Soil and Water Management for Vegetable Production

Vegetables can be grown on diverse soils, but good yields and quality depend on adequate fertility, uninterrupted drainage and on satisfaction of the crop's water and other physical demands. Selection of suitable fields as well as improvement and maintenance of favourable soil physical condition is the initial, basic element needed to ensure successful vegetable production.

Soil Physical Properties

Soil moisture regime, texture, structure and organic matter content are soil physical properties that affect, in interaction with other crop production factors, yield, quality and maturity of vegetable crops. Management of soils for vegetable production must utilize soils whose physical properties do not severely limit production. This is of major concern because the majority of soils in this region suffer in at least one serious physical limitation: excessive moisture (impeded drainage), poor structure (compactness), unfavorable (extreme) texture, stoniness or excessive slope.

Drainage

Impeded drainage, characterized by excessive moisture content within the root zone, for a significant period during the growing season, is one of the most common causes of poor production. The reason for the condition may be day-like soil texture, poor structure, compacted subsoil, topography or poor soil management. Impeded drainage causes poor aeration and unfavourable soil temperature (cooler) regime, causing poor root development, low efficiency of fertilizer use and accumulation of plant-toxic compounds in the topsoil. Also soil trafficability and use of machinery is reduced and the chance of pest and disease damage is greatly increased.

Soil Structure

Compacted subsoils, commonly found as close to the soil surface as 20 cm, can be thin (5 to 30 cm) single layers that are formed naturally, or caused by improperly applied soil management. These "pans" may be continuous or patchy and are underlaid by less dense and more permeable soil. Man-induced "pans" are caused by repeated, excessive and untimely tillage, use of tillage equipment that damages soil structure, depletion of soil of organic matter and untimely traffic over the field. Many compacted sub· soils are very dense, continued in deep layers that are naturally formed (lodgment, basal till).

Soil Texture

The texture of a mineral soil is determined by the proportions of sand, silt and clay as well as coarse fractions (gravel and stones). Loam contains sand, silt and clay in the approximate ratio of 2:2:1. Loamy soils, sometimes called "medium" textured, have favourable physical characteristics such as good drainage, water retention, favourable structure and are easy to till. Soils with a much higher sand fraction may be subject to poor water retention and leaching, while clay and silty soils are often poorly drained and sensitive to structure damage: "slumping", crusting (capping) and cracking. Tillage is often difficult, and tillage while soil is wet often results in formation of clods.

Organic Matter
Most mineral soils contain between 1 and 5 percent of organic matter. Topsoil used for vegetable production should contain in excess of 3 percent organic matter. The organic matter, besides being a minor source of plant nutrient and an important agent in moisture retention, has an important role to play in maintaining soil structure. This is done by binding soil particles together into stable crumbs and aggregates. This, in turn, facilitates water penetration and drainage and allows roots to grow without hindrance.

Poor soil structure may be the result of extreme texture such as prevalence of clay, silt or sand, or poor soil management. Structure and soil physical properties in general can be improved by drainage improvements and by increasing the soil organic matter content.

Liming
The main purpose of liming is to correct soil acidity but soil structure also benefits from liming. Both calcium and to a lesser extent, magnesium, help to stabilize soil aggregates and so improves structure. By promoting crop growth and microbiological activity, lime contributes to root proliferation and humus production from the breakdown of organic matter.

Drainage

Effectively managing the periodic excess of water that occurs in Atlantic Canada is just as important as supplying adequate water during periods of drought at critical stages of crop growth.
Poor drainage is detrimental co vegetable production. When the field with impeded drainage is considered for vegetable production, obtain advice from Perennia staff with respect to the most suitable drainage improvement method, suitable crop selection and soil management techniques. There are a number of techniques designed to improve moisture regime, each of them best suited to particular conditions. The moisture regime improvement methods include subsurface tiling, ditching, land forming, subsoiling and raised bed forming. The last two methods listed not only improve the moisture regime itself, but also increase effective soil depth available for root penetration.

Organic Matter and Crop Rotation

Addition of organic matter may take the form of farm-yard manure, compost or peat and green manuring, where a crop is grown simply for ploughing down (e.g. winter rye or buckwheat).

Soil organic matter breaks down rapidly under the intense cultivation associated with vegetable production. While rotations including grass sod crops are most effective in maintaining organic matter, it may be necessary to rely on green-manure and cover crops where such rotations are not feasible. Ideally, grass should appear in the rotation twice every four to five years but at the very least once every three years. Sod crops are important in the rotation since they maintain porosity and good structure in fine-textured soils (clay & silts). They also improve the water-holding capacity of sandy and gravelly soils. In addition to maintaining good soil structure, the organic matter helps to control several common soil-borne vegetable diseases.

These benefits are greatest on soil which is adequately fertilized. The best fall seeded crops appear to be fall rye or Italian rye grass, with rye grass being an effective crop for spring planting.

Soil Acidity and Liming

Acid soil contains minerals and complex compounds that are toxic to crops. Also efficiency of fertilizer use is sharply decreased with increased acidity. It is of utmost importance to understand acidity and amend the soil by liming.

The pH scale ranging from 0-14 is used to indicate acidity or alkalinity. A pH value of 7.0 indicates neutral; values below 7.0 indicate acid and those above 7.0, alkaline. One should realize that a difference of one unit of pH is in effect a ten fold difference in actual soil acidity or alkalinity. Most vegetable crops grow well in a mineral soil with a pH range of 6.0 to 6.5 and in an organic (peat) soil with a pH range of 5.5 to 6.0.

To correct soil acidity, ground limestone or other liming materials are broadcast and worked into the soil. The rates and type (calcitic, dolomitic) of liming material should be determined by a soil test. As it takes many months for lime to neutralize the soil, fall liming is preferred to a spring application. Do not overlime! Micronutrient deficiencies are most likely to appear on fields that have been limed to values over 6.8.

Seedbed Preparation

This aspect of vegetable culture is probably the most important and one of the most difficult to achieve. A poor seedbed will affect germination, seedling establishment and, ultimately, yield and quality.

A germinating seed requires warmth, air and water. As mentioned previously, a well-drained soil of good structure will be warmer than its poorer counterparts. The crumbs will retain water while, at the same time, allowing drainage of excess water to keep air spaces open. Furthermore, good structure will guard against "slumping" and compaction as well as reduce the probability of crusting (all these factors present serious physical barriers to germinating seeds).

Seedlings also must be protected as much as possible from weeds, diseases and pests which compete with or threaten the young plant. Many specific pesticide programs have been developed and should, of course, be employed before and after seeding. Intensive vegetable production often employs a system of general soil sterilization especially for seedbeds. This ensures a general "kill" of disease inoculum, insects, nematodes and weeds (including their seeds).

Final soil preparation before sowing may include harrowing rolling and dragging until the soil surface is smooth and clod-free. Formation of raised beds is becoming common practice; this facilitates drainage from the seedling root zone and lessens the risk of compaction from wheel tracks.

Do not overtill the soil. Use tillage equipment sparingly especially those which damage soil structure such as roto-tillers, disks, packs and drags. Do not till when the soil is extremely wet or dry.

Fertilizer Materials

All fertilizer salts are toxic to germinating seeds and to plant roots, if applied in sufficient concentration near the seed. Fertilizers vary in toxicity per unit of plant nutrient due to: (1) differences in the amount of salts contained in the fertilizer per unit of plant nutrient; (2)

differences in solubility of the salts in the soil; and (3) a few specific materials or elements are particularly toxic to plant roots (for example, boron). Phosphate fertilizers usually do not injure plant roots. The concentration of phosphorus in the soil solution at any one time is very low.

1. Nitrogen Sources		
Nitrogen Materials	**Form**	**%Nitrogen (N)**
Anhydrous Ammonia	Gaseous	82
Ammonium nitrate*	Dry	33 to 34
Urea*	Dry	45 to 46
Ammonium sulfate	Dry	20
Ammonium nitrate-urea (UAN)	Liquid	28
Ammonium nitrate-urea (UAN)	Liquid	32
Calcium ammonium nitrate*	Dry	17
Calcium nitrate	Dry	15.5
*Nitrogen materials in common use in bulk-blended fertilizers in Atlantic Canada		

Nitrogen fertilizers are available in dry, liquid and gaseous forms. Which of these forms to use is a matter of choice for the individual vegetable grower, depending upon availability of the material, equipment for handling, cost per kilogram of nitrogen, and the cost of application and grower preference.
Ammonium nitrate and ammonium sulfate are similar in toxicity to plants and much safer than urea. Urea is toxic when banded with or near the seed but is not toxic to plant roots when broadcast at rates normally used. Fertilizers containing more than half as much nitrogen as phosphate frequently contain urea.

2. Phosphate Sources	
Phosphate Materials	**% Phosphate (P_2O_5)**
Superphosphate	18 to 20
Triple super phosphate*	44 to 46
Monoammonium phosphate (MAP) [11%N]	50 to 54
Diammonium phosphate (DAP) [18%N]*	46
*Phosphorus materials in common use in bulk-blended fertilizers in Atlantic Canada.	

Most common phosphate fertilizers are not very toxic to seeds and plants and no limit is normally set for the safe rate which may be applied near the seed of vegetable crops.

Diammonium phosphate (DAP) is more toxic than other phosphate fertilizers; thus, more care should be taken than is required with MAP (particularly with sensitive seeds and coarse soils).

3. Potash Sources	
Potash Materials	**% Potash (K_2O)**
Muriate of potash*	60
Sulfate of potash	50
Sulfate of potash-magnesia [11% Mg]	22
Potassium nitrate [13% N]	44
*Potash materials in common use in bulk-blended fertilizers in Atlantic Canada.	

Muriate of potash (KC1) is the most common source of potassium in fertilizers, and is less toxic per unit of plant nutrients than most nitrogen fertilizers; sulfate of potash (K_2SO_4) is even less toxic while sulfate of potash-magnesia has approximately the same toxicity per unit of potassium as muriate of potash.

Potassium nitrate is one of the safer sources of potassium when considered as a nitrogen source.

Fertilizers containing micronutrients (boron, copper, iron, manganese or zinc) are more toxic than the same grades without micronutrients, and maximum safe rates should be reduced. Boron is particularly toxic.

Fertilizer Placement

Phosphorus is most important for early growth and is more available if placed near the seed. For transplant crops, the use of high-phosphorus starter solution may be beneficial.

Nitrogen fertilizers readily dissolve in the soil water and move easily through the soil to the plant roots. Placement of nitrogen is less important than for phosphorus. Part of the nitrogen requirements is usually broadcast, injected or worked into the soil before planting, often to hasten the breakdown of a cover crop. Much of the nitrogen is not applied until side-dressing, in order to conserve the fertilizer from leaching, or to restrain plants from too much vegetative growth.

Too much potassium applied in a band at planting or in the transplant water can injure young seedlings and reduce crop yield and quality. This danger of fertilizer injury is greater on sands and sandy loams than on silt loam and day loam soils. On the coarse textured sands and sandy loams part of the potassium fertilizer requirements should be broadcast and worked into the soil before planting.

Starter Solutions

Water soluble fertilizers (e.g. 10-52-10) and liquid fertilizers (e.g. 6-24-6) which contain N, P, and K are used as starter solutions at planting time to stimulate the growth of young transplants.

Side-dressing

The purpose of side-dressing is to supply additional nutrients during growth of the crop. Most commonly, nitrogen is the nutrient that is supplied after the plant has reached a certain stage of development. With crops that produce fruit (e.g. peppers or tomatoes) it is important not to have too much vegetative growth early in the season, or flowers will not develop, or may drop off if they do develop. For this reason, it is usually advisable to put only a moderate amount of nitrogen in the soil at the time of seeding or planting. After the plant has set some fruit and is no longer in danger of becoming excessively vegetative, extra nitrogen can be applied. The timing and amount of nitrogen side-dressing must be judged from the appearance of the plants. On coarse, sandy soil it may be advisable to add potash as well as nitrogen.

Fertilizer through the Irrigation System

Many fertilizers, but particularly nitrogen, may be applied through the irrigation system during the growing season. In some crops it is difficult to move along the rows with machinery without damaging the plants, whereas the irrigation water will penetrate evenly over the whole area without damaging the plants.

General Fertilizer Requirements

The requirement of a crop for any one of the fertilizer elements depends on many factors specific to the particular field and intended use of the crop. For example, the actual requirement for nitrogen can be affected by the previous crop, plant population, weather, cultivars selected, and whether the crop is to be marketed directly from the field or stored. The requirement for all fertilizer elements varies between direct seeding or transplanted production as well as date of establishment. In general the closer an element can be applied to the actual time of use by the particular crop and after as much of the variability created by the climate (such as excessive rainfall) is known the more effectively the requirements can be determined. The following tables provide a general guideline to the requirements for nitrogen, phosphorus, potassium, and micronutrients for various vegetable crops under differing production management systems

Table 1: Nitrogen Requirements of Vegetable Crops on Mineral Soils {Kg/Ha of N)

	Soil Production Management System			
Crop	**A**	**B**	**C**	**D**
Asparagus	100	140	90	60
Beans (dry or	40	70	30	20
Beets	60	90	50	30
Carrots	100	140	90	60
Celery	150	200	140	110
Cole Crops	150	200	140	110
Cucumbers	80	120	70	50
Lettuce	150	200	140	110
Onions	120	160	110	80
Parsnips	100	140	90	60
Peas	40	70	30	20
Peppers	80	120	70	50
Pumpkins	80	120	70	50
Radish	60	90	50	30
Rhubarb	150	200	140	110
Rutabagas	40	70	30	20
Spinach	100	140	90	60
Squash	80	120	70	50
Sweet Corn	120	160	110	80
Tomatoes	100	140	90	60
Turnips	40	70	30	20

*A – Row crop rotation (no plowdown)
B – Heavily cropped soils (low In organic matter)
C – Crop to follow a mixed sod plowdown
D – Crop to follow a legume sod plowdown

Table 2: Phosphorus and Potassium Requirements of Vegetable Crops on Mineral Soil (Kg/Ha of P_2O_5 and Kg/Ha of K_2O)								
	Phosphorus				Potassium			
Crop	Low	Medium	High	Very High	Low	Medium	High	Very High
Asparagus	200	150	100	50	350	250	150	100
Beans (dry or snap)	60	45	30	0	75	50	25	0
Beets	200	150	50	0	175	125	72	25
Carrots	200	150	50	0	175	125	72	25
Celery	250	200	150	75	350	250	150	100
Cole Crops	250	200	150	75	175	125	75	25
Cucumbers	250	200	150	75	75	50	25	0
Lettuce	250	200	150	75	250	175	100	75
Onions	250	200	150	75	175	125	75	25
Parsnips	200	150	100	50	175	125	75	25
Peas	60	45	30	0	75	50	25	0
Peppers	200	150	100	50	175	125	75	25
Pumpkins	200	150	100	50	175	125	75	25
Radish	100	60	40	20	75	50	25	0
Rhubarb	200	150	100	50	250	175	100	75
Rutabagas	200	150	100	50	175	125	75	25
Spinach	100	60	40	20	250	175	100	75
Squash	200	150	100	50	175	125	75	25
Sweet Corn	200	150	100	50	250	175	100	75
Tomatoes*	250	200	150	75	250	175	100	75
Turnips	200	150	100	50	175	125	75	25

*Maximum rates for banding of fertilizer at transplanting

1) These are general requirements for broadcast applications and may be reduced for band applications. Specific recommendations for each crop require a Soil Test.
2) Results from field experiments indicate that less fertilizer is required under mulch, especially on high fertility soils. This is due to the reduced leaching under mulch. Over

fertilization favors vegetative growth and thus may delay maturity and even reduced yields.

Table 3: Micronutrient Sources and Typical Rates of Applications			
		Application Rate of Actual Element	
		Soil	Foliar
Nutrient	**Common Sources**	**Kg/Ha**	**Kg/1000L**
Calcium (Ca)	Calcium chloride 36% Ca	-	2.2-4.0
	Calcium nitrate 20% Ca	-	1.2-3.4
Magnesium (Mg)	Dolomitic limestone 6-13% Mg	27.5-33.0	-
	Epsom salts (magnesium sulfate) 9.6% Mg	27.5-33.0	3-5
	Sulfate of potash-magnesium 11% Mg	17.0-22.5	-
Boron (B)	Various sources are available 8-21% B	1.0-3.0	0.2-0.6
Copper (Cu)	Copper sulfate 13-25% Cu	7.0-14.5	0.5-1.5
	Copper chelates 9-13% Cu	-	-
	Copper oxide 60-80% Cu	-	-
Manganese (Mn)	Manganese sulfate 26-28% Mn	-	0.5-1.0
	Manganese chelates 9-12% Mn	-	-
Molybdenum (Mo)	Sodium molybdate 39% Mo	-	0.1-0.25
Zinc (Zn)	Zinc sulfate 36% Zn	4.0-12.0	0.6
	Zinc chelates 9-14% Zn	1.0-2.0	-
	Zinc oxide 78-80% Zn	4.0-12.0	-

Water Requirements

Water constitutes 80-95 percent of the fresh weight of vegetable crops. The availability of water is desirable at all stages of growth for all crops; however, there are, for each crop, additional critical periods. All vegetables share one or more of the following uses for water:

1. As an aid in germination of seeds
2. In establishing transplants
3. To convey fertilizer to the root zone.

Adequate moisture must be available to germinate the crop, whether direct-seeded or subsequently transplanted. For direct-seeded crops, this involves difficult decisions for the farmer, especially where irrigation is not available. The best policy is to prepare the field for sowing and to sow after rain has brought the soil moisture to a level approaching field capacity. Soils with significant proportions of clay or organic matter will retain moisture, (therefore staying at optimal condition for seeding) for longer periods. Rain or irrigation after sowing may cause a physical barrier to emerging seedlings such as carrots. Anticrustant materials have been tested for their effectiveness in preventing this barrier from forming; sawdust appears to be the most effective and can be applied as a thin layer in a narrow band over the seed row.

Transplanting leads to a traumatic shock for all plants. Considerable damage may be done to the roots and water loss may exceed uptake until new roots grow; thus, wilting occurs. Seedlings produced in cells (such as in the "Speedling" system) will, of course, receive considerably less setback."Hardening-off", by reducing the level of watering prior to transplanting, may give plants a better ability to withstand shock.

Water is an important medium to carry fertilizer to the roots after top-dressing on dry soil. It can also be beneficial when soil is already at a high moisture level, especially where nitrogen may have been leached after heavy rains.

Water Requirements for Specific Crops:

A. Leafy vegetables

The cole crops, lettuce, celery and spinach need a fairly constant and abundant supply of moisture for maximum yields. The soil should thus ideally be adequately moist in the root zone at all times. The highest yields and best quality usually result when there have been no checks to growth because of a shortage of water or nutrients. It should be emphasized that, especially with the leafy vegetables, maximum response to water depends also on a sufficient supply of nutrients, particularly nitrogen.

Celery benefits greatly from an even supply of water; soils with high moisture-holding properties such as peat bogs are therefore well-suited to celery production. Cauliflower, when subject to early water stress, may later exhibit harmful effects such as premature heading or buttoning".

Transplanted crops need water most critically at two periods of growth: until they are established and in the last two weeks before harvest. This latter period is when rapid growth (and, therefore, yield increase) occurs. If irrigation is feasible to supplement rainfall, it can profitably be employed. Water in excess of 25 mm during this rapid growth period should be avoided in cabbage and lettuce, to avoid the danger of burst heads. Brussels sprouts have the greatest need for water during the first period (establishment); it is unlikely that water needs at harvest maturation warrant irrigation except in extremely dry years.

B. "Fruit" vegetables

The legumes (peas and beans) respond best to adequate water during flowering and pod development. After germination, an over-supply of water should be avoided since it may lead to excessive stem and leaf growth, as well as disease. Watering during pod development will tend to increase seeds per pod, size of individual seeds and delay the onset of toughness.

Other "fruit" vegetables (tomatoes, squash, cucumbers, peppers and sweet corn) also require water, especially at the time of flowering and fruit development. Outdoor tomatoes will not normally need water between establishment of the transplants and the onset of flowering. (Those grown in bags of peat or compost will probably need regular water because of root restriction). Water shortage during fruiting will result in smaller fruits and lower yields as well as aggravating physiological problems such as blossom end rot. On the other hand, maximum yields may be accompanied by a poorer flavor compared with fruit grown under drier conditions. The optimum water requirement will depend, in such cases, on grower experience and judgment.

Sweet corn, after establishment, does not normally suffer from dry conditions until flowering (tasseling). Water, at this point, whether as fortuitous rain or well-timed irrigation, will ensure a full set of well-filled kernels.

Cucurbits (cucumbers, squash) benefit from plentiful, though not excessive, water throughout their life. Rapid growth to build up leaf area is essential at first; after fruit-set, water is required to swell the fleshy fruits.

C. Root vegetables

Carrots, parsnips, turnips, rutabagas and radish do not respond favorably to a high amount of water; lush top growth will result at the expense of root development. Ideally, soil should remain relatively (but not excessively) dry. Sudden increases in soil moisture after a dry spell may cause cracking, especially in carrots and parsnips.

D. Onions

Onions benefit from adequate soil moisture while developing a deep root system. After this, response to water is not so marked. Wet conditions during the later stages of bulb formation may delay maturity and affect adversely the storage life of the bulbs.

Irrigation

The actual water requirement of vegetable crops depends on many factors such as soil type, depth of soil and plant root characteristics.

However for continuous vigorous growth of vegetable crops, they require a uniform supply of approximately 25 mm of rainfall per week. Whenever rainfall amounts are less than this, supplemental irrigation water should be considered. Irrigation is thus as important a consideration as cultivar, fertilizer or pest control in producing optimum yields.

Water available for crop growth depends upon the soil's ability to retain water following rainfall or irrigation. Sands and coarse sandy loams retain less than 25 mm of water in the top 30 cm of soil, or a supply for no more than 7 day's crop growth. On these soils a weekly schedule of 25 mm of water from rainfall or irrigation maintains high crop yields. Heavier applications of irrigation water waste fertilizer by leaching nutrients from the root zone. Excessive irrigation may cause crop injury by moving herbicides from the soil surface to crop roots.

Fine sandy loams and silty loams retain 40 to 60mm of water for crop growth. On these soils heavier and less frequent irrigations improve crop yield. Irrigations can be scheduled every 10 to 14 days at rates to provide a total of 40 to 50 mm of rainfall or irrigation.

Irrigation to cool crops during hot weather may increase crop yield. Cooling results when field heat evaporates irrigation water from crop and soil. Irrigation-cooling has only recently become practical, with solid-set system and automatic controls and valves which continually turn on and off series of sprinklers in a field. The water required for irrigation cooling is less than the amount needed for soil irrigation. Rates of 2 mm of water per hour for 2 to 3 hours are effective. Irrigation-cooling is scheduled when air temperature is 30° C or higher at noon.

References

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