1. Soil, Media and Water Quality Management

When used correctly, fertilizers can help produce high crop yields cost effectively. Always apply fertilizers at a rate consistent with soil fertility, measured by OMAF-accredited testing (see Appendix C, *OMAF-Accredited Soil, Leaf and Greenhouse Media Testing Laboratories*, on page 79). Low-fertility soils may need nitrogen, phosphorus, potassium and micronutrients at levels at least equal to crop removal. However, high-fertility or heavily manured soils may not benefit from added fertilizer due to increased costs and possibly reduced yields.

Field Nursery Production

Field Soil Testing

The OMAF-Accredited Soil Testing Program

Be sure to use an accredited testing service. To be accredited, a laboratory must use OMAF-approved testing procedures, demonstrate acceptable analytical accuracy and precision and provide OMAF fertilizer guidelines based on the test results.

The OMAF-Accredited Soil Testing Program enables optimum fertilizer and lime application for crop production. Use this program, along with plant analysis and observation of plant nutrient-deficiency symptoms, to determine the fertilizer requirements for a specific crop on a specific field.

The program provides guidelines for the amounts of phosphate, potash and magnesium fertilizers needed, plus the type and amount of lime. The application rates provided in this publication should produce high economic yields when accompanied by good management practices. Higher application rates will sometimes produce higher yields, but the increase is likely to be small and not worth the additional cost.

Soil Tests from Unaccredited Laboratories

Some farmers ask OMAF staff to interpret results from unaccredited laboratories. If the laboratory correctly uses tests identical to those used by OMAF-accredited laboratories and expresses test results in the same units, the OMAF fertilizer requirements for phosphate and potash can then be determined.

Soil tests such as exchange capacity, aluminum and copper are not accredited by OMAF because these tests do not contribute to better fertility regimes. For example, research shows that on Ontario soils, using exchange capacity to adjust potash applications can make the process of adjusting soil fertility less reliable.

The laboratories listed in Appendix C on page 79 are accredited to perform soil tests on Ontario soils and to analyze plant and greenhouse media samples. Please note that these labs may also offer other testing services that are not accredited by OMAF.

When to Sample Field Soil

Always allow enough lead time for a soil analysis. Take soil samples in the autumn from fields to be fertilized in the spring. To avoid problems with bad weather in late fall, fields may also be sampled earlier in the season.

How to Sample Field Soil

It is important to sample soil correctly:

- Use a sampling tube or a shovel to sample soils.
- Sample each field or section of a field separately.
- Take at least 20 soil cores, 15 cm deep, from any field or area up to 5 ha in size. Take proportionately more cores from fields larger than 5 ha. One sample should not represent more than 10 ha. The more cores collected, the more likely the soil sample will reliably measure the field's fertility.
- Use a zigzag pattern to distribute the sampling sites evenly across the field.
- If the soil or crops look different in different sections of the field, or if sections of the field were previously fertilized, manured or limed differently, sample those sections separately, even if these areas are too small to fertilize separately in the future.

- Do not sample recent fertilizer bands, dead furrows, areas adjacent to gravel roads, or areas where lime, manure compost or crop residues have been piled.
- Collect the soil in a clean plastic pail. Do not use galvanized pails.
- Break up the lumps and mix the soil thoroughly (preferably with hands).
- Contact the OMAF-accredited lab for soil sample boxes. Place about 250 mL of the collected, well-mixed soil in a plastic bag, put the bag in a soil sample box and label the sample (e.g., date, field, depth, other information). Soils for nitrate-nitrogen analysis must be kept cool (4°C). However, it's a good idea to keep *all* soil samples cool until they are delivered to the lab for analysis.
- Sample each field once every 2 or 3 years.
- With every soil sample, be sure to enclose a field information sheet describing the soil management practices used on this field (see below).

Field Soil Management Practices

Good soil management practices, including fertilization, play a major role in ensuring a profitable crop yield. In order for laboratories to provide a reliable fertilizer guideline, they need information about the field, the crop to be fertilized, manure application and legume sod plowed down. Record this information on the field information sheet that must accompany each soil sample sent for analysis. For more information, see *Best Management Practices: Managing Crop Nutrients,* Order No. BMP20E.

Field Soil Micronutrient Testing

OMAF offers accredited tests for manganese and zinc. Use these tests in conjunction with visible deficiency symptoms and plant analysis. OMAF-accredited tests are not available for boron, copper, iron or molybdenum.

- Manganese availability decreases with increasing soil pH. Do not add more lime than is needed to correct acidity.
- Control zinc deficiency by preventing soil erosion and using animal manures. If necessary, prompt use of zinc fertilizers and foliar sprays can help to reduce symptoms of zinc deficiency.
- If the soil test exceeds 200, zinc contamination may have occurred.

How to Sample Field Soil Micronutrients

It is important to sample soil correctly. See *How to Sample Field Soil*, on page 1, for soil sampling instructions. Micronutrient deficiencies often occur in small patches. In these cases, soil and plant samples taken from the entire field may not reveal the problem. It is best to sample problem areas separately.

Use clean, plastic containers in good condition. Soils being tested for micronutrients can be easily contaminated by dirty or dusty sampling tools and containers. Do not collect or mix samples in metal containers. Galvanized (zinc-plated) sampling tools will elevate soil test results for zinc.

Foliar Analysis (Plant Tissue Testing)

Foliar analysis is the best way to diagnose micronutrient problems. It measures the nutrient content of plant tissue. OMAF uses foliar analysis to diagnose suspected nutrient disorders in field-grown and container-grown nursery stock. Table 1–1, *Average Foliar Nutrient Content of Healthy Nursery Stock,* on page 3 specifies normal foliar nutrient concentrations for nursery stock. Note that nutrient concentrations in established landscape stock may be somewhat lower.

When to Sample Plant Tissues

Nutrient levels vary widely with plant age. It is best to take plant tissue samples in July or early August for routine analysis or whenever symptoms appear.

How to Sample Plant Tissues

It is important to sample plant tissues correctly. From deciduous trees and broadleaf evergreen shrubs, select approximately 50 fully expanded leaves midway along a shoot of the current season's growth. From conifers, select 15–20 shoots of current season growth, each approximately 10 cm long. Remove the needles and rinse them in distilled water (discard the twigs). Deliver fresh plant materials directly to the laboratory. If they cannot be delivered immediately, air-dry the tissue samples and ship them in paper bags to avoid spoilage. Submit a sample of healthy leaves from the same area to allow comparisons.

See Appendix C on page 79 for a list of labs and the tests provided by each one.

Understanding Soil pH

pH measures soil acidity or alkalinity on a scale from 0 to 14. The midpoint of the scale, 7, is neutral. Values below 7 are increasingly more acid, while values above 7 are increasingly more alkaline. In general, use lime to raise pH (making the soil more alkaline) and sulphur to lower pH (making the soil more acid). Soil pH testing helps determine any necessary pH adjustments.

Soil pH and Nutrient Availability

- Many soils in Ontario have an alkaline pH. At pH levels above 6, iron (Fe) and manganese (Mn) become less soluble (and therefore less available) the higher the pH. Symptoms of iron and manganese deficiency appear as yellow leaves with green veins: a condition called "interveinal chlorosis." Manganese deficiencies are more common in soil than iron deficiencies.
- Most nursery stock grows well between pH 5.0 and pH 7.2.
- Plants such as red maple, pine, red oak, tuliptree and birch may exhibit iron and/or manganese interveinal chlorosis if the pH is above 6.5.
- For ericaceous plants and conifer seed beds, the pH should be below 6.5.
- Long-term use of fertilizers such as ammonium sulphate, ammonium nitrate, urea, potassium sulphate and mono-ammonium phosphate will gradually reduce soil pH over several years. This is most likely to occur on light, sandy soils and can be corrected by liming the soil.
- Anhydrous ammonia causes a marked, though temporary, soil pH increase when first applied.
- Superphosphate and muriate of potash have little or no effect on soil pH.

Buffer pH Testing

Different soils with identical pH values will require different amounts of lime or sulphur to reach a desired pH level depending on clay and organic matter content. Where soil is acidic (pH less than 7), an additional soil test, the buffer pH, determines the amount of lime required to increase soil pH to the target level. The actual lime needed is also determined by the target pH for the crop. The lower the buffer pH value on a soil test, the more lime that will be required to neutralize it. See Table 1–2, *Lime Requirements to Correct Soil Acidity Using Buffer pH* on page 4.

Limestone Type

Both calcitic limestone and dolomitic limestone are available in Ontario. Calcitic limestone is mainly calcium carbonate, while dolomitic limestone is a mixture of calcium and magnesium carbonates. Use dolomitic limestone when the magnesium in the soil is 100 ppm or less. It is an excellent, inexpensive magnesium source for acid soils. Use either calcitic or dolomitic limestone when the magnesium in the soil exceeds 100 ppm.

TABLE 1–1. Average Foliar Nutrient Content of Healthy Nursery Stock

Nutrient	N %	P %	K %	Ca %	Mg %	Mn ppm	Cu ppm	Zn ppm	B ppm	Fe ppm
Field-grown										
Conifers	1.7	0.24	1.0	1.0	0.2	88	6	31	35	87
Broadleaf evergreens	2.3	0.27	1.1	2.5	0.3	25	5	27	42	120
Deciduous trees and shrubs	2.8	0.25	1.7	2.4	0.4	62	7	25	58	133
Container-grown										
Conifers and broadleaf evergreens	2.5	0.4	1.4	2.0	0.3	52	5	24	48	127

Limestone Quality

Two main factors affect the ability of limestone to reduce soil acidity. *Neutralizing value* is the amount of acid a given quantity of limestone neutralizes when it dissolves totally. Neutralizing value is expressed as a percentage of the neutralizing value of pure calcium carbonate. A 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 less needs to be applied.

Fineness rating describes the limestone's particle size. The more finely ground the limestone, the greater its acid-neutralizing ability. Limestone rock has much less surface area than finely powdered limestone and neutralizes soil acidity much more slowly.

Agricultural Index

OMAF uses the Agricultural Index to compare the acid-neutralizing effectiveness of different limestone samples. Lime with a high Agricultural Index rating is worth more than lime with a lower rating because a smaller quantity achieves the same result.

For example, if ground limestone A has an Agricultural Index of 40, while ground limestone B has an Agricultural Index of 80, the application rate of A must be twice the application rate for B to achieve the same effect. Limestone A is therefore worth half the price of limestone B per tonne.

OMAF soil test guidelines assume an Agricultural Index of 75. To calculate the correct application rate for limestone of a different quality, use the following formula:

Calculating Limestone Application Rates

$$\text{application rate} = \frac{75}{\text{Agricultural Index}} \times \text{application rate from soil test}$$

Raising Soil pH

When soil tests indicate the need to raise pH, use lime. Table 1–2, *Lime Requirements to Correct Soil Acidity Using Buffer pH,* below, gives general lime application rates required to obtain the correct soil pH for most crops, based on soil pH and buffer pH.

TABLE 1–2. Lime Requirements to Correct Soil Acidity Using Buffer pH

Limestone needed (tonnes/hectare) based on an Agricultural Index of 75		
Buffer pH	**Target Soil pH = 6.5**	**Target Soil pH = 6.0**
	Lime if soil pH falls below 6.1	**Lime if soil pH falls below 5.6**
7.0	2	0
6.5	3	2
6.0	9	6
5.5	17	12
5.0	20	20

Tillage Depth

These lime recommendations should increase soil pH to the target value in the top 15 cm of the soil. If the soil is plowed to a greater or lesser depth, proportionately more or less lime will be required to reach the target pH.

Lowering Soil pH

Because lowering the pH of alkaline soils (pH greater than 7) is expensive, it is not practical to acidify large areas. Many fields in southern Ontario vary quite a bit in soil pH. Several soil test samples throughout the field can be taken and used to create a detailed map of soil pH, perhaps with the aid of GPS technology. Plant crops that require more acidic soils in those lower pH zones, according to your soil test map. Avoid growing acid-loving species in high pH soil that will not be able to meet their nutrient requirements.

If the starting soil pH value is 7 or less, sulphur is the first choice for lowering pH. Other acidifying materials (e.g., aluminum sulphate, iron sulphate) are less effective than sulphur and may be toxic to plants. Apply sulphur at least every other year to keep the soil pH near the desired level. Test the soil pH in the spring. If necessary, apply sulphur at the recommended rate to help adjust soil to the correct pH value (see Table 1–3, *Soil Acidification to pH 5.0 Using Sulphur,* on this page). In small areas, an alternative is to lower the soil pH by replacing the soil or amending it with large quantities of acid peat or another acidic organic material. Test the pH of any organic amendment before using it. Leaf mould, compost and peat may be alkaline rather than acidic.

TABLE 1–3. Soil Acidification to pH 5.0 Using Sulphur

Elemental sulphur required (kg/100 m²) each year for 2 successive years		
Initial pH	**Soil Type**	
	Sand	**Loam**
7.0	7.4	22.6
6.5	6.0	17.5
6.0	4.0	12.0
5.5	2.0	6.0

Soluble Salts in Soil

High concentrations of water-soluble salts in the soil interfere with plant water uptake. This can delay or prevent seed germination, kill new transplants and seriously slow the growth of new and established plants. Levels of soluble salts can be tested by measuring electrical conductivity (EC). The EC measurement is expressed in units of millisiemens/cm (mS/cm). See Table 1–4, *Soil Electrical Conductivity (EC) Readings,* on this page. Table 1–4 interprets soil conductivity readings in Ontario field soils using a 2:1 water:soil paste mixture (based on volume).

Ontario soils are naturally low in soluble salts. As a result, these salts rarely cause crop production problems and are not routinely measured in soil tests. However, excessive fertilizer application, road salt run-off and chemical spills can cause soluble salts to build up in the soil. This problem is most severe when soil moisture is low and salt concentrations are high. Improving soil drainage in order to encourage more natural leaching may help reduce levels of soluble salts. If salt problems are suspected, send a soil sample to an OMAF-accredited laboratory for a soil EC reading. See *How to Sample Field Soil*, on page 1, for soil sampling instructions.

TABLE 1–4. Soil Electrical Conductivity (EC) Readings

EC Reading (mS/cm)	Rating	Plant Response
0–0.25	Low	Suitable for most plants when using average amounts of fertilizer
0.26–0.45	Medium	Suitable for most plants when using average amounts of fertilizer
0.46–0.70	High	May reduce seedling emergence and cause slight to severe damage to salt-sensitive plants
0.71–1.00	Excessive	May prevent seedling emergence and cause slight to severe damage to herbaceous and juvenile woody plants
greater than 1.00	Excessive	Expect poor seedling emergence; may cause damage to herbaceous and juvenile woody plants

OMAF-accredited laboratories test for soluble salts by measuring the electrical conductivity (EC) of a soil/water slurry. The higher the concentration of soluble salts, the greater the soil's conductivity. If testing indicates a salt problem, correct it by leaching the soil with water.

Fertilizer Use

Fertilizing Field Nursery Stock

Fertilize nursery stock regularly to achieve optimum growth and maximum profit. Dry and liquid fertilizers produce similar results, so choose a suitable fertilizer formulation on the basis of soil test results, consistent supply, handling equipment available, application cost and cost per kilogram of nutrients. Use Tables 1–7 to 1–10, on pages 7–8, when choosing fertilizer formulations.

OMAF provides reliable soil test information for phosphorus and potassium. See Table 1–5, *Phosphorus Requirements for New and Established Field Nursery Stock*, on this page and Table 1–6, *Potassium Requirements for New and Established Field Nursery Stock*, on page 7. Because field soil nitrogen levels fluctuate rapidly, nitrogen soil tests are unreliable.

Fertilizing Seed Beds and Transplant Liner Beds

Before planting beds in the spring, incorporate about 50 kg of actual nitrogen per hectare. Additional nitrogen may be required when planting particularly rapid-growing species. Add organic matter, such as rotted barnyard manure or compost, at a rate of about 45 t/ha. Growing green manures on the land provides another good source of organic matter. Adjust rates of nitrogen fertilizers if manure is applied. See Table 1–13, *Manure Application Rate and Approximate Nutrients Supplied* on page 16. When fresh, undecomposed organic matter that is low in nitrogen is added to soil, incorporate nitrogen to compensate for microbial decomposition. For example, for every tonne of fresh sawdust, add 15 kg of actual nitrogen. When preparing seed and liner beds, incorporate phosphorus and potassium as indicated by a soil test. In early spring of the second season, apply phosphorus and potassium as indicated by a soil test and apply nitrogen at the rate of 50–75 kg/ha.

Fertilizing Established Field Stock

Fertilize established field stock based on phosphorus and potassium soil test results. See Table 1–5 on this page and Table 1–6 on page 7. As noted earlier, field soil nitrogen levels fluctuate rapidly, making nitrogen tests unreliable. The actual amount of individual nutrients in common fertilizer can vary greatly. Use Table 1–7, 1–8 and 1–9 on page 7 to determine actual amounts of nitrogen, phosphorus and potassium found in common sources of fertilizer. Use Table 1–10, in conjunction with Tables 1–7 to 1–9, to determine how much fertilizer will supply a given quantity of elemental nitrogen per specified area when the percentage of nitrogen in the fertilizer formulation is known.

Apply fertilizer in the spring, 1–2 weeks before growth resumes (just before bud break or as the first flush emerges).

To avoid stimulating succulent growth in the fall, do not apply high rates of nitrogen after mid-July. Apply small amounts of nitrogen regularly throughout the growing season or via a slow-release formulation.

TABLE 1–5. Phosphorus Requirements for New and Established Field Nursery Stock (using the 0.5 N sodium bicarbonate method of phosphorus extraction)

Phosphorus (0.5 N sodium bicarbonate extractant)

Soil Test Value (ppm)	Response*	Phosphate (P_2O_5) Required (kg/ha)	
		New Planting	Established Planting
0–3	HR	140	100
4–5	HR	130	90
6–7	HR	120	80
8–9	HR	110	70
10–12	HR	100	70
13–15	HR	90	60
16–20	MR	70	50
21–25	MR	60	40
26–30	MR	50	30
31–40	MR	40	20
41–50	LR	0	0
51–60	RR	0	0
61–80	NR	0	0
80+	NR	0	0

***Explanation of 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

TABLE 1–6. Potassium Requirements for New and Established Field Nursery Stock (using the 1 N ammonium nitrate method of potassium extraction)

Potassium (1 N ammonium nitrate extractant)

Soil Test Value (ppm)	Response*	Potash (K_2O) Required (kg/ha) (New or Established Planting)
0–15	HR	130
16–30	HR	120
31–45	HR	110
46–60	HR	100
61–80	HR	90
81–100	HR	80
101–120	MR	70
121–150	MR	60
151–180	MR	40
181–210	LR	0
211–250	RR	0
250+	NR	0

***Explanation of 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

TABLE 1–7. Nitrogen Sources

Nitrogen Materials	% Nitrogen (N)	Other Elements Supplied
Ammonium nitrate	34	—
Urea	46	—
Calcium ammonium nitrate	27	4%–6% Calcium (Ca), 0%–2% Magnesium (Mg)
Ammonium sulphate	21	24% Sulphur (S)
Calcium nitrate	15	19% Calcium (Ca)
Potassium nitrate	12	44% Potash

TABLE 1–8. Phosphorus Sources

Phosphorus Materials	% P_2O_5	Other Elements Supplied
Superphosphate	20	20% Calcium (Ca), 12% Sulphur (S)
Triple superphosphate	44–46	21% Calcium (Ca)
Monoammonium phosphate (11-52-0)	48–52	11% Nitrogen (N)
Diammonium phosphate (18-46-0)	46	18% Nitrogen (N)

TABLE 1–9. Potassium Sources

Potassium Sources	% K_2O	Other Elements Supplied
Potassium chloride (muriate)	60–62	—
Potassium sulphate	50	18% Sulphur (S)
Sulphate of potash magnesia	22	11% Magnesium (Mg), 20% Sulphur (S)
Potassium nitrate	44	12% Nitrogen (N)

Fall fertilization can be a great opportunity for increasing nitrogen uptake and plant growth in perennial crops. Plants that are fertilized in the fall usually experience better spring growth than plants that are fertilized in the spring. Apply up to one-third of the year's fertilizer requirement after top growth ceases and the danger of top growth stimulation has passed (late September to late October). Roots of most nursery crops will grow and absorb nutrients whenever soil temperatures stay above 5°C. Nitrogen is either taken up quickly by roots, lost through leaching or sequestered by bacterial activity. By splitting the total annual amount of nitrogen over several applications, losses can be minimized. A total of 100–150 kg of actual nitrogen per hectare can be used in 1 year. Rapid-growing species may need more nitrogen during particular growing conditions.

For optimum fertility, sandy soils need more nitrogen and potassium fertilizers than clay soils. When no soil test is available, apply 100 kg of actual nitrogen per hectare using a 3-1-2 ratio fertilizer. Do not apply fertilizer in late fall or winter. It will not be absorbed because of the cold soil temperatures and may be lost through run-off.

Use Table 1–10, *Nitrogen Equivalency Table*, on this page when determining how much fertilizer is required to apply a specific quantity of elemental nitrogen.

Fertilizing Landscape Plantings

Most soils have enough inherent fertility to grow plants, so there is usually little need to fertilize thriving landscape plants. However, soil health, texture and nutrient-holding capacity can be a real issue in newer residential and commercial sites, especially those developed in the last 20 to 30 years. Fertilize based on soil test results, soil characteristics, type of plant and desired growth. Fertilizing, adding organic matter and improving soil aeration in the root zone can help increase the chance of successful plant establishment after transplanting and improve plant vigour for years to come.

Trees growing in lawn areas benefit from fertilizers applied to the grass. Apply herbicide-free turf fertilizer at a rate slightly above the suggested rate for grass. Any complete, high-nitrogen fertilizer should be adequate for trees and shrubs. Most studies show that nitrogen improves plant growth more than phosphorus and potassium. Distribute the required amount of fertilizer evenly on the soil surface. Begin well beyond the drip-line of the canopy (as much as twice the distance from the trunk to the drip-line). Extend the fertilizer inward to two-thirds the distance between the drip-line and the trunk. If paving obstructs part of the area under the branch spread, reduce the quantity of fertilizer accordingly. For landscape plantings, apply nitrogen at 1.0–1.5 kg actual N per 100 m^2. Irrigate thoroughly after fertilizer application. Increase the application rate in the case of low tree vigour, a long growing season and/or well-drained, sandy soil.

TABLE 1–10. Nitrogen Equivalency Table

% Nitrogen in the Fertilizer	Kilograms of Fertilizer Needed to Supply:		
	0.5 kg of actual nitrogen/100 m²	**50 kg of actual nitrogen/ha**	**100 kg of actual nitrogen/ha**
5	10	1,000	2,000
6	8.33	833	1,667
7	7.14	714	1,429
8	6.25	625	1,250
9	5.55	556	1,111
10	5.00	500	1,000
11	4.55	455	909
12	4.16	417	833
13	3.84	385	769
14	3.57	357	714
15	3.33	333	667
16	3.12	313	625
17	2.94	294	588
18	2.77	278	556
19	2.63	263	526
20	2.50	250	500
21	2.38	238	476
22	2.27	227	455
23	2.17	217	435
24	2.08	208	417
25	2.00	200	400
26	1.92	192	385
27	1.85	185	370
28	1.79	179	357
29	1.72	172	345
30	1.67	167	333
31	1.61	161	323
32	1.56	156	313
33	1.50	152	303
34	1.47	147	294
35	1.43	143	286
46	1.09	109	217

Split fertilizer applications during the year. Apply fertilizer in the spring, after the first foliage flush expands. Fertilize again in the fall after top growth ceases and the danger of growth stimulation has passed (late September to late October). Apply up to one-third of the annual amount of nutrients in the fall. To prevent run-off, do not apply broadcast fertilizer to frozen or saturated soils. *To avoid stimulating top growth into the fall, do not use large amounts of fertilizer with readily available nitrogen between mid-July and mid-September.*

If fertilizer is applied only once, use fertilizers with at least 60% or more of the product in slow-release form. This will ensure the nutrients become available slowly, with minimum leaching. Pressure injecting slow-release fertilizer into the soil is a good way to ensure nutrients remain in the root zone for uptake. Use a sub-surface method of tree fertilization if the soil needs aeration or when it is important not to overstimulate the vegetation growing on the surface.

Fertilizer Application Rates

Use the following formula to determine the nitrogen application rate of any nitrogen fertilizer formulation:

$$\text{kg fertilizer per } 100\text{m}^2 = \frac{100}{\%\text{ N in fertilizer}} \times (0.5 \text{ kg N}/100\text{m}^2)$$

To calculate kg of fertilizer/hectare, multiply the result by 100.

Organic Amendments to Soil

Organic Matter Content of Soil

Organic matter helps maintain soil structure, aeration and water penetration. Soil structure and aeration promote root development and plant growth, while rapid water penetration minimizes erosion. When organic matter breaks down and/or is lost through clean cultivation practices, replace it by adding organic amendments to the soil. Table 1–11, *Optimal Organic Matter Content in Agricultural Soils*, on this page provides guidelines for optimal organic matter content in agricultural soils.

TABLE 1–11. Optimal Organic Matter Content in Agricultural Soils

Soil Type	Optimum % Organic Matter
Sandy soils	2–4 +
Sandy loam soils	3–4 +
Loam soils	4–5 +
Clay loam soils	4–5 +
Clay soils	4–6 +

Cover Crops

Cover crops play a major role in soil management. They reduce erosion by providing a ground cover and improve or maintain the soil by adding organic matter. To get the most benefit, plant late-summer and fall cover crops promptly after harvest. While broadcast application and incorporation of cover crop seed can be used to establish cover crops, direct seeding or drilling will ensure faster and more even establishment. See Table 1–12, *Characteristics of Cover Crops Grown in Ontario* on page 10 for more information on some of the common cover crops grown in Ontario.

TABLE 1–12. Characteristics of Cover Crops Grown in Ontario

Species	Normal Seeding Time	Seeding Rate kg/ha	Nitrogen[a] Scavenging Potential	Over-wintering Characteristics	Potential Weed Problem from Volunteer Seed	Nematode Rating[b]	
						Lesion	Root-knot
Grasses							
Ryegrass	April to May or August to early September	13–17	moderate	annual & Italian: partial survival; perennial: overwinters	no	–	–
Spring cereals	mid-August to September	100–125	moderate to high	killed by heavy frost	no	+	–
Sorghum sudan	June to August	50	moderate to high	killed by frost	no	NH[b]	–
Pearl millet	June to August	9–10	moderate to high	killed by frost	no	NH[b]	NH[b]
Winter wheat	September to October	100–125	moderate to high	overwinters well	no	+	NH
Winter rye	September to October	100–125	moderate to high	overwinters very well	no	+[c]	NH
Legumes[d]							
Hairy vetch	August	20–30	low to moderate (fixes N)	overwinters	no	++	+
Red clover	March to April	8–10	low to moderate (fixes N)	overwinters	no	++	+++
Sweet clover	March to April	8–10	low to moderate (fixes N)	overwinters	no	–	–
Non-legume broadleaves							
Buckwheat	June to August	50–60	moderate	killed by first frost	yes	+++	NH
Oilseed radish[e]	mid-August to early September	10–14	high	killed by heavy frost	yes	NH[b]	NH[b]
Nematode Rating Codes: – = poor; + = ability to host; NH = non-hosts							

[a] *The potential for nitrogen uptake is influenced by seeding date, stand establishment and growing conditions. Winterkilled cover crops can accumulate significant amounts of nitrogen the preceding fall. Overwintering cover crops will accumulate a greater portion of nitrogen in the spring. Nitrogen-fixing legumes are less efficient at taking up residual nitrogen.*

[b] *Varietal differences in cover crop species may affect nematode reaction. Select the proper variety selection to ensure this cover crop is not a nematode host as there are documented varietal differences. Some varieties may actually lead to higher nematode populations.*

[c] *Rye whole season rating would be higher (+++).*

[d] *Some diseases caused by* Pythium *and* Phytophthora *can be more severe after legume cover cropping.*

[e] *Oilseed radish residues can be toxic or allelopathic to subsequent crops if the following crop is planted too closely after green manuring. Allow the green manure residues to break down or desiccate before planting the next crop.*

Grasses

Grasses have fine, fibrous root systems that are well suited to holding soil in place and improving soil structure. The most suitable grass species for cover crops are fast growing and relatively easy to kill (either chemically, mechanically or by winter temperatures). Grasses do not fix nitrogen, but they can scavenge large quantities of residual nitrogen left in the field after harvest.

Ryegrass (Annual, Italian or Perennial)

Ryegrass is direct seeded in the spring or from August to mid-September. It can also be seeded with a nurse crop in the spring or broadcast into corn in late June to early July with some success. Annual ryegrass gives the most top growth in the seeding year. It often heads 6–8 weeks after seeding. Italian ryegrass (a biennial) does not head in the seeding year, so top growth is considerably less. However, it has the largest, densest root system of the three types. Annual and Italian ryegrass usually suffer considerable winterkill, but part of the stand may survive. Perennial ryegrass normally survives the winter.

Cautions:

Establishment and growth of ryegrasses can be poor during very hot, dry weather. Cultivation or discing may not completely kill overwintering ryegrass. The nitrogen tied up in ryegrass releases more slowly compared to many other cover crops.

Spring Cereals (Oats, Barley, Spring Wheat, Etc.)

Spring cereals can be inexpensive, easy-to-manage cover crops. Stands seeded from mid-August to mid-September will have 20–40 cm of growth by freeze-up. Early-planted cover crops may produce seeds under warm, wet conditions, but little viable seed is usually set. Spring cereal cover crops are generally killed by late, hard frosts. Volunteer spring cereals are sometimes left to grow as a cover crop until freeze-up. These stands may not be very uniform. Most winterkilled spring cereals leave little residue to interfere with early planting.

Cautions:

Very early seeding may result in considerable growth by freeze-up. If left unplowed in the fall, the mat of dead residue will delay soil drying and warming in the spring, which may delay the planting of early-seeded crops. On erosion-prone knolls, spring cereals often have little growth and have been observed to "blow off" by spring.

Sorghum Sudan and Forage Pearl Millet

Sorghum sudan and forage pearl millet are warm-season grasses. They are extremely sensitive to frost. They have extensive root systems and produce a significant amount of top growth. They are both a good option for a mid-summer green manure crop after early-harvested vegetable crops such as peas, sweet corn or cucumbers.

Plant in mid-June, after all threat of frost is past, through to early August. These crops benefit from the warm temperatures of early to mid-summer. Applying approximately 50 kg of nitrogen per hectare will help the crop achieve maximum top growth. A preplant herbicide treatment is suggested to help establish the crop. Frost will control these grasses in early to mid-fall. If earlier control is needed, most burndown herbicides will be effective.

Planting certain cultivars of sorghum sudan (Sordan 79, Trudan 8) and forage millet in rotation with high-value horticultural crops can reduce plant parasitic nematode soil populations below economic thresholds. It may be necessary to grow these varieties under weed-free conditions for more than 1 year to be fully effective. These cover crops may not entirely replace fumigation under high levels of nematode pressure. However, they are useful in keeping nematode levels low and preventing resurgences in the future. Sorghum sudan and pearl millet do not have to be incorporated green for nematode suppression.

Canadian Forage Pearl Millet 101 reduces nematode populations by inhibiting the ability of nematodes to reproduce in its root system.

Cautions:

Mow before the crop reaches 1 m in height. This encourages root development and tillering and prevents the stalks from becoming woody and slow to decompose. To ensure regrowth, do not mow shorter than 15 cm.

Winter Rye

Winter rye is one of the most consistent, flexible and economical cover crops available. It can be seeded later than any other crop and still survive over winter. For good ground cover and erosion protection, seed it at least a month before freeze-up. Typically, that means seeding it from September into late October. Winter rye grows until freeze-up and then begins growing again in late March to early April (slightly earlier than winter wheat). The growth rate is very rapid during May. Kill the stand in late April or early May either by tilling it or applying a herbicide. Winter rye can be seeded earlier than September (without vernalization or the winter cold, it will not produce seed heads). However, the summer heat and common lack of soil moisture may result in an uneven stand.

Cautions:

Rye will grow very rapidly under warm temperatures in early spring, so monitor growth closely and kill the crop before it grows too tall. If rye is left too long, it can deplete soil moisture and incorporation may be difficult. Rye is an excellent host for root-lesion nematode, particularly when grown as a full-season crop.

Winter Wheat

Seed winter wheat from late August through October. It can be seeded outside this time frame, but weather conditions may reduce top growth. Wheat will survive over winter and begin growing again in April. The stand can be killed by tilling it or applying a herbicide. Compared to rye, winter wheat shuts down earlier in the fall and begins to grow later in the spring.

Cautions:

Winter wheat does not generally provide the same amount of green material to return to the soil or the level of weed suppression that rye provides. Early-planted wheat may be more susceptible to infection with the barley yellow dwarf virus (BYDV), although this will have little impact on growth of the wheat as a plowdown or cover crop.

Legumes

Legume cover crops can fix nitrogen from the air, incorporating it into the soil for the succeeding crop. They also protect the soil from erosion and add organic matter. The amount of nitrogen fixed varies between species. Generally, more top growth indicates more fixed nitrogen. Legume cover crops, such as clover, are 80% as effective at scavenging soil nitrogen as grass cover crops. Some legume species have aggressive taproots that can break up subsoil compaction, but this will require more than one season's growth.

Nitrogen release from legumes can be inconsistent because it is a biological process, affected by soil moisture and temperature. This must be accounted for when calculating fertilizer needs. Excess nitrogen release late in the season could lead to excessive vegetative growth in fruiting vegetables and may delay hardening off for winter.

Hairy Vetch

Hairy vetch must be seeded by mid-August to provide good ground cover over winter. Late seeding may result in winterkill. It grows slowly until freeze-up, establishing a very vigorous, fibrous root with moderate top growth. Hairy vetch may also be drilled into winter wheat when the wheat is about 20 cm tall. Seeding at this stage prevents the hairy vetch from causing a problem with wheat harvest but results in much more vetch growth by freeze-up compared to August seedings. Hairy vetch vines resume growth early in the spring (similar to the time for winter wheat) and may reach 150 cm in length if left to maturity. Cover crop stands are usually killed in the spring by tilling or applying herbicide. Vetch's fibrous root system improves soil structure. It also adds large amounts of fresh organic matter to the soil.

Cautions:

Competition from volunteer cereals can lead to poor stands of hairy vetch. On droughty soils, hairy vetch may deplete soil moisture if it is left to grow until early May. Roundup does not kill hairy vetch effectively. Instead, use 2,4-D, MCPA, Banvel or their mixtures. If hormone-sensitive crops are to be planted, apply these sprays in the fall to avoid harming them. Hairy vetch is slow to establish and provide ground cover, leaving the soil open to erosion and weed seed germination.

Red Clover

While not commonly used in horticultural rotation, red clover is often broadcast into winter wheat in March or early April or seeded with spring cereals. Early seeding gives the best stands. Double-cut red clover is more resistant to dry summer conditions. It produces considerably more top growth than single cut (60 cm vs. 25 cm, respectively).

The bulk of red clover growth takes place from mid-summer until a heavy frost. Red clover can be killed in the fall or spring by tilling or applying herbicide. Unless herbicides are also applied, chisel plowing will not kill the stand completely. Red clover plowdown improves soil structure and adds large amounts of organic matter. Nitrogen is fixed and released slowly to the following crop. It gives excellent erosion protection when left unplowed until spring or killed with a herbicide in the fall (but not tilled).

Cautions:

Roundup alone often doesn't kill red clover effectively. Instead, consider 2,4-D, MCPA, Banvel or mixtures. If hormone-sensitive crops are to be planted, apply these sprays in the fall to avoid harming them.

Sweet Clover

Similar to red clover, sweet clover is most commonly seeded into winter wheat in March or early April or seeded with spring cereals. Either yellow- or white-blossom type may be used. White-blossom type produces somewhat taller top growth.

The bulk of sweet clover growth takes place after the grain is harvested until heavy frosts. Top growth will usually be 30–40 cm tall but not dense. A strong taproot is produced, often 30 cm long and 1 cm across at the crown. If allowed to grow the following spring, sweet clover will flower in July at a height of about 180 cm and then set seed and die. Similar to red clover, sweet clover plowdown stands may be killed in the fall or the following spring by tilling or applying herbicides.

Cautions:

Sweet clover is very sensitive to many herbicides and will not tolerate any phenoxy herbicides, including 2,4-D.

Non-Legume Broadleaves

These broadleaf crops cannot fix nitrogen out of the air, but they may absorb large quantities from the soil. These crops are not winter-hardy, so additional control measures are not normally required. Do not allow these crops to go to seed, as the volunteer seed can become a significant weed problem.

Buckwheat

As a cover crop, buckwheat is most commonly seeded in late June to early August. It grows very rapidly, reaching flower stage and a height of 45–75 cm in about 6 weeks. It has a relatively small fibrous root system and is completely killed by the first frost. Buckwheat provides rapid soil cover and gives good erosion protection during the growing season. It smothers annual weeds and suppresses perennial ones. Moderate amounts of fresh organic matter are returned to the soil. Buckwheat does not fix nitrogen. It can be planted as a green manure crop after early-harvested crops such as peas, snap beans and winter wheat. Buckwheat is often used in organic production systems as a rotation crop to help clean up weed infestations and make phosphorous more available.

Cautions:

The flowers are very attractive to bees. Monitor flowering and take appropriate action to prevent seed set. Late summer seedings may be killed by an early frost before providing significant growth.

Oilseed Radish and Mustard

Oilseed radish is commonly seeded in August or very early September. It is unaffected by early frosts. It can grow to a height of 50–90 cm and blooms in October. If planted too early, the flowers may set seed. Mowing oilseed radish before it flowers will delay seed set while maintaining cover. Leave 10–15 cm of cover crop height to encourage regrowth. The plant has a thick taproot, varying between carrot-shaped and turnip-shaped, with extensive secondary roots. Oilseed radish is killed by freezing in late November or December. It provides a reasonably rapid soil cover and excellent erosion protection over winter. It returns moderate amounts of organic matter to the soil. To ensure good crop growth, make sure the soil contains a large amount of available nitrogen, either from a recent manure application or left over from a previous crop.

Some oilseed radish cultivars (as well as certain mustard cultivars) can help to reduce plant parasitic nematode populations in the soil. The nematode-suppressing cultivars must be incorporated into the soil while they are still green. As the green residue breaks down, it releases a nematode-killing compound (isothiocyanate) into the soil.

Cautions:

Growth will be poor if soil nitrogen levels are low or soil compaction is severe. Scattered volunteer plants usually appear in most crops planted after oilseed radish. To successfully reduce nematode population levels below the economic thresholds, these crops may need to be planted for more than 1 year.

The mild winters of southwestern Ontario may allow some varieties of oilseed radish and mustard to partially overwinter.

For more detailed information on cover crop use and management, see the OMAF website at www.ontario.ca/crops.

Tillage Systems After Cover Crops

In conservation and no-till cropping systems, cover crops can greatly increase the surface residue cover, adding to the potential benefits of the system.

However, there are several management factors to keep in mind:

- Some regrowth of winter annual, biennial or perennial cover crops may occur in the following crop year. Usually this is easily controlled with normal herbicide treatments in the following crop. Allowing a controlled amount of regrowth (for example, windstrips) can provide some spring wind protection.
- Schedule the first conservation tillage operation with overwintering cover crops at least 2 weeks before planting the main crop. This will allow the breakdown of the residue to start.
- Seedbed preparation may be difficult if persistent cover crops are not tilled until spring or if they are allowed to grow too large.
- Cover crops that do not survive over winter may be an option, especially on poorly drained soils or before crops that are planted very early in the spring.
- Consider using burndown herbicides before conservation tillage of overwintering cover crops such as rye. Careful timing, rate and application of herbicides can help keep enough residue on the surface to prevent wind damage to tender crops while they get established.

For more information, see:

- OMAF Publication 611, *Soil Fertility Handbook*
- *Best Management Practices: Managing Crop Nutrients*, Order No. BMP20E
- *Best Management Practices: Soil Management*, Order No. BMP06
- *Best Management Practices: Field Crop Production*, Order No. BMP02
- *Best Management Practices: Nutrient Management*, Order No. BMP05

Applying Manure

Applying manure to fields provides many benefits. It adds organic matter to the soil and supplies many of the nutrients needed for crop production. It increases moisture retention and internal drainage. It also builds structure, increases stability and provides a source of nutrients that supports a diverse biological population in the soil. Keep in mind, however, that many fields require more nitrogen than manure alone can supply.

Store manure in a way that saves the liquid portion and minimizes exposure to air. Do not spread manure from December 1 to March 31 or any time when the ground is frozen and/or covered in snow. For best results, apply manure to cool, moist soils (below 10°C) to minimize nutrient losses.

Manure applications can actually reduce the need to add nitrogen, phosphorus and potassium fertilizers. The nutrient content of manure depends on a variety of factors such as livestock type, age and rations, as well as how the manure is stored and whether water is added. See Table 1–13, *Manure Application Rate and Approximate Nutrients Supplied* on page 16 for general guidelines on the volume of nutrients provided by manure.

Sampling Manure

It is important to know the nutrient content of manure in order to decide how much to apply. This means sending samples to a laboratory for testing. Make sure the manure is sampled correctly, however. For liquid manure, mix the tank contents thoroughly before taking a sample. For solid manure, take forkfuls from many places in the stack, not just from the surface. Mix these samples thoroughly, and then submit 1–2 kg for testing.

Timing of Manure Applications

Manure is made up of two main sources of nitrogen. The readily available mineral nitrogen comes in the form of ammonium. This is a positively charged ion that binds to soil particles and is unlikely to be leached. Generally, if the soil is 10°C or colder, very little ammonium will be converted to nitrate-nitrogen, which can be lost through leaching. This is the reason that manure applied in the late fall has less environmental impact than manure applied in early fall.

The other source of nitrogen is slowly available nitrogen, which comes in an organic form that is bound to carbon. Organic nitrogen is released slowly over time, as a function of temperature and soil aeration.

TABLE 1–13. Manure Application Rate and Approximate Nutrients Supplied

Class of Livestock	Nitrogen (kg/ha)			Phosphate	Potash
	Fall	Spring[a]	Spring C[a]	P_2O_5 (kg/ha)	K_2O (kg/ha)
Liquid manure at 10 m^3/ha (900 gal/acre)					
Cattle and mixed livestock	5	10	12	4	16
Poultry	23	46	58	22	26
Swine	8	15	19	7	14
Solid manure at 10 t/ha (4.5 tons/acre)[b]					
Cattle and mixed livestock	12	24	30	10	44
Poultry	70	140	175	75	96
Swine	15	30	38	20	26

[a] *Spring is spring-applied manure not covered immediately; Spring C is spring-applied manure that is either injected or covered within 1 day.*

[b] *Density of manure in spreader may vary from 400 kg/m³ (25 lb/ft³) for heavily bedded or very dry manure to 1,000 kg/m³ (62 lb/ft³) for semi-solid and liquid manures.*

Container Production

Using Containers

High-density plastic pots are most commonly used for long-term container growing. Fibre pots are useful for short-term growing, for potting of field-grown stock and for winter storage or spring shipping. Fibre pots are not suitable for long-term growing because they soften, decompose and may be damaged by rough handling. Always remove a fibre pot when planting in the landscape. Recently, growers are testing alternative materials for pots, most notably coco coir. These pots have the added benefits of increasing aeration porosity (the percentage of air in the pore space) in the root zone and being compostable.

Pot colour affects mix temperature and root development. Root growth decreases when media temperatures approach 30°C. Black and dark green pots may be 10°C hotter than white or light-coloured pots. The temperature of dark pots may reach almost 40°C on the inner surface of the sunny side. However, white or light-coloured pots are not widely available unless ordered in large quantities from the manufacturer. Use light-coloured pots along the outside rows of a block and for widely spaced plants. It is acceptable to use dark colours in the centre of a pot-to-pot block, since sunlight will not strike the pot wall. To diagnose high-temperature injury, remove the pot and compare root growth on the sunny and shaded sides of the pot.

Root circling, especially in small circular containers, can result in root constriction and eventual plant decline. The most effective way to prevent root circling is to remove the pot after 1 year, prune the roots and spread them out and then re-pot the plant into a larger container with additional media. Pruning the roots of pot-bound plants discourages root circling after re-potting or planting. Tree species in small containers are particularly vulnerable to root circling. Minimize root circling by using square containers or ones with vertical ribs that direct root growth vertically. There are also various types of perforated containers and growing bags that help prevent root circling and increase the fibrous roots in the root zone. Creating air circulation at the base of the containers (e.g., by placing containers on structures that allow air flow) encourages air pruning and root branching where the roots come in contact with the air.

Consider staking the outside rows of container crops to help prevent plants from blowing over, especially in the case of tall plants.

Potting Media

A successful container-growing operation depends on the potting media. The media ingredients need to be free of insects, diseases and weeds; readily available (to ensure a continuous supply); and reasonably priced. Although growers have traditionally used peat, this material can become compacted from frequent overhead irrigation, it is difficult to re-wet once it dries, it has a poor nutrient-holding capacity, and its pH will increase significantly if the irrigation water has a high level of bicarbonate. Composted bark provides good aeration when mixed with peat. Much of the soilless container media used in Ontario is a mixture of composted bark (50%–65%), sphagnum peat (30%–40%) and other composted waste (up to 10%). Peat- and bark-based media have good aeration and moisture-holding properties but limited nutrient-holding capacity.

Other ingredients may be used to increase aeration, such as perlite, vermiculite and coco coir. A small percentage of sand may be used to give the media additional weight to help prevent blow-over. Composted bark or other composted plant waste may be used to increase water-holding capacity and also help to suppress root-disease organisms in the root zone.

Well-decomposed coarse sawdust is a useful media ingredient. Avoid fresh sawdust due to its very high carbon:nitrogen (C:N) ratio. Generally, the higher the C:N ratio, the more slowly the material will decompose. Fresh sawdust has a C:N ratio of 1,000:1, conifer bark has a ratio of 300:1, while hardwood bark has a ratio of 150:1. Materials with high C:N ratios need large amounts of nitrogen in order to break down. Therefore, the breakdown of fresh sawdust can actually sequester nitrogen from the media's fertilizer. To compensate for a high C:N ratio and enhance decomposition, add 1 kg of actual nitrogen (e.g., 3 kg ammonium nitrate, 34-0-0) per cubic metre of bark.

Using Soilless Media

Soilless media differ greatly from field soils both chemically and physically. Slight changes in media components (source, ratio, etc.) can have significant effects on porosity and drainage. Grower-specific management practices, such as watering and fertilizing, will also have a significant impact on media performance at each nursery. Always test media performance by trialing the new media on a small block of plants first.

Manage fertility closely to achieve maximum crop growth potential. High pH affects the availability of many micronutrients (especially iron and manganese). In nursery production, media pH may gradually increase over the growing season due to high levels of calcium and magnesium (bicarbonates) in southern Ontario's irrigation water. Therefore, avoid starting a crop in a growing media with a pH of more than 6.5. Most growers choose media with a starting pH of 5 or less. Adding coarse sand to the media can also lead to high pH values, since coarse sand contains calcium.

For more information about soilless growing media, see OMAF Publication 370, *Guide to Greenhouse Floriculture Production.*

Determining Media Porosity

Adequate media aeration is vital to root growth. Water-holding ability is also important, though secondary to aeration. Since roots require oxygen to function properly, a poorly aerated media will restrict root growth and actually lead to root death. As container media is mixed, handled and used for potting, the coarser materials may be broken down, creating more fine particles. These fine particles can interfere with drainage and aeration by plugging up pore spaces in the media. The media will also become compacted over time through irrigation. Reduced levels of aeration and drainage will decrease the amount of oxygen available to plant roots. The result is root dieback and root disease. Avoid over-packing media during potting, since this practice will also lead to reduced aeration and reduced root growth. Some growers are choosing coco coir and more coarsely textured peat and bark to increase media aeration over the crop cycle. To avoid aeration problems with media, measure aeration porosity regularly and re-pot plants regularly throughout the production cycle. When considering a new media, test the new media in a small portion of the crop. To select the best media, compare plants grown in standard potting mix with plants grown in a new mix.

The *total porosity* of a mix is the space between mix particles that air or water can potentially fill. The *aeration porosity* of a mix is the percentage of space filled by air after irrigation water has drained out. Aim for a total porosity value above 50% and an aeration porosity between 15% and 30%. Too much aeration will not harm the plants, but the media will require frequent irrigation. A potting mix with a high percentage of particles smaller than 0.5 mm results in low aeration porosity and poor drainage. For pine and yew, use mixes with an aeration porosity of 20%–25%. Juniper and white cedar can tolerate lower aeration porosity in the root zone.

To determine media porosity, the grower will need:

- the average growing pot (#1, #2, etc.)
- a method to cover or plug the pot drain holes (e.g., a plastic bag inside pot)
- graduated cylinders (large and small) or other containers designed for measuring liquids
- some dry potting mix

To calculate the porosity of the potting media, follow these steps:

1. Cover or plug the drain holes of the pot.
2. Fill the pot with water to the normal level of the potting media. Pour this water into the graduated cylinder (or other measuring container) and record the volume of this water. This amount of water is the total volume of the pot [A].
3. Make sure the drain holes are still plugged, and then fill the pot with slightly moist media to the normal level of the potting media. Make sure that the pot is level.
4. Slowly add a measured volume of water to the media until a water slick appears on the surface. The volume of water added is the pore volume of the media [B]. Record this number.
5. Without moving the pot, remove the drain hole covers or plugs. Let the water drain into a bucket, then measure the volume of water that drained. This is the aeration pore volume [C]. Record this number.
6. Calculate the media porosity using the following formula:

Media porosity formula

Total porosity (%)	=	(B / A) x 100
Aeration porosity (%)	=	(C / A) x 100
Water retention porosity	=	Total porosity – Aeration porosity

Sample Calculation:

[A] Total container volume	=	5,180 mL
[B] Pore volume (water added to saturate the media)	=	3,354 mL
[C] Aeration pore volume (water drained from container)	=	1,080 mL

Total porosity	=	(3,354 / 5,180) x (100)	=	65%
Aeration porosity	=	(1,080 / 5,180) x (100)	=	21%
Water retention porosity	=	65% – 21%	=	44%

Adjusting Potting Mix pH

It is important to maintain the correct pH range for container crops. Here are some key points to remember:

- Maintain a potting mix pH between 5.5 and 7.0. High levels of bicarbonates in southern Ontario irrigation water can significantly raise media pH over just one growing season.
- Do not use alkaline sand in the media when growing pH-sensitive crops.
- Acidifying fertilizers may help slow down the rise in pH from bicarbonates in the irrigation water. When using fertilizer injectors, apply fertilizer and acid concentrates as separate solutions.

- Irrigation water can be acidified with nitric or phosphoric acid, depending on the bicarbonate content of the water. For more detailed information on acidifying irrigation water, see Chapter 3, "Water, Growing Media and Crop Nutrition," in OMAF Publication 370, *Guide to Greenhouse Floriculture Production.*
- *Juniperus* and *Thuja* will grow adequately at a higher pH, but plants such as *Betula*, *Hydrangea*, *Syringa*, *Rhododendron* and *Taxus* will exhibit iron and/or manganese chlorosis if the pH is above 7.0.

Fertilizing Container Stock

Most container mixes contain little or no soil, resulting in low nutrient-holding capacity. Synthetic fertilizers are required to provide crop nutrients for container-grown plants.

Fertilizers may impact the environment, especially surface and groundwater systems. Organic substrates found in container mix, such as peat and bark, are generally negatively charged. This means that they repel negatively charged molecules, such as nitrates and phosphates. As a result, nitrates and phosphates leach easily from most container substrates, so it is important to provide them in small quantities over the course of the growing season. Controlled-release (slow-release) fertilizers deliver nutrients to the root zone for root uptake in a timed-release format that minimizes losses out of the container. Putting fertilizer on the surface of the media (top dressing) is very efficient in container production. Since pots are susceptible to blow-over, some growers place fertilizer just below the media surface or incorporate the controlled-release fertilizer so it is distributed throughout the media.

To help reduce impacts on the environment and maximize the efficiency of a fertilizer program, take measures to reduce leaching from containers. Reduce the amount of irrigation water used during each irrigation event to minimize the amount of water (leaching fraction) coming out from the bottom of the pot. Pulse or cyclic irrigation (e.g., 20 minutes on, 60 minutes off, 15 minutes on) can also significantly reduce both the leaching fraction and the total amount of irrigation water required. Pulse irrigation will also reduce the concentration of nutrients that can leach out of the bottom of the pot. A leaching fraction of 10%–15% will minimize nutrient loss while preventing salt buildup in the root zone. Design and construct container production areas so that they collect and divert irrigation and leachate water run-off for storage and re-use.

How to Sample and Test Container Media

In general, organic substrates are low in fertility (N-P-K). This makes regular media testing a vital part of successful container production. Sample media every 2 weeks for pH, soluble salt (EC) and nutrient analysis. Once a pattern of nutrient levels has been established, monitoring can be limited to testing every 2 weeks for pH and EC readings, along with an occasional nutrient analysis. For more information about measuring media pH and EC, see OMAF Publication 370, *Guide to Greenhouse Floriculture Production*.

Here are some key points to remember:

- Use a small-diameter sampling probe to sample container-grown stock. To obtain a sample, remove the pot and take a core through the media, midway between top and bottom of the container and midway between the stem and the edge of the pot.
- Take samples from at least 10 pots and then mix them to get one pooled sample of media for testing. A pooled sample will better represent the nutrient status of media in that block. To reduce the impact on the root systems, take smaller media samples from a greater number of pots. Some horticulturalists remove fertilizer prills from the media samples, while others include them. To be consistent between each sampling, remove fertilizer prills from media supplies.
- Refrigerate the sample until it can be delivered to the lab.
- If water-soluble fertilizer is applied with each irrigation event, sample the soil 30 minutes after the application ends.
- If a dry surface fertilizer (granular or pellet) is used, always sample before adding the fertilizer. Insert the probe carefully, avoiding any surface fertilizer residue.

- When both are applied at recommended rates, water-soluble fertilizers normally produce lower salt concentrations than pre-incorporated controlled-release fertilizers.
- Analyze all soil samples from container potting mixes at an OMAF-accredited laboratory using a saturated paste analysis for greenhouse media. Compare these test results with previous samples and with the ranges in Table 1–14, *Media Nutrient Levels for Most Container Crops in Greenhouse Media Tests*, on page 21 to determine trends in pH, EC and nutrient status. Analysis results can then be correlated with plant growth and health symptoms to help establish thresholds for irrigation water and media test results.
- Adding an active source of controlled-release fertilizer in the pot will help keep crops healthy and marketable in retail nursery centres.

Using Water-Soluble Fertilizers

Apply water-soluble fertilizers through a low-volume irrigation system (e.g., drip, spray stakes) using an accurate concentrate diluter or injector. Remember that fertilizer nutrients are salts, so too much fertilizer can actually damage roots.

In theory, water-soluble fertilizers are applied at every watering. However, this may not be the most efficient use of fertilizer. There is evidence that intermittent fertilizer application can result in similar levels of plant growth compared to constant fertilizing.

When water-soluble fertilizers do not contain micronutrients (e.g., iron), add these to the mix before potting or as soluble trace elements during the growing season. Composted waste materials (e.g., composted vegetable waste) are quite often a good source of micronutrients. Dry materials with added bulking agents are less concentrated than compost, making them easier to blend into the mix. Use these as recommended by the manufacturer.

Commercial water-soluble fertilizers come in various formulations (e.g., 24-10-20 or 28-7-7). Use them at the rate of 100–200 ppm nitrogen (i.e., up to 83 g of 24-10-20 per 100 L of water). Fertilizers with high percentages of phosphorus (e.g., 10-52-10) should only be used at very low rates or blended with other low-phosphorus fertilizer formulations.

Avoid the use of water-soluble fertilizers on media with low aeration porosity. In this case, watering to fertilize may cause poor growth due to low aeration. Controlled-release fertilizers may be a better choice.

Using Controlled-Release Fertilizers

Controlled-release (encapsulated) fertilizers work well with container stock. There are three ways to apply them: incorporate controlled-release fertilizers into the potting mix, top-dress them on the media surface or create 2–4 pockets just below the media surface and dibble them into these pockets. Use as suggested by the manufacturer. Incorporating or dibbling controlled-release fertilizers can actually prolong the release pattern of the product and improve plant growth over the season compared to top dressing. Incorporating or dibbling controlled-release fertilizers can also prevent spillage losses that are common with top dressing.

Avoid excessive mixing when preparing a potting mix. Mixing may break fertilizer particles, which can cause problems due to excessive fertilizer salt release. Use potting mixes with pre-incorporated, controlled-release fertilizers quickly, especially during warm weather.

Several controlled-release fertilizer formulations now contain micronutrients. When controlled-release fertilizers do not contain micronutrients (e.g., iron), add these according to the manufacturer's recommendation. Supplemental fertility, particularly nitrogen, may benefit fast-growing crops when using controlled-release fertilizers. In container media, nitrate-nitrogen levels can be determined using the greenhouse media testing protocol at a commercial lab. When media tests show nitrate-nitrogen values under 39 ppm, add supplemental nitrogen to plants.

TABLE 1–14. Media Nutrient Levels for Most Container Crops in Greenhouse Media Tests

Nutrient Concentration		What to Do
Nitrogen (as water-soluble nitrate-nitrogen NO_3N)		
Low	0–39 ppm	Add extra nitrogen to the feeding program.
Normal	100–199 ppm	Continue fertilizing with nitrate-nitrogen and test total salts (EC).
Excess	250+ ppm with high salts	Discontinue fertilizing with nitrate-nitrogen and check total salts as root damage may occur. An exception is when the media contains a significant amount of bark that is not fully composted. Bark mix: Because this media has a high C:N ratio, higher levels of nitrogen are required to ensure enough nitrogen is available to the crop for optimal growth.
Phosphorus (as water-soluble P)		
Low	0–2 ppm	Add additional phosphorus to the feeding program.
Normal	6–9 ppm	Continue fertilizing with phosphorus and test total salts (EC).
Excess	50+ ppm	Discontinue fertilizing with phosphorus.
Potassium (as water-soluble K)		
Low	0–59 ppm	Add additional potassium to the fertility program.
Normal	150–250 ppm	Continue fertilizing with potassium and test total salts (EC).
Excess	350+ ppm	Discontinue fertilizing with potassium and leach with low EC irrigation water. Note that plants may tolerate high levels potassium if the media contains a high proportion of organic material. (Leaching is not effective for removing controlled-release fertilizer that has been incorporated in the media.)
Soluble salts (EC) in mS/cm (mhos x 10^{-3}/cm)		
Low	0.75–2.0	Check for adequate nitrate-nitrogen and potassium levels.
Normal	2.0–3.5	Continue the fertilizer program.
Excess	3.5+	Discontinue the fertilizer program. Note that plants may tolerate high levels if the media contains a high proportion of organic material.
Calcium (as water-soluble Ca)		
Low	0–79 ppm	Add extra soluble calcium to the feeding program. (Calcium levels are easily raised by adding dolomitic lime or gypsum to the media.)
Normal	200–300 ppm	Continue the fertilizer program.
Excess	400+ ppm	Consider reducing the use of fertilizers or media components with significant sources of calcium (e.g., lime, gypsum or soluble calcium).

TABLE 1–14. Media Nutrient Levels for Most Container Crops in Greenhouse Media Tests *continued*

Nutrient Concentration		What to Do
Magnesium (as water-soluble Mg)		
Low	0–29 ppm	Apply 0.5 kg/1,000 L of magnesium sulphate in water.
Normal	70–200 ppm	Continue the fertilizer program.
Excess	200+ ppm	Consider reducing the use of fertilizers or other media components with significant sources of magnesium (e.g., dolomitic lime or soluble magnesium).
Miscellaneous		
Sulphate levels should not exceed 300 ppm in a greenhouse media test.		
Chloride levels should not exceed 50 ppm in a greenhouse media test.		
pH should fall between 5.0 and 6.5 in a greenhouse media test.		

Check soil test values in early June of the second growing season after using pre-incorporated controlled-release materials. If necessary nutrients are missing, apply supplemental controlled-release fertilizer. Some controlled-release materials are rated to provide nutrition for two growing seasons and others for only 3-4 months.

Controlled-release fertilizers may produce inconsistent soil test results if prills break during sampling, shipping or testing. Most horticulturalists will remove prills before mixing and testing media samples for lab analysis, especially if the prills are at the beginning of their release pattern. It is important to be consistent with media sampling protocols. It is also helpful to take notes about the sampling block (age of media, fertilizer dates, age of plants, etc.).

Measuring Nutrient Levels in Container-Grown Crops

For accurate results, it is important to sample media correctly. See *How to Sample and Test Container Media*, on page 19, for sampling instructions.

Woody plants use nitrogen in the form of both nitrates and ammonium. Under most summer conditions, ammonium nitrogen converts quickly to nitrate-nitrogen due to micro-organism activity. Current container media tests measure nitrate-nitrogen. However, ammonium-nitrogen can be measured on request. Controlled-release fertilizers in the media may produce inconsistent nutrient test results, especially if capsules break during sampling, shipping or testing. Monitor crops for growth and plant health, and compare media tests with nutrient levels listed in Table 1–14, *Media Nutrient Levels for Most Container Crops in Greenhouse Media Tests* on page 21. OMAF-accredited laboratories report container media nutrients in parts per million (ppm). For more information, see OMAF Publication 370, *Guide to Greenhouse Floriculture Production*.

Irrigation Water

Water Quantity

The use of irrigation water for nursery crops usually peaks in late spring and summer. This is also the period of peak water use for most other agricultural operations and, historically, the period when Ontario receives the least rainfall. Nursery growers must conform to the Ministry of the Environment (MOE) regulations regarding daily usage of water.

The taking of water in Ontario is governed by the *Ontario Water Resources Act* (OWRA) and the *Water Taking and Transfer Regulation* (Regulation 387/04). Section 34 of the OWRA requires anyone taking more than a total of 50,000 L of water in a day from a lake, stream, river or groundwater sources, including spring-fed ponds, to obtain a permit from the MOE to take water. All permit holders must collect and record the volume of water taken daily and report this data annually to the MOE. Water conservation is an important part of MOE's Permit to Take Water program. When making an application for a permit, document current or proposed conservation measures.

- **For further information, see the Ministry of Environment's *Permit to Take Water Manual,* the *Guide to the Permit to Take Water Application Form* and other related factsheets online at www.ontario.ca/environment.**
- **Also see *Best Management Practices: Irrigation Management,* Order No. BMP08E.**

Irrigation Water Quality

Irrigation water quality is one of the most important components of a container growing system, yet it is often overlooked. Container-grown crops are irrigated every day, and the chemistry of that irrigation water can have a significant influence on the characteristics of the soilless media, the media solution and the nutrient solution. Over successive irrigation cycles, the chemical properties of the water affect the pH, soluble salts, bicarbonate level and other chemical properties of the media and media solution. Irrigation water quality has a major impact on root growth and, therefore, crop quality. The media in smaller pots is affected more quickly than in larger pots, due to the reduced buffering capacity of the smaller media volume. Symptoms of poor water chemistry may include nutrient deficiency symptoms, such as interveinal chlorosis. Poor water quality can actually reduce the availability of certain nutrients to plants and cause root dieback.

pH is a measure of the concentration of hydrogen ions (H^+) in solution. A high number of H^+ ions results in a low pH, while a low number of H^+ ions gives a high pH. pH is measured on a scale of 1–14, where a pH below 7.0 is acidic, a pH above 7.0 is basic or alkaline, and a pH of 7.0 is neutral. The higher or lower the pH, the more strongly basic or acidic the solution. The pH scale is logarithmic, so each unit in the pH scale represents a 10-fold change in the concentration of H^+ ions. pH can affect the chemistry and availability of dissolved fertilizer nutrients in the soil solution. High pH makes iron and manganese unavailable for plant uptake. The pH of water can also make some pesticides less effective. For example, high pH is known to reduce the efficacy of pesticides such as captan, dimethoate and flumioxazin. pH can change quickly in water and soilless media. For this reason, it is important to know the alkalinity of the irrigation water.

Alkalinity is a measure of the capacity of water to neutralize acids (or hydrogen ions). Alkalinity determines the buffering capacity of water; it defines how resistant the water is to a change in pH. In most sources of irrigation water in Ontario, bicarbonates (HCO_3^-) have the greatest influence on alkalinity. It is not unusual to have groundwater with more than 200 ppm of bicarbonates. These bicarbonates originate from the underlying limestone (calcium and magnesium carbonate) base. High concentrations of bicarbonates neutralize the hydrogen ions, resulting in a lower concentration of H^+ and therefore a higher pH. It is important to note that although there is a general correlation between pH and bicarbonate, the pH level does not determine the buffering capacity of the water. To determine the actual buffering capacity of water, the amount of bicarbonates (or calcium carbonates) present in the water source must be known.

For example, irrigation water from rainwater collected in a cistern may have a pH of 8.3, but its buffering capacity is quite low. Therefore, rainwater would have very little effect on the pH of container media. A chemical analysis of the water would uncover a negligible amount of bicarbonates. In contrast, irrigation water from groundwater sources with a pH of 8.3 would likely have high buffering capacity and would significantly influence the pH of the container media. This in turn would significantly affect nutrient availability in the root zone and, potentially, the efficacy of some pesticides. As these examples show, it is not enough to know the pH level of irrigation water: growers also need to know the level of bicarbonates in order to manage it properly to produce healthy crops.

The high levels of bicarbonates in irrigation water will influence soilless media over time, especially when overhead irrigation is the main method of watering. Although soilless media starts out with a low pH (e.g., 5.0), the buffering capacity of soilless media components is very low. This means irrigating with alkaline water will raise the media pH to 6.0–6.5 within the first 6 weeks. Symptoms of nutrient deficiency may be apparent after just a few months, especially in the case of pH-sensitive crops (rhododendrons, azaleas, red and pin oak, birch, lilac, hydrangea, etc.).

High levels of bicarbonates in irrigation water make it more difficult to lower the pH to an acceptable level for growing plants. Although acidifying fertilizers (those that contain ammonium-nitrogen and sulphur) can help neutralize some of the bicarbonates, acid injection may be the only effective solution for very alkaline water (i.e., water with >200 ppm bicarbonates). High levels of bicarbonates and high pH can be corrected by injecting nitric or sulphuric acid or a combination of both. If acid is used to correct water pH, make sure the injector is rated to handle acid. The volume of acid that needs to be added depends on the bicarbonate level of the water. For more information on water quality and correcting pH, see Chapter 3, "Water, Growing Media and Crop Nutrition," in OMAF Publication 370, *Guide to Greenhouse Floriculture Production*.

Soluble salts in irrigation water can also significantly affect plant growth in container production. The concentration of soluble salts is assessed by measuring electrical conductivity (EC). The soluble salts of most concern in irrigation water are sodium, chloride and sulphates. The pH and alkalinity of the irrigation water have a direct effect on the pH and alkalinity of the soilless media and the media solution. The EC of the irrigation water has a direct effect on the EC of the soilless media and the media solution too. High EC in the media solution can be the result of over-fertilizing or using poor-quality irrigation water. Either way, it can interfere with the crop's root function, and the resulting reduction in water and nutrient uptake may lead to root damage and death. Symptoms of high concentrations of soluble salts include small, dark-green leaves, wilting (even when the media is wet), marginal leaf necrosis, stunting and death. The specific symptoms may vary depending on the level of salts in the water and the salt tolerance of crop. If the EC of irrigation water is higher than the suggested ranges (see Table 1–15, *Acceptable Ranges for Chemical Properties of Irrigation Water*, on page 25), use alternative water sources on the most sensitive plants (e.g., herbaceous material and young woody material) and/or dilute water to bring the EC down to an acceptable level. Many plants can tolerate a higher EC if they are watered regularly and leached periodically.

TABLE 1–15. Acceptable Ranges for Chemical Properties of Irrigation Water

These ranges are general guidelines. Ornamental crops vary greatly in their sensitivity to soluble salts and the chemical properties of water, depending on their species, size and age and on the volume of the container.

Chemical Property	Acceptable Range for Most Container-Grown Woody Crops	Acceptable Range for Most Container-Grown Herbaceous Perennials/Greenhouse Crops
pH	5.0–7.0	5.0–7.0
EC (soluble salts)	less than 1.75 mS/cm	less than 1.0 mS/cm
Calcium carbonates ($CaCO_3$)	less than 150 ppm	less than 120 ppm
Bicarbonates (HCO_3)	less than 150–200 ppm (lower if not being leached with rainfall)	less than 100–150 ppm (lower if not being leached with rainfall)
Sodium (Na)	less than 70 ppm	less than 60 ppm
Chloride (Cl)	less than 140 ppm	less than 100 ppm
Sulphur (S)	less than 70 ppm	less than 70 ppm
Sulphates (SO_4)	less than 200 ppm	less than 200 ppm
Iron (Fe)	—	less than 5 ppm
Boron (B)	less than 0.8 ppm	less than 0.5 ppm

Water Testing

Along with media and leachate analysis, it is useful to test irrigation water throughout the growing season. Water quality is usually best in the spring, when water volumes are at their highest because of snowmelt and high rainfall. Unless road run-off contributes significantly to your source of irrigation water, soluble salts are more dilute in spring, giving lower EC values. Bicarbonate levels are also lower in spring. For these reasons, test irrigation water quality in the spring and compare it with summer and early fall water tests.

Iron levels can be a problem in irrigation water since iron is easily oxidized and forms precipitates that can block irrigation lines or cause uneven spray patterns. Calcium and magnesium (carbonates) will cause similar issues. Test water samples for a number of chemical attributes (see Table 1–15 above). In OMAF Publication 370, *Guide to Greenhouse Floriculture Production*, see Table 1–8, *Maximum Desirable Concentrations of Specific Ions in Raw Water Used for Irrigation Purposes in a Greenhouse Using Soilless Substrates*.

Collect samples of irrigation water below the water surface but above the bottom, around the level where the intake line sits. Try to collect water samples when the bottom sediment hasn't recently been disturbed. Collect approximately 500 mL and refrigerate the sample until it can be submitted to the lab.

When lab results indicate certain chemical properties appear beyond the acceptable range, options may include:

- finding an alternative source of irrigation water where chemical properties fall within the acceptable ranges
- finding an alternative source of irrigation water for plants that are most sensitive or have the smallest container volume
- leaching excess solutes from container media through supplemental irrigation with the same water source
- treating the irrigation water to remove salts — reverse osmosis, for example is an effective but costly solution that is limited by the capacity of the treatment system