CHECKLIST
BMPs for VEGETABLE PRODUCTION
REGULATIONS

Regulations

- √ For information on the Wetlands Protection Act or the Water Management Act, contact he Massachusetts Department of Environmental Protection (http://www.mass.gov/dep/water/approvals/wmgforms.htm).
- √ For Information on Land Use Regulations contact the Massachusetts Department of Agricultural Resources (http://www.mass.gov/agr/legal/regs/index.htm)
- √ For information on Pesticide Use Regulations contact the Massachusetts Department of Agricultural Resources http://www.mass.gov/agr/legal/regs/pesticides_regulations_list.htm)
- √ For information on Fertilizer and Lime Regulations contact the Massachusetts Department of Agricultural Resources (http://www.mass.gov/agr/legal/regs/index.htm)
- √ For information on Agricultural Composting Regulations contact the Massachusetts of Agricultural Resources (http://www.mass.gov/agr/legal/regs/index.htm)

CHECKLIST
BMPs for VEGETABLE PRODUCTION
SITE SELECTION

- √ Collect a history of fields including crops grown**,** diseases and pest problems, and pesticides and herbicides used.
- √ Choose a site with well drained soils, free from flooding, high water table, and rocks.
- √ Avoid steep slopes to prevent erosion and low areas which are prone to cold pockets. Gently sloping land is best.
- √ Check soil survey maps for data on soil texture for your site; these are available from the Natural Resources Conservation Service (NRCS). (http://www.ma.nrcs.usda.gov/technical/soils/index.html).
- √ Identify wetland and water resources. These resource areas include (but are not limited to) streams, ponds, bogs, marshes, swamps ,floodplains, isolated land subject to flooding, wet meadows, salt ponds, salt marshes, and fish runs. Agricultural activities are subject to the jurisdiction of the Massachusetts Wetland Protection Act (WPA). For information on the WPA contact the Massachusetts Department of Environmental Protection. (http://www.mass.gov/dep/water/waterres.htm)
- √ Determine if adequate water supplies are available. The Water Management Act (WMA) authorizes the Massachusetts Department of Environmental Protection to regulate the quantity of water withdrawn from both surface and groundwater supplies. The WMA consists of a registration program and permit program. For information on the WMA contact the Massachusetts Department of Environmental Protection (http://www.mass.gov/dep/water/approvals/wmgforms.htm).

CHECKLIST
BMPs for VEGETABLE PRODUCTION
SOIL CONSERVATION AND TILLAGE

√ Minimize soil loss by soil conservation practices such as crop rotation, contour cultivation, strip cropping, and conservation tillage.

√ Rotate crops that provide limited soil cover with crops that provide a higher amount of cover. Rotating crops provides yield advantages and residues from crops influence soil properties that impact soil aeration and drainage.

√ Contour Plowing is the practice of planting crops across the predominant slope of the land, along the contour, to reduce soil erosion by water.

√ Planting cover crops between rows can prevent soil erosion. Strip crops that provide a high amount of cover can filter sediment in runoff from crop rows.

√ Always plant cover crops in a field that is out of production. Cover crops reduce erosion, protect water quality, reduce weed establishment, and enhance nutrition of the subsequent crop.

√ Leave crop residue from previous crop on soil surface to act as a mulch. This will also add organic matter to the soil which enhances soil fertility, soil structure, and water holding capacity. This practice may be impossible where disease and insect issues dictate incorporating plant debris.

√ Deep tillage practices such as deep, vertical tillage, subsoiling, or ripping break up restrictive soil layers (hardpan) and improves water infiltration thus reducing runoff and erosion.

√ Avoid tillage and crop production in areas that are prone to excessive erosion. Permanently vegetate these areas to protect the soil.

√ Conservation tillage can consist of tillage practices such as;

- No-till planting
- Strip rotary tillage
- Till planting
- Annual Ridges
- Chiseling or Disking

√ Construct diversions for controlling surface runoff water, stabilize diversions by vegetating waterways, and construct sediment basins.

√ Buffer strips are narrow strips of permanent plant cover that are established across the slope and alternated with crop areas reduce erosion and transport of sediments.

√ Soil drainage characteristics are considered and subsurface drainage systems are installed to reduce soil saturation and surface water.

SOIL CONSERVATION

Soil erosion is the process that occurs when wind, water, and other factors cause soil to deteriorate or disappear completely. The key to preventing erosion and maintaining farmland is the farmer. Soil conservation practices such as contour faming, conservation tillage, crop rotation, cover crops, and grassed waterways contribute to good soil and water quality. Many of these soil conservation practices also contribute to improved soil structure and fertility.

The government is involved in preventing the effects of soil erosion. In 1935 the Soil Conservation Service was establish to administer a program of assistance in soil and water conservation in cooperation with Conservation Districts. This agency is now known as the Natural Resources Conservation Service (NRCS) and provides (among other programs):

- Soil suitability guidelines based upon soil surveys for agriculture and other uses
- Best Management Practices for erosion control and water protection
- Sediment interception systems design
- Water facilities such as farm ponds design
- Terrace, irrigation, and drainage systems design
- Developing cropping systems to reduce erosion
- Promoting wildlife and woodland conservation
- Supplying adapted materials for conservation planting
- Expertise on land use planning

See www.nrcs.usda.gov for access to publications and technical information.

Minimizing Soil Loss

Growers realize that soil loss is a normal consequence of agricultural production. If this soil is not replaced, the field may lose its productive capacity. Many growers use compost to replace some of the topsoil that is lost. Aged compost can be applied at high rates if thoroughly incorporated. Another option for depleted soils is incorporating large quantities of wood chips or bark mulch and one year of growing green manure cover crops to allow decomposition of this large volume. All forms of soil removal can be diminished by adding mineral and organic matter during the growing cycle.

- After harvest incorporate composted manure, straw or other organic materials. This addition of stable organic matter enhances native soil fertility, improves soil structure and water holding capacity, and contributes to resistance to erosion.
- Plant cover crops to protect against winter erosion. This practice also adds organic matter to the soil. Cover crop roots contribute to soil structure. Nutrients are trapped in the soil and released to the spring crops.
- Always plant cover crops in any field that is out of production.
- Install subsurface drainage systems in upland soils to prevent soil saturation, prevent surface water ponding, and reduce surface runoff and erosion.

Best Management Practices for soil erosion are a combination of management, cultural, and structural practices that agricultural scientists have pinpointed as being the most effective and economical way of controlling soil erosion without disturbing the environment. They range from protection of the natural environment to the construction of artificial devices. Some of these practices are crop rotation, contour tillage, strip cropping, terracing, grass waterways, diversion structures, riparian strips, and conservation tillage.

Crop Rotation

There are many reasons why crop rotation makes farmland more productive. It improves the efficiency of nitrogen uptake and utilization. The yield advantage of crops being rotated is greater than that of continuous crops. Conservation tillage systems which leave much of the prior crop residue on the soil surface are better adapted to crop rotation. Crop residues from corn and other grain crops influence soil properties that influence soil drainage and aeration. Rotating crops can reduce the potential for serious insect and disease infestations, especially where some form of conservation tillage is practiced. Crop rotation is good for soil health because it leads to changes in tillage, nutrient removal, and root depth. Some crops can increase the activity of beneficial microorganisms.

Contour Cultivation

A special tillage practice carried out on gently sloping land, contour cultivation can reduce the velocity of surface water runoff. It should not be practiced on steeply sloping land as it will make soil erosion worse.

Strip Cropping

Strip cropping is a planting technique where different crops are alternated in strips in the same field. This BMP controls both wind and water erosion. If the strips are planted along the contour, water movement is minimized; if the strips are planted crosswise to the contour, wind erosion is reduced. Contour strip cropping is where the crops follow a definite rotational sequence, and tillage is held closely to the exact contour of the field. Field strip cropping consists of strips of a predetermined width planted across the general slope of the land. When strips are combined with grassed waterways, this technique can be used where contour planting is not feasible. The buffer strip cropping technique uses strips of grass or legume crops laid out between contour strips of crops in irregular rotations. These strips may be even or irregular in width or placed on critical slope areas of the field.

Grassed Waterways and Diversion Structures

Grassed waterways force storm runoff water to flow down the center of an established grassed strip. Large quantities of water can be diverted without resulting soil erosion. Grassed waterways can also be used to trap and filter sediment, but can lose their effectiveness if to much sediment accumulates. The use of crop residues, buffer strips, and other soil conservation techniques can make grassed waterways more effective. Diversion structures are similar to grassed waterways and are channels constructed across slopes to force water to a desired outlet.

Riparian Strips

Riparian strips are simply buffers of grass, shrubbery or other vegetation that are allowed to establish on the banks of streams, ponds, or other water features. These strips slow runoff water and filter out sediments. They can reduce sediment flow and the attached nutrients and pesticides by 30-50%.

Conservation Tillage

Conventional tillage provides a smooth soil surface that is prone to serious erosion and runoff problems, especially on sloping land. Conservation tillage is any planting tillage system that leaves 30% or more of crop residue on the soil surface after planting is completed and employs reduced or minimal tillage operations. There are many different conservation tillage systems:

- No-till planting prepares only a strip of soil 2 inches wide for the seedbed and leaves most of the soil surface undisturbed and covered with crop residue. This results in a colder and wetter environment for the seed.
- Strip rotary tillage prepares an 8 inch wide and 2-4 inch deep strip of soil with a rotary tiller or basket cultivator and leaves the rest of the soil undisturbed. Crop residue between the cropped strips conserves the soil.
- Till planting sweeps the crop residue into the area between crop rows. The soil between the rows is not tilled and is resistant to rain drop impact and runoff.
- Ridge tillage also known as Annual or permanent ridges are formed by a rolling disc bedder and spring planting occurs with little soil preparation. Soil conservation is improved by increasing amounts of crop residues and contour planting.
- Chiseling or disking does not turn the soil surface over but leaves it rough and cloddy with a lot of crop residue. This reduces both raindrop impact and surface runoff velocity.

Cover Crops

Methods to increase organic matter in the soil include winter cover crops and green manure crop rotation.

Grasses and small grains are typically used in a green manure program. Small grains are grown in the fall and killed with an herbicide or plowed in before they produce seed in the spring. Sorghum-sudangrass hybrids are used as a summer cover crop when planted in April or May. They must be mowed to prevent seed formation and are generally incorporated in the fall.

Cover crops are grown to maintain vegetative cover on the soil and protect the soil from water and wind erosion as well as improving soil productivity. They reduce weed competition and improve soil tilth and soil fertility. Choice of a cover crop is determined by a farmer’s desired benefit. Cover crops are grown to protect and enrich the soil. They protect the soil from water and wind erosion and can aid in reducing soil compaction. Legumes can fix nitrogen from the air and provide nitrogen for a subsequent cash crop with a high nitrogen demand. Other cover crops don’t create nutrients, but they can conserve those nutrients which might be lost to leaching. Some cover crops are deep rooted and can obtain nutrients from below the root zone of most vegetables. When these crops are incorporated, these nutrients will be released into upper layers of soil. Fast growing cover crops suppress weeds by smothering them and depriving them of sunlight. High seeding rates are used in cover crops grown for weed suppression.

Non leguminous Crops
Winter Rye
Oats
Annual Ryegrass
Sudangrass
Sorghum-sudangrass
Japanese Millet
Buckwheat

Legumes
Red Clover
White Clover
Sweet Clover
Hairy Vetch
Alfalfa
Mixtures of legumes/grass

Soil Tilth

Soil tilth is a term used to describe the physical condition of the soil and includes bulk density, porosity, soil structure, and soil aggregate characteristic. Tilth has an effect on water, air, and nutrient movement as well as affecting soil biological populations. Compaction of soils by equipment and personnel destroys soil tilth. Once compaction occurs and porosity reduced, plants roots have less access to oxygen and water movement is impeded. Soil compaction is difficult to ameliorate; it is better prevent it.

The addition of cover crops to soil reduces its compaction, decreases soil bulk density, and increases porosity. This enhances the movement of air, water, and nutrients to plant roots. By contributing organic matter, cover crops improve soil structure, soil aggregation, and enhance soil biological communities.

SUSTAINABLE SOILS: SOIL HEALTH AND SOIL QUALITY

A standard soil test describes nutrient levels (phosphorous, potassium, calcium, etc.), but provides no information on the soil's biology or physical properties. Agricultural scientists are beginning to describe the soil condition in terms of soil health or soil quality. A good soil feels crumbly, drains well and warms up quickly in the spring, does not crust easily, has no hardpan, soaks up heavy rains and stores moisture, and supports high populations of soil organisms. Soil health encompasses more than the nutrient status of the soil and includes such properties as:

- Soil texture and structure
- Soil compaction and the presence of a hardpan
- Water infiltration
- Water holding capacity
- Bulk density
- Nitrate and salt concentration
- Aggregate stability
- Earthworm numbers
- Soil respiration as a measure of soil biological activity

Soil is composed of minerals, water, air, and organic matter. Most soils are 45% mineral, 25% each air and water, and 2-5% organic matter. The mineral portion of the soil consists of three particle sizes categorized as sand, silt, or clay. Soil texture refers to the relative proportions of sand, silt, or clay. A loam soil consists of these three particle sizes in roughly equal proportions. Sand particles consist mostly of quartz and hold no nutrients. Silt particles are smaller than sand, but are also mainly quartz. Clay is the smallest particle and its plate-like structure results in a large surface area which can hold plant nutrients. Soil structure refers to the aggregation of sand, silt, and clay into larger structures. Both soil texture and soil structure determine pore space for air and water movement, ease of erosion and tillage, and depth of root penetration. Soil texture is relatively constant, but soil structure can be improved or destroyed by cultural practices.

Soil also contains living organisms such as earthworms, bacteria, protozoa, arthropods, algae, and fungi. Soil dwelling organisms decompose plant residues and release the nutrients over time to plants. Soil organic matter also contains dead organisms and plant matter in various stages of decomposition. The final stage of decomposition is the stable, dark, colored humus. Both humus and organic matter act as sources of plant nutrients and contribute to soil structure.

The benefits of organic matter and humus are many and include granulation of the soil into water stable aggregates, decreased crusting, improved water infiltration, and increased water infiltration and retention. A soil with these properties is said to have good tilth. Good tilth is dependent on aggregation which can result from earthworm and soil microbial activity. Organic matter is required for a diverse soil microbial community. Organic matter also contributes to improved physical structure of the soil. Organic matter is an important source of plant nutrients. Soil organic matter must be renewed by plants growing on the soil, animal manures, and compost.

Earthworms are an important soil organism as their tunneling activities improve soil aeration and increase water infiltration. Earthworms burrows channel air deeper into the soil, allowing microbial activity at greater depths. These tunnels also allow for greater plant root penetration. Earthworms consume organic matter, soil, and soil microbes and expel soil clusters known as castings. Worm casts are high in soluble nutrients and contribute significantly to soil quality. Earthworm populations can be enhanced by reducing or eliminating soil tillage, adding animal manure, and growing green manure crops. There are other soil arthropods such as millipedes and springtails that are also primary decomposers.

Bacteria are the most abundant soil microorganism and there are many different species present with different functions. One major role of bacteria is nutrient recycling. Some species release nutrients, some break down soil minerals, and others stimulate root growth by producing hormones. Several species of bacteria transform gaseous nitrogen to nitrate that is available to plants. A few species fix nitrogen in the roots of legumes. Bacteria convert ammonium to nitrate and back again. Bacteria produce polysaccharides that bind soil particles together, improving soil structure. Fungi also break down organic matter and release nutrients to plants. Fungi produce plant hormones and other secondary metabolites like antibiotics. Fungi can consume or compete with other harmful soil microorganisms like plant parasitic nematodes. Mycorrhizae are fungi that live in association with plant roots and improve water and nutrient uptake. They produce antibiotics and hormones that promote plant growth and suppress disease organisms. Actinomycetes (thread bacteria) also decompose organic matter into humus and produce antibiotics. The presence of Actinomycetes results in the sweet, earthy smell of soil. Algae improve soil structure by producing slimy substances and some can fix nitrogen which is released to plants. All these microorganisms interact with each other in the soil ecosystem. Strategies to increase both the number and diversity of soil microorganisms contribute to a healthy and productive soil.

Soil Health Assessment

The USDA Soil Quality Institute provides a Soil Quality Test Kit Guide which allows the measurement of water infiltration, water holding capacity, bulk density, aggregate stability, earthworm number, and soil respiration. The Soil Quality Test Kit Guide can be ordered from the USDA at http://soils.usda.gov/sqi/files/KitGuideComplete.

Techniques to Build Soil Quality

- Include a cover crop in rotation.
- Add organic matter through animal manures or compost.
- Green manures
- Practice reduced tillage. Tillage destroys natural soil aggregates and reduces soil porosity. Plow pans develop in many situations, especially if heavy equipment is used or soils are wet.
- Minimize synthetic nitrogen use. Excess nitrogen without the addition of carbon speeds organic matter depletion.
- Continue to monitor soil health and quality.

CHECKLIST
BMPs for VEGETABLE PRODUCTION
WATER MANAGEMENT AND IRRIGATION

Protecting Water Quality

√ Best management practices reduce or prevent water pollution by reducing or eliminating pollution sources and transport potential.

√ Place a high priority on avoiding surface runoff.

√ Cultural practices to minimize soil erosion include:

- Contour Farming
- Deep Tillage
- Inter-row cover cropping
- Inter-row Mulching. Applying plant residues or other suitable materials to the soil surface.

√ Structural practices to control pollution sources and transport include:

- Buffer strips
- Constructed wetland
- Water Diversion
- Field Border
- Filter strips beyond field border
- Grassed waterways.
- Sediment basins

√ Protect water source from animal contamination by fences or gates, and the proper storage of manures.

Water Conservation

√ Do not overwater. Irrigate according to the water requirements of crop.

√ Use rain shut off devices to prevent irrigation system operation during rain events.

√ Collect irrigation and rain runoff and use for irrigation.

√ Water early in the morning or between the hours of 6 PM and 10 AM when temperatures and winds are at their lowest levels to reduce water loss.

Wellhead protection

√ Protect wellheads from pollution by pesticides and fertilizers by staying at least 100 feet from the well when mixing, loading, and storing agricultural chemicals.

√ Periodically inspect and maintain well construction. Keep well sealed from contaminants by well casing and well cap.

√ Install backflow prevention devices.

√ Monitor well water quality periodically.

√ Know site specific characteristics that impact aquifer vulnerability.

Irrigation

√ Schedule irrigation properly by accounting for soil moisture and crop water use. The crop water requirement is equal to the quantity of water lost from the plant by transpiration plus the water evaporated from the soil surface.

√ Soils vary widely in both water holding capacity and infiltration rate. Know soil types and their characteristics.

- √ Time irrigation to avoid water movement beyond the rooting zone. Never water if the soil is visibly wet.
- √ Adjust irrigation according to crop needs; consider crop species, canopy size, plant population, rooting depth and stage of crop growth to determine water requirements.
- √ Irrigation application rates should not exceed the infiltration and percolation rates of the soil.
- √ Apply irrigation uniformly and accurately. Irrigation system design should include such components as flow meters and pressure gauges.
- √ Properly design, install, and maintain irrigation systems to ensure efficient and uniform irrigation. Irrigation efficiency is dependent on good design, correct installation, and proper maintenance of irrigation system. Use only qualified professionals for design and installation of irrigation systems.
- √ Consider technological advances like smart controllers and tensiometers to schedule irrigation.

Drip (Trickle) Irrigation

- √ Drip or Trickle irrigation is a method of slowly applying small amounts of water directly to root zone.
- √ Drip irrigation uses less water than sprinkle irrigation and requires lower flow rates and operating pressures, leading to lower energy and equipment costs.
- √ Drip irrigation systems require a higher initial investment in equipment and are labor intensive to install. Once in place, drip systems can be regulated automatically.
- √ Drip irrigation can reduce insect and disease damage because leaves are not wetted. Weed pressure is reduced by lack of moisture between rows.
- √ Filtration and water treatment may be required to keep drip systems from clogging.

WATER MANAGEMENT

Protecting Water Quality

Best Management Practices that reduce water pollution are closely related to soil conservation practices as both aim to reduce the movement of soil and sediment and associated nutrients and pesticides. The effectiveness of BMPs is site specific and is related to soil characteristics, slope of land, and distance from water bodies. Mechanisms to protect water quality can be grouped into these categories: increasing infiltration, reducing runoff and percolation, controlling erosion and encouraging sedimentation, and reducing chemical (nutrients/pesticide) inputs.

Runoff occurs when rainfall or irrigation exceed the infiltration capacity of the soil. The factors that impact runoff include crop characteristics, topography, soil properties, and the frequency, duration, and intensity of rainfall events. Fields with dense crop canopies have less runoff than widely spaced row crops. Steeper slopes result in more runoff at a higher velocity. Fine textured soils such as clays have lower infiltration rates and higher runoff than coarse textured soils such as sands. The USDA NRCS provides the following soil classifications:

- Group A: lowest runoff potential; deep sands with little silt or clay
- Group B: moderately low runoff potential; sandy soils not as deep as Group A
- Group C: moderately high runoff potential; shallow soils with large proportions of clay and colloids
- Group D: Highest runoff potential; mostly clay with high swelling content, and shallow clays which are impermeable

Know the soil types in your fields and their runoff potential. In field practices that reduce runoff from crop fields include contour farming, deep tillage, inter-row cover crops, row direction, and cover crops. Tillage, planting, and other farming operations performed on or near the contour of the farm slope reduce runoff, erosion, and the transport of sediment and associated pollutants. Tillage operations such as deep plowing, subsoiling, or ripping fracture restrictive soil layers (hard pan) and increase infiltration. Establishment of herbaceous plants in inter-row areas during the growing season reduces runoff and erosion. Straight rows laid out across the dominant field slope where contour farming is not feasible reduce water runoff and soil erosion. Winter cover crops reduce runoff and erosion and have the added benefits of capturing nutrients and weed suppression.

Percolation is the process by which water applied as irrigation or rainfall moves through the soil and beyond the plant root zone. This water may transport dissolved nutrients and chemicals and depending on the depth to water table, may reach ground water. Percolation rate is dependent on soil characteristics and the amount of soil compaction. Management practices to reduce percolation include drip irrigation and proper scheduling of irrigation. Drip irrigation systems deliver water directly to root zone and reduce the volume of water applied. Irrigation scheduling based upon monitoring of the soil moisture status, crop water requirements, and weather conditions can minimize application of excess water that may exceed the soil’s infiltration capacity.

Soil displaced by runoff or erosion adversely affects water quality. The amount of erosion and sediment transport is determined by soil particle detachment by raindrop splash, transport by raindrop splash, detachment by runoff, and transport by runoff. The rate of detachment is influenced by raindrop size, distribution, and velocity. The rate of detachment by runoff is influenced by the velocity of runoff over the land surface; most transport of soil particles occurs by runoff. Some soils display a degree of resistance to erosion, while others are highly erodible. In addition to soil properties, soil erosion is influenced by rainfall amount and intensity, soil cover, and slope. A dense vegetative cover can absorb the energy of rainfall, decrease the velocity of runoff, increase infiltration, and reduce sediment detachment and transport. Best management practices for erosion control include cultural and structural measures. Because cultural techniques that reduce runoff also result in less soil erosion, these techniques have been discussed above and include:

- Contour farming
- Deep tillage
- Drip irrigation
- Inter-row cover cropping
- Inter-row mulching
- Irrigation scheduling
- Row direction
- Winter cover cropping.

Structural practices to control pollution sources and transport:

- Establish buffer strips: Narrow strips of permanent, herbaceous cover established across the slope and alternated with crop areas.
- Constructed wetland: Wetland established between fields and receiving waters to treat surface runoff through physical (settling), biological (microbial degradation), and chemical (decomposition and conversion to breakdown products) processes.
- Water Diversion: Channel constructed to intercept and divert runoff from field.
- Establish field Border: Strip of permanent grasses established at edge of field traps sediment in runoff leaving crop fields and can direct runoff to desired areas.
- Riparian Borders: Area of native grasses, forbs, or trees and shrubs adjacent to and upslope from water bodies that receive runoff from fields.
- Establish filter strips beyond field border: Strip or area of herbaceous vegetation situated between crop fields and receiving water.
- Grassed waterways: Natural drainageway within a field shaped and vegetated to concentrate runoff and prevent gully formation.
- Construct sediment basins to collect and store sediment and to detain runoff.

Water Conservation

Quality vegetable production requires adequate soil moisture. Supplemental irrigation is required in most years; however, over-irrigation can reduce crop yield and quality. Apply water based upon crop needs. A convenient method of determining the crop water requirement is to base irrigation upon evapotranspiration rate which is equal to the quantity of water loss from the plant (transpiration) plus that which is evaporated from the soil surface. The evapotranspiration rate will be affected by solar radiation, air temperature, wind speed, and relative humidity. Numerous plant factors also affect the crop water requirement including, crop species, stage of growth, plant canopy density, plant population, rooting depth, and the stage of growth and development of the crop. Cultural practices also influence the evapotranspiration rate. Cultivation, mulching, weed growth, and method of irrigation are important factors to consider. Shallow cultivation may reduce soil crusting and improve water filtration. Weeds compete with crop plants and increase the amount of water lost from transpiration. Mulches reduce evaporation from the soil, but can also reduce the amount of water that can reach plant roots from rain. Sprinkler irrigation wets the entire field; water loss from evaporation is greater than trickle irrigation. Soil factors such as levels of silt, clay, and organic matter and degree of compaction also have to be considered. Soils with higher water-holding capacity require less water than sandy or compacted soils. Tensiometers are another method for measuring soil water. Tensiometers measure soil tension, a measure of how tightly water is held in the soil. Soil tension increases as moisture in the soil decreases. Field capacity is the moisture content at which the soil is holding the maximum amount of water it can against gravity. No irrigation is required at field capacity; the water is readily available for plant uptake.

Irrigation

Soil moisture in the range between field capacity and the wilting coefficient (point where wilting of plants occurs) is available to plants. It is advisable to begin irrigating vegetables before half the available water has been used. If soil moisture is depleted below this point, the plants will be under moisture stress, yield will be reduced, and various disorders such as tip burn and blossom end rot will occur. The application of irrigation should not exceed the infiltration and percolation rates of the soil. If the application rate exceeds infiltration and percolation, water will accumulate on the surface and become subject to runoff and erosion. Soil compaction interferes with both infiltration and percolation. Compaction can foster the survival and dispersal of plant pathogens by impeding drainage. Soil crusting interferes with water infiltration. Avoid soil compaction and soil crusting by the addition of organic matter, appropriate tillage practices, and restricting equipment traffic over fields. Do not over water; plants will develop deeper roots and ultimately require less frequent watering when not over watered. Never irrigate when the soil is visibly wet. Determine the moisture status of the soil with evaporative pans or soil tensiometers. Irrigate according to the requirements of the crop, not on an irrigation schedule of fixed duration and frequency. Apply only enough irrigation to replace soil water depletion based upon evapotranspiration, soil type, and root depth. Avoid applying more irrigation than can be contained in the root zone. Water early in the morning or between the hours of 12 AM and 6 AM when winds and temperatures are at their lowest level to reduce evaporative loss, if possible. Avoid excessive irrigation after fertilization which can lead to leaching, surface runoff that pollutes water bodies, and leads to inefficient utilization of the fertilizer. When irrigating on slopes or in areas with clay or compacted soils, a series of light water applications (cycle and soak) may be an appropriate strategy to account for lower infiltration rates of these areas. Irrigation efficiency is dependent upon a good irrigation system design, correct installation and proper maintenance, and good water management practices.

Design irrigation systems based on knowledge of soil type and infiltration rates, crop requirements, site characteristics such as slope, exposure to wind and sun, and annual rainfall. Sprinkler size should be chosen based upon the crop, distance between laterals, pumping pressure and volume, and the soil properties like percolation and infiltration. Sprinkler placement should be staggered on adjacent laterals to provide a triangular pattern in the field. A triangular pattern with overlapping patterns provides the most uniform coverage. Never mix different types of sprinklers within the same zone or mix sprinklers from different manufacturers. Properly space sprinklers based on nozzle performance and pressure requirements to provide uniform coverage. Irrigation systems should be designed to account for local climate variation. Smart controllers are one tool that can adjust watering to changing conditions throughout the season. Irrigation design should account for hydraulic factors such as pressure, friction losses, elevation changes, and gravity drainage that require control devices. Irrigation systems should be designed to avoid runoff, low head drainage, overspray, and application of water to hard surfaces such as roads. Separate stations/zones for the top and bottom of sloped areas. Properly size valves and pipelines to maintain proper pressure and coverage.

Drip or Trickle Irrigation

A well designed drip or trickle irrigation system conserves water and fertilizer, and does not require labor once the initial installation is complete. Water is applied next to the plant on the soil surface or near the root zone, subsurface. Evaporative losses of water from the soil are reduced. Fewer weed seeds germinate between rows because there is less water available beyond the crop root zone. Weed roots may grow toward the moist zone, especially if plastic mulch is used. Some expertise is required to install and operate a drip irrigation system. It is desirable to consult a knowledgeable professional. Good equipment and proper installation are essential to release the benefits of drip irrigation systems. Factors to be considered when installing drip irrigation include:

- Water source: Surface water like ponds and streams will likely contain algae, small organisms, silt, and clay. Well water may also contain silt or clay. These particles can clog the small diameter emitters; filters are required to remove particulate matter. Surface water might have contamination from runoff, including disease propagules.
- Slope. A slope of 2% or less is ideal for drip irrigation. The length of lateral lines, the pump size, and pressure regulators are chosen based upon slope.
- Soil: The soil type determines the soil wetting patterns which dictate the depth of the drip tape and distance between emitters. Soil type also determines the frequency and duration of irrigation. Sandy soils require close spacing of emitters and more frequent but shorter duration irrigation. In clay soils, emitters can be more widely spaced due to lateral movement of water and irrigation is less frequent and of longer duration.

Drip irrigation should apply water uniformly throughout the crop root zone. Drip tape should have a coefficient of manufacturing variation number (CV) which tells how much variability to expect. Select drip tape with a CV of 0.05 to 0.1. Rate of irrigation delivery is a function of the size and spacing of the emitters. Another important consideration is the length of drip lines. Length is determined by pump size, field size, and the slope of the land. Drip tape is rarely laid out in lengths greater than 400’ due to variations in water pressure which can affect wetting uniformity.

Tape should run across the slope or down hill. Tape thickness is usually between 4 and 10 mil and is determined by the highest water pressure expected and the length of time it will be used. The longer the tape will be in the ground and the higher the expected water pressure, the thicker the tape should be. Tape can be reused for 2-3 years, but the labor costs of retrieving and cleaning the tape may make reuse impractical. The tape should be placed as close to the plant as is possible and so that the emitters are pointed upward to prevent particulate matter from settling. Tape is often laid between double rows and lateral movement of water is relied upon. Tape can be laid on top of the soil or a few inches below the surface. Tape laid on the surface is subject to damage by production practices, wind, animals, and solar heating.

For a given area, drip irrigation uses less water and at a lower rate than sprinkler irrigation; smaller pumps can be used. The required pump capacity is determined by the flow rate of the tape, length of tape, and pressure loss due to friction or elevation. The choice of filters is based upon the quality of the water source. Screen or mesh filters are inexpensive, easy to install, and adequate where contamination of the water is low (wells or public water supply). If the water comes from a river or pond, screens will have to be cleaned often and a sand filter is preferred. A sand filter can be cleaned by back flushing and are often operated in pairs so that clean water from one filter can be used to clean the other filter. The filter size should be large enough to accommodate the volume of water. The sand should be of the correct type-crushed, sharp-edged silica or granite. The sand will not need to be replaced unless it is contaminated. A third alternative are disc filters which consist of a series of discs with microscopic grooves that are stacked upon each other. Disc filters require less water for cleaning than sand filters.

Mainlines deliver water from the pump to the laterals and can be composed of metal pipe, PVC pipe, or lay flat hoses. The size of the pipes is determined by the distance the water must travel and the pumping rate. Friction losses due to pipe length, elbows, and junctions should be considered in system design. System design may require a qualified designer. When the pipe is laid down, care should be taken to prevent soil or debris from getting into the system, for it will clog the emitters. Flushing the lines before connecting the tape is connected will prevent this problem.

Specify water conserving devices such as check valves, flow regulators, and pressure regulators. A check valve or back flow preventer should be installed to allow the water to flow in one direction only. They prevent water from flowing backward into a water source and protect the water source from injected fertilizers or pesticides. They are required by law whenever a system includes injectors. Vacuum relief valves are installed to prevent soil from being sucked into emitters when the system is shut off. Pressure regulators to maintain the desired pressure of water flow are required. They supply the appropriate pressure to the tape and protect filters and other system components. The size of pressure regulator is related to the rate of water flow. Use climate sensors such as rain, freeze, or wind sensors to stop irrigation when unfavorable weather occurs. Specify water conserving irrigation methods such as smart controller technology that uses evapotranspiration data or soil moisture sensors to schedule irrigation.

Fertigation

Fertigation is the injection of soluble fertilizer into irrigation water. Nitrogen or potassium can be applied through a drip system. With drip irrigation, it is possible to apply small amounts of nitrogen weekly or even daily which can improve nitrogen management. Small weekly applications result in more efficient crop use of nitrogen than one or two larger applications by Sidedressing. The irrigation system should not run longer than the time needed to wet the root zone to prevent leaching of fertilizer. The entire system should be filled with water at full operating pressure before fertilizer is added and the system should run long enough to flush fertilizer from all lines. There is the potential for fertilizer to react with chemicals in the irrigation water, especially at water pH above 8.0. Calcium and magnesium can react with phosphorous; bicarbonates in water can react with calcium in the fertilizer causing precipitation of calcium carbonates. Sulfates in fertilizer can react with calcium in the water resulting in precipitates that can clog emitters. Water testing labs can analyze water for pH, calcium, magnesium, and bicarbonates or a simple test can be performed. Mix fertilizer into a container of irrigation water at the required concentration and let it sit at least as long as the mixture would be in drip lines. If the water becomes cloudy or a precipitate forms, this also likely to happen in the irrigation system. Acid can be injected into the irrigation water to lower water pH. This requires special handling procedures and special precautions to avoid personal injury or crop damage.

Chemigation

Chemigation is the injection of a pesticide into irrigation water and must be performed according to the specific directions upon a pesticide label. The pesticide for chemigation must have the crop and irrigation system as specified on the label. Chemigation can provide excellent control of pesticide application timing and may result in a decrease in the total amount of pesticide applied.

CHECKLIST
BMPs for VEGETABLE PRODUCTION
NUTRIENT MANAGEMENT

Soil Testing

- √ Test soils each year to determine nutrient levels. Fertilizer should be applied when a soil test indicates that extractable amounts of nutrients in soil are below optimum levels.
- √ Divide farm into areas for sampling based on crop and soil type.
- √ Use proper sampling tools such as a sampling tube. Take a core from at least 15 random spots in the area to be tested, 6 inches deep, and mix together cores for a consolidated sample. Place approximately one pint in a sample bag. Identify samples and keep a record of where the samples were taken.
- √ Test the soil pH and determine liming requirements.
- √ Maintain a soil pH between 6.0-6.5 for most crops.
- √ Apply lime well in advance of the crop in order for the soil reaction to occur.
- √ Do not overlime. The resulting high pH can interfere with micronutrient availability.
- √ Test soil for micronutrients every 2-3 years. Apply micronutrients only when a specific deficiency has been identified or if a particular crop has a known need for a specific micronutrient.
- √ A specific micronutrient deficiency is likely to reoccur and that micronutrient may need to be applied on a routine basis.
- √ Micronutrient deficiencies that occur mid-season are difficult to correct. Foliar applications are not particularly effective.
- √ Incorporate micronutrients into soil prior to planting.
- √ Test manure and other soil amendments to determine their nutrient content and take into consideration when determining nutrient application.

Nutrient Management

- √ Nutrients should be applied at the level required to grow the crop, taking into consideration typical losses from leaching, volatilization, microbial action, and soil reactions.
- √ Nutrients should be applied uniformly unless it has been determined that sections of a field need higher or lower rates of application.
- √ Depending on the crop, fertilizer and soil type, split fertilizer applications can result in greater nutrient uptake by crop and lower nutrient loss to the environment.
- √ Consider fertilizer release rates based upon crop, site characteristics, and application frequency to reduce adverse environmental effects.
- √ Nutrient application equipment should be properly calibrated to prevent under or over fertilization. Equipment should be cleaned well between uses to prevent corrosion and maintain equipment life.
- √ Crop rotations with diverse crops can utilize residual or excess nutrients.
- √ Cover crops can be employed to capture available nutrients and provide organic matter to the soil.

√ Soils with an organic matter of 5-10 % have improved cation exchange capacity (CEC). Increasing the CEC allows the soil to retain more nutrients. Organic matter promotes good soil structure and improves moisture retention, and soil permeability.

Special Considerations: Nitrogen

√ Excessive rates of nitrogen fertilization can cause nitrate contamination of water resources.
√ Establish yield goals based upon previous five year average.
√ Credit all sources of nitrogen toward crop nitrogen requirement including organic matter, crop residues, manure, soil nitrate, and irrigation water nitrate.
√ Use slow release nitrogen fertilizers where appropriate.
√ Split nitrogen fertilizer applications. Sidedressing is an important consideration in nitrogen management.
√ Avoid fall application of nitrogen fertilizers.

Special Considerations: Phosphorous

√ Sample the tillage level of soil (soil depth that is cultivated) to determine available phosphorous levels and apply fertilizers according to soil test recommendations.
√ Credit all available phosphorous from manure and other sources.
√ Employ filter strips around crop fields to retain phosphorous in surface runoff.
√ Incorporate phosphorous fertilizers.
√ If phosphorous levels in soil are high and the pH is an acceptable range, little benefit can be obtained from additional phosphorous applications.

Organic Fertilization

√ The key to appropriate use of organic fertilizers is to know the nutrient content of the material and the decomposition (nutrient release) rate.
√ Base application rate on nutrient content of organic material and crop needs.
√ Calibrate application equipment to ensure proper application rates.
√ Do not apply uncomposted animal manures on crop land. √ Organic material serves as a soil amendment by adding organic matter to the soil and improves moisture holding capacity of soil.
√ Phosphorous levels in soils may determine optimum application rates for organic material.
√ Consider food safety issues when applying organic materials.
√ Determine carbon to nitrogen (C: N) ratio. Organic matter with a C: N ratio of greater than 25 can result in nitrogen loss from the soil as microbes use nitrogen to consume the carbon. Additional nitrogen may need to be added.
√ Apply only finished compost. Finished compost has no recognizable components and will not heat up. It should have low ammonium, high nitrate, and a pH near neutral.

Fertilizer Application

- √ Avoid fertilizer applications over exposed bedrock, frozen, saturated, or snow covered soils.
- √ Avoid application of unnecessary fertilizer applications which reduce farm efficiency and lead to water resource contamination.
- √ Shut off valve on applicator equipment so that no fertilizer is applied in the turn area.
- √ Use split applications to avoid losses from leaching. Minimize the amount of nitrogen applied at planting before crop emerges or is able to fully utilize nitrogen in the soil.
- √ Keep accurate records of fertilization rates and crop yield to guide future fertilization decisions.
- √ Controlled released fertilizers allow better control of nutrient release and degrade based upon soil temperature and moisture.
- √ Always incorporate controlled release fertilizers.
- √ Do not exceed the recommended fertilization rate. The application rate of a 1:1:1: (N, P, K) should be based upon the nutrient that is required at the lowest level.

NUTRIENT MANAGEMENT

The “Plant Nutrient Recommendations” tables for each crop in the New England Vegetable Recommendation Guide (vegetableguide.umassextension.org) can be used to determine nutrient needs based on soil test results. These tables are found in each crop section. Nitrogen recommendations are based primarily on crop needs and are discussed later in this section under “Nitrogen Inputs.” Phosphorus and potassium recommendations are based on soil test results in relation to crop needs.

In general, the goal should be to maintain nutrient elements within the *high* or *optimum* range as reported on the soil test. When nutrient levels are within this range, the needs of most crops will be met. If levels are *low* or *medium (below optimum)*, most crops would benefit by adding the appropriate nutrient(s) to increase levels to high or optimum. However, if levels are at *above optimum* or *very high* levels, there will be no additional benefit and excess levels may reduce crop yield or quality and may cause environmental harm. This happens in fields where soil testing was not used to monitor fertility levels or when nutrients are applied even when soil levels are sufficient. When a nutrient is above optimum levels it should not be included in any amendments until the excess is used up by crops. It may be wise to temporarily stop applying compost until nutrient levels are in the desired range. This is a practical way to manage nutrient levels if small to moderate amounts of mixed crops are to be grown.

If a significant acreage of a particular crop is to be grown, fertilizers should generally be tailored to the specific needs of that crop, based on the amounts of nutrients that the crop is expected to remove during the growing season. If the soil tests indicate that a nutrient is high/optimum it is likely that the soil will supply enough to meet the crop’s needs. However, many growers will apply enough of the nutrient to replace what is removed by the crop. If the test level is above optimum/very high, additional applications should normally be avoided unless the crop has an unusually high demand for a specific nutrient. For example, a large crop of tomatoes can be expected to remove a large amount of potassium and it may be justified to apply some of this nutrient even if the soil test indicates a level somewhat above high/optimum. The nutrient recommendation tables for each crop have been developed on this basis. This can also be a practical way to determine nutrient needs of high value crops, even when they are grown on a small scale. It is important to keep in mind that factors other than nutrients may limit crop potential, and simply adding more nutrients will not solve such problems.

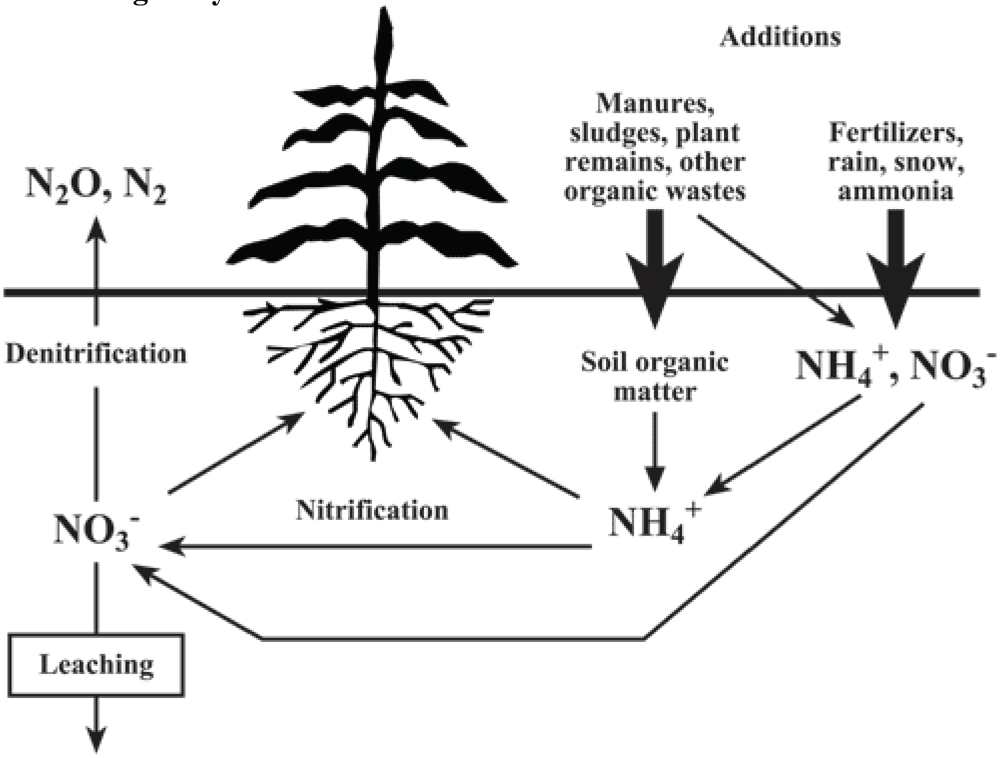
Nitrogen

Nitrogen (N) has a pronounced and often dramatic influence on the growth and yield of crops. Management of soil and fertilizer N is difficult because N undergoes numerous transformations and is easily lost from the soil. These losses concern growers for two principal reasons: 1) the losses can and often do adversely affect plant growth and crop yield, and 2) when N is lost in the nitrate form, there is a chance for contamination of groundwater and drinking water supplies.

The Nitrogen Cycle

The N cycle (Fig. 1) illustrates N inputs, losses and transformations. When inputs exceed plant needs, nitrates can accumulate in the soil and pose a threat to groundwater. Conversely, when plant-available forms of N from the soil and any inputs are too low, crop growth suffers. The key to successful management of N is to find the relatively "thin line" between too much and too little N. It is not an easy task. N transformations and losses are affected by soil conditions and the vagaries of the weather. The rates of most N inputs are difficult to accurately estimate.

The Nitrogen Cycle



Nitrogen Inputs

As can be seen from the N cycle, there are two sources of the N used by plants:

Soil organic matter**:** The total amount of N in the plow layer of agricultural soils is surprisingly large. One can estimate the total N in pounds per acre in the 6" to 7" of surface soil by multiplying the soil's organic matter content by 1,000. Thus, a soil with 4% organic matter contains about 4,000 lbs total N per acre.

The amount of this total N available to plants in any one year, however, is relatively small. Research has shown that for most soils 1% to 4% of the total N is converted (mineralized) annually to forms plants can use. For soil with a total of 4,000 lbs N per acre, a 1% to 4% conversion would produce 40 to 160 lbs N per acre annually for plant use. If the crop needs 200 lbs N per acre for adequate growth and development, some additional N must come from non-soil sources. Manure and/or fertilizer are the most likely candidates to furnish rapidly available N. The rate of mineralization is dependent on microbial activity, especially bacterial activity. Such activity is favored by warm soils with adequate, but not excessive moisture and a pH above 6.0. These conditions are also favorable to most vegetables. On well managed soils used for vegetable production, 20 to 40 lbs of N per acre will become available during the growing season for each percent of organic matter if the weather is favorable.

Manures and other waste products: The N content of manures and their N fertilizer equivalents are highly variable. Differences in N content are due to the species of animal, the animal's age and diet, the moisture content of the manure, handling and storage and the amount of bedding in the manure. The N fertilizer equivalent of a given manure varies not only with the animal species and the total N content of the manure, but also with the time of application and time elapsed between spreading and incorporation. The values are based on numerous analyses of Connecticut manures as well as published data from other states. If specific manure analysis data for the farm are not available, growers should estimate N credits. ***NOTE: Manure often contains human pathogens. Serious illness has occurred from eating produce where fresh manure was applied***

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Previous cow manure applications: Up to 50% of the total N in cow manure is available to crops in the year of application. Between 5% and 10% of the total applied is released the year after the manure is added. Smaller amounts are furnished in subsequent years. The quantity of N released the year after a single application of 20 tons per acre of cow manure is small (about 15 lbs N per acre). However, in cases where manure has been applied at high rates (30 to 40 tons per acre) for several years, the N furnished from previous manure increases substantially.

The buildup of a soil's N-supplying capacity resulting from previous applications of cow manure has important consequences for efficient N management, two of which are:

The amount of fertilizer N needed for the crop decreases annually;

If all the crop's N needs are being supplied by cow manure, the rate of cow manure needed decreases yearly.

In cage layer poultry manure, a higher percentage of the total N in the manure is converted to plant-available forms in the year of application. Consequently, there is relatively less carry-over of N to crops in succeeding years. This is due to the nature of the organic N compounds in poultry manure. This does not mean, however, that there is never any carry-over of N from poultry manure applications. If excessive rates of poultry manure (or commercial N fertilizers) are used, high levels of residual inorganic N, including nitrate, may be in the soil the following spring. High levels of soil nitrate in the fall, winter and spring have the potential to pollute groundwater.

Previous crops: Previous crops can supply appreciable amounts of N to succeeding crops. Legumes, such as alfalfa and red clover, can furnish 100 pounds or more of N to crops that follow. Other legumes, mixed grass-legume stands and grass sods supply less N to succeeding crops (Table 3). Keep in mind that most of the N is in the leaves, not the roots. If a legume hay crop is harvested, most of the N is removed from the field along with the hay.

Nitrogen Credits for Previous Crops

Previous Crop	Nitrogen Credit Lbs N per acre
Grass sod	20
"Fair" clover (20-60% stand)	40
"Good" clover (60-100% stand)	60

“Fair” alfalfa (20-60% stand)	60
“Good” alfalfa (60-100% stand)	100
Sweet corn stalks	30
“Good” hairy vetch winter cover crop	106
Corn for grain	40

Compost as a nutrient source: Finished compost is a dilute fertilizer, typically having an analysis of about 1-1-1 (N-P2O5-K2O). The nitrogen content of composts varies according to the source material and how it is composted. In general, nitrogen becomes less available as the compost matures. Nitrogen in the form of ammonium (NH4+) or nitrate (NO3-) is readily available, however in a finished compost there should be little ammonium, and any nitrate that is produced could have leached away, especially if the compost is cured or left out in the open. The majority of the nitrogen in finished compost (usually over 90%) has been incorporated into organic compounds that are resistant to decomposition. Rough estimates are that only 5% to 15% of the nitrogen in these organic compounds will become available in one growing season. The rest of the nitrogen will become available in subsequent years.

Synthetic chemical fertilizers: Fertilizers used to supply N include urea (46-0-0), diammonium phosphate (DAP: 18-46-0), monoammonium phosphate (MAP: 11-48-0), ammonium nitrate (34-0-0), urea-ammonium nitrate solution (UAN: 32-0-0), calcium ammonium nitrate, calcium nitrate, potassium nitrate and various manufactured and blended fertilizers such as 15-8-12, 15-15-15 and 10-10-10. In bulk blended or custom blended mixes, N-containing fertilizers with almost any grade can be provided.

Nitrogen Losses

Nitrogen losses occur in several ways. Some, such as volatilization, denitrification or immobilization, result primarily in N being unavailable to crop plants. Leaching loss results in potential groundwater contamination in addition to reduced crop growth.

Nitrogen Credits from Manure Incorporated Before Planting

	Time(s) of Application		
	April/May[1]	Fall Only[2]	Other Times[3]
Kind of Manure	lbs N/ton		
Dairy (cow)			
solid	5	2	3
liquid	16	18	12
Poultry, cage layer			
fresh (20-40% D.M.)[4]	16	5	8

sticky-crumbly (41-60% D.M.)	22	7	11
crumbly-dry (61-85% D.M.)	32	10	16

1 "April and/or May" credits are for manure applied and incorporated in April and/or May for spring-planted crops and for manure applied and incorporated within four weeks of planting at times other than spring.

2 Use "fall only" values for manure applied in no-till or maintenance situations where the manure is not incorporated.

3 "Other times" means times other than April and/or May or fall only for manure applied for spring-planted crops. "Other times" also means any combination of times from fall through May other than April and May for spring-planted crops. Examples: March, February, March and April; November, April and May.

4 Dry matter.

Volatilization Losses: These losses occur mainly from surface-applied manures and urea. The losses can be substantial — more than 30% of the N in topdressed urea can be volatilized if there is no rain or incorporation within two or three days of application. Losses are greatest on warm, moist sandy soils with pH values above 7.0. Delaying the incorporation of manures after they are spread also leads to volatilization losses of N. The Pennsylvania State University estimates, for example, that only 15% of the total N in poultry manure and 20% of the total N in cow manure is available to the crop in the year of application if the manure remains on the surface for more than seven days after spreading. It is also estimated that about 50% of the N is lost after two days.

Leaching Losses: Nitrogen can be lost by leaching in either the ammonium or nitrate form. Usually, much more N is leached as nitrate than as ammonium. Leaching losses are greatest on permeable, well-drained to excessively-drained soils underlain by sands or sands and gravel when water percolates through the soil. Percolation rates are generally highest when the soil surface is not frozen and evapotranspiration rates are low. Thus, October, November, early December, late March and April are times that percolation rates are highest and leaching potential is greatest. This is why nitrate remaining in the soil after the harvest of annual crops such as corn in September is particularly susceptible to leaching. Of course, leaching can occur any time there is sufficient rainfall or irrigation to saturate the soil. The use of cover crops following cash crops can take up this residual N and prevent it from leaching. The N will then be released for crop use after the cover crop is plowed down in the spring.

Denitrification Losses: These losses occur when nitrate is converted to gases such as nitrous oxide (N_20) and nitrogen (N_2). The conversions occur when the soil becomes saturated with water. Poorly drained soils are particularly susceptible to such losses. In especially wet years on some soils, more than half the fertilizer N applied can be lost through denitrification.

Immobilization: Immobilization occurs when soil micro-organisms absorb plant-available forms of N. The N is not really lost from the soil because it is held in the bodies of the microorganisms. Eventually, this N will be converted back to plant-available forms. In the meantime, however, plants are deprived of this N, and N shortages in the plants may develop. Immobilization takes place when highly carbonaceous materials such as straw, sawdust or woodchips are incorporated into the soil. Manure with large amounts of bedding may cause some immobilization.

Crop Removal of Nitrogen: In most cases, the greatest removal of N from the soil is via crop removal. Good sweet corn crops typically remove over 150 lbs of N per acre annually. Anticipated crop removal of N is one of the factors used in making N fertilizer recommendations. Depending on the crop, variable amounts of the N absorbed by the crop are returned to the soil after harvest in nonharvested plant parts. With sweet corn this can be as much as 100 lb N/A. As these leaves and stalks decompose, the N is released into the soil for use by a subsequent crop. Again cover crops can take up much of this N and hold it against leaching.

Topdressing and Sidedressing Nitrogen

Topdressing is defined as a fertilizer application to a crop any time after planting. In popular usage, topdressing sometimes refers to a broadcast application of fertilizer made after planting. However, the fertilizer can be sidedressed as a band along the side of the row of a growing crop. Sidedressing is usually done during cultivation. Spraying dilute solutions of fertilizer on crop foliage is also a form of topdressing.

Sidedressing is an important component in nitrogen management. As much of the needed nitrogen as practicable should be sidedressed or topdressed. For example, with sweet corn, one-half to two-thirds of the total nitrogen required by the crop can be sidedressed.

Pre-Sidedress Soil Nitrate Test (PSNT)

Adequate nitrogen is necessary to obtain optimum yields and quality. However, excess nitrogen does not increase yield, and usually reduces yield of pumpkins, winter squash, peppers and probably tomatoes. It may also contribute to physiological disorders and increase susceptibility of crops to certain diseases. Excess nitrogen is subject to leaching and run-off and can contaminate water supplies. Excess nitrate-nitrogen levels in drinking water is a serious health hazard. Nitrogen is also expensive.

Soil organic matter, compost, legume cover crops and manure can contribute much or all of a crop's nitrogen needs. To determine if topdressing or sidedressing is needed, a PSNT can be used to measure the nitrate-N level during the growing season. If nitrate-N is high, additional N is not necessary, and, in fact, reduces yield or quality of some vegetable crops. Sidedressing or topdressing N reduced yields of peppers, butternut squash and pumpkin if the soil nitrate-N level was already 30 ppm or greater. However, if the N level was lower than 30 ppm, additional N was usually beneficial.

Samples for the PSNT should consist of a well-mixed composite of 10 to 20 cores or slices of soil to a depth of 12". Avoid sampling fertilizer bands or areas that may have received extra N. About one cup of the composite should be dried to stabilize the nitrate. A good method is to spread a thin layer of the soil on a cookie sheet to air dry. Use a fan to reduce drying time. Do not place damp samples on absorbent material because it can absorb some of the nitrate. You can skip the drying step if you can deliver the samples to the soil testing lab in less than 24 hours. Fields should be sampled for the PSNT about a week before the time when side or topdressing is normally done. This should allow adequate time for drying, shipping, and testing (turn around time in the lab is about 24 hours) and for you to plan your program.

As with field corn, sweet corn does not respond to N application if the soil nitrate-N level exceeds 25 ppm as measured by the PSNT. Based on research and experience in New England, New Jersey and New York, a threshold of 30 ppm seems appropriate for peppers, tomatoes, butternut squash, pumpkins and probably other vegetable crops.

Plant Nutrient Percentage for Different Fertilizer Sources

Fertilizer Source Material	Total Nitrogen N%	Available Phosphoric Acid P_2O_5	Water Soluble Potash K2)%	Combined Calcium Ca%	Combined Magnesium Mg%	Combined Sulphur S%
Ammonium sulfate	21					23
Ammonium nitrate	33 to 34					
Anhydrous ammonia	82					
Calcium nitrate	15			19		
Diammonium phosphate	18	46				
Epsom salts					10	13
Granulated Sulfur						90 to 92
Gypsum				19 to 23		15 to 18
Monoammonium phosphate	11	48				
Muriate of potash			60			
Nitrate of potash	13		44			
Nitrate of soda-potash	15		14			
Nitrate of soda	16					
Super phosphate		20		18 to 21		11
Sul-po-mag			22		11	23
Sulfate of potash			50			17
Triple super phosphate		44 to 46		13		

Urea	45 to 46					

Plant Nutrient Percentage and Conversion Factors for Boron Nutrient Sources

Fertilizer Source Material	Plant Nutrient Counts %	Pounds of Material Required to Supply 1 Pound of Boron
Fertilizer Borate Granular*	14.30 (B)	7.0
Fertilizer Borate-48	14.91 (B)	6.7
Solubor	20.50 (B)	4.9
Fertilizer Borate-68	21.13 (B)	4.7

Fertilizer

Fertilizer recommendations for vegetable crops should be made in conjunction with a soil analysis report. Repeated use of the same analysis fertilizer without regard to soil test level will likely lead to excess levels of certain elements or nutrient imbalances. For example, yearly applications of 10-10-10 can lead to excess levels of P_2O_5. (See nutrient recommendation tables for each crop and Table 5.)

Fertilizer grades refer to the guaranteed percentages of plant nutrients. The ratio refers to the proportion of nitrogen (N), phosphate (P_2O_5) and potash (K_2O) in the fertilizer. For example, the grade is 5-10-5, and the ratio is 1-2-1. High analysis fertilizers are those with grades such as 20-20-20, 35-0-0 or 0-46-0, and are more economical to use on the basis of price per pound of nutrient.

Liquid starter fertilizers are materials that are completely water soluble and are high in phosphorus content such as 16-32-16, 10-52-17 or 9-45-15. These materials are used at the time of transplanting. Dry starter fertilizer can be banded at the time of seeding. The band is normally placed 2” below and 2” to the side of the seed. When using either dry or liquid starter fertilizer, follow label directions because an excess of starter could burn seeds and young seedlings. Starter fertilizer promotes early and rapid growth that leads to greater yields with certain crops such as tomatoes, pepper and melons. See individual crops for rates.

Phosphorus

Phosphorus (P) is referred to as P_2O_5 for the purposes of soil testing, fertilizer grades and recommendations. We don’t apply P in this form, but it has become the standard over many years. Most vegetable crops use relatively little P compared to nitrogen (N) or potassium (K). For example, sweet corn takes up about 155 lb/A of N and about 105 lb/A of K, but only about 20 lb/A of P. However, growers commonly apply about 100 lb/A of P. This is justified if P soil test levels are low, because most of the applied P becomes fixed in the soil and unavailable to plants. However, if soil test levels for P are high and the pH is adequate, there is little if any crop response to additional applications. Plant uptake of P is very slow in cold soils. For this reason, when planting early, it is advisable to apply a starter fertilizer high in P in a band about 2” below and 2” to the side of the seed when planting, or as a liquid around transplants.

Potassium

Potassium (K) is expressed as K_2O similar to the way P is referred to as P_2O_5. Crop need for K varies considerably. It is important that the soil K plus the applied K is enough to meet crop needs. However, excessive levels should be avoided because K can interfere with the uptake of Ca and Mg (see “Base Saturation”). K is subject to leaching on sandy soils low in organic matter, so if high amounts are needed, split applications should be used.

Calcium

Calcium (Ca) is usually supplied in sufficient quantities by liming if appropriate liming materials are chosen (see “Soil pH and Liming”). If soil pH is high and Ca is needed, small amounts can be applied as calcium nitrate fertilizer (15% N, 19% Ca). Ca can also be supplied without affecting pH by applying calcium sulfate (gypsum) which contains 22% Ca or superphosphate (14% to 20% Ca).

Magnesium

Magnesium (Mg) is most economically applied as dolomitic or high-mag limestone (see “Soil pH and Liming”). If liming is not needed, Sul-Po-Mag (11% Mg, 22% K) can be used. You can order blended fertilizer containing Mg.

Minor Elements

Minor or trace elements are difficult to analyze accurately with soil tests. Plant tissue analyses are more reliable for determining whether or not plants are getting sufficient quantities. However, soil tests may alert you to potential problems. Of the minor elements, boron (B) is most likely to be needed to supplement soil levels. Cauliflower, broccoli, cabbage and beets are most likely to require application of additional B. Boron also leaches readily from soil. CAUTION: Some plants are sensitive to high levels of boron. Sensitive crops should not be planted on fields following crops that have received boron application. Table 2 lists crops according to their sensitivity to boron.

CHECKLIST
BMPs for VEGETABLE PRODUCTION
MANURE MANAGEMENT

√ Always use composted manure, not fresh manure. Composting is a method of manure storage that stabilizes nutrients.

√ If fresh manure is applied, follow with cover crops to sequester soluble nutrients or allow 90 days to harvest for crops not in contact with soil and 120 days for crops in close proximity to soil.

√ Do not harvest produce that is consumed without cooking within 120 days of fresh manure application.

√ Have manure analyzed to determine nutrient value. The nutrient content of manure is highly variable due to animal species, the animal's age and diet, moisture content, and the amount of bedding in the manure.

√ Determine manure application rates to avoid over fertilizing. Keep accurate manure application records. Calibrate manure application equipment to insure proper application rates.

√ Apply manure uniformly over field. Incorporate manure when appropriate to avoid nutrient loss and odor concerns.

√ Do not apply manure on:

- Saturated soils
- Frozen or snow covered soils
- On steep slopes where runoff may occur
- Shallow to bedrock soils or bedrock outcroppings.
- On areas having standing water.

√ Manage barnyards, feedlots, and pastures to control manure concentration. Provide adequate storage for the time that manure cannot be field applied.

√ Divert clean water away from manure storage areas and barnyards. Treat runoff by use of settling basins, manure pits, or filter strips.

√ Control and limit livestock access to water bodies.

MANURE MANAGEMENT

Manure application to soil can improve soil quality by the addition of organic matter, nutrients, and microorganisms that contribute to biological soil activity. Animal waste should be applied during the soil preparation process; do not harvest fresh produce within 120 days of fresh manure application. Animal waste such as cow manure or poultry litter are best applied after composting and incorporated into the soil. Composting stabilizes plant nutrients and reduces the amount of ammonium nitrogen which can cause phytotoxicity. Determine the amount of composted manure to apply to a soil based upon a nutrient analysis and soil test recommendations. If the amount of nitrogen exceeds crop needs, nitrogen and phosphorous can be loss to the environment through leaching to the groundwater or surface runoff to water bodies.

The timing of manure application should be so that plant nutrients are released when the plants are growing. Early spring to early summer is the ideal time to apply composted manures. Manure should be applied uniformly over the field; calibrate application equipment to ensure proper application rates. Manure should not be applied to saturated soils, frozen or snow covered soils, on shallow to bedrock soils, on steep slopes, or on areas with standing water.

Manure Storage

Provide adequate storage for manure for the time that it can not be applied to the field. Manure should be stored in suitable field stacking sites or properly designed storage facilities. Field storage should not exceed two weeks of duration and should not occur where water runoff will pollute water bodies. Manure should not be stored on coarse textured sandy or gravelly soils and during periods of high rainfall. Keep storage piles covered during rainfall events.

Manage barnyards, feedlots, and pastures to control manure concentration. Divert clean water away from barnyards and feedlots, including roof runoff. Treat the runoff from these areas by settling basins, manure pits, or filter strips with level spreaders.

Manure and Microbial Food Safety

Vegetable growers have to be aware of the potential for microorganisms present in manure to contaminate fresh produce. Illness definitively associated with consumption of fresh produce is a very low probability event. However, it is equally clear that outbreaks of illness associated with fresh produce have occurred in recent years. While most individuals can recover from foodborne illness, the very young, the very old, and immuno-compromised may suffer complications, including those resulting in death.

Properly composted manures are not a source of microbial contamination on fresh produce. Become informed about proper compost management for pathogen reduction and document the method of pathogen elimination of applied manure. Document the specific compost management of each lot. Maximize the time between application of manure to fields and harvest. Do not apply fresh manures within 120 days to harvest. Always incorporate manure into the soil.

Domestic animals should be excluded from fields during the growing and harvesting season. Control and limit livestock access to water bodies. Divert clean water away from manure storage areas and barnyards. Provide adequate storage for manure that cannot be field applied. Do not locate vegetable production in areas that may receive drainage, runoff, or drift from animal operations. Wild animal presence can not be excluded but should be minimized to the extent possible by methods identified by wildlife experts. Minimize the presence of vector attractants such as cull piles within production areas. Identify potential sources of contamination that may affect water and eliminate them. Ensure that wells are well designed and protected from surface runoff or soil infiltration of contaminants from manure. Water used within two weeks of harvest should be a potable quality.