fertilizers

Muriate of potash (KCl) is the most common source of potassium in fertilizers and causes less damage per unit of plant nutrients than most nitrogen fertilizers. Sulphate of potash (K_2SO_4) is safer than muriate of potash. Sulphate of potash-magnesia has approximately the same level of safety per unit of potassium as muriate of potash. Potassium nitrate is one of the safest sources of potassium.

Fertilizers Containing Micronutrients

As fertilizers containing micronutrients (boron, copper, iron, manganese or zinc) have more potential for damage than the same materials without micronutrients, reduce rates to avoid plant injury. Boron should not be applied in a band because of high potential for crop damage.

Crop Injury from In-Season Granular Fertilizer Applications

Avoid applying granular fertilizers during humid/wet weather. When the foliage is wet, the fertilizer can stick to the leaves and lead to leaf injury when applied during the growing season. Applications are best timed for the afternoon on dry and breezy days to ensure the canopy is dry and allow more granules to be physically knocked off the leaves by the wind before the next dew period.

Foliar Fertilizers

Foliar fertilization can supply micronutrients to the crop, particularly where a deficiency is due to binding of these nutrients in the soil (such as manganese). Quantities of nutrients that can be applied this way are limited because of the danger of injuring the leaves. Combine nutrients carefully so the resulting solution is not too concentrated. Check pesticide labels before mixing foliar nutrients with any pesticide spray. Foliar nutrients containing cytokinins can be damaging to ginseng if applied during canopy development. Cytokinins can interfere with elongation of stems and leaf veins. Application when the leaves are unfolding can cause leaf deformities that reduce the photosynthetic capacity of the plant.

CHAPTER 4

Seed Handling and Seeding

Ginseng seeds are not ready for germination when they are harvested. To germinate, seeds require stratification — a defined period of warm and cold temperatures. In Ontario, the process between berry harvest and seed germination usually takes 18–20 months. This process begins a year before seeding with the harvest of berries from a previous crop. The first 12 months of stratification occur outside of the garden and the final period of stratification occurs in the ground after seeding.

There are no commercial suppliers of ginseng seed with sufficient quantities for large-scale production. Most ginseng growers dedicate part of an existing older garden for berry and seed production, selling any excess seed or buying seed if there is a shortfall. New growers can purchase seed that has already gone through a year of stratification from an existing grower. This seed is called "stratified seed" by the industry, even though it still needs a winter in the field to complete the stratification process.

Harvesting Ginseng Berries

Berries are harvested by hand when they are red. At this point, the embryo is ready to undergo temperature stratification. Seeds from fully ripe, red berries give higher emergence rates than seeds from green berries. Premature berry ripening due to plant stress can also lead to poor seed quality. Avoid harvesting seed from diseased areas of a garden, as they may carry pathogens into seed storage or the next ginseng crop.

Depulping Ginseng Berries

Berries are usually collected into baskets (Figure 25). Before the stratification process can begin, the berries must be depulped.

Figure 25. Ripe ginseng berries harvested into a bushel basket.

Depulping can involve leaving the berries in burlap bags for several weeks in a cool shed to rot the outer pulp. Berries can also be trampled to degrade the pulp, but this increases the chance of seed infection by common moulds that grow on rotting berries.

Aim to depulp berries using a mechanical depulper within 2 days of picking. Seeds are processed in a machine (modified grater) that uses water to rinse the pulp away. The pulp-filled water from the depulper can be spread back on the field and incorporated. Do not add this water to streams or ponds because it may be harmful to aquatic organisms. Do not spread it on land intended for future ginseng production because it can be contaminated with ginseng pathogens. It takes approximately 2 kg of berries to produce 0.45 kg of seeds.

Seed Stratification

To avoid germination issues, it is important to understand the stratification requirements of ginseng seed. At harvest, the embryo in the seed is not fully developed. Full development requires a minimum of 3 months at temperatures between 16˚C–20˚C. During this time, the embryo must remain moist or the process will be suspended. Any periods with temperatures above or below the optimal range do not count towards the 3-month total. For example, if temperatures exceed 20˚C for half the day because the seeds are stored in a hot barn, only half the day counts towards embryo development.

Seed harvest occurs too late in the fall to allow for embryo development, so the seed is usually stored under cool temperatures (<5˚C) for a winter before allowing the embryo to fully develop the following summer. Seed can be stored longer by air drying it before the first winter — to reduce fungal contamination during storage — and keeping it cold for an extended period. This process suspends the seed stratification process. Dried seed must be rehydrated and warmed up in the months ahead of seeding to satisfy stratification requirements.

Once the embryo is fully developed (5 mm in length), the seed needs a cold period of <5˚C for 3 or more months to break physiological dormancy. This process normally occurs in the field after seeding over the following winter. Once this requirement is met, the seed will germinate. Sometimes growers place seed left over after planting in cold storage, in the hopes they can use it the next year. This cold storage provides the requirements for the seed to break dormancy. Once that seed is warmed up, the seed will germinate immediately. If seeding occurs at the typical time in late summer, the seedlings will emerge immediately but be killed off by the first fall frost. Seed can be saved after planting under very specific conditions, but these are not practical for most ginseng growers, so consider longer-term storage only for newly harvested seed (green seed) over the first winter.

Handling Green Seed

Newly harvested, depulped seed is called green seed (Figure 26). Stratification requirements make it important to cool seeds down soon after depulping to prevent premature embryo development. If the green seed has a total of 3 months of temperatures between 16˚C–20˚C during a warm fall, the embryos of some seeds may fully develop prior to seed storage and will be ready to germinate immediately upon planting the following summer. Keep green seed moist and stored at temperatures around 3˚C.

Figure 26. A tub of "green seeds" after depulping. *Source*: Dr. Amy Shi, Ontario Ginseng Growers Association.

Stratifying Ginseng Seeds

Depulped seeds are placed in a seed box for stratification. Mix the seed with two or three parts sand by volume. Ginseng seed was traditionally stratified by burying it below ground, but this caused problems with fungal contamination of the seeds and a lack of temperature controls.

Much of the ginseng industry has switched to above-ground stratification in a temperature-controlled environment. With this system, embryo development and germination can be as successful as a below-ground system as long as temperatures are maintained within the optimal range during the winter and summer before seeding. The risk of fungal contamination of the seed is much lower with the above-ground system.

To begin above-ground stratification, place the seed-sand mixture in plastic boxes. Ensure the seed does not dry out — maintaining about 10% moisture is adequate. The seeds are held at 3˚C for 9 months (mid-August or early September to mid-May) and then for 3 months at 16˚C–20˚C (June through August).

Embryo Development

The length of a normal embryo at seed harvest is about 0.5 mm. By the time the seed cracks, the embryo is 5.0 mm long. About 50% of this growth occurs before seeding and 50% after seeding. Embryos shorter than 2 mm at the time of seeding may indicate a problem with stratification temperatures, which could delay germination by a year if fall field temperatures are not sufficient to complete the embryo development process. Check embryo length and seed moisture levels throughout the stratification process to ensure everything is proceeding as planned.

Seed Size

When berries are all harvested in a single pass, it results in seed lots with great variability in seed size, which can affect germination and plant vigour. There is some evidence to suggest that seeds with a diameter of 4.8–5.6 mm, corresponding to round-hole sieve sizes of 12 to 14, provide the best seeds for good ginseng production. Smaller seeds (<4.8 mm in diameter) and extra-large seeds (>5.6 mm in diameter) may result in poor emergence and smaller roots over the life of the garden.

Assessing Seed Quality

Many things can go wrong with ginseng seed during storage, given the length of time seeds remain moist. There are several ways that ginseng seed can be tested to ensure stratification is progressing properly. Separate any diseased and damaged seeds from healthy ones and identify pathogens associated with seed decay.

Viability Testing

Ginseng seed cannot be adequately tested for germination because of stratification requirements, but it can be tested for viability. A viability test is a chemical test that indicates whether an embryo is respiring. This is often referred to as a "tetrazolium" test because of the tetrazolium dye used for it, which changes from clear to pink. Have the test done by an experienced individual who can correctly interpret the colour changes during the test. Many ginseng consultants and agricultural input suppliers can do this test. If the seed has dried out, frozen or appears in any way abnormal, conduct a tetrazolium test.

Float Testing

Healthy ginseng seeds that have proper moisture levels sink when submerged in water. Diseased seeds often float due to their lighter weight. This float testing provides an opportunity to separate and remove diseased and unviable seeds. Seeds that are too dry also float, so it may be necessary to soak the seeds for several hours ahead of the test to ensure that dry viable seeds sink during the test. Float testing can be done several times throughout the seed handling process, beginning with green seed and continuing over the summer before seeding.

The removal of diseased seeds reduces the spread of disease in the seed box. Be sure to split a random subsample of seeds to visually inspect for proper embryo length and to assess disease levels. Healthy seeds should be a uniform creamy-white and firm to the touch. Diseased seeds often have discolouration and/or a soft texture. If diseased seeds (based on visual inspection) sink during float testing, air dry the seeds and then rehydrate them so the diseased seeds lose moisture and float during the next float test. Healthy seeds should remain dense and sink.

Disease Diagnostics

Laboratories can test ginseng seed and identify fungi or bacteria in damaged seeds. However, many of the fungi and bacteria found on rotting seeds are very common and their presence may not signal a problem. The specific seed pathogens associated with ginseng are unknown, making interpretation of laboratory results difficult. Laboratory tests may be useful for comparing healthy versus poor seed lots, but they may be more beneficial once the specific causes of ginseng seed diseases are identified.

Seeding Ginseng

Ginseng gardens are seeded mechanically after bed formation. Bed-forming and seeding equipment are sometimes combined. A variety of equipment is available to growers ranging from simple seeders with a seed-dropping mechanism, to high-precision air-assist seeders (Figure 27). In any ginseng growing community, there are usually contract seeders to provide services for growers.

Seeding Rate

One kilogram of seed can contain from 11,000–19,000 seeds (5,000–8,500 seeds/lb), depending on seed size and moisture content. Ginseng is typically seeded at 112–123 kg/ha (100–110 lb/acre). A seeding rate of 100 kg/ha (90 lb/acre) will result in a plant stand of approximately 180 plants/m^2 of bed at 100% germination (18 plants per gram of seed). Growers will not achieve 100% germination, so this calculation needs to be

Figure 27. An air-assist seeder used to seed ginseng.

adjusted for the percent viability of the seed based on seed viability testing.

Plant Stand

There is no ideal plant stand for ginseng. Growers decide the optimal plant stand, balancing factors such as root shape, disease pressures and yield. The ginseng stand usually decreases over 3 years to between 80 and 100 plants/m^2 and over 4 years to between 35 and 70 plants/m^2. This decrease is mainly due to shading and the eventual death of weaker plants within the dense canopy in older gardens. Higher seeding rates can result in higher stands after 3 years, but the increase is not proportional to the increase in seeding rate. For example, increasing the seeding rate by 20% may only increase the final stand by 5%. Higher seeding rates contribute to a higher risk of both foliar and root disease due to a dense canopy in older gardens and faster movement of root pathogens from root to root in the soil.

Roots that are crowded in the first year of development are smaller than average by harvest time. Adjusting the seeding rate is an opportunity for growers to address the issue of root shape. High seeding rates may lead to more "pencil-shaped" roots, but pencil roots may also be a factor of soil texture and soil pathogens. Less compacted soil results in longer and thinner roots. Pathogens can result in stubbier or highly branched roots. Experience over time helps growers refine seeding rates to achieve the right balance of yield, root shape and disease pressures.

Mulch Application

A deliberate effort to mimic the forest floor in ginseng gardens is done by applying 5–10 cm of mulch to the surface of raised beds. The choice of mulch depends on availability and price. The most common mulch is straw from cereal crops. Straw is usually applied using round-bale straw spreading equipment (Figure 28). Growers generally use rye or wheat straw — oat straw can be used, but is difficult to find.

Figure 28. Straw being applied to newly seeded ginseng beds.

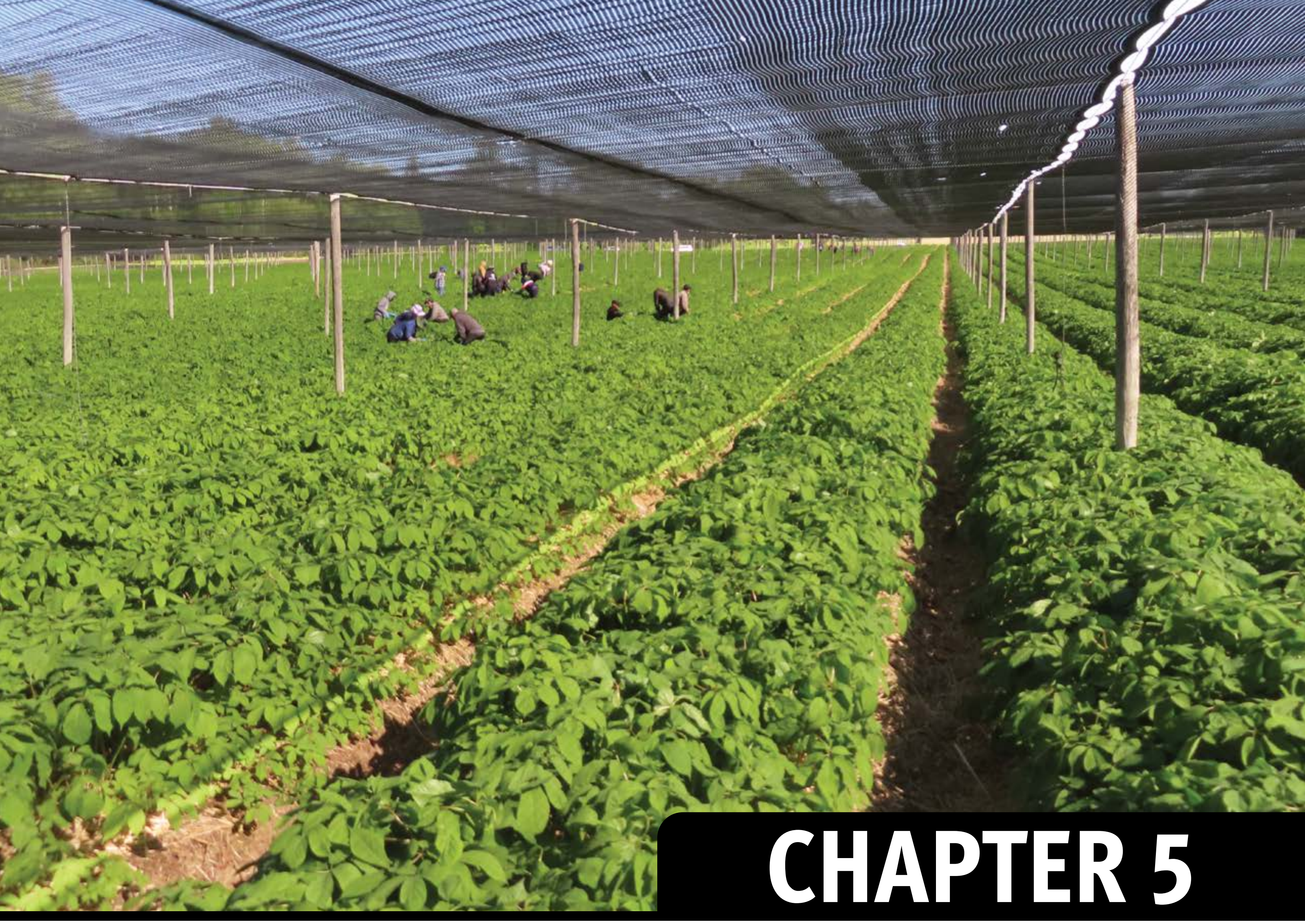
Mulch on the surface of beds preserves soil moisture and moderates soil temperature. The soil temperature below straw mulch usually remains above -5˚C, even in a very cold winter. Areas of thin mulch may lead to colder temperatures in the root zone and could potentially damage the crown of the root or the seeds in new gardens.

The mulch also helps to prevent "heaving" of the roots in the spring. Soil temperatures warm more steadily in the spring without extreme fluctuations under the mulch. Roots that heave out of the soil are usually found on the sides of the beds where the mulch is thinnest. Exposed roots are vulnerable to repeated freezing and thawing, which leads to attack by soil microorganisms that do not normally cause disease unless the plant is weakened. Fluctuating temperatures can be more damaging to both roots and seeds than prolonged low temperatures.

Manage both soil temperature and moisture by applying mulch to the surface of the beds. Once the beds are seeded, apply mulch immediately. If mulch application is delayed, the newly planted seeds may dry out. Drying may not seriously harm the seed but can delay embryo development and contribute to poor emergence and/or delayed germination.

Many growers allow the grains in the straw to grow and form a cereal nurse crop (Figure 29). The nurse crop anchors the straw over winter. Rye or wheat nurse crops continue to grow the following spring and have to be killed off prior to ginseng emergence. Occasionally, growers may seed a nurse crop in addition to the straw, but this is more common in subsequent years (see *Preparing for Winter*, Chapter 5). Research has shown that nurse crops have no negative effect on the ginseng.

Figure 29. Volunteer cereal crop growing in a newly seeded ginseng garden.



CHAPTER 5

Garden Maintenance

Many of the activities involved in garden maintenance between seeding and harvest involve pest control (including weeds) and fertility. Pest management activities are discussed in Chapter 6. *Pests and Disorders*, Chapter 7. *Optimizing Pest Control* and in the Ontario Crop Protection Hub. In-season fertility practices are discussed in Chapter 3. *Soil Management and Fertility*. This chapter covers other practices involved in maintaining the crop between seeding and harvest.

Ginseng Emergence

Ginseng seeds are typically planted in the late summer or fall and germinate the following April. Seedlings emerge through the straw in early to mid-May. Storage conditions during stratification can affect germination. If conditions are too dry, too hot or too cold at the wrong time, embryo development may slow or stop entirely, which can delay germination. Stratification issues have resulted in no seeds germinating the year after planting. Many of the seeds often germinate the following spring, but at a reduced rate due to seed diseases and loss of viability.

Gardens that are 2 years and older emerge earlier than seedlings, typically in late-April or early-May, with the oldest plants emerging the earliest.

Pulling Shade Cloth

Shade cloth must be pulled over the crop before the leaves begin to unfold. Folded leaves can still tolerate full sun if they are not directed upwards. In the forest, plants begin to unfold as the forest canopy closes.

The biggest risks to the shade structure once it is pulled over the garden are wind, late snow, freezing rain and hail. Just a few centimetres of snow can collapse the shade and cause major damage to the structure and cloth material. Windstorms tend to be strongest early in the spring, so delay pulling the shade until just before it is required, if possible. Forecasted weather conditions and labour availability help determine when to pull the shade. Pull shade on the oldest gardens first, since they emerge earliest.

Frost Protection

Frost events are common in the spring and these can damage emerging ginseng plants. There is a historic belief that the shade should be pulled over the crop before spring frost risks occur to help protect the plants like a frost blanket. Recent evidence actually suggests the shade cloth contributes to colder temperatures in and around the garden, potentially increasing the frost risk if that air is not moved out of the garden through a breeze or drainage of the cold air down a slope.

The most reliable strategy to mitigate frost risks is pulling frost blankets (floating white row covers) over the crop before a forecasted frost event. These provide 1˚C–2˚C protection during frost events — often enough to prevent major damage. Put frost blankets on after high winds have subsided to avoid physical damage from the billowing blanket and the risk that the blankets blow off the garden. Frost events usually occur when there is a significant risk of foliar disease, and fungicides cannot be sprayed through the cloth. Protect plants with fungicides ahead of the frost event to ensure foliar diseases do not develop in the warm, humid environment under the frost blanket.

Other frost protection strategies such as frost fans and continuous irrigation are not practical for ginseng growers. There may be ways to use frost fans to displace the cold air that pools in the low ends of ginseng gardens, but additional research is required to ensure they are not just recirculating the cold air.

If frost damage occurs, fungicides will be required to protect against *Botrytis* blight. Wait at least half a day after frost damage before applying fungicides so wounded tissues can heal over. Otherwise, phytotoxicity may occur if excessive fungicide is taken up into the plant. For more information on frost damage and *Botrytis blight*, see Chapter 6, Pests and Disorders. Even if no frost damage occurs, consider reapplying fungicides after the blankets are removed, particularly if they were on the garden for an extended period.

Debudding Ginseng

Once the leaves have unfolded, the plant's energy is concentrated on the reproductive cycle. Root growth is minimal during seed development and resumes in mid- to late-July when the berries begin to mature. Removing the flower bud cluster by hand as the flower bud begins to elongate redirects the plant's energy to the developing root (Figure 30). This process is called debudding and usually occurs in late May or early June when the canopy is almost fully developed (Figure 31). Debudding can result in a 25%–30% increase in root weight. Growers must choose between the development of seed and an increase in root weight.

Figure 30. A ginseng plant ready to be debudded.

Figure 31. A work crew manually debudding a ginseng field.

Manual debudding is time-consuming and expensive. Research conducted on the use of plant growth regulators to induce flower or berry abortion has shown that they come with considerable risk if done improperly. At the time of writing this publication, no growth regulators are registered for use on ginseng.

Some 2-year-old plants have flower buds, but a ginseng garden is usually 3 years old before it has the potential for a seed crop. Gardens yield an average seed crop of 340 kg/ha (300 lb/acre), but some can yield as much as 560 kg/ha (500 lb/acre). The decision to deflower is made early in the season and there is a certain risk associated with it. Most growers choose to debud and leave only a portion of their garden for seed development.

In a hot, dry year, especially under low-cloth shade, high temperatures may cause seeds to abort shortly after fertilization, so there is a risk of a seed shortage if too much of the garden is debudded. Irrigation can help reduce the negative effects of hot temperatures. The extent of debudding across the industry is one of the factors affecting the availability and cost of seed.

Under certain situations, it may not be economical to debud. There is a cost to debudding and it is important to consider whether this cost is worth the added root growth compared to not debudding and growing and selling seed. In some years, seed shortages due to poor weather conditions or increasing overall acreage, can make seed prices increase. Unfortunately, the decision to debud happens long before seed availability and prices are known. In general, when expected seed prices per unit are double the expected root prices or higher for the same weight, it is not worth debudding. However, this depends on how many growers in the industry make the same decision.

Heat, Wind and Excess Water Management

Weather conditions during the season may necessitate modifications to the shade structure or the garden to reduce the damage from adverse weather such as frost, heat, wind and excess water. For best practices to reduce the impact of adverse weather, see sections *Low-Temperature and Freeze Damage*, *Windburn*, *Heat Stress* and *Phytophthora Root Rot and Blight of Ginseng (Phytophthora cactorum)*, in Chapter 6.

Irrigation

The combination of straw mulch, higher humidity and lower wind speeds in a ginseng garden reduces irrigation needs for ginseng compared to other horticultural crops. In some years with consistent rainfall, especially for seedling gardens that have much less canopy, irrigation is not necessary. However, low soil moisture can have a major impact on root growth and berry development and most growers rely on irrigation. Overhead (solid set) and drip irrigation are the most common irrigation systems used for ginseng. Drip irrigation lines are put down over the beds at seeding before straw application. Solid-set systems can be put up at any time after garden establishment or as needed.

Choosing the right times and the right amounts to irrigate can lead to:

- higher yields
- better product quality
- improved plant vigour
- reduction in disease
- more effective use of water (water efficiency)
- reduced irrigation costs

Water and nutrients are used most efficiently when an irrigation event applies only the amount of water that the crop needs and the soil can hold.

Making Irrigation Decisions

Irrigation scheduling is the process of determining and planning:

- when to irrigate
- how much water the crop requires
- how fast to apply water (application rate)
- how often to irrigate

Irrigation is a significant production expense. The maximum economic response to irrigation can only be achieved with a practical and effective scheduling system.

Irrigation Scheduling for Overhead or Drip Systems

Scheduling is possible for any type of irrigation system. The type of system determines the frequency and amount of water applied.

Overhead systems apply larger amounts of water less frequently. Soil moisture depletes to a critical point (generally 50% available soil water) between irrigation applications, allowing the plant to experience some stress. When the plant experiences stress, its water use decreases, as does yield and product quality. The major disadvantage of overhead irrigation is that it wets the plant and soil surface, increasing the risk of fungal diseases and disease transmission. On the other hand, overhead irrigation has the advantage of assisting with fungicide movement. Many fungicides for root diseases require rainfall or irrigation after application to move them into the soil and overhead irrigation provides more control than relying on rainfall.

Drip irrigation makes the most effective use of irrigation water. It constantly maintains soil moisture near the optimum level (generally close to field capacity) in some portion of the root zone. Irrigation applications are frequent and small. Soil moisture decreases only slightly before the next application. Plant water use (transpiration) is maximized. Water is applied directly to the soil surface or just below the soil surface in the crop row. This greatly reduces evaporation losses compared to overhead irrigation, where water can evaporate before it reaches the crop canopy and can also be lost from the plant and soil surfaces. Since drip irrigation does not wet the leaves, workers can enter fields during and after irrigation without the added risks of spreading inoculum of foliar diseases.

Determining Water Requirements

Growers often make irrigation decisions based on observations and historical knowledge, which can underestimate irrigation requirements, potentially leading to yield losses. Irrigation requirements can be better estimated using evapotranspiration (ET) values. This is the amount of water transpired by the plant and evaporated from the soil surface. ET may be expressed as millimetres or inches of water used per day and is affected by temperature, light intensity, wind, humidity, crop cover and crop growth stage.

For optimum crop production, water use (ET) must be replenished by irrigation or rainfall. In a ginseng garden, the temperature is higher than in an open field. However, the ET tends to be lower than in an open field, as there is lower light intensity, less wind and higher humidity. ET values provided by weather stations are based on a full canopy in an open field. ET values for Ontario weather stations are available in the Climate section of farmwest.com.

Estimate actual ET in a ginseng garden using the published data multiplied by a ginseng crop factor (K) (Table 11). The result of this calculation provides an estimate of how much water the crop used in a given period and a more accurate estimate of the amount of water that has to be applied through rainfall or irrigation to replace it. For example, if the total ET value for the past 5 days has been 20 mm and you are irrigating a 1-year-old garden, then the estimated ET for that garden for the period is 20 mm × 0.3 = 6 mm.

Table 11. Peak Summer Ginseng Crop Factors Estimated by OMAFA Staff

Garden Age	% Canopy Cover	Crop Factor (K)
1 yr	20–30	0.3
2 yr	80	0.7
3 yr and older	100	0.8

Figure 32 shows typical daily water use by irrigated tomatoes through the growing season. Crop growth stage has a dramatic impact on water uptake. For ginseng, the curve would be different, with a faster increase in canopy development early in the season and a longer period of water use in the late summer and fall. The most critical periods for irrigation of ginseng are when there is maximum plant canopy (maximum leaf area), which usually occurs by mid-June.

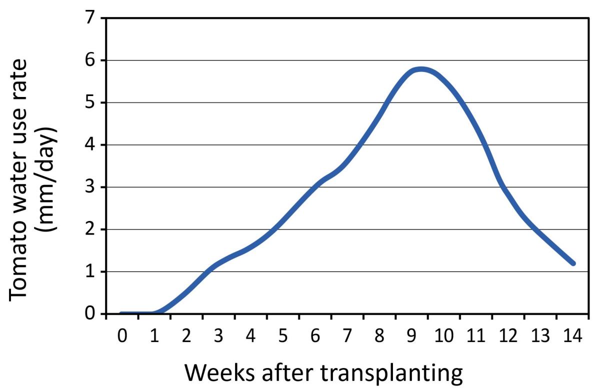


Figure 32. Average daily water use rate for irrigated tomatoes through the growing season in Ontario (adapted from Tan, 1990. *Irrigation Scheduling for Tomatoes — An Introduction*).

Soil

Soil characteristics play a major role in irrigation scheduling. Coarse-textured soils (such as sands) hold less crop-available water than fine-textured soils, such as clays. Soil texture refers to the proportion of sand, silt and clay in a soil. If the texture of a field is in question, it can best be determined through particle size distribution tests from a soil test laboratory. Hand-texturing can also be a useful technique. Most ginseng soils range from sand to sandy loam textures.

Table 12 shows available soil moisture for various soil textures. The lowest moisture level that plant roots can extract moisture from the soil (before they wilt beyond recovery) is called the permanent wilting point. The highest moisture level that a soil can hold against gravity (when the excess has drained after saturation) is called field capacity. Plant-available soil moisture is the water available between the permanent wilting point and field capacity.

Table 12. Typical Range of Available Soil Moisture, Comparing Different Soil Textures

Soil Texture	Available Soil Moisture (cm of water/30 cm of soil)
Sand	1.5–2.4
Loamy sand	2.1–3.0
Sandy loam	2.7–3.6
Loam	3.9–5.1
Silt loam	4.2–5.1
Silty clay loam	4.2–6.0
Clay loam	4.5–5.4
Clay	4.5–5.1

Adapted from Tan, 1990. *Irrigation Scheduling for Tomatoes — An Introduction*.

Rooting Depth

Calculate the maximum amount of crop-available soil water in the root zone by multiplying the available soil moisture for that soil texture (Table 12) by the crop rooting depth.

Typical rooting depth for ginseng is 30 cm. To verify the rooting depth in a garden, dig and measure in a selection of locations across the garden.

Soil Moisture Monitoring

Measuring soil moisture with an instrument can help determine the optimum time to start irrigating and show whether water applications have been sufficient or too much. Maintain soil moisture between field capacity (the maximum soil can hold) and 50% of the available water. See Figure 33 for the available soil moisture for all soil textures.

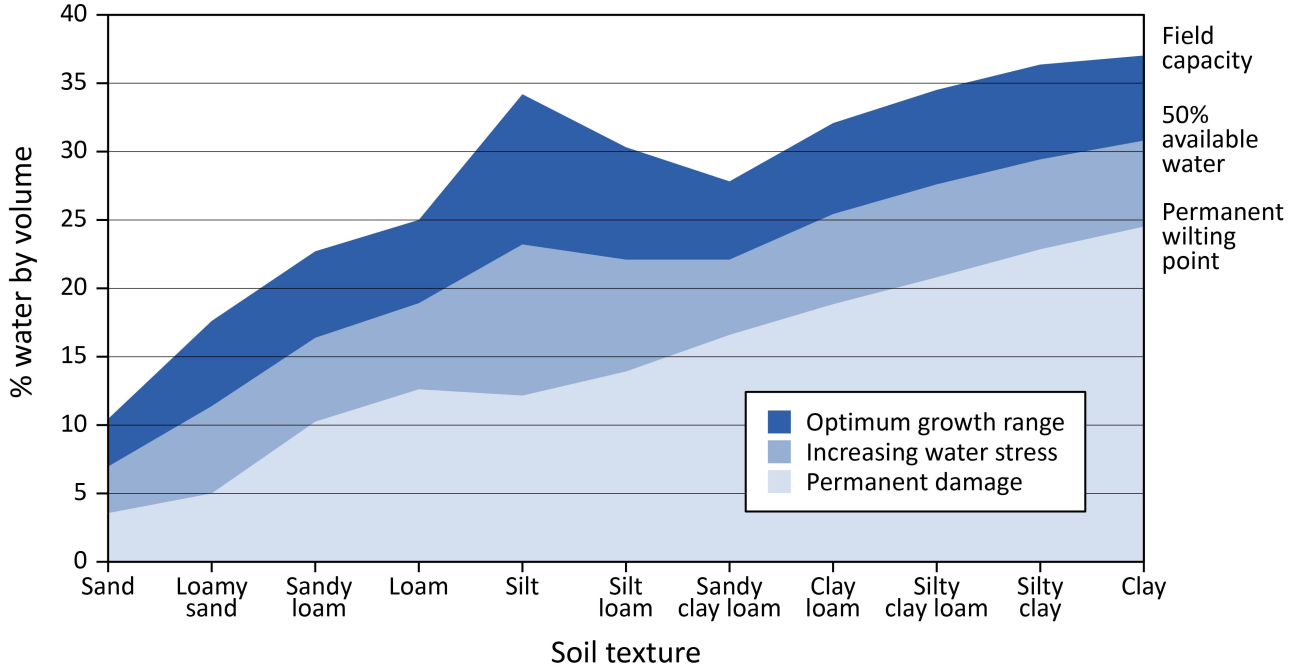


Figure 33. Available soil moisture by soil texture.

Preparing for Winter

Ginseng usually begins to show early signs of senescence in August, but the process can continue for up to 2 months. Initial symptoms of senescence include a slight reddening or purpling of the leaves. Leaves eventually turn yellow and fall off the stem by early October. Once the leaves are no longer green, the shade cloth can be tied back. If the straw is becoming thin at this time, top it up with additional straw. Some growers seed a nurse crop of rye, wheat or oats in the fall to anchor the straw. The nurse crop is typically seeded at a rate of 190–340 kg/ha (3–5 bu/acre) as a broadcast application over the straw. There may be benefits to this practice to ensure the straw does not blow off the beds over winter, there are no studies to suggest whether the benefits are worth the added cost.

CHAPTER 6

Pests and Disorders

Pests are the biggest challenge to ginseng cultivation in Ontario. Ginseng is susceptible to a wide range of insects, nematodes, diseases, weeds and other problems, but diseases are the most economically important. Managing ginseng pests requires proper identification, knowledge of pest biology and constant monitoring of the crop throughout the season to identify issues before they cause economic damage to the crop. This chapter provides an overview of pest biology, life cycles and cultural management of ginseng pests. For more detailed information on pest identification, biology, monitoring and integrated pest management, see the *Ginseng* module of Ontario CropIPM. For a listing of pest control products registered on ginseng pests, visit the Ontario Crop Protection Hub.

Diseases

While any disease can be a major issue under the right conditions, the diseases covered in this chapter are listed in order of their annual impact on root yield and quality.

Phytophthora Root Rot and Blight of Ginseng *(Phytophthora cactorum)*

See Figure 34. Life cycle of *Phytophthora* on ginseng.

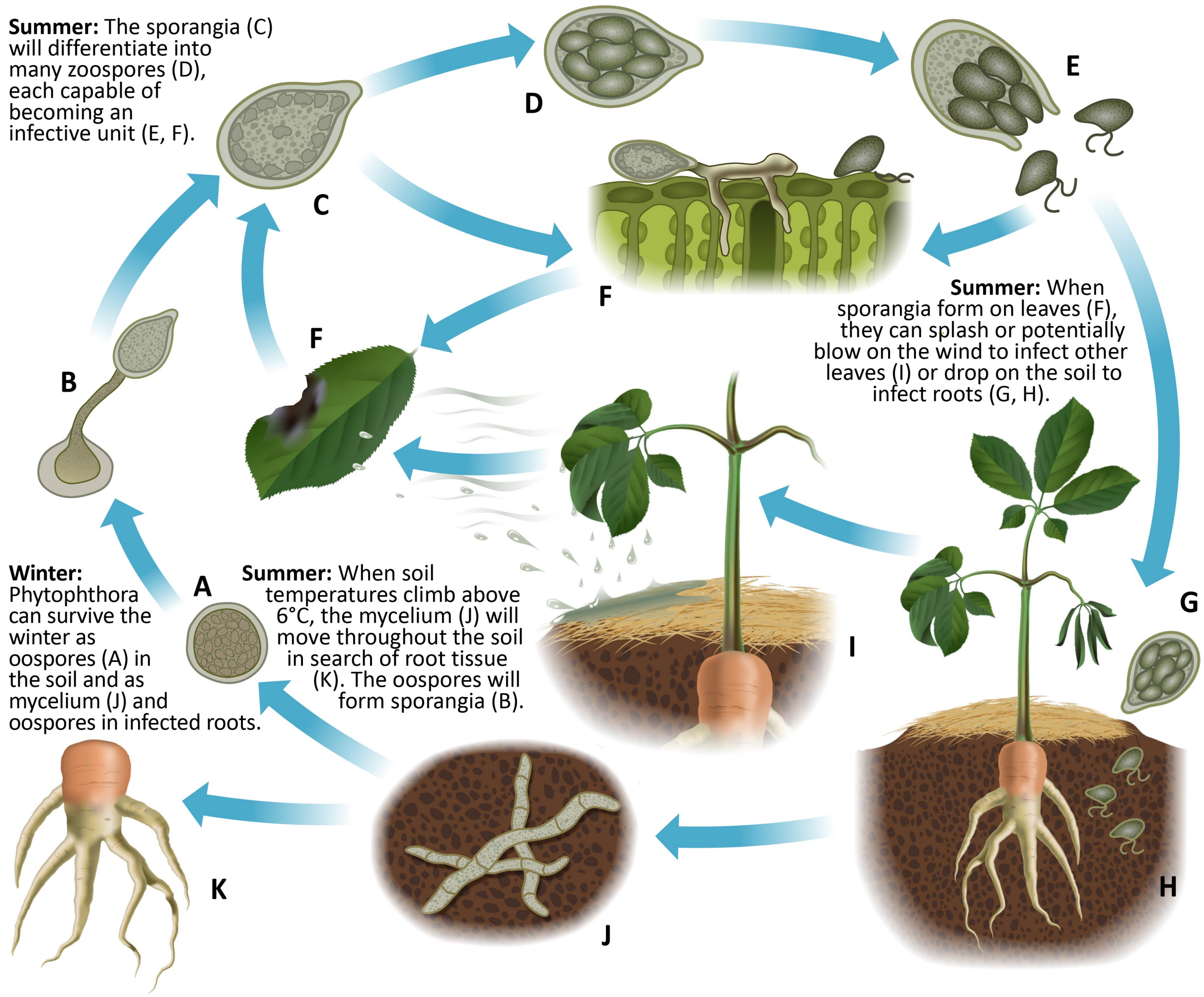


Figure 34. Life cycle of *Phytophthora* on ginseng.

The Pathogen and Symptoms

Phytophthora root rot and blight is a single disease with both a root rot and foliar blight phase. It is one of the most damaging diseases of ginseng and management is required in all gardens every year. Caused by the oomycete (water mould) *Phytophthora cactorum*, this pathogen has a wide host range that includes more than 200 plant species, including apple and strawberries. It is a relative of the pathogen that causes late blight in potato. The root rot phase of the disease is a leading cause of economic loss for ginseng. The foliar phase of the disease can spread geographically very rapidly and can result in increased soil infestations.

Phytophthora cactorum stays in the soil as dormant resting oospores and chlamydospores or within infected plant tissue. It is active in a temperature range of 4˚C–29˚C. The pathogen also produces another reproductive organ called a sporangium (plural sporangia) — a sac that can arise from mycelium or oospores. The sporangium contains about 30 small swimming spores called zoospores and when released, each zoospore is an infective unit. Sporangia form in a temperature range of 10˚C–20˚C, with zoospore release from these sporangia in a temperature range of 4˚C–24˚C, with a peak at 8˚C. In the soil, sporangia form on the surface of infected roots. In the case of foliar blight, sporangia form on the surface of the leaves and travel longer distances through splashing and wind-blown spray. Sporangia might be airborne under certain conditions, but this has not been proven.

Phytophthora diseases of ginseng can spread very quickly. Once present in a garden, it is a constant threat. If environmental conditions favour the disease, severe losses can occur rapidly. Practically all ginseng gardens have some phytophthora root rot by the time they are harvested.

Roots rotted by *Phytophthora* have a typical pinkish-brown appearance (Figure 35). The interior of the root develops a cheesy texture (Figure 36) and when squeezed, a clear liquid oozes out.

Phytophthora root rot causes a distinctive sour odour. Foliar symptoms of the root rot in the spring include the plant showing a classic shepherd's crook appearance with the top arched over and the leaves drooping straight down (Figure 37). This drooping can also occur if a foliar lesion develops on the stem as the shoot is emerging through the soil. Later in the year, root infection leads to a purple discolouration and wilting of the top of the plant (Figure 38).

Figure 35. Pinkish-brown rot typical of *Phytophthora* infection.
Source: Dr. Amy Shi, Ontario Ginseng Growers Association

Figure 36. Cheesy interior of roots decayed by *Phytophthora*. There is no longer any differentiation of the root tissues.

Figure 37. A shepherd's crook appearance of a newly emerged top due to either root infection or infection of the stem as the top emerged through the soil.

Figure 38. Wilting and slight purpling of the leaves due to phytophthora root rot.

Foliar blight causes different leaf symptoms that begin as darkened, indistinct patches on the leaves (Figure 39) and then quickly develop into distinct, dark, water-soaked lesions (Figure 40). Affected leaves eventually droop straight down and become watery and black (Figure 41).

Figure 39. Early symptoms of phytophthora leaf blight on a ginseng leaf. Note the darkened patch from sporulation of the pathogen and initial cell damage. *Source*: Dr. Amy Shi, Ontario Ginseng Growers Association

Figure 40. A distinct, water-soaked lesion due to phytophthora leaf blight. *Source*: Dr. Amy Shi, Ontario Ginseng Growers Association

Figure 41. Wilted and water-soaked leaves due to phytophthora leaf blight infection.

Splashing water can carry zoospores, sporangia and even soil containing mycelium onto the leaves. If sufficient moisture is present, the fungus rapidly grows into the leaf tissue. Any sporangia produced in infected leaves can easily spread through splashing or wind-blown spray. The leaf blight phase of the disease spreads rapidly throughout the garden and potentially into other gardens downwind of infections. Under conditions of prolonged leaf wetness, more foliar infections occur in a wide geographic area if the leaves are not protected by fungicides. Sporangia produced on these leaves can drop onto the soil, especially during rainy periods and begin invading the roots. The fungus overwinters as oospores or as mycelium in diseased plant tissue and as oospores in the soil.

Factors Promoting Disease

Phytophthora is a water mould. The disease is most prevalent where soil moisture is above 60% field capacity or where there is water pooling in the garden. Areas of *Phytophthora* infection can often be found surrounding a leaky irrigation sprinkler or where water drips off the shade cloth (Figure 42). The pathogen can be active at temperatures as low as 4˚C, making roots vulnerable early in the spring and throughout the growing season.

Figure 42. Phytophthora root rot developing in bands through a garden where water drips from the shade cloth.

The movement of machinery and people through standing water can splash the fungus up onto the beds and onto leaves. Rain can splash zoospores and sporangia up to 1 m. Excessive fertilization that creates a dense leaf canopy produces ideal humid conditions for the development of leaf lesions.

Disease Management Practices

Cultural

Management of phytophthora root rot and blight begins with site selection (see *Site Selection*, Chapter 2). Once disease develops in a garden, consider subsoiling the trenches where wet areas persist.

In low areas where water can pool in trenches, partly fill the trenches with bark chips or gravel to avoid splashing. Stay out of gardens immediately after rain (see *Water Management*, Chapter 2).

Use equipment in younger gardens first and wash it off before entering another garden. Use equipment in older gardens last. Have people moving through the garden wear disposable plastic booties and change them between gardens. The impact of equipment on the dispersal of *Phytophthora* cannot be stressed enough. A single focal point of disease can translate into disease along every driveway in a matter of weeks when equipment drags infected soil and water throughout the garden.

Fungicides

Preventive measures are the only effective means of managing *Phytophthora* in ginseng gardens once the fungus is present. Cultural controls can greatly reduce the risk of phytophthora root rot and blight and slow the spread of the disease, but outbreaks still occur. Preventive fungicides are usually required for the management of phytophthora root rot and blight of ginseng. When rain is in the forecast, protect leaves and stems with fungicides before it rains. For root protection, many fungicides must be washed into the root zone with rain or irrigation. In these cases, products can be applied during the rain, with overhead irrigation used soon afterwards if the rainfall was insufficient to move the product into the root zone.

Alternaria Leaf and Stem Blight

(Alternaria panax)

The Pathogen and Symptoms

Alternaria leaf and stem blight of ginseng is caused by the fungus *Alternaria panax* (Figure 43). Ginseng is the only commercially grown crop in Ontario affected by this fungus. There are other species of Alternaria with a wide host range such as *A. alternata* and *A. tenuissima* that have also been found on ginseng. These have not been conclusively proven to cause disease, but there is some evidence they may cause symptoms under certain conditions.

During the growing season, *Alternaria* spores are very common in the environment and move on air currents. *Alternaria panax* can be found throughout the ginseng-producing areas of the world. Spores can be identified under a microscope by their distinctive shape, which appears like segmented bowling pins with very long necks.

In ginseng gardens, most *Alternaria* infections begin on stems early in the season. The fungus requires a definite period of humidity to cause infection. The length of the humid period varies with temperature. Once the plant canopy opens in ginseng gardens,

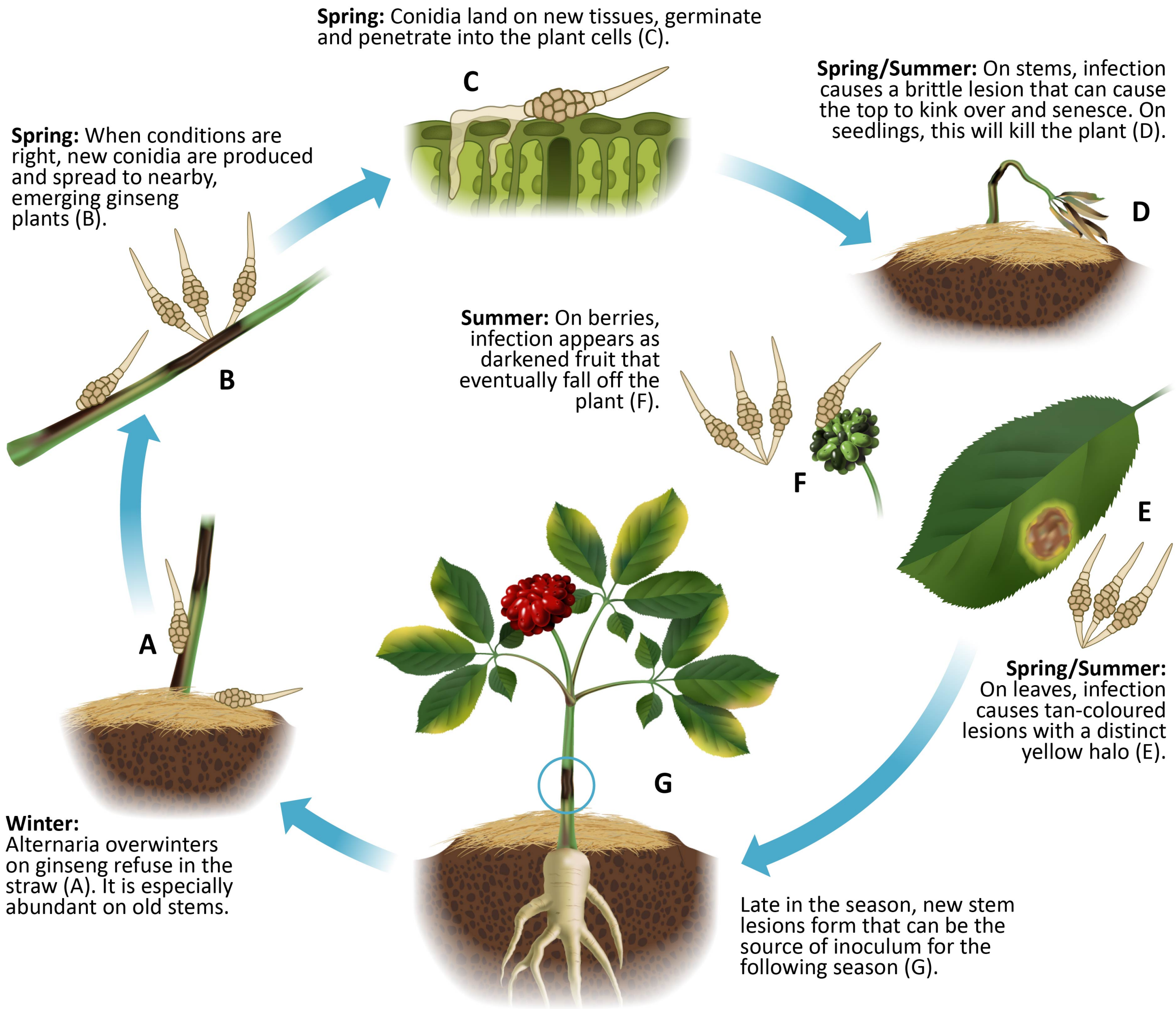


Figure 43. Life cycle of *Alternaria* on ginseng.

the stems are sheltered by the leaves and this results in a humid microclimate, even in relatively dry weather.

The first signs of stem infection are light or tan-coloured areas on the stem above the mulch. These areas soon become dry and brittle. As infection proceeds, the lesions become covered with a sooty layer of dark spores. A sooty residue will remain on a finger that has been rubbed along the dark portion of the lesion. Alternaria stem blight lesions usually cause the stem to buckle at the lesion and topple at a sharp angle (Figure 44).

Figure 44. Alternaria stem blight lesion. Typically found above the straw mulch, the lesions tend to be brittle and cause the stem to fold over sharply.

Stem lesions caused by rhizoctonia crown rot are not as brittle and the stems bend in an arc until the stem collapses. Alternaria stem blight tends to be above the mulch layer, while rhizoctonia crown rot is lower on the stem, either within the straw layer or just above the soil (see *Rhizoctonia Crown Rot* in this chapter).

Figure 45. Dry, tan alternaria leaf blight lesions on leaves, surrounded by a yellow halo. Sometimes a chlorotic spot is the first sign of a new leaf lesion.

Foliar symptoms of alternaria leaf and stem blight are usually distinctive. Typical lesions consist of a dry, tan central area surrounded by concentric dark and light areas and ultimately surrounded by a chlorotic halo (Figure 45). The dark areas are where the spores are formed. Lesions are roughly circular. Severe infections on the petioles, especially at the leaf axil, can cause defoliation. Unchecked, alternaria leaf and stem blight can defoliate an entire garden in less than a week if weather conditions are conducive to disease and the garden is not fully protected with fungicides (Figure 46).

Figure 46. "Blast" caused by severe *Alternaria* infection, giving the garden a burnt appearance. *Source*: Dr. Amy Shi, Ontario Ginseng Growers Association.

Atypical lesions have a dark brown or black appearance and occur under some conditions, but it is unknown if this is due to different species of *Alternaria*, weather conditions such as heat or other factors. Close examination reveals the concentric circles of sporulation. On seedlings in hot weather, stem lesions can cause the stem to become almost black and collapse, resulting in leaf wilting and an appearance similar to damping-off.

Damage to the stem caused by alternaria stem blight causes any developing berries to abort and fall off the plant. If the stem is undamaged, spores can spread to developing seed heads and directly infect the berries. Berries on infected heads become dark and shriveled (Figure 47), eventually dropping off the plant. The fungus overwinters on plant debris in the straw. Spores are formed in the spring and move on air currents throughout the garden.

Figure 47. Shriveled berries that have been infected with *Alternaria*.

Factors Promoting Disease

If alternaria leaf and stem blight is present in a garden, spores are attached to plant debris throughout the winter, particularly on old stems. After the canopy opens in the spring, it is not unusual to find a group of plants with foliar lesions surrounding a stem still standing from last year. Plant debris is the most frequent source of spring *Alternaria* infections in ginseng gardens.

The disease requires humidity to become established and a lush plant canopy promotes the development and spread of stem and foliar lesions. Gardens located in areas of dead air next to woodlots are more likely to develop hot spots. Later in the season, spores are blown into gardens from other infected gardens and from any nearby host plants. Poor spray coverage in the post rows also leads to areas of increased disease pressure in these areas.

Ginseng plants under any type of stress — nutritional issues, low pH or water stress — are more susceptible to alternaria leaf and stem blight. The disease is more common on senescing plant tissue. As the season progresses and plants become more stressed, their susceptibility to disease increases. Gardens stressed by poor fertility, fertilizer or pesticide injury, air pollution and mechanical stresses such as frost, hail or drought, are more likely to develop disease.

Disease Management Practice

Cultural

Locate gardens where air can move freely. If side shades are erected, they should not completely restrict air movement. Garden orientation can also influence air movement, but there are other considerations (see *Shading System Considerations*, Chapter 2). Vent large gardens by raising the shade cloth at intervals to allow heated air to escape. All practices that reduce humidity and encourage airflow help prevent infections. Before planting, soil pH should be between 6.0 and 6.5. Low pH may predispose ginseng to increased disease pressure. Plant density can affect the development of disease. High seeding rates or fertility practices that promote lush foliage create an environment conducive to disease.

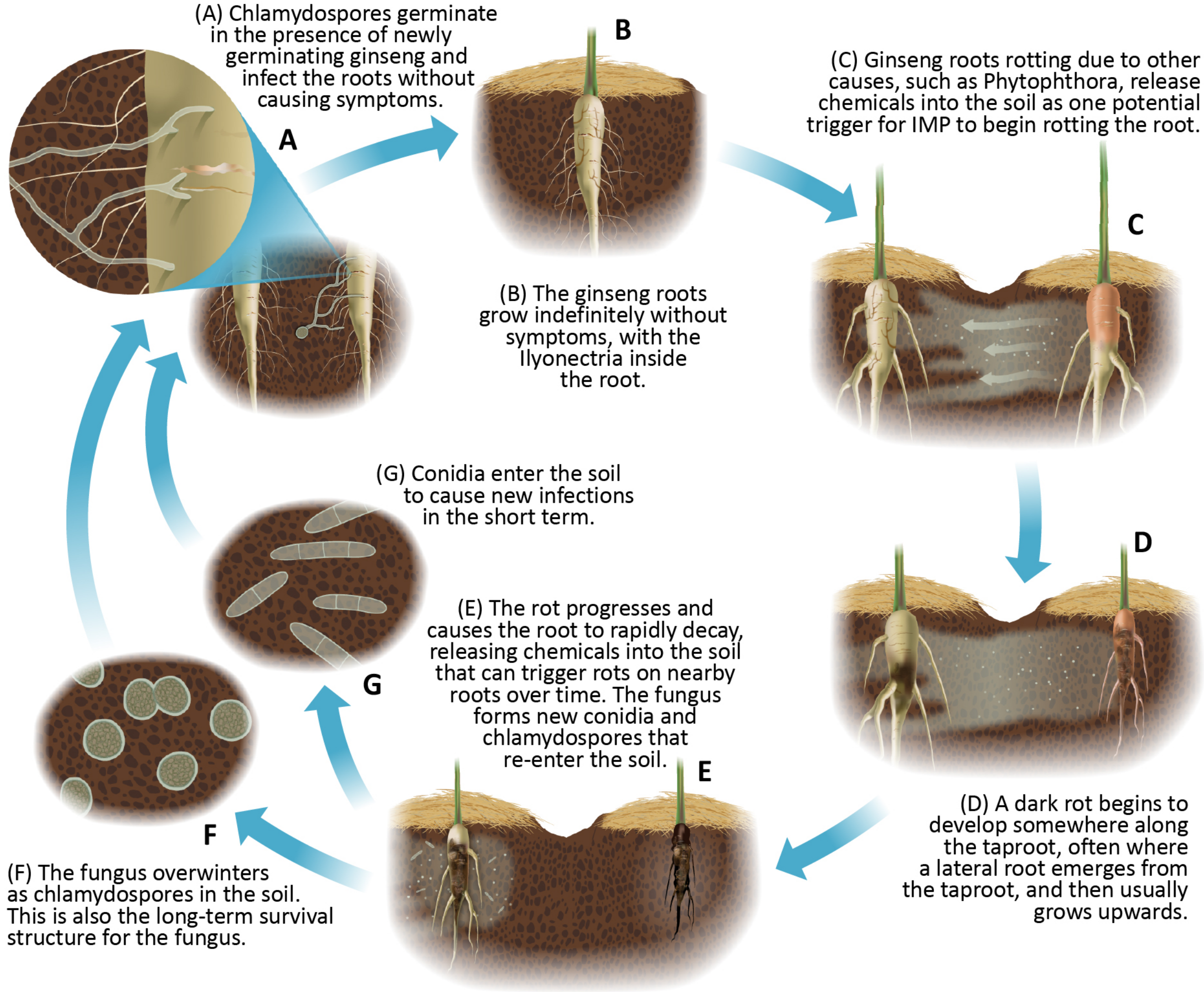


Figure 48. Life cycle of *Ilyonectria* (*Cylindrocarpon*) on ginseng.

Fungicides

Preventative fungicides are required for the management of alternaria leaf and stem blight of ginseng. To be effective at preventing the disease, fungicides must cover the stem and seed heads and the upper and lower leaf surfaces. Consider weather conditions, water volumes, nozzle choice, tractor speed, use of drop arms, sprayer calibration and timing of fungicide application. For more information, see *Optimizing Pest Control*, Chapter 7.

Ilyonectria (Cylindrocarpon) Root Rot of Ginseng

(*Ilyonectria mors-panacis* (formerly *Cylindrocarpon destructans*))

The Pathogen and Symptoms

Ilyonectria (cylindrocarpon) root rot is a significant disease of ginseng in Ontario (Figure 48). This disease does not have the same destructive power as phytophthora root rot and blight or alternaria leaf and stem blight, but is more difficult to control and has a longer-term impact on the ginseng industry due to its involvement in ginseng replant disease (GRD), see *Ginseng Replant Disease (GRD)* in this chapter.

Figure 49. Root completely decayed due to ilyonectria (cylindrocarpon) root rot. The root can be rotted to this extent before above-ground symptoms become obvious.

The pathogen can cause root rots that can go unnoticed until most of the root has decayed away, resulting in the common name *"disappearing root rot"* (Figure 49). This disease is sometimes referred to as rust, but this name is confusing and often leads to misunderstandings. There are other diseases and disorders of ginseng that also use the *"rust"* term, such as abiotic rusty root and rhexocercosporidium rusted root.

Recent research is improving our understanding of this disease. The disease was originally named after the fungus *Cylindrocarpon destructans*. However, research into the genetics of this fungus has shown that it contains several different species, each with unique host ranges. The primary species attacking ginseng is now called *Ilyonectria mors-panacis* (IMP). Ginseng is the only known host of this pathogen, but research suggests it must survive on other hosts and/or on decaying plant matter, given how widespread the fungus appears to be in Ontario fields.

Ilyonectria mors-panacis is a soil fungus found in ginseng-growing areas around the world and is closely related to Fusarium.

The fungus has a simple life cycle (Figure 48) and appears to be common and widespread in the ginseng production area of Ontario. Spores are stimulated to germinate by the roots, resulting in infection. The pathogen spreads within the root by mycelia (fungal threads), often moving upwards from the fibrous roots towards the crown, resulting in a dark-brown rot (Figure 50). This action gradually reduces water and nutrient uptake and results in discolouration and wilting of the tops (Figure 51).

Figure 50. Dark, scaly lesion typical of ilyonectria (cylindrocarpon) root rot on older roots — a disease that can occur at any point along the root.

Figure 51. Reddish discolouration and wilting of a ginseng top due to root damage from ilyonectria (cylindrocarpon) root rot. *Source*: Dr. Amy Shi, Ontario Ginseng Growers Association.

The fungus produces two types of asexual spores — conidia and chlamydospores. Conidia are the main reproductive spores that go back into the soil and cause additional infections in the short term. Chlamydospores are long-term survival spores that remain in the soil for many years and are more resistant to extreme conditions. Spores move with infested soil by wind erosion, contamination of machinery or on the boots of field workers.

Recent research by the Ontario Ginseng Growers Association (OGGA) has shown that the fungus commonly infects roots in all ginseng gardens, but does not necessarily cause disease at the time of infection. The disease appears to be triggered by factors that weaken the plant and its natural defenses against pathogens — herbicide or other pesticide injuries, physical damage, chemicals released by other roots (exudates) and nutritional disorders. More research is needed in this area. Research by OGGA and OMAFA shows the fungus does not spread very quickly from root to root. The spread of the disease in a field may simply reflect differences in how quickly individual plants develop the root rot after being injured. Plants with more injury may succumb to disease faster than nearby plants with less injury, even though all plants were infected by the fungus.

The fungus was once thought to be involved in other diseases of ginseng, particularly rusty root. The term "rusty root" usually refers to superficial, rust-coloured symptoms on the skin of the taproot that only go a few cell layers deep into the root. The reported involvement of IMP in these symptoms probably stems from confusion in the common names used in previous research reports and a lack of photos comparing symptoms in published research. Since IMP is often present in healthy ginseng roots, it can be found in association with any root symptoms without being a cause. The fungus does not appear to directly cause any symptoms other than ilyonectria (cylindrocarpon) root rot. See the sections *Abiotic Rusty Root*, *Rhexocercosporidium Rusted Root* in this chapter, for symptoms and causes of superficial rusty symptoms.

Ginseng Replant Disease (GRD)

Ginseng is not usually replanted on the same land twice due to a complex issue called ginseng replant disease (GRD). The disease can be severe, even several decades after the first crop. As suitable sandy soils for ginseng production are used up, growers must travel farther from their home farms to their fields, resulting in significantly higher costs. Growers also move to less suitable soils and sites, resulting in higher pressures of other diseases.

The causes of GRD are not fully understood. In replanted fields, the rot is primarily caused by IMP, with the same symptoms of ilyonectria (cylindrocarpon) root rot as in fields established for the first time on a site, but significantly more severe in most cases (Figure 52). Although a direct cause has not been proven, the severity of the disease often relates to the amount of root debris deposited by the previous crop.

Root debris comes from two main sources — diseases and harvest. Any root disease causes the root to decay in the field or be

Figure 52. Seedlings affected by replant disease exhibiting the same symptoms as ilyonectria (cylindrocarpon) root rot in new gardens, but with more severe damage and affecting younger roots.

left in the field at harvest. At harvest, some healthy roots are inevitably left behind and decay in the field, including fibrous roots torn off by the harvester and larger roots that fall through or are buried by the harvester. Heavier soils often result in higher disease and more roots remaining in the field at harvest and likely have higher GRD severity. These remaining roots decay rapidly after harvest and likely increase IMP inoculum and chemicals from within the root (exudates) in the soil. These chemicals or their breakdown products may impact the defense of the next ginseng plants to the IMP, causing faster root decay.

Without treatment, GRD can completely destroy a ginseng field within a few months of germination. Until factors in GRD development are fully understood, direct control of GRD is not possible. Management requires proper site selection and management of IMP inoculum in the soil.

Site selection is an important factor in preventing or reducing GRD.

Where possible, avoid sites previously cropped to ginseng. If that is not possible — or you want to attempt replanting — focus on fields with:

- ✓ light textured/sandy soils
- ✓ minimal root disease in the first crop
- ✓ longer period between plantings

GRD management also requires thorough fumigation and other soil disinfestation techniques to reduce IMP inoculum in the soil ahead of planting. Otherwise, control of GRD in-season is the same as managing ilyonectria (cylindrocarpon) root rot.

Factors Promoting Disease

Ilyonectria mors-panacis, the cause of ilyonectria (cylindrocarpon) root rot, does not behave like other soil-borne pathogens of ginseng. Most ginseng diseases occur wherever the inoculum of the pathogen is found in the soil. Once one root is infected, the disease can spread from root to root and longer distances when spores move in soil or air. IMP, on the other hand, is commonly found in seemingly healthy roots without causing disease. Research suggests the pathogen must be widespread in the soil, even though it has a limited ability to spread from root to root.

IMP appears to require a trigger to cause disease. These triggers probably include anything that weakens the plant and reduces its defenses, such as pesticide injury, fertility and pH issues, damage from other pests and chemicals released by decaying ginseng roots. It is common to find ilyonectria (cylindrocarpon) root rot developing on roots at the edge of a patch of missing and decaying roots caused by another pathogen, such as *Phytophthora cactorum*. In these cases, IMP often gets missed because a grower or crop scout assumes the rot is a continuation of the original disease without closely examining the roots. This is the same mechanism as replant disease, but it can occur within a field without a history of ginseng production. Understanding the connection between IMP and other disease symptoms can help a grower manage IMP more effectively.

Identifying high-risk sites

Ilyonectria (cylindrocarpon) root rot is often most severe where ginseng root debris or chemicals/exudates released from ginseng plants have been deposited into the field. Places where there is a higher risk of ilyonectria (cylindrocarpon) root rot due to root exudates include:

- ✓ the edges of patches of other root diseases
- ✓ where harvested root debris or wash water was spread

- ✓ where water has drained or leached from a nearby former ginseng field
- ✓ where wind erosion has deposited soil from a former ginseng field. In this case, the disease is most severe downwind of hedgerows where soil – or snow contaminated with soil – was deposited

Research suggests that it is the movement of root exudates rather than inoculum that is the primary mechanism of the spread of ilyonectria root rot.

Disease Management Practices

Managing ilyonectria (cylindrocarpon) root rot begins with reducing IMP inoculum in the soil. This requires proper soil fumigation procedures or other soil disinfestation techniques (see *Land Preparation and Fumigation*, Chapter 2). In replant fields, reducing IMP inoculum is even more critical because high disease pressures are inevitable without proper controls.

Controlling ilyonectria (cylindrocarpon) root rot involves:

- ✓ choosing fumigants with higher efficacy against fungi
- ✓ choosing TIF plastic to seal the soil after fumigation rather than a roller
- ✓ ensuring thorough fumigation of the entire rooting zone leaving the TIF plastic in place longer to provide a solarization effect
- ✓ avoiding re-contamination of fumigated soil in the bed during bed formation

In replant fields, consider adding other non-fumigation disinfestation techniques (biofumigation or anaerobic soil disinfestation) before or after fumigation to control a wider range of soil pathogens and achieve more thorough disinfestation of the entire rooting zone.

Research suggests that disease transmission through seed is less important now that most seeds are stratified above ground. However, it is still important to ensure the seed is as clean as possible by using good sanitation practices throughout the seed handling process. Submerge seeds and remove any floaters. Use seed treatments or other seed sterilization techniques where available. For more information, see *Seed Handling and Seeding*, Chapter 4.

Ilyonectria (cylindrocarpon) root rot is more difficult to manage with fungicides than other diseases. To be effective, they are best used early to reduce the infection of roots by IMP, which often occurs long before symptoms appear in the field. Once symptoms appear on some plants, more roots in the area may already start to rot and it may be too late for good disease control. To be effective, apply fungicides at a very high water volume, immediately followed by overhead irrigation to move the product out of the straw. Many products bind tightly to the straw once they dry and do not move afterwards, regardless of how much water is applied.

The disease can also be reduced by minimizing the movement of soil contaminated with the inoculum of IMP, ginseng root debris or exudates. At a field level, ensure soil from existing fields does not blow into fields yet to be planted with ginseng. Proper sanitation of machinery and boots is always important for reducing the movement of inoculum, especially after visiting gardens with high disease pressure.

Rhizoctonia Crown Rot

(Rhizoctonia solani)

The Pathogen and Symptoms

Rhizoctonia solani is a soil pathogen. Unlike many other fungi, it does not usually produce spores but grows through the soil vegetatively as a mycelium — the mass of hyphae (long, strand-like filaments) that make up the body of a fungus. When the pathogen encounters susceptible plant tissue, it forms a compact mass called an infection cushion and proceeds to penetrate the host. Once inside the host, it grows rapidly.

Under adverse environmental conditions, it may form small sclerotia (clumps of dark-walled cells). It can also form runner hyphae that crisscross the root surface, looking for a place to establish a new infection cushion.

Using the energy from its host, the fungus can travel and infect adjacent roots within several centimetres of the diseased root. As it moves out from its original focal point, circular areas of disease develop in infected gardens.

Rhizoctonia solani is active under specific aeration conditions that usually occur near the soil surface. Consequently, damage is most common on the crown of the root or the lower stem within the soil. However, if aeration conditions differ, *Rhizoctonia solani* can attack higher up the stem within the straw layer (stem canker) (Figure 53) if conditions are cool and wet for an extended period or lower down the root (root rot) if the soil is dry for an extended period.

Figure 53. Decay of the lower stem within the straw caused by *Rhizoctonia* infection.

Rhizoctonia solani infection usually results in a rusty or darkened discolouration of the affected tissue (Figure 54). *Rhizoctonia* can appear as a dry, corky rot that does not penetrate the root tissue deeply. Roots damaged by the disease are susceptible to invasion by bacterial rots, nematodes and small insects. While rhizoctonia crown rot may be superficial on the root, the secondary invaders may cause increased damage.

Figure 54. *Rusty or dark brown, soft rot at the crown of ginseng roots caused by Rhizoctonia infection.*

Rhizoctonia solani is primarily a pathogen of young roots. Seedling gardens and 2-year-old gardens are particularly susceptible. Infection can occur at any time after seed cracking. *Rhizoctonia solani* can rot seed, prevent emergence by infection of the new root or shoot before it reaches the soil surface or topple seedlings with stem canker shortly after emergence. This can be considered a type of damping-off, but the presence of expanding circles of dying plants distinguishes it from other causes of damping-off. Older roots and stems are less commonly attacked, but rots can develop under ideal conditions, such as prolonged cool and wet weather that leaves the straw water-soaked for extended periods.

Factors Promoting Disease

There are several strains (called anastomosis groups) of *Rhizoctonia solani* in Ontario that differ in their host ranges, symptoms, locations of damage on the plant and environmental preferences. These strains can differ in the severity of the disease, the pattern of damage and the time of year that symptoms occur.

Rhizoctonia is one of the fastest-growing fungi. It travels vegetatively (by mycelial growth) through the soil from plant to plant, so gardens with a high plant density show a more extensive spread of the disease. This type of movement of the fungus results in circles of missing plants (Figure 55).

Figure 55. Circles of missing plants in a garden affected by rhizoctonia crown rot. Each circle is the result of the fungus moving out from a single focus of disease.

High nitrogen levels that promote rapid plant development leave roots and stems susceptible for longer periods of time. Rapid plant growth does not allow plants to harden off quickly.

Disease Management Practices

Cultural

The fungal threads of *Rhizoctonia* can cling to soil particles. Movement of this soil into gardens can spread the disease. Soil can move on wind, water, machinery and the boots of people who pass through the garden. Do not situate gardens where there is runoff from existing gardens or vegetable fields. Workers and machinery should move from new gardens to older gardens, never the reverse. When fumigating, do not introduce unfumigated soil onto beds as they are formed.

The sooner gardens warm up and dry up in the spring, the less the risk of *Rhizoctonia* infection. It is common for growers to allow a nurse crop to grow in newly seeded gardens in the fall. This crop is usually the result of grains contained within the straw. The nurse crop anchors the straw through winter winds and the roots open channels that help drainage and aeration of the soil in the beds. This can help warm the soil in the spring.

Fungicides

Fungicides have been very effective for reducing damage caused by rhizoctonia crown rot in ginseng in recent years. But the reliance of the industry on a small number of fungicides means fungicide resistance could develop at any time and increase disease severity. Rotate fungicides from different groups whenever possible to delay the development of resistance.

Botrytis Blight of Ginseng

(Botrytis cinerea)

The Pathogen and Symptoms

Botrytis blight of ginseng is caused by the fungus *Botrytis cinerea*. This fungus is a pathogen of many fruit and vegetable crops. It causes the grey mould rot that is common to grapes, strawberries, greenhouse floral crops and many vegetables. Botrytis is most active at 18°C–23°C and can infect all parts of the plant, including the roots.

In many crops, botrytis blight frequently becomes established on plants toward the end of the flowering period. The fungus infects the dying tissue of spent petals. It does not generally invade healthy, growing tissue, but when it builds up enough mass on the dying petals, it is able to penetrate any tissue that it contacts. This ability to invade dead and dying tissue makes it particularly threatening to ginseng.

The fungus overwinters as sclerotia — hard, black bodies that can survive winter temperatures and adverse conditions. These sclerotia resemble small mouse droppings. When weather conditions are appropriate, the sclerotia germinate, producing and releasing many spores. If frost, heat stress or other environmental issues result in damage to the emerging ginseng, Botrytis spores can invade the damaged tissues and spread to healthier tissues nearby.

Leaf symptoms usually begin at the tip or leaf edge (Figure 56). Sometimes, if there has been mechanical damage, these symptoms will begin in the middle of the leaf. Infected leaf tissue turns pale, then tan, then glassy. The rot is soft and the affected areas are quite wilted. Stem rot also produces a soft lesion, unlike the brittle lesion caused by alternaria stem blight or the dry, stringy lesion caused by rhizoctonia crown rot. Infected stem tissue often becomes soft, tan-coloured and eventually covered with a mass of grey mycelium and conidia (Figure 57). As the fungus decays infected tissue, it develops the ability to invade adjacent healthy tissue. As one leaf decays and collapses onto another, the other becomes infected (Figure 58). This chain reaction of infection creates hot spots in a garden. During periods of high humidity, many conidia are released from hot spots to form new infection areas.

Figure 57. Botrytis blight on stems damaged by freezing temperatures. In the humid conditions of the plant canopy, disease can progress rapidly.

Figure 56. Tan-coloured botrytis blight beginning on the leaf edge. It can resemble phytophthora foliar blight but does not appear water soaked.

Figure 58. Decaying leaves drooping onto healthy leaves. The fungus is then better able to infect nearby healthy leaves because of the energy it gets from feeding on the decaying leaves.

Infected berries turn purplish and shrivel (Figure 59). As the berries decay, they produce many conidia. Seed heads that become infected produce a mass of "fuzzy" grey conidia (spores).

Figure 59. Purple-coloured berries infected with *Botrytis*.

Botrytis conidia are widespread in the environment, so assume any mechanical damage to the plant will lead to *Botrytis* infection. Hail, frost, tractor abrasion, sandblasting and debudding all cause some degree of mechanical damage. Gardens damaged by early spring frosts are particularly vulnerable to *Botrytis* infection. Frost or freezing damage followed by warm, humid weather results in a rapid rot of affected plant parts.

Damping-off of seedlings can occur in a humid season in a temperature range of 18˚C–23˚C, especially after sandblasting. In these cases, the root is usually invaded and completely disappears. Outside this temperature range, damage still occurs but progresses more slowly. Botrytis blight damage is seldom seen in very hot conditions.

While *Botrytis* is not traditionally considered a root-rotting fungus, lower stem infections can move into roots and cause decay. *Botrytis* root infections may be associated with the reduced plant stand in ginseng gardens over time, but root infections are rare.

Factors Promoting Disease

Anything that causes mechanical damage to the leaf predisposes it to infection by *Botrytis*. In Ontario, sandblasting early in the season can wound leaves and open them to infection. These infections occur at the edge of gardens. Mechanical injury can also occur from fallen shade structures, hail and the movement of machinery and people through the garden. Leaf injury from fertilizers or pesticides can also precede infection.

Temperatures below 23˚C, coupled with high humidity, promote rapid disease. Humidity remains high within the plant canopy even when the outer surface of the leaves appears dry. Sclerotia on the straw, dropping infected petals and falling conidia easily infect lower stem tissue. A dense plant canopy maintains high humidity for extended periods of time and raises the likelihood of infected leaves contacting healthy leaves.

Disease Management Practices

Cultural

Removal of decaying plant debris reduces the presence of Botrytis but does not eliminate it. Ginseng tends to thin out to about 80–100 plants/m^2 after 3 years. Seeding rates that result in higher plant stands promote a dense, humid environment within the canopy. Fertility practices that result in lush canopy development also result in high humidity. This within-canopy humidity promotes botrytis blight at the base of the stem, just above and within the straw mulch.

Guards on machinery that prevent leaf abrasion lessen the disease. Caution workers to move through the garden with care.

A 1-metre rye strip around the perimeter of the garden helps prevent sandblasting.

Fungicides
Time botrytis blight control with periods of susceptibility. After damage to the crop from frost or other issues, apply fungicides preventively if weather conditions are conducive to development of the disease. Some fungicides that are taken up by the plant when there is fresh physical damage can lead to phytotoxicity issues. Growers often delay an application up to a day after damage has occurred to allow the wounds to heal enough to prevent this uptake.

Rhexocercosporidium Rusted Root

The Pathogen and Symptoms

Rhexocercosporidium rusted root (RRR) is caused by the soilborne fungus *Rhexocercosporidium panacis*. This fungus is only known to attack ginseng but likely has other hosts. It was only identified a couple of decades ago and was proposed to be a principal cause of rusty root in Ontario. However, recent research has shown it only causes one version of rusty root that is now rare in Ontario. The fungus has a similar, simple life cycle and biology as *Ilyonectria mors-panacis,* but much less is known about how it gets into Ontario ginseng fields. It may be seed-borne and fields with the disease may have been planted with contaminated seeds obtained from another contaminated field or region.

Rhexocercosporidium rusted root is usually concentrated near the crown of the root and sometimes on the lower stem and rhizome. Symptoms begin as small, raised, reddish bumps that coalesce into a dark and scabby dry rot (Figure 60). The damage only goes a few cell layers deep into the root and rarely impedes the flow of water or nutrients. There is unlikely to be above-ground symptoms of infection and damage is often first noticed after harvest when it is too late to control.

Figure 60. Dark scabby patches mostly near the crown of taproots as a result of rhexocercosporidium rusted root. Note: Small, reddish, raised bumps at the edge of some of the patches, are the initial symptoms of the disease.

Factors Promoting Diseases and Disease Management

The factors that promote RRR are not known. Where it occurs, growers should examine cropping history, the source of the ginseng seed and the sources of other inputs into the field, such as manure and straw. This information may hint at a cause so that further issues can be avoided. There are no registered controls for this disease in ginseng. Some fungicides for similar diseases may reduce disease damage, but this disease is too rare to warrant adjusting the spray program.

Pythium Diseases of Ginseng

(Pythium spp.)

The Pathogen and Symptoms

Pythium (recently renamed as *Globisporangium*) is a common soil-borne pathogen. *Pythium* and *Phytophthora* belong to the same group of fungal-like organisms called oomycetes or water moulds and share several features:

- produce swimming spores (zoospores) that are mobile in soil water

- produce oogonia, reproductive structures (like an egg) that are highly resistant to adverse conditions and can persist in the soil for a long time

Additional structural and chemical features of this class of organisms set them apart from other pathogens. Pest control products that control fungal diseases may not control *Pythium* and *Phytophthora*. The cultural practices that help control these pathogens are critical to the health of ginseng gardens.

Pythium is an opportunistic fungus. It can exist in the soil on organic matter and attack seeds and seedlings (in the case of ginseng) as the opportunity arises. Because it can exist on soil organic matter, *Pythium* is present in a wide variety of soils from season to season. It does not need ginseng to survive and can be found in all agricultural soils in Ontario.

When *Pythium* zoospores infect plant tissue, they form cysts that develop mycelium, which releases toxins and produces an enzyme that dissolves the cell parts that glue plant cells together. This kind of activity produces a soft rot.

Pythium and Seeds
Ginseng seeds remain in the soil for many months between planting in the fall and germination in the spring. During this time, the seeds are susceptible to invasion by *Pythium*. When *Pythium* attacks seeds, the seed coat does not rot away, but the interior of the seed becomes a curdled, "cheesy," creamy-coloured mass (see *Diseases of Ginseng Seed* in this chapter). Some seed can be infected during stratification. This seed often floats, but some infections may not be well established and the disease can easily be transferred to the new garden.

Pythium and Seedlings
In seedling gardens, *Pythium* is part of the damping-off complex. See *Damping-off and Seedling Disease* in this chapter for more information.

Pythium and Older Gardens
Pythium spp. are sporadic pathogens of older plants, although the range of *Pythium* species that can attack ginseng and the conditions that lead to disease symptoms are not fully known. Observations suggest that *P. sylvaticum* can cause damage to older roots. Based on research, other common *Pythium* species like *P. ultimum* and *P. irregulare* cause damping-off symptoms and may cause damage in older roots in some circumstances. General symptoms that indicate roots have been infected with *Pythium* include a proliferation of feeder roots with swollen, brown tips (Figure 61) as the plant tries to overcome root pruning. Above-ground symptoms include an uneven stunting of the canopy, leading to highly variable plant growth. This can occur in large sections of a garden.

Figure 61. *Pythium* infections on the small feeder roots of 3-year-old roots. The feeder root tips are typically swollen and brown. *Source*: Dr. Amy Shi, Ontario Ginseng Growers Association.

Factors Promoting Disease and Disease Management

Like *Phytophthora*, *Pythium* produces swimming zoospores and is more active under wet conditions. Gardens where the surface water drains slowly or where water pools, are more likely to show signs of damping-off or root decay. *Pythium* infections can occur under drier conditions than *Phytophthora*.

Another factor influencing the disease cycle of *Pythium* diseases is contamination of the beds with unfumigated soil. Poor fumigation or movement of unfumigated soil introduces *Pythium* into the new seedbed. Because this fungus is present in virtually all soils in the ginseng growing region, Pythium can be introduced with unfumigated soil from areas below the fumigation zone. After fumigation, the balance of soil microbes is disturbed. Any fungi introduced into fumigated soil do not have as much competition as they would otherwise have from normal soil microflora and microfauna. This allows introduced pathogens to grow and attack seeds and seedlings with ease. Fumigated soil does not stay *Pythium*-free over time. Fumigation reduces the *Pythium* population in the soil, but there are many ways soil can be recolonized. *Pythium* can enter a garden on blowing soil, in water runoff and on machinery and boots. Recolonization occurs to some extent about 3 months after fumigation.

Fumigation is the most effective means of controlling common soil-borne pathogens like *Pythium*. Fungicides are available for control of pythium root rot, but generally, management of phytophthora root rot is sufficient to control pythium root rot. Repeated use of the same *Phytophthora* products can lead to resistance in both *Phytophthora* and *Pythium* spp. When disease develops, consider switching to *Phytophthora* products that offer more control of *Pythium*.

Fusarium

(Fusarium spp.)

Fusarium spp. have been blamed for numerous symptoms on ginseng roots, but they have not been proven as a cause of the symptoms commonly found in Ontario. *Fusarium* species are practically everywhere in the environment and are found on all plant tissues. They are frequently involved in the decay of organic matter in the soil, including plant parts killed by other pathogens. *Fusarium* spp. can also be present within ginseng roots without causing symptoms. For these reasons, they are easy to find in all diseased tissues and in any soil or root diagnostic report. Efforts to induce disease symptoms with several *Fusarium* species found on ginseng roots have failed to reproduce any symptoms.

In general, *Fusarium* spp. are probably secondary issues that could increase the severity of other diseases, but only cause direct symptoms under very specific conditions — wounding by other pests or adverse weather conditions. Without knowing the role of *Fusarium* spp. in ginseng, it is impossible to advise on controls. Focus on the management of other ginseng pathogens.

Damping-off and Seedling Disease

Seedlings attacked by soil pathogens such as *Rhizoctonia, Ilyonectria, Fusarium* and *Pythium* may die before or after emergence, causing typical damping-off symptoms (Figure 62). Damping-off is not a single disease, but rather an early symptom of several root diseases that cannot be distinguished by symptoms because the roots are so small that they shrivel and die before they can be examined. Symptoms of damping-off begin with wilting and collapse of the top. When the root system is dug up, roots are usually rotted away, leaving only a shrivelled portion of the upper tap root. Damping off is best controlled by planting clean seeds and through seed treatments. Fungicides can help prevent further spread of the disease once symptoms are found, but soil tests may be required to identify the fungus causing the symptoms to choose the most appropriate fungicides.

Figure 62. A seedling wilting due to damping-off.

Figure 63. Reddened leaves of isolated plants caused by suspected verticillium wilt.

Verticillium Wilt

Much of what we know about verticillium wilt in ginseng has been assumed based on observations in the field. There has been very little research on the biology of verticillium wilt on ginseng. *Verticillium* is a fungus that causes wilt diseases of a wide range of horticultural crops and ornamentals, particularly potatoes, tomatoes, eggplant and other members of the potato family. When ginseng is grown in the same field after an affected crop, it can develop the same symptoms. The fungus grows into the vascular system and blocks the flow of water and nutrients up to the leaves.

The first evidence of verticillium wilt is discolouration, wilting and collapse of scattered plants in the field (Figure 63). The leaves often turn red, a symptom that can be easily confused with other root diseases of ginseng, such as ilyonectria (cylindrocarpon) root rot. Diagnosis requires an examination of the root. When the root is cut open, the vascular system is often discoloured, resulting in a ring of brown within the root (Figure 64) if the cause is verticillium wilt.

Figure 64. Brown ring in the cross-section of a root, revealing where *Verticillium* has clogged the vascular system.

Other than avoiding fields with a history of the disease and ensuring good fumigation practices, there are no means of controlling this disease in ginseng fields once it is identified. There has been no research on the factors that lead to ginseng infection.

Sclerotinia White Mould

The fungus *Sclerotinia sclerotiorum* has been found in ginseng in the past, but is rare and has not caused economic damage. *Sclerotinia* is a common pathogen that attacks a wide range of crops, causing white mould. In ginseng, damage has been found on the stem near or within the straw and consists of browning of the exterior of the stem.

Disease Identification

The major diseases of ginseng can often be distinguished using symptoms alone. Consult the *Ginseng* module of Ontario CropIPM for proper identification of known pests and disorders of ginseng. In some cases, laboratory identification may be required. *Pythium* and *Fusarium* spp. are typically found on all root samples submitted to a laboratory, even if they are not the cause. Consult OMAFA specialists to help interpret the results of diagnostic reports.

Diseases of Ginseng Seed

Garden health begins with planting healthy seed. Ensuring healthy seed requires good sanitation practices throughout the seed handling process, from the field where it is grown all the way through planting. These practices can reduce the colonization of the seed by pathogens, the rotting of the seed during storage and the transmission of those pathogens into the new garden.

Seed treatments can help reduce disease transmission, but are most effective if seeds are not already infected with pathogens due to poor sanitation practices. Seeds can be infected or contaminated with several common ginseng pathogens such as *Alternaria*, *Botrytis*, *Rhizoctonia*, *Pythium* and *Ilyonectria,* as well as bacterial species. Regularly monitor gardens chosen for seed harvest for diseases and avoid harvesting seeds from diseased areas.

There is insufficient research to differentiate the symptoms of these causal organisms in ginseng seed. Laboratory testing is required to identify the cause in most cases. Bacterial pathogens typically lead to a soft rot of the interior of the seed and no discolouration or consistent fungal structures. Fungi often lead to more distinct symptoms that include discolouration and structures on the exterior of the seed. Decaying seed could also be due to abiotic issues such as incomplete development of the seed in the berry, toxicity of seed treatment products or improper storage conditions. In these cases, any organisms found in the seed could be secondary invaders. If a pathogen is spreading in the seed box, some of the seeds should be only partially affected. If the seed can be easily separated into fully healthy and fully diseased categories, then an abiotic issue is more likely.

Seed can be contaminated or infected with pathogens at any of the following stages:

- in the field, while berries are ripening — they can become infected with pathogens like *Alternaria* or *Botrytis*
- during seed harvest if containers are not sanitized or berries come into contact with soil
- during any post-harvest seed handling activities if the equipment, such as the depulper and any containers have not been sanitized before and between batches
- when mixed with contaminated sand for stratification
- during stratification, when the pathogens spread from one contaminated seed to nearby seeds

There are four methods for minimizing seed contamination.

1. Ensure gardens used for seed production are well protected against common pathogens, especially foliar diseases.
2. Use containers during seed harvest and post-harvest handling composed of materials that can be easily sanitized, such as plastic or stainless steel. Avoid using wood containers or line them with plastic inserts. Sanitize containers after each use.
3. Source the sand used to mix with seeds during stratification from a source not likely to be contaminated with pathogens. Sand derived from local landscape supply companies is more likely to be contaminated than silica or construction sand derived from distant quarries. Purchase new sand every year or store unused sand indoors to avoid the growth of weeds that may further contaminate the sand.
4. Periodically check the condition of the seed in the stratification boxes to ensure diseases are not spreading. If a problem arises, remove the seeds and conduct a float test (See *Float Testing*, Chapter 4). Use new sand to remix the remaining seed for further stratification.

Post-Harvest Diseases and Disorders

Red Root (Varicose Disorder)

Ginseng root occasionally develops lengthwise vein-like red streaks along the root. These streaks may be numerous enough to give the root an overall red appearance. Close examination of the red streaks reveals that they are distinct and occur primarily in the outer layer of the root interior (Figure 65).

Figure 65. Reddish discolouration of resin ducts inside the taproot under the skin is a symptom of red root disorder. *Source*: Dr. Amy Shi, Ontario Ginseng Growers Association.

Ginseng roots contain secretory ducts. Under certain environmental conditions, these ducts become filled with phenolic compounds. As the root dries, these compounds turn orangey-red. This seems to be independent of the drying temperature. Observations suggest that harvesting in hot and dry conditions may lead to increased problems with this disorder.

Mouldy Root

Root decay sometimes occurs during drying under very specific air temperature and humidity conditions. The exact conditions that promote disease in the kiln have not been researched. Sanitation and proper air circulation usually prevent these drying problems. *Rhizopus* (Figure 66) and *Geotrichum* (Figure 67) are two fungi associated with mouldy root in the kiln.

Figure 66. Dark areas on a root typical of *Rhizopus* infection, which can occur where there are pockets of high humidity during drying.

Other pathogens, such as *Ilyonectria*, that are present on the root at the time of harvest may continue to progress in the cooler or kiln post-harvest. Moulds can represent a significant food safety risk through toxin production or as allergens — prevent mould development and remove any mouldy roots before sale.

Figure 67. *Geotrichum* mould on roots, appearing as a dirty white, fuzzy growth. This develops when humidity is excessive during drying.

These post-harvest practices reduce root rots and moulds:

- Remove obviously rotten roots in the field prior to conditioning (Refer to *Conditioning Ginseng Roots*, Chapter 8)
- Keep roots dirty during conditioning or if selling fresh roots, until just before sale. Soil on the surface of the roots contains beneficial organisms that can suppress diseases and reduce the spread from root to root. Washed roots will decay more rapidly
- After washing, ensure roots go immediately into the kiln for drying. Space roots adequately to ensure rapid drying. This is especially important for larger roots that take longer to dry and often have the greatest issues with mould
- Sanitize drying trays, interior surfaces of the kiln and fan blades after each season, especially after a mould outbreak

Nematodes

(Pratylenchus penetrans (root lesion nematode*), Meloidogyne hapla* (northern root knot nematode)).

Nematodes are microscopic, worm-like animals that are widespread in soil, water and plants. Although most are beneficial, some are plant parasites that invade roots and feed on plant tissue.

Plant parasitic nematodes overwinter in the soil, plant roots and crop debris. When soil conditions become favourable, young nematodes migrate to the roots of host plants. Most nematodes live in the top 60 cm of the soil, but they may travel over a metre deep in search of host roots or to stay below the freeze line in winter. Once roots are found, nematodes begin feeding and disrupt the water and nutrient-conducting vascular tissue, resulting in reduced plant growth and yield. They also inject toxins into plants that kill host tissue and, for some nematode species, induce abnormal plant growth (knots or galls). Wounds caused by nematode feeding can also facilitate infection by other soil-borne pathogens.

Above-ground symptoms of nematodes include variable stands (dense plant populations that thin out completely in some areas), senescence and stunted plants. These symptoms can be mistaken for nutritional deficiencies.

The root lesion nematode and the northern root knot nematode are the main nematode pests of ginseng in Ontario. Both have an extremely wide host range that includes many native weeds.

Root Lesion Nematode

The root lesion nematode (RLN) is common in ginseng-growing regions of Ontario and has a wide host range. Ontario research has shown that ginseng is not a suitable host for root lesion nematode, but can be damaged at germination when the nematode has nothing else to feed on. Populations of these nematodes die off quickly and are rarely found beyond the early summer of the seedling year. Figure 68 shows how root lesion nematode populations in soil progress from land preparation through to the seedling year.

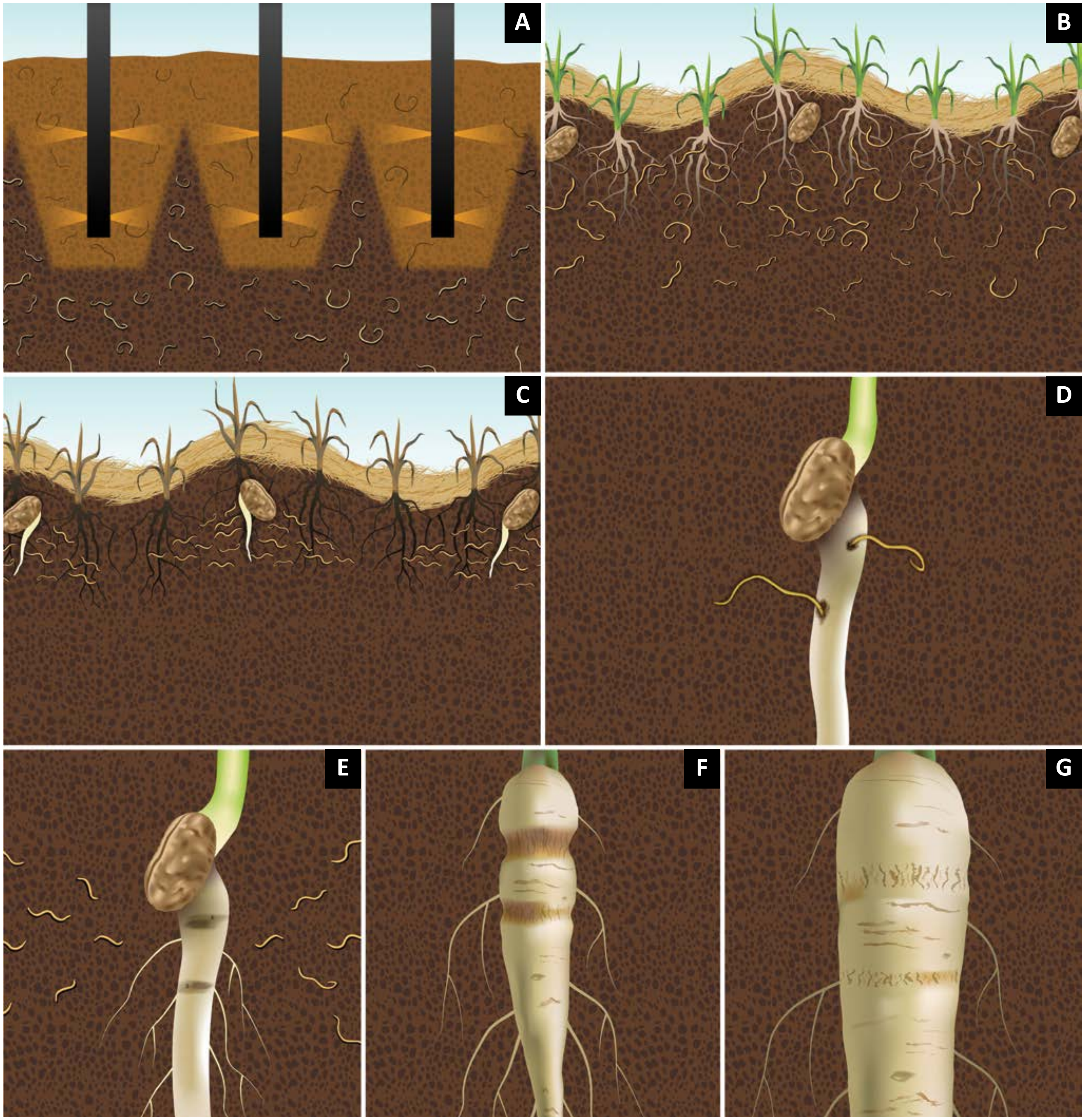


Figure 68. Timeline of root lesion nematode progression in soils from land preparation to ginseng seed germination. A) Fumigation kills most of the nematodes in the treated zone, but leaves some alive between and below the injection shanks. B) The surviving nematodes feed on the roots of volunteer rye - or other grains or weeds - during the fall after seeding. C) When the rye is killed by herbicides in the spring, the nematodes move to the germinating ginseng roots. D) The nematodes cause wounding along the taproot. E) The ginseng is not a suitable host for the nematodes, and they move away from the roots, but the damage inhibits root growth in that area. F) As the healthy parts of the taproot expand, the damaged portion stays behind causing distinct constrictions along the taproot, usually containing a rusty discolouration. G) Eventually the root grows out of the constrictions, but a rusty band remains in the area of the former constriction.

The feeding damage at germination slows down root expansion at the feeding site. This section of the root expands more slowly while the undamaged portions expand normally. As a result, distinct constrictions develop along the taproot (Figure 69) that often contain vertical, rust-coloured lines. Root lesion nematode feeding generally does not persist, so ginseng roots can grow out of these constrictions as they mature and enlarge, leaving only bands of rust-coloured stripes along mature roots at harvest (Figure 70).

Figure 69. Constrictions along the taproot of seedlings, containing vertical, rust-coloured lines are the primary symptom of root lesion nematodes on ginseng.

Figure 70. Mature root that has grown out of the constrictions caused by root lesion nematodes, leaving a pattern of rust-coloured strips along the root.

Root lesion nematode damage may be mistaken for abiotic rusty root (see *Abiotic Rusty Root* in this chapter). While they both include rusty discolouration, they can be distinguished by the location and pattern of the rusty symptoms. Root lesion nematode damage causes distinct constrictions along the taproot and any rusty colouration is confined to the root constrictions. Abiotic rusty root can lead to broad, indistinct constrictions, but rusty colouration usually extends beyond the constrictions. It may become difficult to distinguish between the two when both issues are present in the same field. Once the damage occurs, there is no diagnostic test that can distinguish between the two issues.

Root lesion nematode populations can be very high in the sandy soils typical of Ontario's ginseng growing regions. These nematodes overwinter at various depths in the soil, including deep in the soil where fumigants do not reach. As a result, fumigating ginseng gardens generally reduces, but does not eliminate, root lesion nematode in ginseng soils.

Between fumigation and bed formation, nematode populations can survive and multiply on uncontrolled weeds (Figure 71).

Figure 71. Excessive weed growth in a fumigated ginseng field, providing a food supply for nematodes, grubs or other soil pests of ginseng.

Surviving nematodes from untreated soil can also be mixed with fumigated soil during bed formation (See Figure 24 and Figure 68). Once beds are formed, root lesion nematodes can further multiply on the roots of some varieties of rye or grain cover crops/nurse crops. It is hypothesized that root lesion nematodes then move to the roots of ginseng seedlings when nurse crops or volunteer grains are killed in the spring.

Root Knot Nematode

The northern root knot nematode has also been found in association with ginseng roots. The root knot nematode is much less motile than the root lesion nematode. This nematode spends most of its life cycle within plant tissues where it releases substances to induce the root cells to form enlarged, specialized feeding structures for the nematode. These appear as galls on the feeder roots (Figure 72).

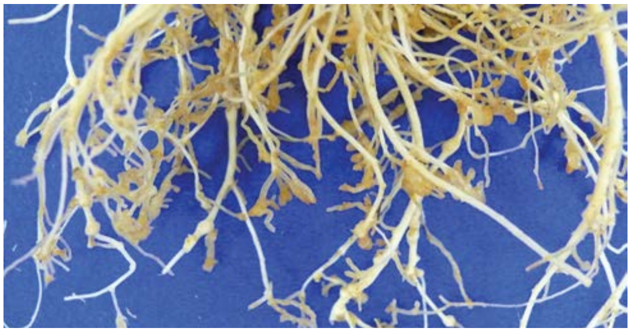


Figure 72. Small galls on the fibrous roots of ginseng caused by root knot nematode.

Damage is often minor on fibre roots, which break off after drying. Where root knot populations are very high, galls can become enlarged and numerous and render the root unmarketable (Figure 73).

Northern root knot nematode populations are patchy in Ontario ginseng soils and rarely increase to severely damaging levels. In contrast to root lesion nematodes, root knot nematodes are generally not as well controlled by fumigants and are better able to use ginseng as a host plant. That is why populations of root knot nematodes tend to increase over the life of a ginseng garden.

Figure 73. Severe root knot nematode damage to a ginseng root showing numerous galls on fibrous roots.

Cultural and Chemical Control

Consider these control options to reduce nematode problems in ginseng.

1. Take soil samples in the fall before the seeding year to determine if nematodes are a problem in the field
2. If nematodes are a problem, consider fumigants with more efficacy against nematodes
3. Between fumigation and seeding, control weeds in the field to ensure there is no food source for any nematodes that survived fumigation to allow them to multiply
4. Ensure thorough fumigation and avoid turning up unfumigated soil during bed formation
5. Control weeds between ginseng seeding and germination
6. Take soil samples again in the fall after seeding to determine the success of fumigation and anticipate the need for other nematicide or management options
7. If soil testing shows root lesion nematodes have survived fumigation, observations suggest that delaying killing off the nurse crop as long as possible in the spring may provide time for the ginseng roots to develop prior to root lesion nematodes moving over from the nurse crop

Soil Sampling for Nematodes

When to Sample

Soil and root samples can be taken at any time of the year when 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.

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

Sample Handling

Nematodes are living organisms that are sensitive to heat and freezing. The laboratory requires living nematodes for extraction and identification. Keep samples at 5˚C–10˚C (in a cooler with an ice pack) and deliver to the laboratory as soon as possible after sampling.

Insects and Invertebrates

Insects are generally less of a problem for ginseng production than diseases. However, slugs, cutworms, grubs, leaf folders and aphids can be damaging in some years and may require cultural or chemical control. Plant bugs and certain other invertebrates are also observed sporadically in ginseng, but do not usually cause economic damage. The following is an abbreviated description of the major insects affecting ginseng. For more detailed information on identification, biology, scouting and control strategies, visit the *Ginseng* module of Ontario CropIPM.

Slugs

(Deroceras, Arion, Helix, Limax spp.)

Slugs are common invertebrates closely related to snails. They are grey, brown or black; have a soft-bodied, legless and slimy appearance; and use a path of mucus to glide along surfaces. The mucus dries into glistening slime trails that are easily identified and are often visible on plant surfaces in the morning. They feed at night, leaving ragged shot-holes in the leaves (Figure 74) and occasionally chewing the side of seedling stems, which can cause them to bend over. They can also chew holes in ginseng berries and occasionally into roots that are close to the soil surface.

Figure 74. Round, ragged holes in ginseng leaves caused by slug feeding.

Slugs are active in ginseng gardens throughout the season. Early-season damage is primarily due to immature slugs and is easily identified by the shot-hole damage to the leaves. Once some damage occurs, it can be more difficult to identify new damage. Look for slime trails on the leaves in the early morning as an indication of recent feeding. Alternatively, monitor for slugs by baiting them with oranges or grapefruits cut in half and placed cut-side down on the straw or using a shallow tin plate filled with beer and buried to the rim. Inspect these for the presence of slugs during dew or prolonged rain periods. When new activity or slugs are found in a garden, apply registered slug baits. This may be required throughout the growing season.

Cutworms

Cutworms are the immature stages (larvae) of night-flying moths in the family *Noctuidae*. They feed at night, often chewing through the sides of stems, especially seedlings, causing the top to tip over (Figure 75). Cutworms are greasy-looking caterpillars that coil up when disturbed (Figure 76). They are often difficult to find because they hide under the straw during the day and are usually monitored by looking for the damage. Control of cutworms with pest control products is highly dependent on properly timing application to ensure the caterpillars are exposed and not protected by the straw. Read pesticide label instructions carefully for timing instructions.

Figure 75. Top of a ginseng stem lying upside down on the straw, severed by a cutworm.

Figure 76. A cutworm larva coiled into the typical C shape.

White Grubs

White grubs are the immature stage of scarab beetles. In Ontario, several species of grubs attack horticultural crops, including the June beetle, European chafer and Japanese beetle. European chafer is thought to be the dominant grub in ginseng gardens, but other species may also be present. Grubs are only observed sporadically in ginseng, but when they occur, the damage can be quite extensive. It is unclear why grubs are a problem in some fields and not others, even when no controls are applied. This unpredictability is probably related to the presence of nearby hosts, weed populations in the field at the time of egg laying and the timing of fumigation in relation to egg laying.

In affected gardens, adult beetles lay eggs in fields being prepared for ginseng production in June or early July (Figure 77). These grubs feed on the roots of weeds over the summer and then on volunteer grains grown to anchor the straw after seeding. The following spring, when the volunteer grains are killed off by herbicides, grubs move over to the germinating ginseng seedlings.

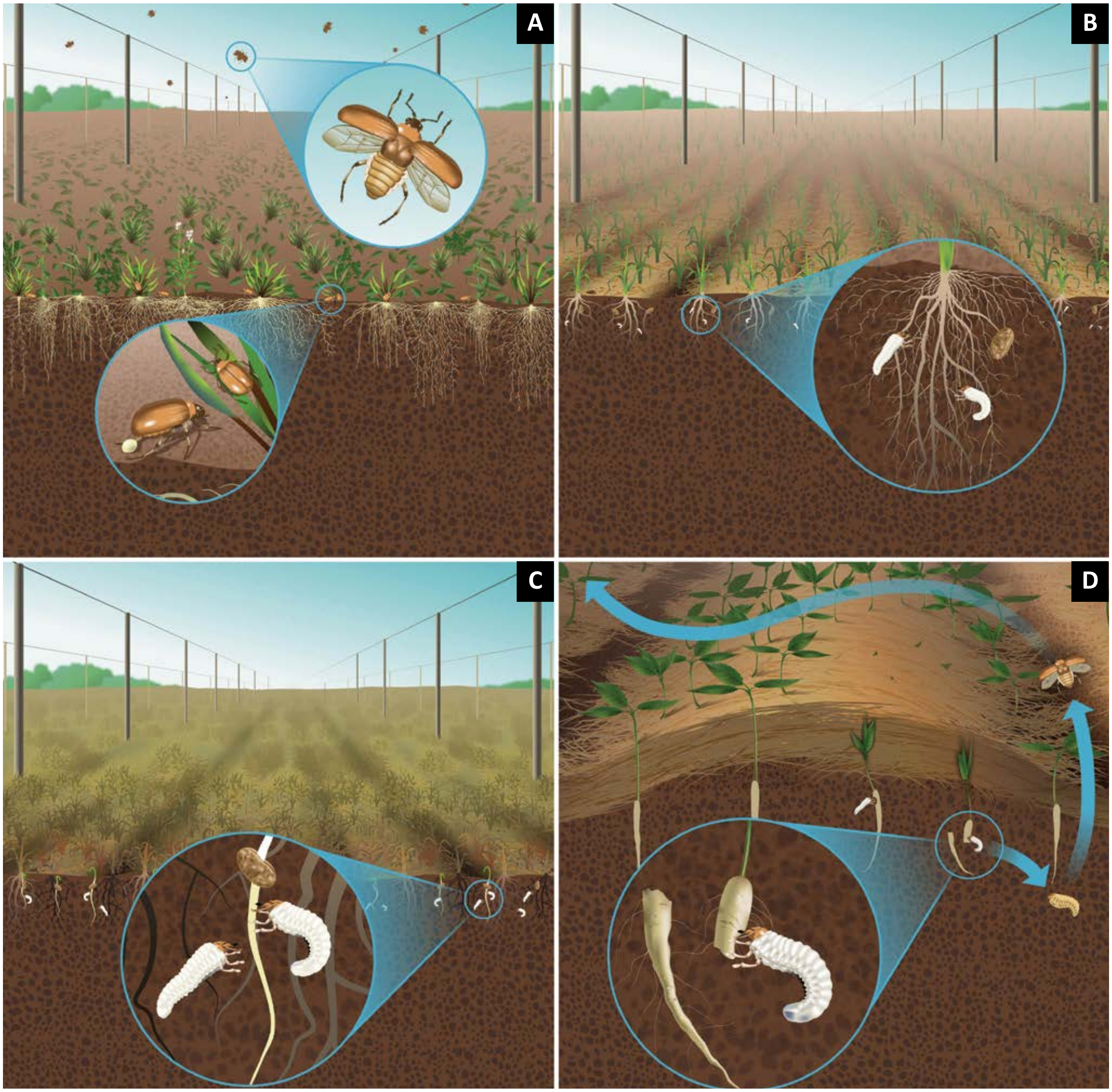


Figure 77. Timeline of European chafer grubs in ginseng. A) Adult beetles fly in late spring or early summer and look for grassy or weedy areas to lay eggs, which can include new ginseng fields that are not managed for weeds between fumigation and seeding. B) Grubs hatch a few weeks later and then feed on roots of weeds initially and eventually rye or other grain crops used to anchor the straw after seeding in August. C) Once the rye is killed off by herbicides in the spring, the grubs move to feed on the germinating ginseng seedlings. D) Grubs move from plant to plant, chewing the roots and pulling the tops into the straw as they chew. This results in a patch of missing plants. The grubs progress to pupae and then adults over the next month or two and exit the garden without laying eggs.

White grubs have six prominent, spiny legs with a C-shaped white body, a tan or brown head and a darkened posterior when they are actively feeding (Figure 78). As they feed, the tops wilt and are pulled down into the straw from below (Figure 79). Eventually, there is a missing patch up to about 30 cm in diameter that becomes more visible in the second year. Grub damage to ginseng occurs exclusively in seedling gardens. Although damage is more noticeable in 2-year-old gardens, grubs are not present at this time.

Figure 78. European chafer grub.

Figure 79. Ginseng tops being pulled into the straw by the grubs

At the writing of this publication, there are no insecticides for managing grubs in ginseng. Grubs may be more of an issue in fields near perennial grasses such as lawns, parks, golf courses and hay. Fumigating in July rather than in the spring could expose the grub eggs or young larvae to the fumigant. Between fumigation and seeding, keep fields weed-free so young larvae have nothing to feed on. There may be biocontrol options that can provide some control, but they may be cost-prohibitive.

Leaf Folders and Leafrollers

Leaf folders and leafrollers are different species of caterpillars that use plant leaves as shelters and food sources. If populations are high, leaf damage can affect yield and increase disease. Rolled leaves are common in ginseng (Figure 80) and were historically thought to be caused by leafrollers, species in the *Tortricidae* family (for example, oblique-banded leafroller). However, recent research has shown that the most common cause of rolled leaves in ginseng is a leaf folder species, *Herpetogramma thestealis*, sometimes called the zigzag *Herpetogramma* (Figure 81).

Leaf folders are in a different family of moths, the Crambidae or snout moths, than leafrollers. The main difference between leafrollers and this species of leaf folder is their feeding habits. Unlike leafrollers, which hide in leaf rolls during the day and come out at night to feed, leaf folders (Figure 82) feed exclusively within leaves that they roll or fold together, occasionally pulling new leaves into their shelter or leaving one shelter to form another. The tendency to remain within their shelter makes leaf folders more difficult to target with insecticides. Leafrollers may still be found in ginseng but are much less common than leaf folders.

Figure 80. Rolled ginseng leaves caused by leaf folders.

Leaf folders are usually patchy in a field and confined to areas near woodlots or fence rows. However, in some years, they can reach damaging levels over much larger areas. The leaf folder life cycle in ginseng is still being studied, but recent research suggests they overwinter as early instar caterpillars in the soil or straw (Figure 83). Young caterpillars have a staggered emergence in the spring. This occurs over a few-week period, roughly coinciding with the emergence of the ginseng tops in older gardens. In areas of thin straw

Figure 81. An adult herpetogramma leaf folder.

Figure 82. A herpetogramma leaf folder caterpillar inside a leaf fold.

Figure 83. Life cycle of herpetogramma leaf folders in ginseng.

cover, both the ginseng tops and the young caterpillars emerge earlier. The caterpillars feed for about 6–8 weeks, pupate within their leaf folds and adults emerge a few weeks later. Adults can be found through July and August. Eggs are laid individually or in small groups on the underside of leaves and are about 0.75 mm across and almost clear, making them difficult to identify in the field (Figure 84). Eggs hatch beginning in late July and a new generation develops through August and September. Initial feeding by the newly emerged caterpillars appears as window-like damage to the leaves, since the caterpillars are unable to chew through the leaf (Figure 85). This new generation rarely develops beyond the second instar, suggesting that they drop to the ground and overwinter at this stage.

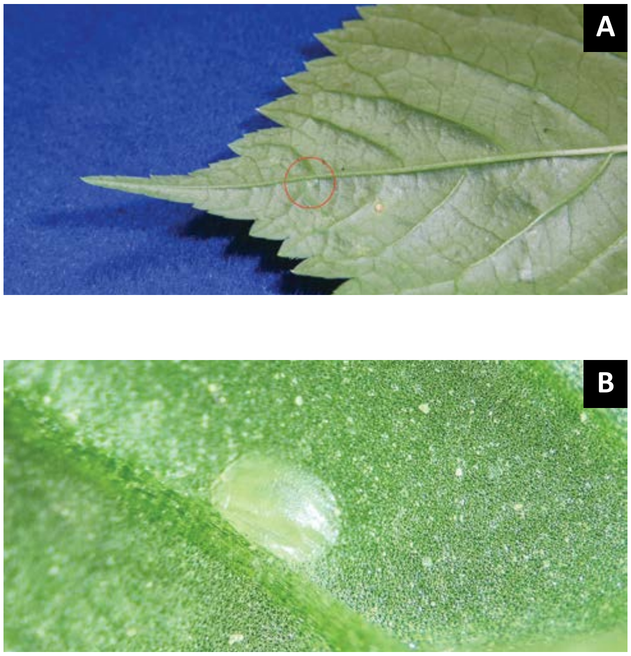


Figure 84. A) A single herpetogramma leaf folder egg on the underside of a ginseng leaflet. B) Close-up view of an egg next to a leaf vein.

Once the damage is obvious, it is often too late to control leaf folders with insecticides, since their habit of staying within the leaf roll prevents them from being exposed to insecticides. Target the caterpillars when they first emerge, around the time the leaves emerge from the straw. Initially, the caterpillars hide between the rolled-up leaves on the emerging ginseng shoots. Once leaves begin to unfold, the caterpillars begin to roll or fold up leaflets, usually beginning at the tips. Due to the staggered emergence of the caterpillars, multiple insecticide applications may be required if scouting indicates caterpillars are present and in high enough populations to warrant control. Scouting should continue all summer to catch the window-like feeding damage of newly emerged caterpillars at the start of the new generation in mid-summer. This emergence occurs over an extended period from mid-July to September, so it is more difficult to effectively time fungicides over the summer compared to the spring. Season-long scouting provides additional periods for controlling this pest in the field if control of the first generation is insufficient.

Figure 85. Window-like damage to leaves in mid-summer due to the feeding of first instar caterpillars.

The understanding of this pest continues to evolve based on research efforts, visit the *Ginseng* module of Ontario CropIPM for up-to-date information on this pest.

Aphids

Aphids, including the potato aphid (*Macrosiphum euphorbiae*) and potentially other species, are observed intermittently in ginseng but can reach damaging levels in some years. Aphids are small, soft-bodied, pear-shaped insects, often pale yellow or green in colour, with straw-like mouthparts that pierce plant tissue and suck the sap from a wide variety of crops. They can be identified by the presence of two "tail-pipes," called cornicles, near the end of their abdomen. Aphids reproduce very rapidly under high temperatures and are usually found in groups or colonies on the underside of leaves, along plant stems or on petioles or peduncles (flower stems) (Figure 86). Feeding damage can lead to leaf and flower distortion and reduce plant vigour, which in turn reduces root growth.

Figure 86. Aphids on the side of a peduncle (flower stem).

Insecticides are only warranted when populations build to damaging levels. There is no threshold for aphids on ginseng, but the use of pest control products might be considered when populations are in the range of 2–5 aphids per plant and increasing over time. Aphids are often naturally controlled by predators and parasites, so regularly scouting is necessary to track population trends.

Other Occasional Insect/ Invertebrate Pests

Several minor insect and invertebrate pests can cause localized damage in ginseng. Learn to recognize these pests and their damage to distinguish them from other issues, but insecticide applications, if registered, are rarely warranted. Four-lined plant bug and millipedes are the most common occasional pests, but several others have been found causing sporadic damage to ginseng fields. For more information on occasional pests of ginseng, visit the *Ginseng* module on Ontario CropIPM.

Four-Lined Plant Bug

Four-lined plant bugs are occasionally found in ginseng gardens. The red and black nymphs emerge in mid-May and suck juices out of the leaves, leaving distinctive circular brown or papery spots that can resemble a foliar disease (Figure 87). Adults are yellow/ green with four black stripes and emerge in mid-June, feeding for a few weeks before laying eggs in the sides of stems and then dying off. There is only one generation per year.

Figure 87. Spotting caused by four-lined plant bug feeding. *Source*: Dr. Amy Shi, Ontario Ginseng Growers Association.

Millipedes

Millipedes are generally considered beneficial in agriculture because they feed on decaying plant material and help build up organic matter in soil. However, certain conditions can lead to a rapid increase in millipede populations. At high densities, millipedes sometimes feed on plant roots, including ginseng. Millipedes have elongated, hard, cylindrical bodies 1–10 cm in length at maturity. They range in colour from white to grey-black and tend to coil up when disturbed. They are distinguished by their many legs, with each body segment bearing two pairs of legs.

Millipedes have been observed sporadically in ginseng attacking emerging seedlings. They may also consume ginseng seed pulp when the seed cracks just prior to germination. Damage typically occurs in prolonged wet conditions or when the straw layer is too thick and the soil cannot dry out. Reducing these wet conditions can reduce issues with this pest.

Vertebrate Pests

Rodents

Voles are rodents that are similar to mice but tend to be longer, have shorter tails and smaller ears that are partially hidden in their fur. The meadow vole or field mouse (*Microtus pennsylvanicus*), is the predominant rodent pest in ginseng gardens. The pine vole (*Pitymys pinetorum*) is rare in ginseng and tends to occur only when gardens are very close to wooded areas.

Meadow voles gnaw on stems and exposed roots of ginseng. Feeding damage appears as elongated areas of chewing along the length of stems (Figure 88). This damage can sever the stem, but the cut is more jagged than cutworm damage. Vole feeding on roots generally looks like gnawing, with tooth marks often evident (Figure 89). Vole feeding is typically restricted to exposed portions of roots.

Figure 88. Severed stems with elongated areas of chewing indicative of vole damage.

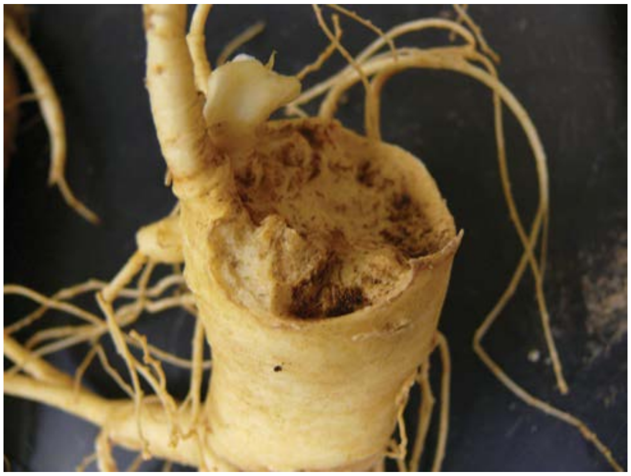


Figure 89. Vole feeding damage to a mature ginseng root.

The most characteristic sign of meadow voles is their extensive system of runways — surface tunnels, approximately 5 cm wide, built by extensive travel and clipping of vegetation close to the ground as they travel. Runways are often built along the length of ginseng beds under the straw. If rodent damage is suspected, remove the straw to check for runways. Pine voles do not use surface runways but construct a system of underground tunnels.

Voles can invade ginseng gardens in the fall as vegetation in surrounding areas is removed. The straw over ginseng beds provides shelter from predators and a source of food. Vole damage is most common in early spring and has been observed in gardens of all ages.

Voles do not like moving through open spaces where they are vulnerable to predators. Maintain a wide, clear area free of vegetation around the perimeter of a garden to prevent invasions. This approach is particularly important in the fall, during and after planting of new gardens. Encouraging birds of prey to perch around gardens by erecting tall perches at intervals throughout the field can help control voles when shade cloth is pulled back. Manual traps, without rodenticide, can be used in ginseng gardens throughout the spring. Rodenticides are not registered for use in ginseng gardens, but it may be possible to control rodent populations in the preplant year if there is no crop grown for food and feed.

Other Vertebrates

Wild turkeys can be a pest in ginseng gardens. They can scratch out the straw, dig up ginseng seed and eat seedlings. Deer are not a significant issue in ginseng after planting, but their hooves can break through plastic tarping used after fumigation or other soil disinfestation techniques.

Abiotic Disorders of Ginseng

Abiotic Rusty Root

Abiotic Rusty Root (ARR) is one of the most damaging issues affecting ginseng, causing superficial, rusty discolouration on the skin of the taproot and affecting the root's marketability. An estimated 40% of all ginseng roots have some level of abiotic rusty root damage, although many of those roots are still marketable. In some fields, abiotic rusty root can reduce marketability by up to 50% or more. This disorder has often been confused with other superficial, rusty symptoms, such as rhexocercosporidium rusted root and root lesion nematode damage. In the past, abiotic rusty root has often been blamed on IMP, but this was due to confusion in the scientific literature. IMP is not involved in abiotic rusty root.

The symptoms of abiotic rusty root include many small, rust-coloured, vertical cracks along the taproot (Figure 90). In some cases, the entire root can be covered. The rust colour is due to the release of compounds from within the root (phenolics) that turn orange/rusty when exposed to oxygen. This is the same mechanism that leads to the rusty colour caused by some ginseng diseases with similar symptoms and why abiotic rusty root and several diseases are often misidentified.

Abiotic rusty root damage is usually only skin deep and can sometimes be washed off. Minor to moderate damage does not affect root function or its nutritional value. In more extreme cases, damage can lead to general stunting of the plant as uptake of water and nutrients is impeded. Extensive damage can also make the root more prone to invasion by other pathogens.

Figure 90. Abiotic rusty root symptoms on a ginseng root, which include rusty vertical cracks over patches of the root. *Source*: Dr. Amy Shi, Ontario Ginseng Growers Association.

Research suggests that abiotic rusty root is caused by the rupture of the skin during rapid root expansion following a period of slower root growth, possibly due to uneven water availability during periods of rapid root growth. For example, this could occur during a heavy rainfall following a period of relatively dry conditions. Uneven fertilization may also be a factor.

There are no controls for abiotic rusty root in ginseng once it occurs. Ensuring there is even soil moisture during the growing season could reduce the risk, especially when roots are expanding the fastest between early June and late July.

Drip-Line Chlorosis

In low- and high-cloth shade systems, some rainwater runs along the cloth and falls through at low points. Where the water falls is referred to as a "drip line." This is not to be confused with drip irrigation lines.

The additional rainwater falling on plants under these drip lines can have major nutritional effects, causing nitrogen and other nutrients to leach from the soil in these areas and potentially changing soil pH. Ginseng under the drip lines begins to show chlorosis (yellowing) by July in most years. In gardens established on level ground, excess rainwater tends to fall randomly between the cables, resulting in an uneven and random chlorosis throughout the garden. In gardens established on slopes, water tends to fall just above a cable, resulting in more distinctive lines through the garden (Figure 91).

Figure 91. Bands of chlorosis (yellowing) through a garden as a result of water falling from the shade cloth.

Due to the increased soil moisture, prolonged leaf wetness and weakened plant defences in these bands, root and foliar diseases tend to begin or be more severe under the drip lines. Both phytophthora root rot and blight and alternaria leaf and stem blight can be severe in these areas (see Figure 42). The excess water falling on the leaves under the drip line can also wash off protectant fungicides, further increasing disease pressures.

There is no way to reduce the amount of water falling from drip lines. Managing the problem requires monitoring plants in these areas to identify the problem when it begins. Once chlorosis begins to develop, additional fertilizer application can reduce damage.

Since it is impractical to target fertilizers to just the affected areas, be careful not to overfertilize the field. Correcting a deficiency in the narrow band affected by drip line chlorosis could result in major overfertilization of the rest of the field. Fungicides may need to be reapplied after heavy rainfall if protectant fungicides are washed off the leaves under the drip lines. The use of slow-release fertilizers may reduce drip line chlorosis by providing a more even supply of nutrients over the season.

Heat Stress

Under extreme heat and drought, ginseng leaves develop dry, tan areas (Figure 92). This disorder is also called “papery leaf spot,” which aptly describes the condition. The symptoms are probably due to overheating of plant cells in the most exposed portions of the uppermost leaves in the canopy, causing them to die and dry out. When the leaves have access to moisture, the water in the leaf cells can help buffer the heat and transpiration can keep them cooler through evaporative cooling. Under moisture stress, the leaves close their stomata and transpiration nearly stops. These stressed leaves are more likely to have heat damage.

Figure 92. Leaves of seedlings showing symptoms of heat stress. Note the papery, dry areas of the leaves.

Anything that impedes the ability of the roots to take up moisture, such as root disease, can have the same effect as moisture stress and lead to a higher incidence of heat stress. Once symptoms occur, there is nothing that can be done to revive the damaged tissue. Papery leaf spot can be prevented to some degree by ensuring adequate soil moisture during hot temperatures and allowing hot, humid air to escape from gardens through a series of vents where the shade material is slightly raised at intervals.

Windburn

Windburn is a problem similar to heat stress that occurs on the edges of gardens exposed to the prevailing winds and is more prevalent when soil moisture is low. Under hot and/or dry conditions, ginseng leaves exposed to the prevailing winds begin to dry out rapidly. If the moisture cannot be replaced from the roots fast enough, the edges of the leaves begin to dry out and senesce (Figure 93). Ginseng is adapted to the calm and humid forest floor environment and can easily be damaged under these conditions. Affected areas of the garden develop a scorched appearance.

Figure 93. Windburn symptoms on ginseng in an area of a garden exposed to the prevailing winds.

Windburn can be delayed or prevented by erecting wind barriers on the sides of gardens exposed to the prevailing winds. These barriers could be a strip of shade cloth or snow fencing attached to the outer row of posts or rows of tall annual plants such as rye planted outside of the garden.

Boron Toxicity

Ginseng requires boron for growth and development, but too much can damage the plant. Excess boron can result in foliar symptoms and smaller roots. The leaf edges appear yellow or white and dry out. If symptoms of boron toxicity appear in a garden, check fertility records to determine if there was an application or measurement error. Boron toxicity can be confirmed by tissue analysis. Suspect toxicity when leaves contain more than 55 ppm boron.

Herbicide Injury

Occasionally, herbicides applied to neighbouring fields or in a perimeter area, may drift into a ginseng garden. If drift of a product containing glyphosate occurs in the fall, even after the ginseng has senesced, there may be residue on the straw the following spring under certain environmental conditions. Glyphosate applied in early spring may also cause damage if the application occurs too close to ginseng emergence, if wet straw absorbs the herbicide after application or if there is rain shortly after application that washes the product onto the emerging tops. Symptoms may be visible in emerging plants in the spring as distorted or strap-like leaves (Figure 94). If drift has occurred, there is a discernible pattern to the area of damage. Damage can be confused with slug and cold temperature damage. Analysis of the leaf tissue is the only way to know if herbicides have caused the symptoms.

Figure 94. Distorted and strap-like leaves as a result of glyphosate applied too close to ginseng emergence in the spring.

Foliar Fertilizers Mixed with Fungicides

Certain fungicides, especially systemic ones, contain small amounts of micronutrients or can help pull micronutrients into the leaf. If these fungicides are mixed with micronutrients, micronutrient toxicity can result. Under warm or hot environmental conditions, leaf injury can be severe enough to cause serious damage to ginseng. Extensive leaf injury results in smaller-than-average roots. Consult product suppliers to determine if a fungicide is compatible with foliar fertilizers.

Foliar Fertilizers Containing Cytokinins

Some foliar fertilizers contain plant-based compounds called cytokinins. These are natural plant compounds that interfere with the growth hormones that promote elongation. Historical evidence suggests that if they are applied to ginseng while the leaf canopy is still unfolding, they can have a distorting effect on leaves and stems. Cytokinin damage may also leave the lower leaf surface thickened and shiny.

Low-Temperature and Freeze Damage

Low-temperature damage to ginseng often occurs in the early spring after emergence. Low, but not freezing, temperatures during the unfolding of the canopy may result in leaf puckering and general stunting of the canopy (Figure 95).

Figure 95. Leaf puckering caused by chilling. This can be confused with other abiotic disorders.

Low-temperature damage can also occur during the winter months when the plant is dormant. Research indicates that temperatures under snow cover are moderated and rarely drop below -5˚C at the crown of the root. The critical temperature for root survival during dormancy appears to be -11˚C for seedlings and -16˚C for older roots. Root damage can occur when soil temperatures drop below -6˚C. The duration of the cold temperatures is also a factor. Taking these into account, growers could expect damage to roots when soil temperatures drop below -6˚C in winters with little snow cover, especially where the straw mulch is thin. To reduce the chances of low-temperature damage over winter, top up the straw each year so there is a consistent straw cover over the beds.

Freeze damage (when temperatures drop and remain below freezing) to ginseng has become more of a problem in ginseng production in recent years. This damage likely happens when the black shade cloth radiates heat upwards at night, resulting in cooler temperatures in and around the ginseng garden than the ambient air. The exact temperature that causes freeze damage to ginseng is not known, but is likely a few degrees below 0°C around the plant tissues. The extent of damage depends on the length of time the temperature remains below this critical temperature. Gardens that are repeatedly exposed to freezing temperatures suffer greater damage. Damage usually occurs first along the perimeter of gardens, where heat can more easily radiate out and in low areas where cold air pools on calm nights.

Symptoms of freeze damage vary with the age of the garden.

Seedlings

Seedling gardens may be permanently damaged by freezing temperatures. Typical freeze damage consists of glassy, drooping leaves that turn black and decompose and weakened, shrivelled stems (Figure 96). Plants do not recover from this damage.

Figure 96. Collapsed and glassy seedlings with shrivelled stems caused by freeze damage.

Older gardens

The most common symptom of freeze injury is sharply bent stems (Figure 97). Some plants may grow upwards after the damage occurs and survive the rest of the season, although yield is reduced. Other symptoms include swollen and split stems (Figure 98), shrivelled stems below the flower head or just below the junction of the leaves and browning of the developing flower buds.

Figure 97. Stem kinking, the most common symptom of freeze damage.

Figure 98. Swollen and split stem. Plants do not usually recover from this damage.

Leaves on older plants may become glassy and droop. This damage becomes whitish and papery over time. This is a common symptom on 2-year-old plants. Recovery from glassy leaves and split stems is unlikely.

All ages of gardens are affected by freeze injury, but the chances of permanent injury decrease as the garden ages.

Plants with freeze damage are more prone to foliar diseases all season. *Botrytis* is a major risk in the days following injury and alternaria leaf blight pressures will then be high all season.

Weeds

The first defence against weeds is in the preplant year(s). Fields are often empty during preparation and it is important to prevent weed growth during these periods. Proper fumigation can reduce weed seed populations in the soil.

Weeds can be introduced into ginseng gardens with the mulch material. Collect or purchase straw from fields with low weed populations. Straws can also hold a considerable amount of grain seeds, which is not always desirable. If they are not desired, consider using straw from grains or grasses that do not survive the winter . Weed seeds can also be introduced to the field in raw manure. Consider using composted manure to reduce weed seed transmission.

Weeds can also enter gardens on the wind. A rye strip set against the prevailing winds around the garden border stops some weed seeds from blowing into the garden. The rye strip also helps prevent sandblasting. In some years and locations, there can be an influx of cedar or maple seeds. When these trees germinate in a ginseng garden, it is very difficult to remove them by hand-weeding without dislodging the ginseng roots. If the garden is in an area where tree seeds may blow into it, erect a barrier of polypropylene cloth set against the prevailing winds to help reduce the number of seeds entering the garden.

Hand-pulling is the most effective method of weed control in existing gardens. Hoeing is not an option because of the high plant density of the ginseng plants and thick straw cover.

The most significant weeds in ginseng in Ontario are:

- scentless chamomile (*Tripleurospermum inodorum*)
- wild buckwheat (*Polygonum convolvulus*)
- pigweed (*Amaranthus retroflexus*)
- cleavers (*Galium aparine*)
- common chickweed (*Stellaria media*)

Other weeds include:

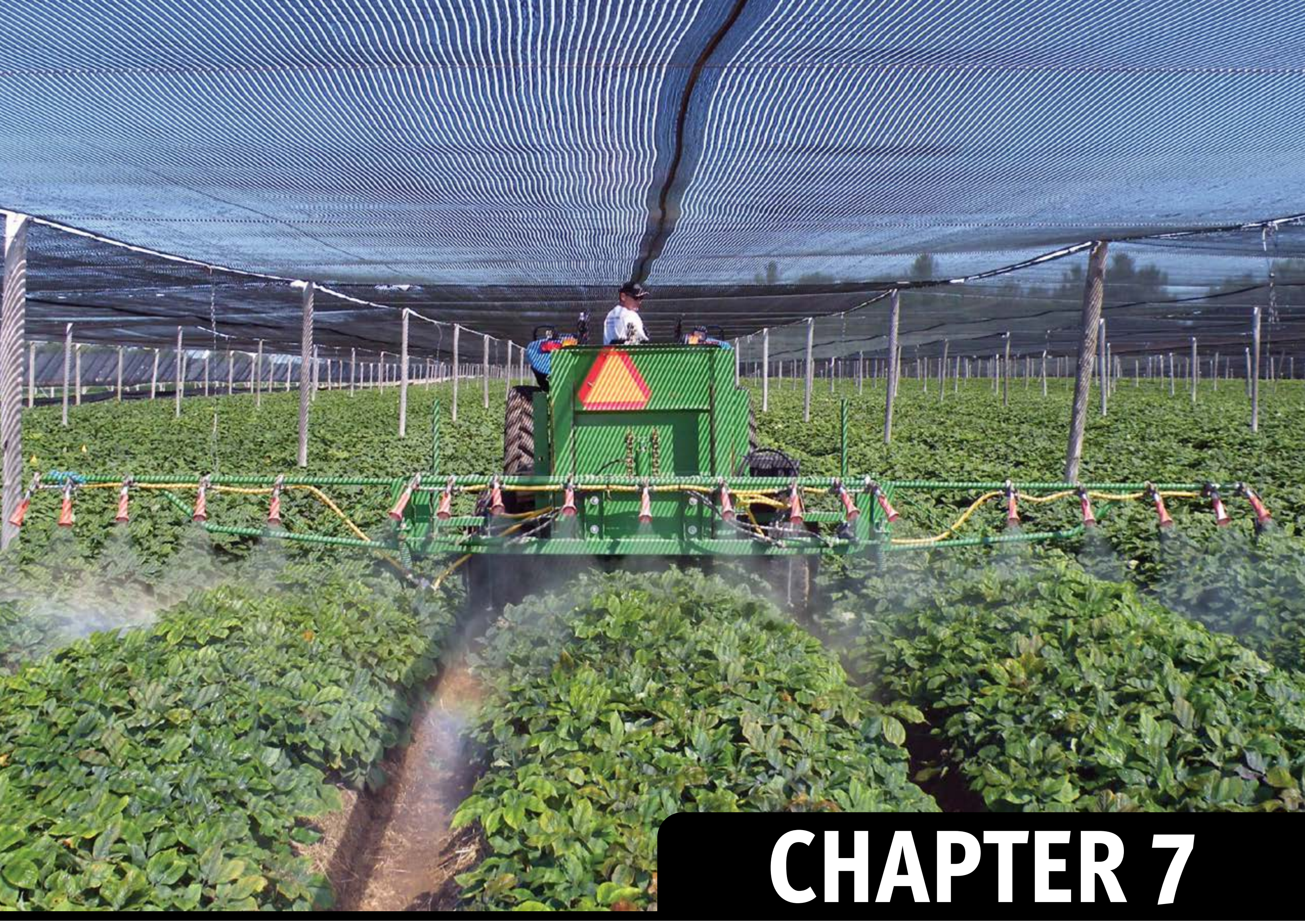
- field bindweed (*Convolvulus arvensis*)
- lamb’s-quarters (*Chenopodium album*)
- dandelion (*Taraxacum officinale*)
- shepherd’s-purse (*Capsella bursa-pastoris*)
- grasses and volunteer cereals from the straw mulch

All the weeds listed above are summer or winter annuals, except field bindweed and dandelion that are perennials. The perennial weeds field horsetail (*Equisetum arvense*) and crown vetch (*Coronilla varia*) can be major problems but are more localized than the listed species.

Scentless chamomile is particularly difficult to control and causes major damage when hand-pulled due to its extensive fibrous root system. Ginseng plants are often pulled up at the same time as the weeds. Control of this species requires management in the crops ahead of ginseng and herbicide application in ginseng gardens very early in the spring, soon after the snow melts.

Herbicides must be timed properly in ginseng to avoid damage to the ginseng shoots. Fall applications of glyphosate have been shown to cause damage to emerging shoots the following spring, probably because it is absorbed into the straw and remains active. That is why fall applications of glyphosate are not permitted on the product label. Spring applications to wet straw may also cause the herbicide to soak into the straw, remaining active and damaging emerging shoots. Rainfall soon after herbicide applications could cause the product to leach into the soil and damage the ginseng shoots.

For more information on weed identification and management, visit *Weeds and Herbicides* on Ontario CropIPM.



CHAPTER 7

Optimizing Pest Control

An effective ginseng protection program follows the principles of integrated pest management (IPM). These principles include accurately diagnosing, monitoring and managing the problem when required (generally if the benefit in increased yield is higher than the cost of the control measure) and evaluating the results.

Scout ginseng gardens regularly to diagnose pest issues before they become a major problem and track their progress over time. Focus on cultural practices that prevent pest issues in the first place, rather than waiting until pest problems occur. These cultural practices include choosing suitable soils for ginseng production, improving drainage, ensuring consistent straw cover, ensuring adequate air flow through the canopy and following good sanitation practices. If a pesticide is needed, apply products preventatively before damage is obvious to prevent economic losses and reduce the overall number of pesticide applications required.

When spraying, learn the basics of application technology, including not only the equipment, but the effects of changing spraying parameters such as pressure or carrier volume, the impact of weather conditions such as wind and relative humidity and the requirements of the product being applied, such as correct timing and safety requirements. Learn how to properly maintain, calibrate and orient the sprayer according to the nature of the target. Monitoring spray results requires the operator to respond to changes in the environment and target during application and to consider these factors when evaluating the outcome.

Farm employees and third-party operators often conduct pesticide applications on the farm. Growers are responsible for ensuring products are applied properly, at the right times and that all farm employees and visitors are following label precautions, such as restricted entry intervals and buffer zones.

Pest Control

Ginseng roots increase in size each year from July through September. Over the lifetime of a crop, an estimated average of 25%–50% of roots are lost to foliar and root diseases. Foliar losses reduce root growth indirectly through a reduction in photosynthetic area and are caused by fungal diseases of any part of the plant, insect feeding or leaf senescence due to abiotic disorders.

Many foliar diseases of ginseng begin on the stem. This is why ginseng spray programs mainly involve applications of protectant fungicides that must cover all plant surfaces. Control of root diseases requires higher water volumes to penetrate the straw layer and reach the root surfaces. This usually requires rainfall or irrigation after application to move the product lower in the soil profile. Some products permanently bind to the straw if they dry on the surface — even briefly — between application and irrigation. Apply pest control products to wet straw and immediately wash them in with overhead irrigation.

Mature ginseng gardens (3- or 4-year-old) are notoriously difficult to spray. The ginseng canopy is highly susceptible to pathogens because of the high humidity and low airflow under the shade structure. If fungi are left unchecked, leaf disease will follow. Defoliation can occur within 7 days of infection in an untreated garden. Once foliar disease becomes established in a garden, growers are forced into a 5–14-day treatment schedule, depending on the product.

Control of diseases on the stem and in the leaf canopy is highly dependent on the selection of appropriate fungicides and how effectively the product is deposited on the target (the entire plant or a specific part of the plant). To control fungi and insects that attack the stems, seed heads and leaves, pest control products must thoroughly cover all these parts, including the underside of the leaves. Applying products with different mobilities in the plant, such as contact, xylem-mobile or translaminar, can help products remain active and efficacious under different weather conditions, pest and plant growth stages. When excessive rain is forecasted or the plant is actively growing, xylem-mobile products may better withstand the rain and move upwards/outwards as the leaves expand. Contact products may be better for protecting plants against initial pest attack, but must be applied preventatively.

Pesticides

The pesticide label is the law. Always follow the instructions on the most current label when applying pesticides. To check the most current label information, visit the Pesticides Regulatory Directorate (PRD) label database and type the name of the chemical in the query box. Links to product labels are also available in the Product Details section of the Ontario Crop Protection Hub. If there is a discrepancy between PMRA's online version of the label and the label on the bottle, follow the online version.

Timing

Most fungicides used in a ginseng disease control program are protectants, not curatives. These products form a protective barrier on the plant that prevents or interferes with initiation of the disease. Protection must be in place before the pathogen can penetrate the plant, where it is less likely to be affected by the fungicide. Protectants are effective while they remain on plant surfaces. Repeated rainfall reduces the amount of fungicide present.

Rainfastness is the ability of a product to withstand rainfall and remain active after application. The term can refer to the necessary time interval between application and any rainfall and the amount of rain the product can withstand before re-application is necessary. Rainfastness is sometimes listed on the product label. If not, contact the manufacturer or search for university or extension resources online.

Insecticides are used much less than fungicides in ginseng production. Some insecticides need to contact the insect to provide control, while others coat the leaf surfaces and are consumed by the insects when they feed on the leaves. If insecticides need to be consumed by the insect, apply them just before the insect is expected to feed. For example, some products for leafroller control must be applied in the evening since leafrollers feed at night. Timing of insecticide application is critical to achieve optimal control. Many insects also need to be controlled at specific growth stages or the insecticide is ineffective.

Target

Thorough pesticide coverage is essential for effective control, including the upper-leaf surface, lower-leaf surface and stem. However, "thorough" does not necessarily mean "high carrier volumes." When a pesticide is intended for leaf surfaces, carrier volumes should not cause runoff or the pesticide will re-distribute and result in poor foliar coverage. On the other hand, high water volumes may be required to initiate runoff and situate a fungicide in the soil where soil-borne disease is a concern. The applicator must know the physical target and the nature of the pest and read the label to confirm how the product is intended to work. There is no point in drenching when spraying for alternaria leaf and stem blight or botrytis blight, but drenching may work for phytophthora root rot. If pest control products are applied under suboptimal weather, such as windy conditions, coverage will be uneven and leave unprotected areas of the canopy. This can lead to disease hot spots and make further product applications less effective in the entire garden.

Sanitation

Sanitation is key to maintain garden health and prevent the spread of disease. Ginseng diseases can be spread via machinery, so work in younger gardens first and wash equipment thoroughly before entering a healthy garden. After working in diseased gardens, wash all equipment with a high-pressure washer to remove soil and plant debris. Boots and clothing can also spread diseases. In diseased areas, train workers to wear disposable booties when weeding, deflowering and picking berries and to dispose of them and wear new ones when moving to the next garden. Sanitizers reduce the inoculum of pathogens that can cling to farm machinery, tools and clothing.

A listing of sanitizers is available in the Reference Listing of Accepted Construction Materials, Packaging Materials and Non-Food Chemical Products Database on the Canadian Food Inspection Agency (CFIA).

Spray Quality

Hydraulic nozzles are classified by their geometric spray patterns, flow rates and range of droplet sizes they produce, collectively referred to as "spray quality." Pesticide labels increasingly specify droplet size and flow rate and should be carefully considered when selecting nozzles.

Table 13. The Impact of Droplet Size

Droplet Size	Number of Drops per Area	Retention	Canopy Penetration	Drift Potential
fine	high	high	low	high
medium	moderate	moderate	moderate	moderate
coarse	low	low	high	low

Table 13 compares the relative merits of three droplet sizes but is not definitive. Casotti or ARAG-style nozzles cannot control droplet size independently of rate. However, standard hollow cone nozzles (moulded or disc-core style) can give the desired rate and spray quality. Medium-sized droplets are a good compromise between coverage, runoff and drift for spray quality.

Nozzles

In 1998, OMAFA research demonstrated that the oscillating-style Casotti head-equipped sprayer did not provide suitable coverage for ginseng. Many growers have since adopted the ARAG Microjet with mixing valve. Contrary to popular belief, the ARAG Microjet does not have air-assist or air-induction but is strictly hydraulic and can create limited air turbulence at high pressures.

Generally, the pressures required to create turbulence are excessive and result in a spray quality that is very prone to drift. Furthermore, high pressures increase fuel consumption, noise and pump wear considerably. There are inherent problems with the ARAG Microjet mixing valve related to valve position and pressure. To overcome the issue, growers have begun adopting a similar ARAG Microjet that does not have the mixing valve and provides the same spray quality and longevity at a cheaper price (Figure 99). Many growers have returned to hollow cone patterns created by standard, moulded hollow cone or disc-core nozzles and report excellent efficacy (see *Nozzle Orientation* in this chapter).

Water Quality

The quality of water sources in a ginseng production area can be highly variable. Some water sources may impact spray quality when used to mix with pest control products due to high or low pH, dissolved solids or particulates. These issues can lead to precipitation of products out of solution in the spray tank, phytotoxicity in the field, clogged sprayers/nozzles and/or incompatible tank mixtures. Ginseng growers often travel long distances to their fields due to ginseng replant disease and may use a range of water sources. Test water sources for pH and other water quality issues and be prepared to treat water before mixing with pest control products. Conduct tank mix compatibility tests (if tank mixing is permitted on the product label) before mixing any products with a new water source. For more information on water quality, its impact on spray quality and how to treat water, consult Sprayers101.

Figure 99. Custom-made ginseng sprayer. A standard design in Ontario.

Drift

Pesticide spray drift is the aerial movement and unintentional deposit of pesticide outside the target area.

Spray drift has many negative impacts:

- less product being deposited on the target, resulting in reduced efficacy
- financial loss associated with wasted pesticide and time
- risk of damage to human health, susceptible plants such as adjacent crops, non-target organisms such as wild and domestic animals and pollinating insects, the environment and property

While pesticide drift cannot be entirely eliminated, spray operators can greatly reduce the potential for it to occur. For more information on the causes of drift and how to mitigate it, see bedriftaware.ca and Sprayers101.com.

Nozzle Orientation

Position nozzles to ensure a consistent and uniform swath at the target depth and confirm with a visual check for gaps. Many ginseng boom sprayers employ hollow cone disc core nozzles on 30-cm centres. Nozzles on boom ends are directed at post rows and drop arms are positioned behind tractor wheels (and/or between beds) with nozzle tips directed back up into row canopies. This arrangement provides adequate coverage of the upper and lower leaf surfaces and the stem and seed head, where disease most frequently begins. Recalibrate sprayers as the season progresses or when moving to gardens of a different age to confirm good working order and reorient nozzles and boom height to match canopy changes as they grow and fill.

An extensive discussion of nozzle choices, orientation and pressure settings is available at *How to Spray Ginseng* on Sprayers 101.

Carrier Volume

A leaf can only retain a limited volume of spray. Once wetted, the surplus runs off to the lower leaves and onto the soil. Once runoff has begun, the amount of product deposited does not increase beyond the concentration applied, regardless of the volume used. If properly calibrated, the same amount of product should be deposited on all portions of the target without incurring runoff. The difficulty is knowing the correct volume to apply for foliar applications of products. If the target is the lower stem or the roots, runoff may be desirable and water volumes should be increased.

The application target varies for each product, depending on the pest or disease to be controlled. Application volume should reflect the location of the intended target. For foliar and stem applications, increase spray volumes as the crop ages to compensate for increased canopy area/density and the increased difficulty in canopy penetration. A table relating spray target, relative volume and formulated product is available at How to Spray Ginseng on Sprayers 101.

Travel Speed

It may be tempting to rush an application to optimize product timing based on pest growth stage, pest pressure, weather conditions and work rate. However, higher speeds increase the potential for drift and can distort the spray pattern. Slower speeds yield better results by giving the spray more time to penetrate the canopy. Aim for an average ground speed of 5–6 km/h.

Coverage, Canopy Penetration and Evaluation

Ginseng in older gardens form a solid ceiling of leaves that resists spray penetrating to the stem and crown below, making under-leaf coverage very difficult to achieve. Obtaining a balance between canopy penetration and foliar coverage does not always require a compromise. Larger droplets do improve penetration and finer droplets improve coverage, but higher carrier volumes and slower forward speeds have a greater impact on penetration than manipulating droplet size. Many studies (and regional experience) have demonstrated that air-assist technology increases canopy penetration by displacing leaves and greatly reducing the incidence of drift. When using air assist, select a rate that rustles leaves enough to open holes in the canopy, without damaging seed heads. Spray coverage indicators, such as food-grade dyes and water-sensitive paper, are cheap and efficient tools for evaluating spray coverage. For more information on the importance of spray coverage and methods to assess it, see article *Coverage is King* and related articles on Sprayers101.

Adjuvants help enhance the performance or physical properties of pest control product applications. Many products are already formulated with adjuvants to optimize performance. If a product requires the addition of an adjuvant, it is listed on the product label and may be crop-specific. Refer to adjuvant articles on Sprayers101 for information and precautions before adding adjuvants that are not specified on the product label.

Calibration

Calibrate spray settings at the beginning of the spray season and mid-way through the season. Re-calibrate any time changes to the sprayer or tractor are made (such as new tires, replaced nozzles, replaced hoses).

Regular sprayer calibration:

- confirms the sprayer is operating correctly
- confirms each nozzle is delivering the desired output and spray quality
- confirms the correct product rate is applied
- reduces product wastage and environmental impact

There are many sprayer calibration methods. Sprayer manufacturers and crop advisors often provide these. Do not mix and match steps from different methods. For more information about calibration, see Sprayers101.com.

Pesticide Resistance

Pesticide resistance is the ability of an organism to survive in the presence of normally lethal doses of a pesticide. Resistance can occur in any pest population — fungi, insects or weeds.

Resistance can develop from the repeated use of the same pesticide. In any pest population, there is a mixture of individuals with different traits. A few individuals in the population may have a trait for resistance to a particular product, usually due to a random genetic mutation. When the pesticide is applied, the resistant individuals survive, while most of the susceptible individuals are killed. If this process is conducted repeatedly, the resistant individuals become dominant in the population and the pesticide no longer controls that pest. Modern pesticides often have very specific modes of action on a pest that make the development of resistance much more likely.

The chances of having a few resistant pests in a field increases as the pest population increases, making resistance more likely if pesticides are not applied until the population in the field is high. Applying pesticides preventatively before populations increase can delay the development of resistance.

There can often be a small proportion of a pest population with resistance to one pesticide, but there are far fewer resistant to two pesticides with different modes of action. For example, if there is one resistant individual out of every 100 for each pesticide with a different mode of action, then only one in every 10,000 individuals would be resistant to two pesticides and one in every 1,000,000 would be resistant to three. The development of resistance can be prevented or delayed by rotating pesticides with different modes of action. A pest that survives one pesticide is much less likely to survive the other.

The number of available products for ginseng pest control is limited and new products are rare. Always rotate products to ensure that current products remain effective. Resistance hurts the grower in lost pest control and the industry because resistant populations quickly spread from the field where they first developed.

Here are some key considerations for managing resistance.

- Avoid unnecessary pesticide applications through regular scouting to catch problems before they get out of hand and by increasing the interval between applications when weather conditions are less favourable for the pest
- Rotate products from different chemical groups. Chemical groups are listed on the first page of the product label. Products within the same chemical group have similar modes of action and should be considered the same product for resistance management, even if they are different active ingredients. For example, if your last fungicide application contained a group 9 fungicide for *Alternaria* control and a group 40 product for *Phytophthora* control, avoid using the same products or any other products in group 9 or 40 in the tank mix for your next fungicide application
- Product rotations for resistance management need to consider each pest separately. A product applied for one pest does not help in the resistance management for another pest, unless the same product provides control of both pests
- Follow label requirements for maximum applications or volumes per year. These are designed to minimize resistance development. Products with the same active ingredient but different trade names are considered the same product for maximum applications

For more information on understanding and managing resistance, visit the Ontario Crop Protection Hub.

CHAPTER 8

Harvesting and Handling Ginseng Roots

Preparing for Harvest

Before harvesting ginseng roots, remove the shade structure entirely from the garden. Scrape the beds clean of plant refuse and straw before harvest (Figure 100). If plants have not fully senesced (died back), scraping the beds pulls up and injures roots. Accelerate senescence by removing the shade early and allowing the sun to kill the foliage. Shade removal is also necessary if the garden needs to be harvested early because disease threatens plant survival. Plant dieback after pulling the shade can take 4 days to 2 weeks, depending on the weather. Once the stems have dried, they separate easily from the rhizome.

Figure 100. A bed scraper removing the stems and straw from the beds ahead of mechanical harvest.

Harvesting Ginseng Roots

Ginseng roots are usually harvested with a modified potato digger (Figure 101). Larger diggers can pick up the roots, remove most foreign materials such as rocks and straw and place the roots into bins (Figure 102). Workers are usually required on the back of the digger to remove additional foreign materials and any rotted roots. Smaller diggers pull the roots out of the ground and leave them on the soil surface (Figure 103). For all automated diggers, a few workers usually follow along to pick up any roots missed by the machine (Figure 104). These types of diggers sometimes require several passes over a garden to move most of the roots to the soil surface. These roots are often collected by hand, which should be done as soon as possible after digging. Roots left on the soil surface for long periods can become infected with opportunistic soil fungi such as *Rhizopus*. These infections go unnoticed until the root is removed from the kilns and grey patches appear on the roots. See *Post-Harvest Diseases and Disorders*, Chapter 6. Some growers use a combination of harvesting techniques, including one machine to move roots to the surface of the bed and a second machine to pull them off the beds and place them into bins (Figure 105).

Figure 102. Fully automated ginseng harvester.

Figure 103. A modified potato digger placing roots onto the surface of the soil for either hand harvest or further machine harvest. This machine is usually followed by a crew of workers to manually collect any roots missed by the machine

Figure 101. A modified potato digger undercutting a ginseng bed. The soil and root mixture rides up a conveyor of metal slats causing the soil to fall through and any root or larger debris to ride up the conveyor, ending up on top of the soil.

Figure 104. Workers collecting any roots missed by an automated ginseng harvester.

Figure 105. A) A harvester removing roots from the surface of the soil. B) Rear view of the same harvester with roots moving up a conveyor and being dumped into wooden bins.

The quality of ginseng roots is affected by root age at the time of harvest and harvest date. Ginseng root quality is linked to various components of the ginseng roots and sensory qualities that are important to the market. To optimize quality, it is important to understand these quality factors and how they are affected by root age at harvest, harvest timing and postharvest practices.

Ginseng Quality Factors

The vast majority of North American ginseng is sold to traditional Asian markets and several factors determine the quality of roots. Appearance is one of the most important factors. High-quality ginseng mimics the appearance of wild ginseng roots, with darker skin colour, wrinkling of the root surface and a cream-coloured interior (Figure 106). Buyers also consider scent and taste of the ginseng when making purchases, both of which are influenced by starch, sugar content and many other root components. A higher sugar content is generally preferred, resulting from the conversion of starch to sugar.

Non-traditional markets, such as natural health product manufacturers, may consider medicinally active components such as ginsenosides as part of the determination of ginseng quality — higher contents of these compounds are usually preferred. The concentrations of heavy metals and pesticides in the root are also important in many markets, especially when exporting ginseng. These concentrations must be below maximum residue limits established by each country and can be close to zero if the product is not registered on ginseng or is not acceptable to the importing country. Some markets are more restrictive than others.

Figure 106. Dried ginseng root with a creamy interior.

There is a range of biologically active chemicals in ginseng, including ginsenosides, gypenosides, alkaloids, polypeptides and polysaccharides. Ginsenosides and polysaccharides have been evaluated in clinical trials. This publication does not make recommendations on the health benefits of ginseng.

Ginsenosides

The ginsenosides in ginseng are chemicals that belong to a group of compounds called saponins and fall into one of two categories — protopanaxadiols and protopanaxatriols. Thirty ginsenosides have been identified in ginseng. Asian ginseng (*Panax ginseng*) can be distinguished from North American ginseng (*Panax quinquefolius*) using ginsenoside profiles — Asian ginseng contains ginsenoside Rf and North American ginseng does not.

The overall ginsenoside content of ginseng roots varies depending on the production system (Table 14). See *Factors Affecting Root Quality* in this chapter for a description of how field production practices affect ginsenosides.

Table 14. The Relationship of Production System and Total Ginsenosides by Weight in Ginseng Roots

Root Source	% Total Ginsenosides by Weight
Wild ginseng	4.2
Woods-cultivated ginseng	4.4
Field-cultivated ginseng	3.8
Field-cultivated fibre roots	7.8

Testing for Ginsenosides

Ginsenoside testing can only be done by a commercial laboratory and is only beneficial if the customer requires it or if it adds value for marketing purposes. Different labs may use different procedures for analyzing the constituents of a ginseng root. Results from different labs cannot be compared unless they are using the same extraction procedures.

Polysaccharides

Non-starch polysaccharides make up the fibre content of ginseng. The polysaccharide component of ginseng consists of sugars, uronic acids and lignin. Total polysaccharides range from 7.8%–9.9% of the root weight.

Total starch and sugar content influences the taste and smell of ginseng, which is very important in the marketplace.

Conditioning Ginseng Roots

Harvested roots are placed into bins stored under cool, moist conditions in a refrigerated area for 2–6 weeks to condition them. Plastic or wooden bins are used, but plastic is preferred since it is easier to sanitize after each use. The conditioning process improves the sugar content of the root and its appearance and internal colour. The storage conditions simulate the natural processes that occur late in the fall to prepare the root for winter, such as converting starch to sugars to lower the freezing point of the root. The length of conditioning depends on how much of the natural process has already occurred in the field at the time of harvest and depends on fall temperatures in the field. Roots harvested in August and September typically require 4–6 weeks of conditioning. Roots harvested in October typically require 2–4 weeks of conditioning. Roots harvested in November or later may not require any post-harvest conditioning unless fall temperatures are unusually high. Conditioning should be done at 3˚C–8˚C. Conditioning outside this range could cause discolouration and poor starch conversion. The higher the temperature, the more problems can be expected with root rots and decay. Most growers opt for storage temperatures at the lower end of this range. The length of conditioning and the ideal temperatures can be refined over time as growers become experienced with different fall weather conditions, harvest times and their preferred root quality characteristics.

Dry Matter Content

At conditioning temperatures, there is about a 1.5% dry matter loss from respiration during the first 14–21 days. The dry matter content of fresh root is about 30%, but this varies with age. One-year-old roots in the field have a dry matter content of about 25%, while 4-year-old roots have a dry matter content of about 31%.

Root Appearance

The greatest impact of post-harvest, low-temperature conditioning before kiln drying appears to be moisture loss, resulting in surface wrinkling and darkening of the surface colour. Roots with a shrivelled and darkened exterior are often preferred in the marketplace. After 40 days of low-temperature storage at 85%–90% relative humidity, roots can lose 27% of their original weight (25.5% moisture and 1.5% dry matter). Significant wrinkling does not occur until 20% moisture has been lost.

Washing and Grading Ginseng Roots

After conditioning, ginseng roots are washed using varying equipment (Figure 107). Do not wash the roots too vigorously as this results in a white surface colour that can reduce the value of the roots. After washing, roots are minimally graded to remove any diseased ones and potentially separate lower-quality roots, such as those with surface discolouration. This grading can also be done after drying.

Figure 107. Root washing drum, often used as part of the washing line.

Drying Ginseng Roots

Washed roots are arranged on trays (Figure 108), placed in forced air kilns (Figure 109) and dried to about 5%–8% moisture. The optimum drying temperature is 38°C based on research by Dr. Bruce Reynolds at Agriculture and Agri-Food Canada, who examined drying temperatures at 32°C, 38°C and 44°C, and the effects on ginsenoside, starch and sugar concentration and root colour. Adjusting the temperature in the kiln can be used to manipulate quality factors to meet specific market requirements.

Figure 108. Drying trays stacked in kilns so air can circulate freely.

Figure 109. Open ginseng drying kiln showing the trays stacked inside.

The moisture content of dried roots is slightly higher when roots are not conditioned. Conditioned roots take slightly longer to dry. The average weight of a 3-year-old dried root is 5 g. After drying, roots are usually packed into cardboard barrels or boxes lined with plastic bags. Properly dried ginseng root has a light tan or creamy-coloured interior.

Effects of Drying Temperature on Ginsenoside Content

Optimal drying temperatures for ginsenoside recovery are 32˚C–38˚C. The concentration of malonyl ginsenosides decreases if drying temperatures are increased from 38˚C to 44˚C. Total ginsenoside concentration can be reduced by 26% at a drying temperature of 44˚C and by 17% at a drying temperature of 38˚C, compared to experimentally dried roots without the loss of ginsenosides. Only gypenoside XVII increases at the higher temperature (see *Ginseng Quality Factors* in this chapter).

Effects of Drying Temperature on Starch and Sugar Content

Starch hydrolysis (conversion of starch to sugar) occurs at 32˚C, 38˚C or 44˚C during forced air drying of ginseng. More starch is converted to the sugar sucrose when ginseng is dried at 32˚C or 38˚C than at 44˚C. Sucrose is the main sugar found in North American ginseng.

Effects of Drying Temperature on Root Colour

Internal root colour darkens as the drying temperature is increased from 32˚C to 44˚C. At 44˚C, the root is darkened enough to significantly reduce its value.

Storage of Dried Roots

If roots are dried properly, they remain marketable for several years under ideal storage conditions. Exposure to moisture, light and oxygen decreases storage life and the impact on root degradation increases as temperature increases. Dried roots are best stored in sealed containers that prevent the reabsorption of moisture from the air and block light from reaching the roots. If containers cannot be sealed, reduce humidity in the storage room as much as possible. Removing oxygen from the system is not practical for ginseng growers. Lowering the temperature of the storage room, if economical, reduces the negative effects of moisture and oxygen. The quality of ginseng roots degrades slowly over time, even if stored properly.

Sanitation During Conditioning and Drying

If the weather is wet at harvest or if soil adheres to roots in the cooler, there is a chance that opportunistic fungi such as *Rhizopus* may invade the root tissue. *Rhizopus* infection is discussed in *Post-Harvest Diseases and Disorders*, Chapter 6. Soil is a source of *Rhizopus* infection, so take all possible measures to avoid soil contamination of rooms, fan blades and storage containers.

In the Coolers

The floor of the coolers should be as free of soil as possible. Before roots are placed in the cooler, sanitize floors with a sanitizing material approved for use in facilities containing food products. For a listing of approved sanitizers, consult the sanitizer section of the Reference Listing of Accepted Construction Materials, Packaging Materials and Non-Food Chemical Products.

Vented plastic storage containers are preferable to hold roots because they can be adequately sanitized. Wooden containers such as pallet boxes and bushel baskets can become contaminated through re-use and may be a source of root infection. Sanitize fan blades before use each year, as they can be another source of infection.

In the Kilns

Use the same sanitizing procedures in the kilns as described for the coolers. Sanitize drying trays and fan blades before loading the kiln and ensure any resulting fumes have dissipated before loading roots into the kilns. Food safety programs require all post-harvest surfaces to be made of materials that are easily sanitized.

Grading Ginseng by Root Shape

Several factors affect the perceived quality of dried ginseng root in the marketplace, including the shape of the root. Wholesale and retail markets may recognize as many as 20–40 root-shape categories. The traditional grading systems used by buyers and wholesalers separate dried roots into various levels of preference, mainly based on shape. Labour availability and limited understanding of the detailed shape preferences of the Asian market means grading for export markets is normally done in Asia after the product is sold. Understanding the distribution of root into several main classifications can help a grower relate quality to production practices and growing conditions from one year to the next. This knowledge can help growers modify practices to maximize quality and position roots to maximize the selling price.

Preferred roots are thick but relatively short. Wholesalers often prune portions of lateral root branches from dried roots to produce a more desirable shape.

Researchers at Agriculture and Agri-Food Canada in Delhi, Ontario developed a five-category classification system for dried roots that differentiates root shapes encountered in ginseng production. It has proven useful in separating desirable from undesirable root shapes (Figure 110).

Figure 110. Ginseng root shape categories. A) Spider, B) Fibre, C) Chunk, D) Fork and E) Pencil. Chunk and pencil shapes usually have the highest value.

The classification method is useful for researchers comparing quality effects of different treatments and for growers who want to compare root quality in different batches prior to sale.

Root Shape Classification

Root shape categories are variations of five main root shapes that are described using terms common in the trade — chunk, pencil (carrot), forked, spider and fibre. The relative contributions of root branches or the main taproot to total root dry weight are important factors in separating certain grades, especially the chunk and forked grades.

These are the five grades of ginseng root shape:

- Chunk: Taproot shorter than 5 cm with ›80% of dry weight in the main taproot
- Pencil: Taproot longer than 5 cm with ›80% of dry weight in the main taproot
- Forked: ›20% of dry weight in lateral root branches with the majority of roots growing downwards from the crown
- Spider: ›20% of dry weight in lateral root branches with the majority of roots growing horizontally or upwards from the crown
- Fibre: Roots or root pieces less than 2 mm in diameter

Roots that do not fit the exact definitions for these grades are placed in the categories that most closely match their appearance.

Adapted from research reported in the Canadian Journal of Plant Science, 2003. (Roy, R.C., Grohs, R. and Releeder, R.D. 2003. A method for the classification by shape of dried roots of ginseng (Panax quinquefolius L.). Canadian Journal of Plant Science 83(4):955–958)

Factors Affecting Root Quality

Root Age

Ginsenoside Content

In the commercial production of ginseng, the total ginsenoside concentration in roots increases with plant age over the 4 years that ginseng is in the ground. Total ginsenoside content increases to about 5%–8% in year 4 and then levels off.

Starch and Sugar Content

Root age has minor effects on the starch levels of ginseng and a greater effect on sugar content. Sugar increases in concentration over 4 years from 3% in the first year to 6% in the fourth. During this time, starch concentration shows a corresponding slight decrease from about 55% in the first year to about 49% in the fourth. The effects of plant age beyond 4 years have not been studied.

Root Size and Shape

Ginsenoside Content

No difference in the total ginsenoside content of roots weighing 2–8 g dry weight has been observed in research trials. The average fresh weight of a ginseng root at 3 years of age is about 15–20 g. A root weighing 20 g fresh likely weighs 5–6 g dried. Roots lighter than 2 g contain slightly more total ginsenosides than larger roots. Prongs and fibres contain the highest concentrations as ginsenosides accumulate in the periderm — the outer surface layer of the root — and smaller roots have a higher proportion of periderm per weight of root. Other than the periderm effect, root shape does not have a major impact on ginsenoside content.

Harvest Date

Ginsenoside Content

Total ginsenoside levels decline after mid-September and can decrease by about 14% by November.

Starch and Sugar Content

In starchy roots such as ginseng, there is always a certain amount of conversion of starch to sugar. Starch concentration decreases as the harvest date is delayed. The formation of sucrose accounts for about 80% of the starch loss. The other 20% results in the formation of other forms of carbohydrates, possibly polysaccharides. This characteristic increase in sugar concentration has been observed in potato and parsnip and protects the root from freezing.

Root Colour

Root colour is slightly darker in roots harvested between mid-August and mid-September than in roots harvested later in the fall.

Dry Matter Content

Harvest date within a normal range does not affect the dry matter content of ginseng roots. Root moisture and dry matter levels do not change between August and November.

Packing and Marketing Ginseng

After drying, ginseng is normally packed into cardboard boxes or barrels lined with plastic and then sealed. Air-tight sealing methods (vacuum sealing) are preferred for longer-term storage. Sealing prevents rehydration of the root, which can reduce quality. Store the barrels or boxes in a cool, dry location until they are shipped.

There are a few opportunities for domestic sales and value-added product development, but the vast majority of Ontario ginseng is exported as whole dry roots. Most ginseng is exported to Asian destinations, especially China. Most of the grading of the roots occurs in Asia.

Buyers often contact growers directly. Price is determined by the market and fluctuates considerably from year to year. Growers need to develop and maintain a thorough understanding of the market to know when to sell and at what price. Some regulations must be followed for exporting ginseng from Canada. The Ontario Ginseng Growers Association (OGGA) keeps track of market conditions and export regulations and is a good resource for growers who are ready to sell and ship root.

CITES Requirements for Exporting Ginseng

The Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) classifies animals and plants into one of three appendices, depending on the impact commercial trade may have on the species' survival.

CITES began as the United Nations Environment Program in 1975, as international trade was endangering more wild species everywhere on the planet. Today, CITES is an international consensus on sustainable mutual management of natural resources that includes over 180 member states (parties). A conference is held every 3 years by delegations from all of the parties. They decide on modifications for the appendices, evaluate progress in the restoration and conservation of species and evaluate the needs of the different endangered species. The CITES Secretariat carries out these decisions and is based in Geneva, Switzerland.

How Does CITES Work?

CITES operates through an import/export permit system. Rules and regulations associated with CITES apply to the export of Canadian ginseng, listed under CITES in Appendix II. Appendix II plants are not considered threatened with extinction but may be if their trade is not regulated. Appropriate permits are required for the international movement of Appendix II plants. Any CITES-listed species imported into Canada, exported from Canada or attempted to be exported without the necessary permits is subject to seizure and forfeiture and the importers/exporters may be subject to prosecution.

CITES and the Export of Ginseng

The exportation of wild North American ginseng (*Panax quinquefolius*) is prohibited from Canada. Only cultivated ginseng may be authorized for export from Canada. CITES export permits are also not issued for illegal material, such as roots collected in violation of provincial species at risk regulations (see *Regulations Impacting Production of North American Ginseng in Ontario*, Chapter 1).

The exportation of cultivated North American ginseng (Panax quinquefolius) always requires a Canadian CITES export permit issued by the Canadian Wildlife Service. The requirement for CITES permits applies only to whole and sliced ginseng roots and parts of ginseng roots. CITES export permits may be single-use or multiple-use.

A CITES export permit is not required for exporting live ginseng plants, ginseng seeds and manufactured parts or derivatives, such as powders, pills, extracts, tonics, teas and confectionery.

The Canadian Wildlife Service may issue multiple-use export permits for cultivated American ginseng. These permits are restricted to ginseng exporters who frequently export ginseng shipments in a year and/or export these within short time frames.

Multiple-use export permits for ginseng are subject to strict conditions and procedures. Protocol differs depending on whether they are for personal or commercial purposes. Only original permits are accepted.

A multiple-use export permit for personal use may only be used to export shipments of <4.5 kg. Multiple-use export permits for personal use may be accompanied by a specified number of sticker permits. Each sticker permit is individually numbered and should be used in sequential order.

Sticker permits are comprised of three sheets:

- the first sheet is to be returned to the CITES Management Authority
- the second sheet is for the permit holder's records
- the third copy is the actual sticker

The quantity of the ginseng shipment and the country of import must be written on the top copy (the information transfers to the other two sheets). The sticker should then be affixed directly to the ginseng shipment to accompany the package upon export. All unused stickers must be returned to the CITES Management Authority upon expiration of the permit.

Commercial multiple-use export permits may only be used to export ginseng shipments of >4.5 kg. A specified number of certified-true copies of the permit are provided to the permit holder. Prior to export, the name, address and contact information of the consignee should be written on the permit and the quantity and destination of the shipment. The shipment number and date of shipment must be indicated in the appropriate box. Once all the information is filled out, a copy of the permit must be made and sent to the CITES Management Authority. The certified-true permit accompanies the shipment to its destination. Every permit requires validation by a Canadian Customs Officer for each shipment exported prior to it leaving the country. Return any unused certified-true permits to the CITES Management Authority upon expiration of the permit.

Contacting CITES

A CITES permit application form created specifically for members of the Ontario Ginseng Growers Association, along with instructions for filling out the form, are available at: *Trade in protected species permits: application forms* on Canada.ca.

Send applications to the CITES Permit Office by one of the following methods (use only one method to send the application):

Mail: CITES Permit Office
Environment and Climate Change Canada
351 St. Joseph Blvd.
Gatineau, Quebec K1A 0H3

Fax: 855-869-8671

Email: cites@ec.gc.ca

The Canadian Wildlife Service can be contacted at:

Management Authority
Convention on International Trade in Endangered Species (CITES)
Canadian Wildlife Service
Environment and Climate Change Canada
Gatineau Quebec K1A 0H3

Tel: 1-800-668-6767 (toll-free number)

Phytosanitary Certificates

A phytosanitary certificate indicates that a shipment is free from recognized or quarantinable pests. Countries importing ginseng seed may require a phytosanitary certificate. The importing country lists the pests or conditions associated with certification. If ginseng seed or living roots are being shipped out of Canada, check with the importing country to determine what rules, if any, may affect the shipment. Knowing the rules in advance will avoid situations where a perishable product may be held up before entry. It is the responsibility of the grower or exporter to obtain a phytosanitary certificate, which includes arranging inspection of the material and paying the associated fee. Phytosanitary certificates can be obtained through the Canadian Food Inspection Agency (CFIA).

Appendix A. Ministry Resources

OMAFA Ginseng Advisory Staff

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Agricultural Information Contact Centre
Provides province-wide, toll-free technical and business information to commercial farms, agri-businesses and rural businesses.

Tel: 1-877-424-1300
Email: ag.info.omafa@ontario.ca
Web: Contact/Feedback Form

Ginseng on Ontario.ca

- Cost of Production of Ginseng in Ontario

Appendix B. Other Resources

Ontario Ginseng Grower's Association (OGGA) A non-profit organization representing the producers of North American Ginseng (*Panax quinquefolius*) who grow, harvest and sell the root. The Association supports research into new production methods and harvesting advances. They also develop strategic marketing direction for the industry, while working with government and industry partners to develop the growing market for North American ginseng.
www.ginsengontario.com

Agriculture & Agri-Food Canada (AAFC)
Agriculture and Agri-Food Canada supports the Canadian agriculture and agri-food sector through initiatives that promote innovation and competitiveness.
https://agriculture.canada.ca/en

AAFC Research Centres
https://agriculture.canada.ca/en/science/agriculture-and-agri-food-research-centres

Canadian Food Inspection Agency — Plant Protection
Services and information on plant pests and invasive species, import, export, trade, fertilizers, soil and soil-related matter, grains and field crops, seeds, cannabis, forestry and horticulture.
https://inspection.canada.ca/en/plant-health

University of Guelph — Plant Agriculture
www.plant.uoguelph.ca

Lab Services Division - Agriculture and Food Laboratory (AFL)
AFL offers a variety of services ranging from: microbiological testing, agrochemical testing, DNA methods, identification of food contaminants, allergen testing, method development and tests for residues from drugs, pesticides, plant, soil and water.
www.uoguelph.ca/labserv/

Appendix C. Accredited Soil-Testing Laboratories in Ontario

OMAFAs agronomic soil laboratory accreditation program was established in 1989 to:

- Ensure accurate results, within acceptable ranges, from any of the accredited labs.
- Support the use of soil test extractants appropriate for Ontario soils and for which fertilizer response calibration data exists.
- Promote the use of OMAFA accredited labs to Ontario's agriculture and horticulture businesses.
- Promote the use of Ontario Soil Management Committee (OSMC) approved fertilizer recommendations.
- Approve new soils laboratories that meet the performance criteria.

The accreditation program requires independent appraisal of the soil testing quality by OMAFA in coordination with the North American Proficiency Testing Program (NAPT), as well as rigorous self-evaluation by participating labs. Accreditation ensures reliability (precision and accuracy) of soil testing and a commitment to continuous quality enhancement.

As of now, there are eight tests accredited by OMAFA for soil testing in Ontario:

- pH
- buffer pH
- nitrate-nitrogen
- phosphorus
- potassium
- magnesium
- zinc (reported as Zn index)
- manganese (reported as Mn index)

Visit Ontario.ca for a list of laboratories accredited to perform soil tests for pH, buffer pH, P, K, Mg, Mn index, Zn index and Nitrate-N on Ontario soils.

For specific questions regarding the soil testing analysis or specifications, please contact the appropriate company for their latest information.

Appendix D. 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	=	1 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		
5 mL	=	1 tsp
15 mL	=	1 tbsp
28.5 mL	=	1 imp. 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 × 0.014	=	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 × 1.8) + 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) × .5556

Abbreviations

%	=	per cent
°	=	degrees
bu.	=	bushel
cm	=	centimetre
cm^2	=	square centimetre
ft.	=	feet
g	=	gram
ha	=	hectare
in.	=	inches
kg	=	kilogram
L	=	litre
m	=	metre
m^2	=	square metre
mL	=	millilitre
t	=	tonne

Notes

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