DISSERTATION

A GUIDE FOR SMALL-SCALE ORGANIC VEGETABLE FARMERS IN THE ROCKY MOUNTAIN REGION

Submitted by

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ABSTRACT OF THE DISSERTATION

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The steady growth over the last twenty-five years in the organic agriculture sector has been paralleled by growth in the number of farmers' markets and community-supported agriculture (CSA) operations, reflecting increased consumer interest in "buying locally". Small organic farms represent the core of the local growers involved and invested in this trend in Colorado and yet have had little research to direct or support their forays into organic agriculture. Agricultural research focusing on organic systems and the challenges in soil fertility management, pest and disease management, and plant breeding appropriate for organic production has lagged. The research in organic production that has been done in the US has occurred largely on the east and west coasts and upper Midwest where climatic conditions are different from that of the arid, inter-mountain west. In 2002 the Horticulture and Landscape Architecture Department at Colorado State University initiated the Specialty Crops Program, and soon after the Rocky Mountain Small Organic Farm Project (RMSOFP) was established to address issues relevant to small-scale organic farmers in Colorado and the region. Within this context a prototypic small organic farm was developed on certified organic land at the Horticulture Field Research Center (HFRC) neat Ft. Collins, Colorado. A variety of research projects have been undertaken ranging from cultivar trials of vegetables, to evaluations of phytochemicals of vegetables grown on organic and conventional plots.

This production guide for small-scale organic farmers provides a basis for future research, education, and outreach efforts that can be made available to farmers, extension workers, teachers and students. It is a comprehensive production guide for small-scale organic farmers in the climatic zones similar to those found in Colorado. Topics included are: soil fertility management, tillage, irrigation, and pest management. Detailed production recommendations for melons, tomatoes, spinach and lettuce are presented, with cultivar trial results of melons, tomatoes and spinach. Fifteen organic vegetable farmers from Colorado were interviewed about their production practices, and their comments are included.

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Introduction

The number of farms and acreage dedicated to organic vegetable farming continue to increase in Colorado and across the nation. The most recent USDA agricultural census reported that Colorado was the third largest organic vegetable producer in the country with 5,222 acres (excluding over 1,400 acres of potatoes), representing about 7% of the nation's organic vegetable acreage (USDA/ERS, 2008). The Organic Trade Association's 2007 Manufacturer's Survey reports that the United States organic industry grew 21% to reach $17.7 billion in consumer sales in 2006. Organic foods, representing over 95% of all organic product sales, experienced an annual growth in sales of 20.9% in 2006. Of organic food sales, organic fruits and vegetables saw a 24% increase in 2006, representing $6.7 billion in sales (OTA, 2007). This trend in growth has persisted for over 20 years in the United States, and OTA projections are for these trends to continue well into the future. Opportunities for small organic farmers in Colorado have increased markedly over the past 10 years, as more farmers' markets have been established around the state. The advent of Community Supported Agriculture (CSA) has provided markets to farmers that are unable to access an increasingly concentrated and centralized market system in the United States.

In spite of this unprecedented growth in organic agriculture, research in organic production systems has lagged (Sooby, 2003) and much of the knowledge base used by organic farmers has been "home-grown" and passed informally, from farmer to farmer. There is a growing body of literature that provides organic farmers with scientifically proven production methods, but much of this literature is based on systems representing the rain-fed production areas of the east and west coasts of the country which do not translate well to Colorado or other areas of the arid intermountain west. Furthermore, small-scale farmers face unique challenges in terms of scale-appropriate technologies and market access, forcing them to be highly diversified and often very inefficient relative to large, mechanized farms.

This publication aims to serve as a comprehensive guide to production and decision-making guide with methodologies appropriate for Colorado organic vegetable farmers. It draws on research completed by the author, collaborative research projects in which the author participated, case studies, farmer surveys, and supportive material from other sources. Four crops are highlighted, representing warm and cool season crops commonly grown by small-scale farmers.

Chapter 1 SOIL FERTILITY MANAGEMENT

Organic soil fertility management

Organic soil fertility management is based on the premise that adequate crop nutrition is provided by practices that enhance soil structure, tilth, and the micro- and macronutrient availability required for crop production. "Soil health" is a term commonly used by organic farmers to describe (1) the soil's ability to provide crop nutrition, and (2) the diversity of soil microorganisms that play critical roles in nutrient cycling, enhancement of nutrient uptake by roots, and protection from plant pathogens in the rhizosphere. Crop rotation, incorporation of green manures, and supplementation of required nutrients with animal and crop byproducts and mined elements provide the foundation for healthy soils in organic production. Appropriate tillage practices, which minimize the possibility of erosion, compaction, and deterioration of soil structure, also play key roles in organic soil management. In addition to being widely recognized as good agricultural practices, they are required for organic certification by the USDA National Organic Program (NOP) regulations which are detailed in "Soil fertility and crop nutrient management practice standards" Title 7, Part 205§ 205.203 of the Federal Register (USDA, 2002b).

The starting point for developing an organic soil fertility management plan is to understand the condition of the soil, and then to identify the objectives and steps to enhance the soil's health and productivity. A good first step is to obtain a soil test and submit it for analysis at a soil testing laboratory (Appendix E lists regional soil testing labs and how to choose a lab). This will provide a baseline of information enabling the farmer to begin to make decisions based on the physical, chemical, and biological characteristics of the soils in question. The following sections detail many of the options and practices used by organic farmers to maintain and improve their soil.

Elements to be considered for organic production in Colorado soils

Colorado soils, like soils anywhere, are diverse in physiochemical properties; however, there are some overriding properties that will be assumed to be characteristic of Colorado soils. The majority of Colorado's farm land is of calcareous origin, and is characteristically alkaline. Alkaline soils (pH greater than 7.0) present some challenges for soil fertility management because several plant nutrients are less available under high pH conditions (Hawkes, 1985). The macronutrient phosphorus as well as the micronutrients boron, iron, and zinc fall into this category (Foth, 1996; Havlin and Westfall, 1984) and require special management approaches. Potassium is naturally present in high concentrations (Barbarick, 1985; Soltanpour et al., 1979), and calcium (Ca), magnesium (Mg), and sulfur (S) are found in adequate amounts in most Colorado soils (Ells, 1993).

Taking into account the common characteristics of Colorado's farmland soils (soils are alkaline and possess ample potassium, calcium, magnesium, and sulfur), the following sections will address strategies and recommended practices for organic growers to correct common nutrient deficiencies and improve characteristics of their soils.

Common strategies employed by organic growers in soil fertility management

Crop rotation and use of green manures, animal manures, and other animal and plant by-products, and mined materials provide organic farmers with the majority of nutritional requirements for their crops. Farmers generally use a combination of all of these strategies, emphasizing different components of these options depending upon the nutrient requirement of the following crop, the time frame of cropping, and the availability and cost of the different options. Green manures can provide much of the required nutrition, and shortfalls can be corrected with the use of composted animal manures and other animal and plant by-products prepared for agricultural use. Some farming operations may be too small to afford retiring land from cash crop production to produce a green manure crop, in which case soil fertility relies on the application of organic fertilizers. The following sections describe the different options suited to Colorado conditions for organic vegetable producers, with special emphasis on sustainable methods that rely primarily on home-grown, rather than imported inputs.

Green manures

Green manures are crops that are not harvested or removed from the field, but rather are incorporated into the soil providing a variety of benefits. Green manures enhance soil fertility and physical properties of the soil by increasing soil organic matter (SOM), and fixing atmospheric nitrogen by using legumes. In the process of increasing SOM, organisms recycle plant material into plant available nutrients. Green manures are also valuable weed management tools, smothering and displacing weeds. Additionally green manures provide habitat for beneficial organisms living below and above the soil surface that are critical in a biologically and economically balanced ecosystem. Pollen and nectar of many green manure crops are important food and energy sources for a wide array of beneficial arthropods. Green manures also provide soil protection from wind and precipitation, thereby reducing erosion. The roots of green manure crops sequester large amounts of nitrogen that may otherwise leach out of the root zone, or out of reach of shallow rooted vegetable crops.

The choice of plant species to be grown is based on specific objectives; primarily those that provide soil improving attributes such as maximization of biomass production to increase SOM content and/or the maximization of nitrogen fixation. Other secondary/complimentary objectives commonly include choosing a species whose dense canopy and fast growth competes well with weed species, and providing habitat for beneficial arthropods.

The incorporation of vegetative matter into the soil increases organic matter content of the soil. A complex of soil dwelling organisms feed on this vegetative matter, breaking it down into “active” and “stable” fractions of organic matter. The active fraction is characterized as the easily and quickly consumed polysaccharides (sugars, starches, hemicelluloses, pectins) and proteins that are rich in nitrogenous compounds; these are the food for microorganisms (Clark, 2007; Stevenson and Cole, 1999). The consumption of these compounds (especially proteins) by microorganisms results in release of nitrogen as well as phosphorus, sulfur, and other elements required for plant nutrition. The active fraction of organic matter is thus most important in the immediate conversion (or cycling) of plant-held nutrients back into plant-available nutrients. The stable fraction of organic matter is composed of lignins and celluloses which are more slowly degraded (Quemada and Cabrera, 1995), and contribute to the production of humus, an important component that contributes to the physical structure of soil, water holding capacity, and cation exchange capacity. Humus production is a very slow process, and is probably negligible under common crop/green manure rotations that include cultivation which readily oxidizes much of the exposed organic matter (Alison, 1973).

Generally, grasses and non-leguminous species have a higher percentage of lignin in their stalks and leaves—especially as these plants reach maturity—and decompose more slowly than annual legumes. Succulent annual leguminous crops generally produce a higher percentage of sugars, starches and proteins and decompose more rapidly (Angers, 1992). Perennial legumes, which have strong fibrous stems as well as succulent leaves, contribute to both the active and stable fractions of SOM when they are incorporated into the soil. Leguminous plant roots, hosting nitrogen-fixing bacteria, release significant amounts of nitrogen into the soil when they are degraded. Soil pH may also be lowered by increasing SOM, making elements such as phosphorus, iron, and zinc more available, which may otherwise be tied-up in alkaline soils (Bolan and Hedley, 1990; Sarrantonio, 2007). The rate of decomposition of SOM and the subsequent release of plant nutrients are important considerations in organic production. These factors compel the farmer to synchronize crop nutritional needs with the rate of mineralization (i.e., the process by which organic forms of plant nutrients are converted into mineral forms which are then absorbable by plant roots). This may be possible in general terms, but additional fertility is often needed to span the gaps of crop needs and nutrient release from SOM.

The objectives of using green manure must be understood and management issues taken into account when determining the appropriate green manure to be grown. Among the many factors to consider are soil fertility objectives, crop timing, irrigation considerations, and tillage options. Objectives must also be matched with the feasibility of producing any given green manure given the farm's specific climatic, soil, and management constraints.

Identification of the objective of the green manure.

Green manures contribute to soil fertility by adding organic matter, recycling plant nutrients, and converting atmospheric nitrogen into plant useable forms of nitrogen when leguminous green manures are grown. Green manures also sequester plant nutrients (especially nitrogen) making them less susceptible to loss by erosion and leaching. These are probably the greatest benefits of green manures and are also the most easily quantifiable, because SOM and nitrogen are both easily measured with soil tests. The quantifiable nitrogen contribution from a green manure crop may be used when determining the fertility requirements for subsequent cash crops, as well as for estimating the value of a green manure crop relative to the cost of other nitrogen sources, such as compost and other animal and plant byproducts. Additional activity of soil microorganisms is a well-recognized benefit associated with increased SOM, but measurement and quantification is not practically applicable to small farmers and is therefore only acknowledged as a significant benefit.

Of the macronutrients required by vegetable crops, nitrogen and phosphorus are most often the production limiting nutrients in Colorado soils. Increasing soil nitrogen and retaining resident nitrogen are two functions of green manure crops. Animal manures are generally applied to supply phosphorus in soils with pH >5.5 (Dorozhkin, 2007; Nelson and Janke, 2007; Rajan et al., 2004), and are also important sources of nitrogen and micronutrients.

Micronutrients (essential elements used in very small quantities, e.g., B, Cu, Fe, Cl, Mn, Mo, and Zn) present in the soil become increasingly available as organic matter is increased in alkaline soils. Organic acids associated with SOM result in minor reductions in soil pH, making micronutrients such as iron and zinc slightly more available (Bolan and Hedley, 1990; Clark, 2007).

Nitrogen fixation

When the primary objective of growing a green manure crop is the addition of nitrogen to the soil, a leguminous species is used. Leguminous crops grown under ideal conditions may fix atmospheric nitrogen into plant useable nitrogen forms at rates in excess of 250 lbs/ac/yr when incorporated into the soil. However, under normal conditions nitrogen contributions of leguminous crops are more modest, generally ranging from 80-175 lbs/ac (Clark, 2007). Specific green manure crops are covered later in this chapter.

Nitrogen sequestration

Non-leguminous crops do not fix atmospheric nitrogen, but sequester nitrogen in the form of proteins in their plant parts. Grasses, and forbs (including many brassicas) that have dense and extensive fibrous root systems, effectively trap and sequester nitrogen and other plant nutrients and are termed "trap crops". If the objective of the green manure crop is to keep resident nitrogen in the field from being lost to leaching, a green manure crop which effectively sequesters nitrogen would be used.

Soil organic matter

If the primary objective is to increase SOM, a green manure crop which produces the greatest amount of biomass would be used.

Nutrient mining

If mining or relocation of nutrients in the soil which are normally out of reach or are unavailable to the cash crop's roots because of soil chemistry is the objective, a green manure whose roots system or root exudates mine and solubolize nutrients would be chosen. Hoffland, Findenegg, and Nelemans (1989) report that malic and citric acid produced by rape seedling roots may make insoluble P more available to subsequent crops. Deep rooted grasses and brassicas that are credited for sequestering nitrogen also access and transport nutrients to shallower depths where they can be utilized by some shallow rooted vegetables like lettuce and spinach. Alfalfa, a common rotational leguminous crop with deep tap roots, is credited with raising nutrients from deep in the soil soil profile (Lampkin, 1990).

Beneficial habitat

Beneficial arthropod (predators, parasites, and pollinators) habitat is a byproduct of many green manure crop choices, but it may also be a primary objective. Where development of beneficial habitat is the objective, pollen and nectar producing green manures would be chosen to provide food sources. Buckwheat for example are especially attractive to lady bird beetles and syrphid flies (Poncavage, 1994) and Dutch white and red clovers attract a wide range of predacious and parasitic insects (Atthowe, 2007).

The rhizosphere (or root zone) of cropping systems is also enhanced biologically by providing habitat for beneficial organisms including soil-dwelling arthropods, earthworms, beneficial fungi, bacteria, and predatory nematodes. Predatory ground beetles and rove beetles thrive in plantings of grass (Brown, 2007) and "the greatest success in biological control of nematodes has involved the conservation and enhancement of antagonists naturally in the soil" (Ferris et al., 1992)

Other benefits of green manures

Benefits of green manures that are well-known but more difficult to quantify include the enhanced water retention and water penetration resulting from an increase in SOM (Vaughan and Ord, 1985). Much of the soil improvement derived from the use of green manures and cover crops may be credited to mycorrhizae which produce the water insoluble protein glomalin that "glue" particles of soil, bacteria, fungi, and other organic matter into soil aggregates (Sparling, 1985). Mycorrhizal fungi associated with plant roots act as extensions to root hairs, aiding in root exploration and absorption of plant nutrients.

Green manures also serve as cover crops by playing a critical role in reducing soil erosion by wind or water, thereby complementing many of the objectives listed above. A combination of different species in a green manure crop may provide a combination of nitrogen fixation, sequestration, and biomass production (Ranells and Wagger, 1997).

Objective: maximization of nitrogen contribution

Leguminous crops that fix nitrogen from atmospheric N contribute the highest amount of nitrogen to the subsequent cash crop (Hartwig and Ammon, 2002) . The amount of nitrogen supplied by the green manure is a function of the amount of dry matter produced, with roughly 70-85% of the nitrogen contribution coming from the vegetative portion of the plant, and the remainder from the roots. Hairy vetch produces the highest amount of nitrogen relative to other species commonly grown (Holderbaum et al.1990; Sarrantonio 2007). Estimates can be made to determine how much nitrogen can be expected to be fixed from a green manure crop. However, N-fixation varies from species to species and from year to year depending upon weather, stand density, resident soil nitrogen (Mueller and Thorup-Kristensen, 2001), and the developmental stage at which the green manure is "turned-under" or incorporated into the soil. When resident soil nitrogen is relatively high, legumes tend to utilize the available nitrogen in lieu of fixing their own from the atmosphere. Nitrogen fixation is also optimized when soil moisture is not a limiting factor in plant growth. Maximum nitrogen incorporation is possible when the legume crop is beginning to flower; once seed begins to form, nitrogen is diverted from nodules on the roots to the developing seeds (Mueller and Thorup-Kristensen, 2001). Table 1.1 presents legume species that are commonly grown in Colorado, and expected nitrogen and biomass productivity.

Table 1.1 Legume species commonly grown in Colorado and expected nitrogen and biomass productivity (adapted from Clark, 2007, Duke 2002, Foster, 1990)

	Rates of nitrogen fixation (lb/ac/yr)	Rates of dry matter production (lb/ac/yr)
Field pea	90–150	4000–5000
Hairy vetch	90–200	2300–5000
Red clover	70–150	2000–5000
Sweetclover	50-180	2000-7500
White clover	80–200	2000–6000

Estimation of nitrogen contribution from green manure crops, SOM, and residual nitrogen.

Dr. Marianne Sarrantonio has developed a formula with which farmers can estimate the amount of nitrogen a green manure crop will produce (Sarrantonio, 2007). For this formula to be used, above-ground biomass of the crop is estimated by taking several representative samples of a known area, drying them, and calculating yield of dry matter per acre. If the crop is a legume, it is estimated that the material contains 3.5%–4% N just before flowering. If incorporation occurs after flowering, the material is estimated to contain 3%–3.5% N. For grasses and cereal grains, 2%–3 % nitrogen is common just before flowering and 1.5%–2.5% nitrogen after flowering.

If the residue is incorporated immediately, about half of the total N is mineralized and becomes useable. However, if the residue is left on the surface (as in a no-till crop) about one quarter of the total N becomes plant available (Sarrantonio, 2007). Once the nitrogen content from residual, SOM and green manure sources is calculated, it is possible to calculate any additional requirements, based on which crops will follow Appendix A provides estimates of available nitrogen from a green manure crop.

Green manure crop choices for maximum nitrogen contribution in Colorado.

The following discussion of green manures represents only the most commonly grown species, which have been well proven under Colorado conditions.

Hairy vetch (Vicia villosa)

Hairy vetch is a winter annual legume which is widely used and considered one of the most valuable green manure species because of its potentially high nitrogen and biomass contribution. It is considered the most winter-hardy of the cultivated vetches (McLeod, 1982a) and is widely grown in Colorado.

Hairy vetch is generally sown in the fall in Colorado, and little vegetative growth occurs before the plant becomes dormant for the winter. Most of the growth occurs early the following spring. Hairy vetch is relatively drought resistant, but fall irrigation allows for better establishment and winter survival. Filling the soil profile with water in the fall provides the green manure crop with sufficient moisture to sustain growth into the spring (Grant, 2008).

Hairy vetch is a trailing plant, and is generally grown with a grass companion crop onto which it climbs. Its tolerance of shade also allows it to be used in orchards and vineyards. Its vining nature makes it a good competitor with annual weeds.

Grown by itself, hairy vetch can produce 2,300–5,000 lbs/ac/yr dry matter and contribute 90–200 lbs/ac/yr N (Clark, 2007; Hargrove, 1986; Hofstetter, 1988a; Smith et al., 1987). It is also credited with loosening top soil, penetrating tight subsoils, and freeing K and P (McLeod, 1982b). The crop may be killed by mowing in the spring. If allowed to seed, the hard seeds may continue to germinate over a period of years, causing fields to become weedy in some instances. However, this has not been a serious concern in Colorado (Grant, 2008).

Hairy vetch tolerates a wide range of soil pH—from 4.9 to 8.0 (Duke, 2002)—and is well adapted for most areas in Colorado. It is seeded at rates ranging from 25–60 lbs/ac depending upon factors such as whether or not it is interplanted with another crop (Hofstetter, 1988b), the quality of the seed bed, and the sort of planting equipment available. Lower seeding rates are used when inter-seeded with other species and when sown into well-prepared seed beds with an accurate planter. Higher rates are used when the seed bed is rough, and the seed is broadcast rather than drilled. Seed bed preparation follows guidelines for any crop—the better prepared the seed bed, the better the establishment. When overseeding into a standing crop, however, establishment is bound to be compromised because good soil to seed contact is reduced. Seed drilling into a well-prepared seed bed is preferred, but disking and cultipacking after broadcasting is an option. Irrigation immediately after planting is important to establish a uniform stand. Seeding dates of mid to late August in Colorado generally allow the crop to become established before the first hard freeze. The seed should be inoculated with inoculum type "C" or pea/vetch inoculum (Clark, 2007).

Timing of mowing and/or incorporation of the green manure depends on the stage of maturity and whether hairy vetch is grown with a grass crop. Sickle mowers work well if the trailing hairy vetch is supported by the grass; otherwise a flail mower, power spader, rototiller, heavy disc, or plow can be used to mow or directly incorporate the vetch into the soil. Flail mowing at high rates of speed kills the crop and leaves behind a relatively coarse mulch that can be planted.

Hairy vetch is also useful as forage, hay, or silage (Duke, 2002). Limited fall growth, however, prevents it from being a good winter pasture crop in Colorado.

Sweetclover (Melilotus officinalis)

The sweetclovers are not true clovers (*Trifolium*) but instead belong to the genus *Melilotus*. White sweetclover (*Melilotus alba* Desrousseaux) and yellow sweetclover (*Melilotus officinalis* [L.] Lamarck) are the common sweetclovers used as green manure (Metcalfe and Nelson, 1985) and perform well in Colorado.

Sweetclovers are tall, erect, annual or biennial legumes with strong tap roots. They are quite tolerant of high and low temperatures, and are not reported to be winter killed (Duke, 2002). Sweetclover is more drought tolerant than many legumes, and survives Colorado conditions with minimal irrigation. McLeod (1982a) states that sweetclovers are able to mobilize P and K through their deep tap roots. Sweetclover thrives in soils with pH >6.8 (Johnny's Selected Seeds . Research, 1983; McLeod, 1982a), and on soils ranging from heavy clays to gravels and relatively high salt levels (3–6 mmhos/cm) (Duke, 2002)

Sweetclover is generally seeded at 10–15 lbs/ac, either broadcast on disked ground and cultipacked, or drilled ½ inch deep with or without a grass or other legume. Sweetclover seed is hard and requires scarification for quick germination and emergence (Duke, 2002). Inoculation of seed with alfalfa seed inoculum before planting is appropriate.

The relatively low percentage of leaf cover produced by sweetclover and its slow establishment allows weeds to develop (SAREP, 2008), so good weed control should be in place during establishment. Cereal nurse-crops can be useful to this end. Sweetclover's slow establishment and growth in the spring fit better into crop rotations spanning 1½ to 2 years rather than as winter cover/green manure. Once established, it is quite drought tolerant, and with timely mowing annual weeds are easily controlled.

Biomass production ranges from 2000–7500 lb/ac (Duke, 2002; Foster, 1990). Reports for nitrogen fixation by sweetclover range from 50–180 lbs/ac (Duke, 2002; Foster, 1990). The tap root development is widely cited as capable of opening tight and compacted soils.

Sweetclover also has a number of alternative uses ranging from fiber production to flavoring, and is an excellent bee crop.

Field pea (Pisum sativum L.)

Field pea is a winter or summer annual that is widely used as a green manure crop and is often interplanted with hairy vetch and a cereal grain species such as rye. Field pea is also known as “winter pea” and “spring pea” (Graves et al., 1988). Field pea provides relatively high amounts of biomass (4000–5000 lbs/ac) and nitrogen (90–150 lbs/ac), especially during cool spring weather (Clark, 2007). Its fibrous root system is credited with loosening top soil and its succulent stems and leaves break down quickly when incorporated.

Field pea germinates at temperatures as low as 39° F, but optimum germination occurs at 75° F. Optimal growth is under cool conditions, and it is severely limited by hot dry conditions (Duke, 2002). In Colorado conditions, where the spring season may be very short, it is best to use field pea as a fall planted green manure, thus allowing the fall established crop to grow quickly during the short window of time in the spring before temperatures become too high. When sown in the early fall, winter survival is increased, and greater spring growth is achieved (Auld et al., 1979). Winter dormancy allows field pea to overwinter (Auld et al., 1979) well in most areas of Colorado, especially if snow cover or a cereal nurse crop provide protection from desiccation. If planted in the spring, peas should be sown when soil temperatures at seeding depth reach 40° F. Field pea will grow to a height of about 2 feet, climbing on companion crops. Irrigation is required for optimum production in Colorado, with a combined precipitation and irrigation requirement of 20 inches for optimum production (Graves et al., 1988). Recommended seeding rates are 50–90 lbs/ac when drilled, or 90–150 lbs/ac when broadcast. When interplanted with a cereal rates may be cut in half (Graves et al., 1988). Field pea is adapted to a wide range of well-drained soil types and pH levels, but germination is inhibited under highly salty conditions (EC > 6 mmhos/cm) (Duke, 2002; McLeod, 1982a). Pea has a relatively short seed life, and seed should be germination tested if more than 2 years old (Duke, 2002). Seed should be inoculated with *Rhizobium leguminosarum*, Type "C", which is also used for a variety of vetches.

White clover (Trifolium repens)

White clover is included in this section because it can be used in no-till or "living mulch" production systems (Atthowe, 2008b; Hartwig and Ammon, 2002). Also known as Ladino and New Zealand white clover, it is an extremely winter-hardy, perennial legume, which when stressed may act as an annual (Duke, 2002). White clover is low growing, reaching heights of only 8–10 inches, but its thick stands produce 2,000–6,000 lb/ac/year of biomass. It reseeds itself readily and spreads by stolons, producing a thick mat. Good establishment of the crop before entering the winter season increases winter survival. White clover grows best under cool, moist conditions, but also thrives under irrigated conditions. Its relatively shallow root system requires irrigation similar to alfalfa, which in Colorado may amount to 1 inch per week during the production months. It tolerates soils with high water tables and/or poor drainage better than some other deeply rooted legumes. The literature is ambiguous in terms of soil pH tolerance by white clover; Duke (2002) states that the species tolerates both high and low pH, but McLeod (1982b) states that white clover does not tolerate high pH. Observations of good sweet clover growth in several locations in Colorado, where pH ranges from 7–8, suggest that white clover thrives in a variety of conditions. It grows in soils ranging from sandy to heavy clay, provided the soil is kept moist (Carlson et al., 1985; Gibson and Cope, 1985). White clover's tolerance of shade allows it to grow well in intercropped green manures, but as is the case with other legumes, it does not compete well with grasses if nitrogen levels are high, or if phosphorus is limited (Gibson and Cope, 1985; Mackay, 1989). Seed should be sown shallowly or on the surface (Gibson and Cope, 1985) into a finely prepared seed bed. Drilling is preferred, but broadcasting, followed by a cultipacker works relatively well. When interplanting with a cereal, Gibson and Cope recommend drilling the cereal first, and then broadcasting the clover seed and cultipacking the field, thus avoiding planting the clover too deeply (Gibson and Cope, 1985). Seeding rates of 5-9 lbs/ac when drilled, or twice that rate if broadcast, are recommended. If interplanted, seeding rates of 4-

6 lbs/ac reduce interspecies competition (Duke, 2002). White clover is commonly overseeded into established vegetable crops, such as sweet corn, where it grows and establishes slowly in the shade of the crop, but grows quickly when the over-story crop is harvested and light levels increase.

When overseeding into an established vegetable crop, white clover should be sown at least 40 days before the first killing frost (mid-August in most parts of Colorado). The seed should be inoculated with type "B" rhizobial inoculants. Initial establishment depends on there being adequate moisture until at least 4 true leaves have developed. Once well-established, the stand requires close grazing or mowing or the stand may deteriorate due to disease problems (Ron Walser, NMSU Alcalde Center for Sustainable Agriculture, personal communication). White clover, with its dense, stoloniferous mat of vegetation, can reduce weed pressure; 57% reduction in weed biomass was recorded in California vineyards when planted to white clover. Dr. Walser reported that white clover out-competes bindweed where planted as a permanent cover crop in trellised, small fruit plots. Nitrogen contribution by white clover ranges from 80–200 lbs/ac in the year following establishment. When grown as a perennial cover, partial cultivation, which kills some plants, triggers nitrogen release. Merit, a Ladino type of white clover, has done well in Nebraska studies when seeded in the fall (Clark, 2007).

Green manure management for maximum nitrogen contribution

Each of the legumes mentioned that are used for green manures has specific production requirements, such as adequate irrigation for initial establishment, proper seeding depth, and, very importantly, the inoculation of the legume seed with the proper species of nitrogen-fixing bacteria.

Inoculation of legume seed

Inoculation of legumes greatly enhances their ability to fix atmospheric nitrogen in nitrogen deficient soils. Legumes, like any plant, will use soil nitrogen when it is available;

however, when nitrogen is in short supply legumes may fix atmospheric nitrogen. Legumes' ability to fix nitrogen depends on their roots encountering the right strain of rhizobial bacteria, which allows a rhizobial symbiosis to occur. Soil may be inhabited by the required rhizobial species from previous crops of the same legume, but time and environmental conditions may have reduced the population of these bacteria to levels that are inadequate for effective re-colonization of the newly planted legume. Only fresh inoculum of the appropriate strain should be used, and the expiration date on the package should be adhered to. Seed treatment by the farmer immediately before planting is recommended. While pre-treated seed is available for some legumes, performance has been variable, possibly because of storage conditions after seed treatment (Deaker et al., 2004).

On-farm seed treatment involves making a slurry of the inoculum in which the seed is coated. The powdery rhizobia adhere to the seed coat better when the slurry contains a sticking agent such as a weak sugar solution, milk, or a commercially produced sticking agent recommended by the manufacturer of the inoculum. The seed is stirred in the slurry to thoroughly coat it, and then allowed to dry in the shade. Once dry, it is ready to be planted. If the inoculated seed is not used immediately, it can be recoated. The shelf life of rhizobia is short, and should be protected from direct sunlight and heat. Checking the roots of the legume in the pre-bloom period for nodules on the roots (generally pinkish in color when opened), verifies that inoculation and rhizobial symbiosis has been successful. Carefully digging up the plant and washing the soil away from the roots will show the extent of nodulation. If simply pulled from the soil, many of the nodules will be torn from the roots. Once the legume has bloomed, nitrogen fixation ceases, and the nodules are sloughed off the plant. The rhizobia will reside in the soil until another legume root of the correct species encounters it and the cycle resumes.

Other potential legume green manures for Colorado:

Berseem clover (*Trifolium alexandrinum*) is grown as a winter annual in the southern U.S. and southern valleys of California. It is not winter-hardy and would be limited to summer production in Colorado. It is reportedly tolerant of high pH and salty soils and has similar irrigation requirements to that of alfalfa (SAREP, 2008).

Forage soybean (*Glycine max* [L.]) is a warm season annual that produces abundant biomass (2–6 ton/ac) under higher temperatures (Seiter et al., 2004). Grown as forage in the eastern U.S., its biomass and nitrogen-fixing potential suggest that it may be a useful green manure as well. Several cultivars are available and evaluation under Colorado conditions is underway.

Cowpea (*Vigna unguiculata* [L.]) is a warm season annual that is generally grown east of the Mississippi River and in California where it produces quick weed suppressing cover and high levels of nitrogen fixation. Once established, cowpea is drought tolerant and should require less irrigation than other summer legumes (Clark, 2007).

Medics (*Medicago spp.*) is well suited to dry conditions and alkaline soils where other moisture loving legumes will not survive. The hard seed may stay dormant for years and needs scarification for high germination rates. This crop may work well as a living mulch in Colorado (Munoz and Graves, 1988).

In addition to choosing a crop that contributes N to the soil, species that trap or sequester soil nitrogen fall into the category of nitrogen managing crops. The adage, " a penny saved is a penny earned," applies to the conservation of soil nitrogen, which is prone to leaching. Jackson et al. (1993a) reported a wide range of nitrogen sequestration depending on the species of green manure used. In their study they found N sequestration of white mustard>oilseed radish>cereal rye>annual ryegrass, ranging from 182 lb/ac to 75 lb/ac, respectively. These amounts are significant, and represent large savings in nitrogen applications. Additionally, they provide environmental protection from potential run-off and ground water contamination by nitrogen.

Objective: maximize biomass production.

As stated earlier, soil organic matter plays a critical role in soil health and soil fertility. In Colorado, where soils are generally low in SOM (< 2 % SOM), incorporation of green manures is an excellent option for increasing SOM. Evaluation of a green manure's potential biomass production should take into account the below-ground biomass contribution of roots in addition to the above-ground vegetative matter. Grasses, including cereal grains, produce extensive fibrous root systems, making up 15%–50% of the total biomass produced by the plant (Bolinder et al., 1997). In addition to producing up to 5 tons/ac/yr of biomass, grasses are credited with the ability to sequester a large percentage of the available nitrogen in the soil, reducing nitrate losses to leaching during irrigation or wet periods. These stored nitrogen reserves are released slowly into the soil as the lignin and cellulose plant components are broken down. Some *Brassica* species have been shown to sequester even higher amounts of nitrogen than cereal grains, and are widely used in some parts of the state (especially in the San Luis Valley) for this purpose as well as for disease suppression. The relatively high lignin content and high total biomass production of grasses make them good choices for building soils.

Grasses may be grown alone or are commonly interplanted with other grasses, legumes, or forbs, such as buckwheat. Some grasses are winter-hardy, and are sown in the late summer or early fall for overwintering. These winter-hardy species cover the soil, providing protection from erosion through the winter, and produce the majority of their growth in the following spring. Frost-sensitive grass species can be sown in the late summer and die in the winter, but they provide winter soil cover. Frost-sensitive grass species are incorporated into the soil early in the spring before a cash crop is planted. Grasses such as sorghum-sudangrass are best adapted for midsummer production: they thrive in the summer heat, produce large amounts of biomass, and compete well with weeds.

There are a number of strategies that combine the utilization of grasses for biomass production and weed suppression. The following section details the use of the most commonly grown non-leguminous species, whose primary purposes are biomass production and weed suppression.

Grasses commonly used as green manures in Colorado include winter-hardy species, (winter wheat, cereal rye, and triticale) and the frost-sensitive species (spring barley, oats, and sorghum-sudangrass). Of these grass species, cereal rye is the most efficient at sequestering residual nitrogen. In the San Luis Valley, cereal rye took up more than 70 lb N/A in fall when planted by October 1, compared to other grasses, including wheat, oats, barley and ryegrass, which were only able to take-up about half that amount in fall (Delgado et al., 1999).

Other non-grass green manures used for biomass production include *brassicas*, such as canola and rape (*Brassica napus*, *B. rapa*). Canola/rape is commonly grown in the San Luis Valley in rotation with barley and potatoes. These crops produce as much biomass (4000–6000 lbs/ac) or more than some of the better grass species (Delgado et al., 2007), and are credited with excellent nitrogen sequestration and disease and weed suppression.

Green manure crop choices for maximum biomass contribution in Colorado.

The following discussion of green manures represents only the most commonly grown species, which have been well-proven under Colorado conditions. Certainly there are many more species that have not yet been evaluated in Colorado and may be excellent choices.

Cereal rye (Secale cereale L.)

Cereal rye, or rye, is a widely adapted cool-season annual grass that is commonly planted in the late summer or early fall and incorporated in the following spring or early summer. Its winter hardiness exceeds that of all other cereal crops (Stoskopf, 1985), and it is the most drought tolerant of cereals (Evans and Scoles, 1976), making it a good candidate for all production areas of Colorado. It has the best-developed root system among annual cereal crops (Starzycki, 1976) and is considered to be among the best green manures for improving soil structure (Clark, 2007). Rye grows well with supplemental irrigation in Colorado, but it will tolerate drought. Rye germinates at low temperatures (37–41°F), but optimal germination occurs at 77–88°F (Stoskopf, 1985). Rye's quick germination and growth enables it to smother weeds. Recommended seeding rates vary greatly, from 60–160 lbs/ac, depending on whether the crop is interplanted or grown alone. Lower seeding rates are used when interplanting with legumes or under drought conditions, and higher rates may be used under good growing conditions when the crop is intended solely as a green manure crop where weed suppression and maximum biomass production are the objectives. Stoskopf (1985) recommended seeding rates as high as 300 lbs/ac when sown late, and complete soil coverage to reduce erosion is the objective. Drilling the seed into a well-prepared seed bed is preferred, but it may be broadcast, then disked lightly and cultipacked. Overseeding of rye into established crops such as sweet corn is successful at nearly any developmental stage of the corn crop provided the corn is well established and will not need to compete with the rye for water or fertility. Rye is grown by itself or interplanted with legumes or forbs. It provides a strong, erect structure to support vining legumes such as pea or vetch. Rye benefits from good soil fertility, but also tolerates low fertility (McLeod, 1982b).

Incorporation of rye residue into the soil can be challenging if not done while the growth is still tender. Once the plant produces a seed stalk, it becomes very tough and difficult to chop. Other grasses also become tough when mature, but not to the extent of rye. Another reason for early incorporation of rye is the possibility of mature seed setting and reseeding which can result in volunteer rye becoming weedy in following crops. While this is not generally a serious problem in vegetable cropping systems where frequent cultivation occurs, rotation with wheat or another cereal grain results in dockage if contaminated with cereal rye.

Wheat (Triticum aestivum)

Both winter and spring wheats are widely grown cereal crops in Colorado, and may also be used in much the same way as cereal rye and triticale green manures. Winter wheat is winter hardy and is somewhat easier to incorporate than rye, but it does not produce as much biomass. Sown in the late summer or early fall, it will grow into the fall, go dormant over the winter, and put on most of its vegetative growth in the following spring. In Colorado, delaying planting until October reduces biomass yield 100 fold when compared to August planting (Delgado et al., 1999). Higher amounts of biomass are produced using long-stemmed cultivars, but these may lodge and become more difficult to incorporate than shorter, stiffer stalked cultivars. Wheat can be established with minimal moisture, but greatest biomass is dependent upon adequate moisture. Filling the soil profile with water in the fall will provide sufficient moisture for the fall and early spring growth; this equates to 3-5 inches between the time of seeding and April, and an additional 0.25 inches/day thereafter until the green manure is incorporated (Al-Kaisi and Shanahan, 1999). Optimal biomass production depends not only on soil moisture, but also on adequate soil nitrogen (30–35 ppm NO_3-N) (Davis et al., 2005; Eck, 1988)

Wheat is a good nitrogen scavenger. Delgado et al (1998) reported wheat scavenging 5 feet deep in Colorado's San Luis Valley, providing valuable nitrogen to subsequent shallow-rooted vegetable crops such as lettuce. Because green manure wheat is not harvested for grain, all of the P and K absorbed during its growth is recycled and available to the subsequent crop.

Triticale (x Triticosecale)

Triticale is a hybrid cross of rye and wheat and shares many of the same properties of these two species when used as a green manure or cover crop. This winter-hardy annual grass is generally sown in the fall with a legume, and it is incorporated the following spring. All cultural practices for triticale are the same as for wheat and rye. Self-sterile triticale is available and will not reseed itself, which is advantageous if incorporation of the crop is delayed until after seed set. Triticale is also used as forage, for which the awnless seed head is preferred.

Sorghum-Sudan (Sorghum bicolor x S. bicolor var. Sudanese)

Sorghum-sudangrass hybrids (known by Sudax and the DeKalb Seeds trade name Sudex) are fast growing, annual, warm season grasses providing the greatest amount of biomass of any of the green manure crops grown in the U.S. (4,000–18,000 lbs/ac). It is an excellent nitrogen scavenger, weed suppressor, and soil builder due its fibrous root system. It is planted in the late spring or summer, is very heat tolerant and relatively drought tolerant. Sorghum-sudangrass is well adapted to most Colorado soil types, and tolerates a wide range of pH values (pH 5–9) (Clark, 2007). It is also a valuable forage crop which can be integrated into a green manure system. Grazing should not occur after frost or other stress events, or before the crop is 24 inches tall due to toxic effects to livestock of prussic acid concentration in the plant tissue. Mowing sorghum-sudangrass when it reaches a height of three feet reportedly encourages root development, resulting in increased SOM (Clark, 2007). Sorghum-sudangrass is also effective at penetrating and breaking up compacted soils (Clark, 2007). If allowed to grow to full height (over 10 feet in some areas) the mass becomes difficult to incorporate; mowing periodically to a height of 6 inches reduces the buildup of tough fibrous stalk material. Alternatively, sowing by mid- to late July and relying on frost to kill the crop eliminates the need for mowing and produces good winter soil cover. Incorporation of the massive quantities of organic matter produced by sorghum-sudangrass may result in C:N ratios of greater than 20:1, causing temporary nitrogen deficiency in early spring vegetable crops the following year. Incorporation of residue prior to a killing frost avoids this problem (Mishanec, 1997). Clark (2007) recommends using a front mounted flail mower in order to avoid tractor tires pushing the crop over and developing skips where the mower goes over the flattened grass.

Sorghum-sudangrass is broadcast at 40-50 lbs/ac, or drilled ½ to 1 ½ inches deep at 35 lbs/ac, when soil temperatures are at least 65˚F (Clark, 2007). For best production, it should be provided with adequate nitrogen fertilization (75–100 lb/ac) (Clark, 2007).

In addition to providing dense canopies that smother weeds, the roots produce the allelochemical sorgoleone, which is responsible for suppression of many weeds (Einhellig and Souze, 1992; Scott and Weston, 1991; Weston et al., 1998).

Sorghum-sudangrass combined with buckwheat or forage soybean are options that should work well for most of the warmer regions of Colorado. Interplanting with either of these large seeded crops will require drilling, or working the seed into the soil if broadcast.

The mustards

White or yellow mustard (*Brassica hirta* or *Sinapis alba*)

Rapeseed (*B. campestris*)

Brown or Indian mustard (*B. juncea*)

Black mustard (*B. nigra*)

Canola (*B. napus*, *B. rapa*)

Oilseed radish (*Raphanus sativus*)

The mustards include several species of *brassicas*. They are cool season annuals, and include the widely grown oil seed crops, rape seed and canola. All of these species are excellent green manure crops, producing as much or more biomass as grass green manures, and sequestering more nitrate than grasses (Delgado et al., 2007; Jackson et al., 1993). Mustards break down quickly when incorporated, and release the sequestered nitrogen more readily than do grasses. Mustards are commonly grown in the San Luis Valley in rotation with barley, potatoes, and lettuce. As green manures, the mustards provide good weed suppression because of their quick developing canopy and allelopathic properties (Bialy et al., 1990; SAREP, 2008). Additionally, mustards have been the focus of a great deal of interest because glucosinolates found in *brassicas* degrade into biocidal sulfur thiocyanate compounds which are being evaluated as naturally occurring bio-fumigants to manage bacterial and fungal plant diseases as well as nematodes and weeds. There have been mixed reports regarding their efficacy (Hartz et al., 2000; Larkin and Griffin, 2007).

Some hardy mustard cultivars will survive to 10°F, and are grown in parts of the country as a fall-seeded green manure where they are over wintered. In Colorado, fall-established mustards will be winter killed in all but the mildest of winters. With vegetable crops that are harvested early in the summer, there is the opportunity to plant mustards in the late summer when the mustard crop acts as a nitrogen trap crop. Seed can be sown in the winter with germination and emergence occurring in the early spring, or sowing can be postponed until very early spring. The small seed is best drilled ½ to 1 inch deep in a firm seedbed at rates of 5-12 lb/ac. Pre-irrigation is suggested to aid in quick germination. Spring planted mustards will be severely challenged by flea beetles along the Front Range of Colorado however, in mountain valleys, where flea beetle is less prevalent, the mustards are good green manure options. Mustards are intolerant of flooded conditions, and are only moderately drought tolerant. Irrigation for mustards is similar to cereal grains, requiring about 20 inches of water per season, with peak usage of 0.3 inches/day (Efetha, 2008). Late summer plantings that freeze in the winter are reported to provide a nearly residue-free soil surface in the spring, allowing for direct seeding a subsequent crop without further seed bed preparation – a considerable savings in time and money. Incorporation of mustard green manures is done before seed is formed; if allowed to set seed, mustards readily reseed and can become weedy. Mustards can be intercropped as well, with grasses or legumes, as described above.

Recommended practices for green manure establishment

Seed bed preparation

As for any crop with an expected return, a good seed bed increases the chances that a crop will establish quickly and uniformly, enabling it to compete well with weeds. It allows the seed to have good soil/seed contact, so that the seed is able to take up moisture from the soil and initiate germination. Cloddy seed beds, and seed beds with a great deal of plant residue will generally have uneven moisture, resulting in spotty and uneven emergence of the green manure crop, unless rainy weather or continuous irrigation is used to maintain adequate moisture for green manure seed germination. Minimum tillage systems require the use of specialized drills that slice through crop residue, and place the seed into the soil below the residue. Over-working the soil to pulverize clods, however, can be very destructive to soil structure and can also oxidize SOM.

Reducing risk by increasing diversity

A common strategy to reduce risk of poor establishment of any single species is to sow a mixture of one or two grasses and one or two legumes, such as rye, triticale, hairy vetch, and field peas. The combination generally uses a grass to legume ratio of 3:1 with a total seeding rate of 80–90 lbs/ac. By increasing the diversity of species used for green manure, the likelihood of success of at least one species is improved, especially when seed bed preparation or other conditions for crop establishment are less than ideal. Additionally, mixtures of green manure species enhance the biodiversity of organisms living in the system, which is the basis of healthy ecosystems and organic agriculture.

Seeding options for green manure

Drilling for small-seeded legumes such as clovers should be shallow (less than ½ inch); most other green manures are sown about 1 inch deep. Seeding larger-seeded species slightly deeper is dependent upon the soil moisture content, and whether or not irrigation will be needed to germinate the crop. Overseeding or broadcasting green manure seed into an established crop allows green manures to become established while a cash crop is growing. Broadcasting may be done by hand or mechanically. Since calibration of application rates when broadcasting can be difficult, seeding rates are generally increased to make up for these inherent inaccuracies. Shallow cultivation immediately after or prior to overseeding provides crevices for seed to fall into and increases soil/seed contact, which enhances germination. Foot and machinery traffic after overseeding should be minimized until the over-sown green manure is established.

Broadcasting seed into crop stubble or on bare ground requires that the seed be pressed into contact with the soil, in which case a cultipacker is used. Increasing seeding rates 25%–100% for broadcast seeding is generally recommended to compensate for the decreased success of germination.

Drilling into crop stubble requires specialized drills with trash coulters ahead of the opening discs so that seed falls into the soil below the surface residue. Drilling into stubble requires special attention to the moisture in the seed bed, which may dry more quickly than bare soil. In organic systems, where herbicides are not used, sowing into stubble without any prior cultivation may also result in greater competition from emerging weeds. Seeding into stubble rather than a well-prepared seed bed, however, offers greater protection of the soil from erosion and protection of SOM from oxidation if exposed to the elements.

Soil temperature

Soil temperature is of greatest concern in the early spring when soils have not warmed enough for rapid germination. Cereal grains, field peas, and vetches will all germinate with soil temperatures in the 40° F range. Early emerging green manures that favor cool weather will provide early cover and compete well with later emerging weeds. They also produce the greatest amount of biomass before the high temperatures of summer arrive. Planting early season green manures later in the spring results in quick emergence and establishment, but growth may be slowed and reduced under hot temperatures. Warm season green manures, such as sorghum-sudangrass, and some of the clovers germinate and establish more quickly in warm soils. Table 1.2 presents soil germination temperatures of several green manure species.

Table 1.2 Germination temperatures for selected green manure crops

Crop	Minimum germination temperature (°F)	Ideal germination temperature (°F)	Reference
Cereal rye	34	77–87	(Clark, 2007; SAREP, 2008)
Buckwheat	45	55–75	
Sorghum-sudangrass	60	>60F	
Mustards	41–50	59–68	(McKenzie, 2000)
Field pea	40	75	(Duke, 2002)
Hairy vetch	60	64–77	(Clark, 2007; SAREP, 2008)
Medics	45	59–70	
Clovers	34–41	64–77	(Clark, 2007; McKenzie, 2000)

Irrigation

Sufficient soil moisture immediately after planting and during germination and emergence of the green manure crop is critical for quick establishment and efficient competition with weeds. Irrigation throughout the growing period will provide the greatest biomass production. Clearly, budgeting irrigation becomes an important concern in Colorado's arid and often irrigation-limited conditions. Irrigation requirements differ markedly depending upon soil type due to differences in water holding capacity. Typically the green manures that are grown in

Colorado require similar amounts of water as cereal grains and alfalfa – approximately 20 inches of combined precipitation and irrigation per season, with peak usage of 0.3 inches/day (Al-Kaisi and Shanahan, 1999; Eck, 1988; Efetha, 2008). Deeply rooted clovers and drought-tolerant cereals are good choices if irrigation is a limiting factor.

Furrow and sprinkler irrigation are common systems in Colorado, and drip irrigation is becoming more widely used. For the establishment of small-seeded green manures, such as clovers, it is important to keep the soil surface in moist condition during germination and initial establishment. Sprinkler irrigation used frequently and for short intervals allows the green manure crop to become established without using a great deal of water, when compared with furrow irrigation. It may not be practical to provide adequate moisture across an entire field surface using drip irrigation. However, it is possible to moisten the entire soil surface with drip irrigation in soils where good capillary action allows water to move laterally through the soil, and if drip tape is not deeply buried.

Weed management -

Stale-bed technique

When time and irrigation allow, a "stale-bed" technique is an excellent way to reduce weed pressure. This technique requires the seed bed to be prepared and irrigated prior to sowing the green manure crop. After weeds germinate and emerge, they are cultivated at a shallow depth, or flame cultivated to kill the weed seedlings (flame cultivation is probably too expensive to be considered in green manure production). This destroys a generation of weeds prior to sowing the green manure crop. The green manure crop is sown immediately after the cultivation.

Post-emergence cultivation

Post-emergence cultivation is tolerated by cereal grains soon after emergence if a rolling cultivator is used. This tool provides very shallow cultivation and when used at the appropriate time will remove emerging annual weeds without uprooting recently emerged cereal green manures. Once the green manure is 4-5 inches tall, however, the rolling cultivator will tangle in the green manure crop and not operate properly. Large-seeded legumes that have developed a strong tap root can be cultivated with a rolling cultivator, but breakage of the growing point of the legume is a greater risk than with grasses, which have growing points at or below soil level in their early development.

Green manure timing

Fitting green manures into crop production and rotation cycles requires planning. The choice of species needs to be appropriate for the time of the season, the objective of growing the green manure needs to be understood, and timing of field preparation, sowing, irrigation, and weed management must fit into the larger farm management plan. Generally, Colorado growers plant green manures in early spring, midsummer, or late summer. A production cycle that includes vegetable cropping and green manures might look something like this:

- An early, spring-planted green manure is followed by a mid-season vegetable crop, which is followed by a late summer/fall planted green manure. In this scenario, an early-planted legume such as pea or vetch could add nitrogen for the following cash crop, or a cereal could be used as an early-season, weed smothering crop, and add biomass and organic matter. However, sufficient nitrogen for the following cash crop may be tied-up during the degradation of the green manure's biomass.

- An early, short-season vegetable crop is followed by a midsummer green manure. Weed suppression and building of organic matter can be achieved by planting a fast-growing biomass producer such as Sudax or buckwheat, and incorporating it in time to plant an overwintered vegetable crop such as spinach, garlic or onion.

- A mid-season vegetable crop is planted after an overwintered green manure crop has been incorporated. This allows for maximum biomass production and nitrogen fixation and early season weed suppression prior to a mid-season vegetable crop planting.

The ability to enter the field and complete the green manure incorporation, seed bed preparation, and planting in time to proceed to the next step is a challenge, and requires prior planning and good weather conditions. Despite the challenges, having continuous soil cover, weed suppressing covers, and soil building green manures are all highly beneficial practices representative of well managed organic systems.

Green manure incorporation and tillage considerations

Cereal rye and other grasses regrow following light tillage, particularly if tilled under when 8 inches or less in height (Schonbeck, 1988). This is not a problem if the field is not to be immediately planted to a cash crop. If re-growth interferes with a subsequent cash crop, deeper and more thorough tillage overcomes the problem. Incorporation of green manures before they become tough also speeds the degradation process and minimizes nitrogen tie-up.

Timing of green manure incorporation

Timing of incorporation of green manure crops is generally determined by the developmental stage of the green manure crop, but it may also be a function of timing subsequent cash crops. The developmental stage of the green manure is an important consideration for maximizing biomass and/or the nitrogen contribution of the green manure crop. Ideally, incorporation of green manure takes place far enough in advance of planting the subsequent cash crop for nitrogen mineralization to synchronize with the cash crop nitrogen needs. The rate of mineralization of organic nitrogen depends on a number of variables that may not be manageable. It is generally accepted that soil moisture and temperature are positively correlated to the rate of mineralization of nitrogen (Stanford et al., 1973), impacting the rate of biological activity responsible for the breakdown process by which organic nitrogen is converted into mineral, plant available N. However, mineralization may be less responsive to low soil temperatures than previously assumed; researchers have found that N mineralization occurs at a high rate even at soil temperatures of 38°F (Magid et al., 2001).

If green manures are left to sit on the surface, such as in a no-till situation, volatilization of ammonium (NH_4) can result in significant loss of nitrogen from the vegetative portion of the green manure crop. Volatilization of NH_4 from killed green manure crops is stopped when incorporated into the soil (Janzen and McGinn, 1991), so it is recommended to immediately incorporate mowed or flail-chopped green manures for maximum nitrogen contribution.

For maximum nitrogen contribution from legumes, incorporation should occur at the initiation of flowering; after this point, the nitrogen stored in nodules in the roots translocates into the developing seeds. Nitrogen stored in nodules is not released to the soil until a legume is killed (Clark, 2007). In systems where perennial legumes are grown as a living mulch, destruction of some of the living mulch (for example, strip tilling in the planting row) and/or winter-killing of some of the legume results in a release of nitrogen from the roots to the soil (Atthowe, 2008a). In mixed plantings of cereals and legumes, synchronized maturation provides greatest biomass production and maximum nitrogen contributions. This is generally the case for fall-sown cereals, winter peas, or hairy vetch, which begin flowering at roughly the same time the following spring. Summer-grown green manures, such as sorghum-sudangrass may be mown multiple times in lieu of incorporation. This practice increases root development, which is beneficial for soil structure (Clark, 2007). Buckwheat does not tolerate low mowing and is incorporated during full bloom for maximum biomass contribution and to prevent the production of seed which may grow and compete with subsequent cash crops.

Delaying incorporation of green manure crops and allowing them to mature generally increases C:N ratios, slowing the availability of nitrogen that is held in the green manure's biomass (Gaskell and Smith, 2007a). Nitrogen mineralization of incorporated green manures follows a predictable pattern, Figure 1.1 (by Gaskell and Smith , 2007) presents a hypothetical illustration of N mineralization following cover crop incorporation relative to crop use requirements.. However, matching this curve of nitrogen availability perfectly with that of the needs of a subsequent cash crop is improbable because of the many variables that effect mineralization rates.

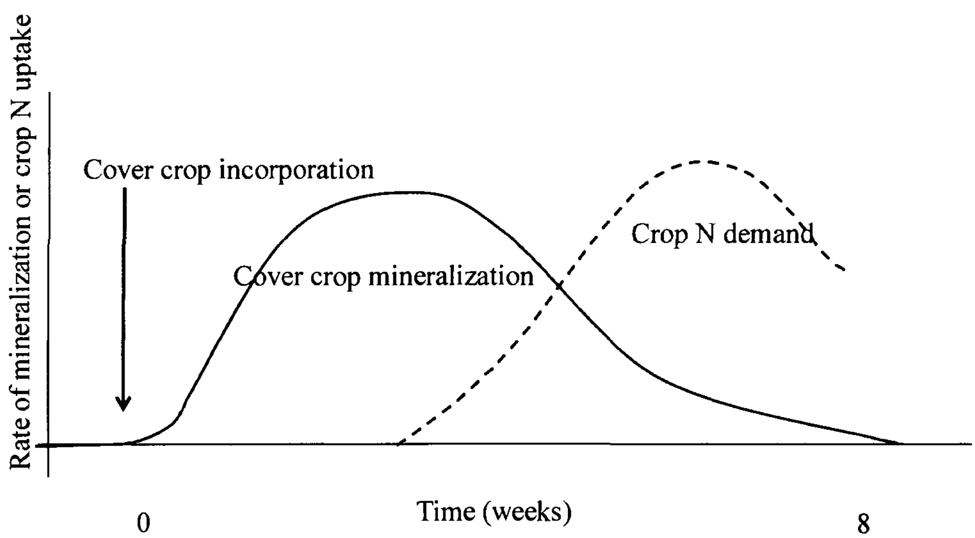


Figure 1.1 Hypothetical timing of nitrogen (N) mineralization from soil organic matter, cover crop residue, and organic fertilizer in relation to crop N uptake. (Adapted from Gaskell and Smith, 2007.)

Cereal grains lignify and are tougher to chop as they mature, so it is best to incorporate green manure cereals before they begin heading (producing a seed head). Allowing cereal grains to set seed also presents the problem of the green manure reseeding itself and becoming a weed in the following cash crop. The heading of cereal crops occurs quickly, so the producer should be prepared to act quickly when the time comes. Intentional reseeding can be allowed if the following crop is a green manure; in such a case, the seed is allowed to fall before the first crop is disked, or shallowly incorporated. Vetch, which produces some hard seed, is more prone to becoming weedy in subsequent crops, because some of the seed will remain dormant for a long period of time.

Animal manures and composted manure

Green manures do not always fit well into vegetable production cycles, and may not provide sufficient crop nutrition as a sole source of vegetable crop nutrients. This is especially true for phosphorus, which is commonly tied-up in Colorado's high pH soils and which is recycled—but not increased—by using green manures. The efficiency of nitrogen fixation and mineralization patterns determine the level of nitrogen provided by leguminous green manures. Animal manures and composted manure provide an excellent source of nitrogen and phosphorus as well as other essential elements. The Organic Farming Research Foundation reported that 57% and 22% of U.S. organic producers regularly apply compost and manure, respectively (Walz, 1999). A more recent survey conducted by the author in Colorado (see following section "Farmer Survey") found that 66% of organic vegetable producers use compost regularly, and 34% use manure regularly, 27% use both compost and manure, and 7% used neither manure or compost.

Animal manure

Animal manures are abundant and available to organic farmers in Colorado, and provide an excellent source of macro- and micronutrients as well as organic matter. Organic standards have very clear requirements regarding the use of animal manures in order to minimize the potential for pathogen transmission onto food products, as well as environmental contamination resulting from their overuse. NOP regulations (NOP Rules subsection 205.203) require animal manures to be composted or handled in the following manner:

> (i) Applied to land used for a crop not intended for human consumption;
>
> (ii) Incorporated into the soil not less than 120 days prior to the harvest of a product whose edible portion has direct contact with the soil surface or soil particles; or
>
> (iii) Incorporated into the soil not less than 90 days prior to the harvest of a product whose edible portion does not have direct contact with the soil surface or soil particles; (USDA 2002a).

A variety of issues are relevant when estimating the value of manure/compost applications for soil fertility management. Animal manures vary considerably in quality depending on the species of animal, the animal feed composition (including Na and P salts in feed rations), bedding that is mixed with the manure, and how the manure is handled (Rosen and Bierman, 2005). The nitrogen contribution of manure/compost is also impacted by how the manure was handled and how the manure is applied to the field. Manure from confined production facilities where feed rations include high percentages of grain and high concentrations of salt will be different from animals fed rations relatively higher in hay and fiber. Poultry manure from a confined layer operation where no bedding is used will differ from a broiler operation where sawdust or other bedding material may be present. Different manure storage methods also impact the quality of manure. Less ammonia is volatilized in manure that is continuously removed and piled compared with manure left exposed to the elements in the feedlot for extended periods. Aerobic composting of manure also results in loss of nitrogen in the process. Additionally, the time between spreading compost/manure and incorporating it into the soil affects the amount of N available to the subsequent crop, minimizing the amount of time from spreading to incorporation maximizes the utility of N (Terman, 1979).

Laboratory analysis is necessary for accurate assessment of the fertilizer value of manure or compost. This analysis assures that adequate and properly balanced nutrient applications are made to meet production objectives. Manure composition estimates in Table 1.3 serve as relative comparison only, allowing the farmer to consider advantages of different sources before going to the expense of multiple lab analyses (see Appendix E for a list of testing laboratories in Colorado).

In addition to establishing the composition of the manure it is important to consider the rate of mineralization of the organic N in the manure for fertility management. Mineralization rates vary a great degree depending on temperature, precipitation, C:N ratios, and the composition of the manure or compost inputs. Trends of mineralization rates are generally accepted to range between 20%–40% during the year of application, with extremes being less than 10% and greater than 50% (Eghball et al., 2002). The rate of mineralization following manure application declines to about 5% per year by the fourth year. Animal manures typically mineralize 30%–40% of their organic N in the first year, while composted manure mineralizes about 20% of the organic N in the first year after application (Gilbertson et al., 1979). However, in a multiple year field study comparing manure and compost mineralization rates, both types of material were found to mineralize at the same rate of 20% for the first year after application (Eghball, 2000). Making management decisions is difficult when using such a wide range of possible outcomes, so conservative recommendations are generally made to insure against under-fertilization.

Manures and composted manures are applied primarily for N and P contributions. Other contributions including micronutrients and organic matter are also beneficial and are considered secondary benefits. Crop nutrient planning is generally based on the crop's N needs. When manures are used to fulfill the N requirement, the N:P ratio present in manures results in over-application of P for most vegetable crops. Phosphorus is likely to accumulate over a period of years to concentrations that exceed crop needs, potentially becoming an environmental contaminant. This can be avoided by relying on leguminous green manures in the crop rotation to balance the N and P inputs. Because soil P levels reach excessive levels after multiple years of manure/compost application, P, rather than N, should be used to determine the amount of manure applied, and other sources for N considered.

Phosphorus contribution from manure/compost also varies with the source of the materials. Phosphorus is quite stable and not prone to volatilization as is NH_4 nitrogen. It remains in the soil where it is incorporated and moves little, providing that soil erosion is minimized. Manure and compost sources of P are preferred because they remain available to plant uptake. Other phosphorous sources such as rock phosphate and bone meal become immobilized in the high pH soils characteristic of Colorado agricultural lands (Elliott et al., 2007).

Compost

Compost application to soils is widely accepted as a beneficial practice. It increases SOM, suppresses many plant pathogens (Hoitink et al., 1997), and provides a relatively stable source of nutrients which are less prone to loss through leaching than manures (Eghball, 2000). Weed seed viability is greatly reduced (Larney and Blackshaw, 2003), and human pathogens associated with manure are reduced to undetectable levels when thermophilic composting is done properly (Lung et al., 2001). Additionally, reducing the volume of manures by composting is a benefit in terms of transportation costs.

Compost is made from a variety of materials ranging from yard waste to animal carcasses. For the purposes of this discussion compost will be limited to that produced primarily from animal manures, which is the most commonly used for commercial-scale vegetable production in Colorado. As with uncomposted animal manure, the quality of the end product is directly related to the inputs and how the compost is processed. NOP rules define compost process as follows:

> "The product of a managed process through which microorganisms break down plant and animal materials into more available forms suitable for application to the soil. Compost must be produced through a process that combines plant and animal materials with an initial C:N ratio of between 25:1 and 40:1. Producers using an in-vessel or static aerated pile system

> must maintain the composting materials at a temperature between 131 °F and 170 °F for 3 days. Producers using a windrow system must maintain the composting materials at a temperature between 131 °F and 170 °F for 15 days, during which time, the materials must be turned a minimum of five times" (USDA 2002a).

As in the case of manures, knowing the composition of the compost and how readily nutrients will become available to crops are important considerations. It is difficult to determine precisely the rate of mineralization of plant nutrients and their subsequent availability to crops. Variables in the compost feedstock, the degree of decomposition, and the C and N ratios in the soil where the compost is applied impact the utility of the compost in terms of nutrient availability (Cambardella et al., 2003). Unfinished compost may actually tie-up nitrogen in the soil. Carbon-to-nitrogen ratios of > 18:1 tend to tie-up N in the soil; C:N ratios < 18:1 are desirable because N will be released to the crop rather than being utilized by decomposing bacteria. "Stability" and "maturity" are terms that describe compost's degree of biological degradation as it relates to specific use requirements (Bary et al., 2002). Stable compost is no longer rapidly decomposing, and reaches a level of "maturity" which allows seeds to germinate witout danger of high temperature or ammonia killing emerging plants.

As with uncomposted animal manures—and for practical purposes—compost is used primarily as a source of N and P. Composting of manure transforms inorganic N into more stable organic forms, which mineralize more slowly than manure N (Rosen and Bierman, 2005). In Colorado, where P is tied-up due to the high pH of soils, the choice of compost based on its relative P concentration favors the use of poultry manure composts. Long-term or heavy applications of composted manure – as is the case with use of manures - results in accumulation of P over time, and care should be taken to avoid over application of P. If, however, soil tests indicate P deficiency, composted poultry manure provides relatively higher concentrations of this element, and may be a preferred material. As with the use of manures, laboratory analysis of compost is needed to make appropriate soil fertility management decisions. Table 1.3 presents common ranges of compost and manure compositions. Soil analysis is required for accurate assessment of soil fertility, and to avoid waste and/or negative environmental impacts.

Table 1.3 Common analysis of manures and composted manures

Source	Dry matter (%)	Approximate composition (% dry weight)			Reference
		Total N[1]	P_2O_5	K_2O	
Source of compost					
Composted poultry manure	20–45	1.8–2.2	4.2–4.3	2.3–2.6	A–1Organics, 2008; Chaney, 1992; MidWestPlanService, 1993; Rosen and Biermam, 2005
Composted dairy manure	45–76	0.9–1.3	1.2–1.3	2.3– 2.9	
Source of manure					
Dairy	15–25	0.6–2.5	0.2–1.1	0.6–3.6	Chaney, 1992; Hawkes, 1985; Maynard and Hochmuth, 1997; MidWestPlanService, 1993; Reid, 2007
Feedlot	20–50	1.0–2.5	0.9–1.6	2.4–3.6	
Horse	15–25	0.7–3.0	0.2–1.2	0.7–2.2	
Poultry	20–30	1.6–4.5	0.9–6.0	0.4–2.4	
Sheep	25–35	1.2–4.0	0.5–1.9	1.2–4.5	
Swine	20–30	0.5–4.0	0.3–2.5	0.5–2.2	

[1] Total N = NH_4 plus organic N.

Note that the values of elemental nitrogen in composts may be lower than those of raw manure – a consequence of the composting process during which volatilization of ammonium occurs. The choice to use compost or manure may depend on availability and/or cost. If manure is available on-farm, the question of which type may be a mute point. However, if a farmer is applying compost from an off-farm source, availability and/or proximity of the source may become the deciding factor. Transport cost is possibly a limiting factor in the decision to use manures and composts from off-farm sources. While manure may be free for the taking, compost ranges in cost from \$15–\$25 per cubic yard.

Cautions for use of manures and composts

Calculation of nutrient values of manures and compost should always take into account the percent moisture of the product. Calculation of nutrients should be made on a dry matter basis in order to make accurate comparison of different products, costs, and required application rates. A calculation table is included in Appendix A.

Salts

Depending on how the compost is made, and the source of feedstock, salt levels in compost may be higher or lower than in manure. It is unlikely, however, that under properly irrigated production the salts contributed from compost would be a primary cause of salt-related crop damage. Vegetable production on saline soils and/or with irrigation water with high salt concentrations is not advisable. However if this situation is unavoidable, careful consideration should be given regarding salt concentrations of manure and/or composted manure.

Herbicide residue

Several years ago (2000) yard waste composts in some areas were found to be contaminated with herbicides used on turf that was a feed stock of those composts. Picloram and clopyralid were two of the herbicides identified (Bezdicek et al., 2000). The trace levels of contamination resulted in herbicide damage to crops where the compost was applied. While commercial composters are careful to avoid contaminated materials, it is important to inquire about the source of materials used by composters, and to protect oneself from possible contamination issues that could jeopardize production and organic certification.

Other organic fertilizers

In addition to composts and manures, a wide variety of materials are used as soil amendments and foliar fertilizers. Because of cost, they are generally used to supplement a comprehensive soil fertility program based on use of green manures and composts. These materials are applied dry to the soil, generally as a side-dressing, are mixed into irrigation water, or are applied as foliar sprays. The rate of speed at which these fertilizers are available to the crop varies a great deal.

Table 1.4 gives a brief description of fertilizer materials that are allowed by the NOP, and which are appropriate for use on alkaline soils. The NOP national list is available on the NOP web site (USDA, 2002a), with §205.601 and §205.602 being applicable to crop production. Additionally, the Organic Materials Review Institute (OMRI) evaluates whether materials fit the criteria of the NOP rule, and makes recommendations regarding their acceptability. Until OMRI's recommendations are included in the NOP list, they may or may not be accepted by certifying agencies. Producers should always consult their certifying agency before using an OMRI approved material that does not appear on the NOP list.

Table 1.4 Organic nutrient sources

Fertilizer material	%			% PAN[1] at 28 days DAP[2]	% PAN by end of season	Rate of nutrient release	Notes
	Total N	P_2O_5	K_2O				
Alfalfa meal	2.5-5	0.5-1	2	11	26	Slow	Locally produced and a good source of nitrogen, but relatively slow reacting. This is an example of a home-grown fertilizer that is comparable to composted manure in terms of nitrogen value.
Bat guano	1-10	4-10	1-2	-	-	Medium	Mined from caves; this is a good source of N and P.
Blood meal	12.5-15	1.5-3	0.6-1	60	75	Medium-Fast	Locally produced, and a source of quickly available nitrogen, but it may be cost prohibitive.
Bone meal - steamed	1-2	27%	0	17	32	Slow	Locally produced and a source of calcium and phosphorus; however, in high pH soils this phosphorus doesn't dissolve and is not plant available.

[1] PAN=plant available nitrogen
[2] DAP=days after planting

Table 1.4 cont. Organic nutrient sources.

Fertilizer material	%			% PAN[3] at 28 DAP[4]	% PAN by end of season	Rate of nutrient release	Notes
	Total N	P_2O_5	K_2O				
Chelates and sulfates of Mn, Fe, Cu, Zn	-	-	-	-	-	-	Use of chelates is allowed when deficiency exists for that nutrient.
Chilean nitrate	16	0	0	-	-	-	NOP only allows to be used for 20% of total N need. Mined in Chile.
Colloidal phosphate	0	20%P 1-2% P_2O_5	0	-	-	Slow-Medium	Comprised of clay particles surrounded by phosphate, with slow reaction in alkaline soils. This phosphate source is best mixed with compost or manure under alkaline soil conditions.
Cottonseed meal	6.6-7.0	2.5-3	1.5	60	75	Slow-Medium	Imported from cotton production areas in the US, cottonseed meal is a good source of N and at higher application rates may reduce soil pH marginally. Beware of pesticide residues, and check with organic certifier before using.

[3] PAN=plant available nitrogen
[4] DAP= days after planting

Table 1.4 cont. Organic nutrient sources.

Fertilizer material	%			% PAN[5] at 28 DAP[6]	% PAN by end of season	Rate of nutrient release	Notes
	Total N	P_2O_5	K_2O				
Blended and pelletized composts and manures.	2-3.5	2	2	32	47	Medium	Pelletized products of dried compost or manure base and fortified with other nutrients such as rock phosphate. These materials are easy to handle with fertilizer spreading equipment and are reliably formulated. Possibly high salt contents. Check with certifier regarding additives. Relatively expensive.
Epsom salts	-	-	-	-	-	-	Applied as a foliar magnesium fertilizer when deficiency appears
Feather meal	5-15.0	0.0-3	0.0-3	60	75	Slow	Locally produced and a source of moderately slow release nitrogen
Fertibor®	0	0	0	-	-	-	Water soluble boron that is soil applied or fertigated.
Fish emulsions	4	4	1	-	-	Medium-fast	These are rich sources of N, but variable concentrations depending on whether enzyme or acid emulsified. If higher than 5% N, it has probably been fortified with fertilizer. Fish emulsions use entire fish and fish parts from a diminishing ocean resource., .
Fish meal	10-11	5.0-6	0	60	75	Medium	These are rich sources of N. Fish emulsions use entire fish and fish parts from a diminishing ocean resource.

[5] PAN=plant available nitrogen
[6] DAP= days after planting

Table 1.4 cont. Organic nutrient sources.

Fertilizer material	%			% PAN[7] at 28 days DAP[8]	% PAN by end of season	Rate of nutrient release	Notes
	Total N	P_2O_5	K_2O				
Greensand K and micronutrients	0	1.5	5.0-7	-	-	Very slow	Imported from the east coast, this potassium and phosphorus source is insoluble in high pH soils.
Kelp meal	1.0-1.5	0.5	2.5-8.0	0	5	Slow	Ocean harvested and dried, kelp provides N, and a variety of micronutrients in small amounts. Kelp by-products are also extracted and sold in liquid form for foliar feeding; however the concentration of nutrients provided probably has marginal if any beneficial impact.
Rock phosphate	0	1-2%	0	-	-	Very slow-unavailable	Rock phosphate is derived from marine deposits and mined in several areas in the US. Phosphate is 1-2%, but unavailable in alkaline soils. *Hard* rock phosphate is from volcanic rock deposits, is largely unavailable.
Seabird guano	11-13	8-12	1-3	15	72	Medium	Mined primarily in Peru and Chile, this is a good source of N and P. Its transportation costs to Colorado may make its use prohibitive.

[7] PAN=plant available nitrogen
[8] DAP=days after planting

Table 1.4 cont. Organic nutrient sources.

Fertilizer material	%			% PAN[9] at 28 days DAP[10]	% PAN by end of season	Rate of nutrient release	Notes
	Total N	P_2O_5	K_2O				
Soybean meal	6.5-7	1.2-1.5	1.5-2.4	-	-	-	Relatively high concentration of N and P, however phytotoxicity of seedlings has been reported.
Sul-Po-Mag	0	0	22	-	-	-	Sulfer 22%, potassium 22% and magnesium 10%; foliar application may be done when deficiency appears.
Wood ash	0	1.5	5	-	-	Fast	Very alkaline and often high in salts and other contaminants. Not recommended in Colorado.
Worm castings	.5-1.5	.5-2.5	.3-1.3	-	-	Medium	Low analysis of macro nutrients, and not used in large scale production, but very favorable results have been seen when used in seedling mixes for transplant production.

Information in Table 1.4 has been adapted from: (Andrews and Foster, 2007; Gaskell and Smith, 2007b; Maynard and Hochmuth, 1997; Pline-Brown and Davis, 2007; Wallace, 2001; Young and Holt, 1977; Zublena et al., 1997).

[9] PAN=plant available nitrogen
[10] DAP=days after planting

Phosphate sources

Prepared fertilizer products provide the percentage of total N, P_2O_5, and K_2O on their labels. Depending on soil pH, either H_2PO_4, HPO_4 or PO_4 is the plant-available form of P. Some organic sources of these nutrients are sold as animal feeds in which case the total % P should not be confused with the plant-available P. P_2O_5 is 2.3 times the total P listed on these products (e.g., bone meal, which has 12% total phosphorus, is equivalent to 27% P_2O_5). It is important to consider the solubility of different P sources in alkaline soils. Most organic sources of phosphorus are not readily soluble in alkaline soils. One way to make these materials (such as colloidal phosphate or bone meal) more available is to add them to composting manure, where organic acids solubilize the phosphate and increase its availability (Wallace, 2001). Some farmers acidify their irrigation water to lower the pH in the root zone enough to solubilize tied-up P. Supplemental phosphate applications may not be needed when animal manures/composts are used regularly.

Soil fertility management decision process

Once the content of the manure/compost is known appropriate application rates may be made based on baseline soil fertility and contributions made by green manures. Combining the information from soil and compost or manure testing, and estimating nutrient provisions from green manure crops, a farmer is able to make reasonably accurate decisions regarding soil fertility management.

Using the nitrogen budget calculation discussed previously for green manures, calculation of compost or animal manure applications may be made. Accurate nutrient budgeting for specific crops and during specific stages of a crop's development is difficult in organic systems because of the many variables that will impact rates of mineralization and availability of nutrients for the crop's use. See appendix A "soil fertility amendment calculations" for examples of calculations used to determine organic amendments based on soil fertility analysis and crops to be grown.

* * *

Farmer Survey

A telephone survey was conducted in the fall of 2008 with 15 organic farmers representing a cross section of Colorado's organic vegetable producers. The farmers were selected because they were known to have several years of production experience, and were members of one of the organic producer associations in the state (Colorado Organic Producer Association, Valley Organic Growers). Ninety one questions were asked of each of the producers (see Appendix D). The farms surveyed were located in the following areas:

- Twelve farms from the Front Range (north of Colorado Springs)
- Two farms from the Arkansas River Valley (east of Pueblo)
- One farm from the southwest part of the state (Cortez).

Farmer Survey: Green Manures

In the survey of organic vegetable farmers in Colorado, three quarters reported using green manures as part of their soil fertility and weed management programs. Forty percent of the respondents reported that they use green manures annually on at least some part of their farm, 33% of the farmers use green manures occasionally, and 26% do not use green manures in their vegetable operations. All of the farmers using green manures use either cereal rye or triticale in their fall-planted green manure mixes. Beyond this similarity there were many legumes that were included in mixtures, including hairy vetch, red clover, Dutch white clover, and field peas. Twenty six percent of the farmers reported using summer-planted buckwheat and sorghum as green manure. One farmer who grazes his green manure crop includes a smorgasbord of grasses, legumes and brassicas, including popcorn, millet, triticale, vetch, oats, rutabaga, fodder turnip, fodder beet, and buckwheat.

All of the farmers asserted that green manures helped smother weeds, but more importantly added organic matter and fertility to their soil. One farmer who has been unsuccessful with green manures stated that his ditch does not run late enough in the fall to establish a green manure crop, and his limited irrigation during the summer must be dedicated to the production of high value cash crops. Three of the farmers said that timing was difficult, because field preparation and management in the early fall coincides with a heavy work load. Another obstacle to the use of green manures mentioned by the farmers was timing the growing of green manures between cash crop cycles; there was not enough time in tightly cycled cash crop rotations.

Farmer Survey; Compost and Manure Use

It was interesting to learn that soil fertility was reportedly less of a problem, and required fewer inputs over the years. The farmers that had the fewest soil fertility issues were those that had been farming their land the longest, and those that reported concerns had only been on their land 1-3 years.

Soil testing is done regularly by nearly all of those surveyed. Only one farmer no longer soil tests, feeling that her farm has reached a balance of nutrients that sustains good yields with minimal off-farm inputs, All of the other farms soil test at least every three years; of those half of them test every year, and the other half is evenly split; testing every two or three years. When asked if they followed the recommendations provided by the soil testing lab, again, half said they always did, and the others said that they sometimes did, and one stated that it was dependent upon cash flow, and whether or not he could afford to buy the inputs. Compost is used slightly more widely than manure among the farmers surveyed; with 66% of the respondents using compost annually and 40% using manure (one farmer uses both). Five of those using compost reported having received analysis of the compost from the suppliers, the other farmers made their own compost and did not test it.

One of those using manure was quite emphatic that the process of composting volatilizes so much nitrogen that he sees little value in applying it. It is interesting to note that nitrogen is the whole reason he applies manure, and the phosphorus levels on his farm have become exceedingly high as a result of many years of applying average application rates of manures (10-20t/ac every 2-3 years). Two of the respondents have cattle on their farms, and they both felt that with rotation of alfalfa, and grazing, they were able to rotate into a vegetable crop every 6-8 years without needing to apply any additional nutrients to the field, and they reported that their soil tests showed they were right. The farmers that were using manure used a variety of sources and type of manure. One farmer uses liquid dairy manure from a neighboring farm, two used dairy barn manure, one used turkey, and two use mixed barnyard manure (poultry, cow, horse). Four of the manure users reported applying manure annually, and two said it depended on soil testing and/or when the corral needed to be cleaned.

Five of the farmers using compost or manure had it trucked to the farm at considerable expense. The average trucking distance was 15.1 miles one way, but two growers had is trucked nearly 30 miles one way costing $200 for delivery. Compost costs ranged from $13 to $20 per yard (about 0.6 ton) , resulting in $397 to $475 per acre for a typical application rate of 10t/ac including a nominal spreading cost of $15/ac. Manure on the other hand can usually be found for free, but hauling coasts are the same, resulting in a cost per acre of $181/ac if spread at the same rate. Using a common dairy manure composition of 1.5% N, and compost 1.1% N(Chaney, 1992), 10 ton /ac application would provide 300, and 220 lb total N ac respectively, at a cost of $0.61/lb N using a manure source and $1.81/lb N using a compost source of N. In terms of N value, the manure is clearly a better buy. Table 1.5 illustrates comparative costs compost and manure in terms of nitrogen value.

Table 1.5 Comparison of compost and manure costs provided by organic farmer survey respondents on the Front Range of Colorado.

	Material costs					Spreading costs		Nitrogen cost		
	cost/yd	cost to haul/yd	cost/yd to spread	ttl cost/yd	$/lb material	application rate(lbs/ac)	applic cost (material + delivery + spreading)	%N	lbs N applied	cost N/lb
manure	$ -	$ 10.00	$ 0.90	$ 10.90	$ 0.01	20,000	$ 181.67	1.5%	300	$ 0.61
compost	$ 13.00	$ 10.00	$ 0.90	$ 23.90	$ 0.02	20,000	$ 398.33	1.1%	220	$ 1.81

Chapter 2 Tillage

Tillage and cultivation are crucial to organic production, and can play both beneficial and destructive roles depending on how they are managed. Any tillage of soil results in oxidation of and destruction of soil organic matter and reduction of soil humus; however, tillage can also be used to incorporate biomass and manures resulting in net gains of organic matter.

The soil fertility and crop nutrient management practice standard of the National Organic Program (Rule: § 205.203), is as follows: "The producer must select and implement tillage and cultivation practices that maintain or improve the physical, chemical, and biological condition of soil and minimize soil erosion" (USDA, 2002a).

Certainly, tillage exposes soil to the destructive forces of wind and water erosion, and practices that mitigate these forces should be used. Minimum and no-tillage systems have gained favor in conventional agriculture because they provide protection from soil erosion, but these systems are also very reliant on the use of herbicides for weed control. Organic producers have been slow to adopt minimum tillage because of a perception that it is herbicide-dependent. Researchers are working on developing minimum tillage systems that may be appropriate for organic vegetable production systems. Rodale Institute as well as Dr. Ron Morse at Virginia Polytechnic Institute and State University have pioneered work in this area, with very promising results, but until more information has been gathered, and these systems have been tested in Colorado, the tried and true cultivation methods of organic vegetable production systems will prevail.

In this discussion, tillage systems that are commonly used in Colorado vegetable production are outlined and discussed, citing objectives, strengths, and weaknesses especially as they address small-scale organic growers. Because Colorado's variety of soils, crops and production systems offers a wide range of possible approaches to tillage, this discussion will inevitably be incomplete.

Primary tillage

Primary tillage consists of deep tillage that incorporates crop and green manure residue into the soil, allowing it to be broken down by soil organisms. Traditionally, this included complete inversion of the top soil with a tool such as a moldboard plow (Figure 2.1). By moldboard plowing in the fall, freezing and thawing breaks the large clods down into fine particles, facilitating early spring land preparation and making a fine seedbed. These practices have been the major causes for serious and widespread erosion and top soil loss as well as rapid depletion of SOM. The adoption of reduced tillage and no-till systems in recent decades has greatly reduced soil erosion in the U.S., but vegetable production, and organic vegetable production in particular, has lagged in adapting conventional, reduced tillage methods to fit organic systems.

In addition to the perception that reduced tillage is reliant on herbicide use, there are other reasons why vegetable production has continued to rely on residue-free tillage approaches.

1. Vegetables represent high-value crops that are commonly furrow-irrigated in Colorado. Residue on fields impedes the flow of water through furrows.
2. An advantage to bare-soil production is soil temperature. Bare soils warm more quickly in the spring, resulting in earlier and more vigorous crop development and production.
3. Agronomic row crop machinery adapted to handle thick crop residues has not been widely adapted to vegetable crop use.

4. Many vegetable crops are double- or triple-cropped during a single season. This involves burying the previous crop residue and quickly preparing the field for a subsequent planting – practices that are not conducive to reduced tillage or no-till.

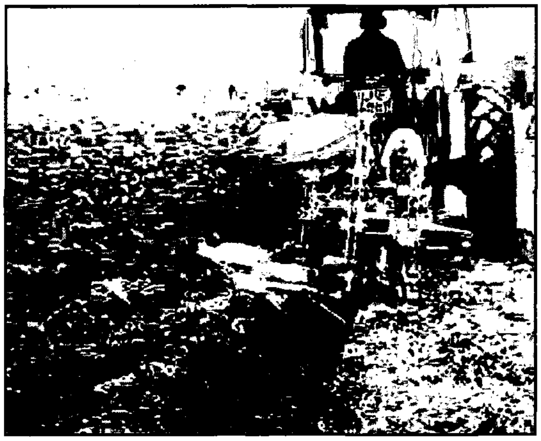


Figure 2.1 Moldboard plow.

As a result of the above considerations, residue-free tillage is still the rule in organic vegetable production, where moldboard plows continue to be widely used.

Alternatively, chisel plows (Figure 2.2) also loosen and open the top soil, mixing in surface residues without leaving the surface free of plant residue. Chisel plows work to about the same depth as moldboard plows—8–10 inches in most soils under normal conditions. Surface residues slow the speed of wind at the soil surface, thereby reducing wind erosion. Residues also serve as a sort of absorptive mat that allows precipitation to infiltrate the soil, reducing the probability of water sheeting and running across a surface, resulting in water erosion. Additionally, surface residue provides habitat for a wide range of arthropods and micro biota—adding to the ecological diversity and micro-habitat stability by virtue of increased species diversity.

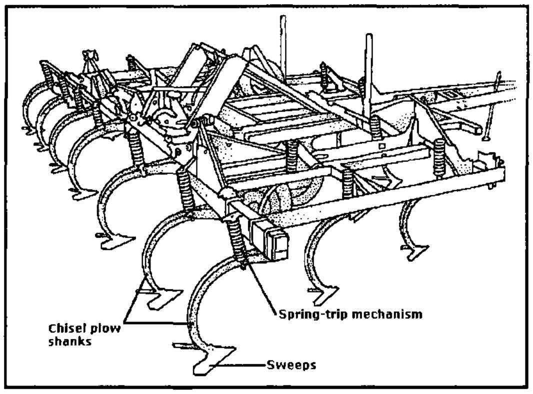


Figure 2.2 Chisel plow with sweeps. Illustration from Bowman (2002).

Deep ripping is another type of plowing that is generally used to rip deeper than 12 inches, and to break up plow pans or soil compaction resulting from heavy equipment operating on the field. Deep ripping is also used in some cases to manage surface water penetration, since it leaves surface residue largely intact while opening channels for aeration and water penetration. Figure 2.3 shows a large ripper.

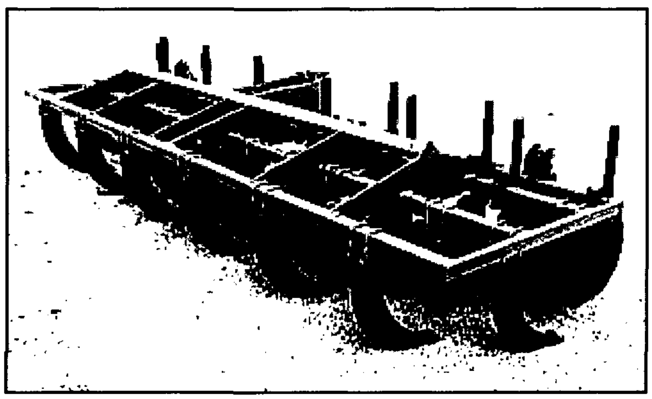


Figure 2.3 A large deep ripper (from www.bighambrothers.com).

Secondary tillage

Residue incorporation

When chisel plowing or ripping is practiced, the remaining surface residue is generally incorporated into the soil with a disc; this chops and incorporates much of the residue into the surface, and breaks up large clods allowing a fine seedbed to be prepared. Multiple passes with a disc are sometimes needed to incorporate heavy residues, and considerable compaction of the soil can occur. Discs are also used on unplowed fields to incorporate crop residue in lieu of moldboard plowing. Rotary tillers (rototillers) and spading machines are also used to incorporate surface residue and produce a fine seedbed.

Regardless of the tool or tools being used, soil type and soil moisture determine when and how they should be used. Very dry soils are difficult to penetrate, and working wet soils results in deterioration of soil structure and compaction. Sandy and loamy soils are more forgiving and easier to work, while clay soils can only be worked when soil is neither bone dry nor too wet. Each farm, and often each field, has its own characteristics that need to be considered. Weather, time of year, and cropping cycles also determine when and how a soil is worked. In Chapter 12, production techniques for specific crops is covered, with specific tillage practices required for specific crops.

Seedbed preparation

Seedbed preparation follows primary tillage. Seedbed preparation requires breaking large clods into finer particles, resulting in good soil/moisture/seed contact that is critical for uniform germination and emergence of crops. When moldboard plowing has been done and the surface is residue-free, a mulcher (also called a culti-packer or rolling harrow) is used to break and pack the larger clods down into finer particles., Depending on the soil condition, two or more passes may be needed to achieve a fine seedbed. Mulching is done immediately before planting in most cases, to reduce the time period between final field preparation and planting. For some very early, spring-planted crops such as onions and spinach, mulching is done in the fall at some risk of wind erosion. Fall soil preparation with its inherent erosion risk does, however, afford the farmer a field that is ready to plant early in the spring. This reduces the risk of wet weather postponing early spring field work. Another practice is to fall plow, leaving the field "rough" through the winter, and then mulching in the early spring as soil conditions allow. By leaving plowed land surfaces rough, wind speed at the soil level is reduced and soil is less prone to wind erosion. However, many soil types are at risk if left uncovered during the winter, and rhizosphere microbiota are compromised, especially during a dry, open (without snow cover) winter.

Field planing (also known as floating or leveling) is done if furrow irrigation requires a uniform slope for water to flow, and where harvest operations require a flat and uniform contour for harvest equipment to function properly. Subsequent cultivation practices work best when field conditions are uniform and the field is as level as possible. Where plastic mulches are applied to beds, a very level and uniform surface is needed to apply the plastic. Planing tends to pulverize clods into very fine particles that are especially prone to erosion. Planing also compacts soil further and can only be done with a dry soil.

Many smaller farming operations are limited in the number of tillage tools available or the tractor horsepower required to pull heavy-draft primary tillage equipment. Rototillers and spaders represent multiuse tillage tools that can be run with lower horsepower tractors, and are able to incorporate residue and prepare a fine seedbed in a minimum of passes. Larger rotary tillers are tractor drawn (figure 2.4) and usually power take-off (PTO) powered; however, some models are ground driven, which requires less horsepower. Two-wheeled (walk behind) tractors are also common power sources for rotary tillers. Rototillers and spaders differ in the types of tines that are used, and the manner in which the blades cut the soil. Rototillers spin fixed, cutting blades on a horizontal shaft either in the direction of travel or in a reverse direction, chopping the soil at high speed and pulverizing clods. Spaders cut into the soil with narrow spades that are attached to a cam, resulting in an oscillating digging action. The relatively slower speed action of spaders also breaks down clods and produces a fine seedbed but purportedly preserves some soil structure. Spaders work at slower ground speeds and require relatively friable soil to work well.

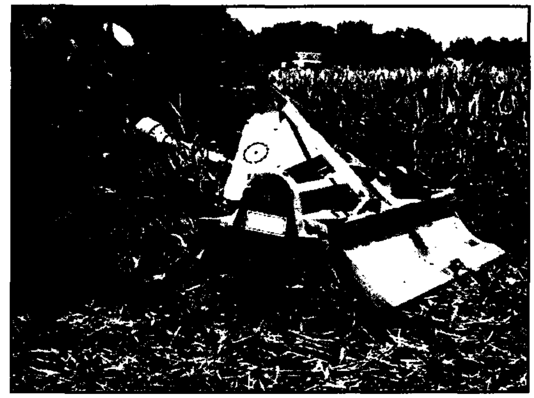


Figure 2.4 Rototiller incorporating green manure and preparing a seedbed at CSU's HFRC.

Rotary tillers are quite popular among small growers because they serve multiple purposes, and can quickly turn a cropped field into a seedbed. However, there are drawbacks to their use, especially with regard to the spread of vegetatively propagated perennial weeds. The slicing action of rototillers chops plant material into small pieces which is a very effective way to spread vegetatively propagated weeds such as field bindweed and Canada thistle. Also, when rototillers are used repeatedly on fields without interim deep primary tillage, a compaction layer directly below the tilling depth may develop which restricts root development, soil aeration, and, ultimately, yields. Operational costs of rototillers and spaders are also relatively high because of the wear and tear on machines and fuel use.

Custom tillage rates calculated by Edwards (2008) and Tranel (2007) are outlined below.

- Rototilling: $150/ac
    - Two passes with a tractor-drawn rototiller to reduce a standing crop to a seedbed costs $75/ac/pass.
- Conventional tillage costs about $56/ac
    - Chisel plowing + 2 passes with disc + 2 passes with mulcher.
    - Chisel plowing @ $14/ac
    - Mulching @ $11/ac

Minimum tillage for vegetable crops

Minimum-tillage and no-till systems are not yet widely used in vegetable production in Colorado, however, there are opportunities and reasons to explore the possibilities of minimum tillage in organic vegetable production. Some of the advantages of minimum or no-till include: soil and moisture conservation; reduced oxidative destruction of SOM, preservation of mycorrhizae and other beneficial organisms in the rhizosphere (Galvez et al., 2001; Gosling et al., 2006), reduced tractor operation, and the possibility of reduced need for weed control (Sayre, 2003). Pest pressure may also be reduced, as demonstrated by Dr. M. Bartolo in the Arkansas River Valley, where straw mulches resulted in fewer thrips on onions (Cranshaw and Bartolo, 2007).

Research in minimum or no-till systems elsewhere in the country has included crop rotation with green manures that are knocked down and killed using flail mowers or rolling tools that leave a thick mulch on the soil surface (see Figure 2.5). Side dressing fertilizer and planting into the organic mulch requires specialized equipment that cuts through the deep residues.

Figure 2.5 Rolling cereal rye cover crop (from: www.va.nrcs.usda.gov).

Some of the challenges include the need for specialized equipment to incorporate compost or manure into the soil without tilling the entire surface. Perennial weed control would be difficult without the ability to cultivate and may require reliance on very expensive organic—and only marginally effective—herbicides (Boyd et al., 2006; Byczynski, 2003; Daniels, 2003;

Hoagland et al., 2008; Tworkoski, 2002) and hand weeding. Minimum tillage in vegetable crops would probably be restricted to drip and/or sprinkler irrigated fields.

The choice of a green manure or cover crop to be used in a minimum tillage rotation is important in terms of crop timing as well as the ability to kill the cover crop with mechanical rolling or flail mowing. The winter-hardy cover crops discussed in Chapter 1 must be in the flowering stage to be effectively killed by rolling (Moyer, 2008). This would generally occurlin mid- to late May, which is too late for early spring planting of vegetable crops in Colorado. Cover crops that winter-kill, such as sorghum-sudangrass or oats, would allow early spring planting if they had produced sufficient biomass the preceding fall to produce a thick weed-smothering mat when rolled.

Cultivation

Weed management on small organic farms is probably the most commonly expressed challenge, and should be a focus of field planning and design before any seeds go in the ground. A major part of that plan is anticipating:

1. What weeds will be present and when,
2. How weeds respond to different cultivation practices,
3. How the soil conditions will affect the first two issues.

Properly planned layouts and plans of action allow for efficient mechanical cultivation; the alternative is hand weeding which can easily take away much if not all of the potential profit from a crop. Weedy fields reduce yields through competition for nutrients, light and water, impeded harvest processes, and increased labor costs, and they may harbor pests and diseases. Commonly, small-scale farmers lack the familiarity, expertise, or access to tractor-drawn cultivation equipment resulting in higher operational and opportunity costs. Because small, diverse, organic vegetable farms produce crops with different cultural requirements, different planting cycles, and different crop architecture, field layout and design benefit from extra forethought.

Planning for cultivation

Very diverse crops can be organized in a field based on plant architecture that allows the use of tractor drawn cultivation implements in the field. Alternatively, cultivation equipment can dictate how a crop is spaced in the field, perhaps compromising the most efficient use of space for the most efficient use of a limited array of cultivating options. For example, bush beans, peppers, and eggplant are generally upright and bushy in habit. These are also warm-season crops which are not planted before the danger of frost has passed, allowing for stale-bed cultivation (see description below) to occur before planting. These crops are often planted two rows onto a bed, but can also be planted in single rows on a bed, allowing the use of the same cultivation tool set-up for all three crops. Small, leafy greens such as lettuce and spinach, which are often planted two or more rows on a bed, would require a different cultivator configuration than peppers, but could be grouped with other multi-bed, low stature crops such as beets, radishes, carrots, and so on. By designing the field layout to fit cultivator configurations, effective and efficient mechanical cultivation can proceed at a fraction of the cost of hand weeding.

Timely mechanical cultivation in organic systems saves hundreds or thousands of dollars per acre in hand weeding costs, and contributes to elimination of weed seedlings. There are many practical approaches to this that are well-tried and proven.

Cultivation when weed seedlings are just germinating and emerging is the most effective time for control. This stage is commonly known as the "white thread" stage, because small-seeded weed species look like white threads when discovered in the soil. Plants at this stage are extremely vulnerable to damage, exposure, and desiccation; this short window of vulnerability is a period of time that, if missed, has season-long impacts in terms of weed management. A common management practice to address this early vulnerability is "stale-bed" technique. Using this technique, the seedbed is prepared and irrigated before planting, allowing weed seeds to germinate and emerge, at which time a blind (that is, the entire surface is cultivated), shallow tilling kills the weed seedlings. Shallow tillage is critical because deeper tillage brings more dormant weed seeds to the surface, many of which germinate when exposed to light. Multiple blind cultivations may be used if time allows, or planting may follow immediately.

A variety of tools are used in blind cultivation. On bedded fields, rod weeders (hydraulically powered square rods) spin just below the soil surface in the opposite direction of the tractor travel, destroying seedlings. Rotary hoes, spring toothed tines, and rolling baskets are also commonly used for high speed and very shallow cultivation. More aggressive blind field cultivation can be done with field cultivators that can uproot slightly larger weeds.

Just before crop emergence blind cultivation is repeated, and on larger, more deeply planted crops a blind cultivation is used about a week after crop emergence (rod weeders are not used after seeding). Flame cultivation can be used very effectively before crop emergence, avoiding the chance of disturbing an emerging crop seedling. This practice is used very successfully with slow germinating vegetable and herb crops such as carrots, cilantro, parsley, parsnips, and onions, which germinate more slowly than many weeds. Careful attention to the rate of germination and emergence of the crop is critical. A rule of thumb is to flame when the first seedling of the crop is beginning to emerge. A day or two delay after this may be too late if emergence is even, so the flamer should be ready for use in anticipation of the correct timing. Eliot Coleman (1995) suggests placing a pane of glass on top of the bed, warming the soil underneath and speeding germination of the crop by a couple of days, thereby providing the grower a couple of days' notice ahead of crop emergence. Flaming of annual broadleaf weed seedlings requires only a moment of exposure to kill the plant. Discoloration of the leaf, and the ability to leave a finger imprint on the wilted leaf indicate that cells have been burst and the plant has been killed. Grass and perennial weeds require repeated treatment after re-growth occurs to use up the weed's carbohydrate reserves, and kill the plant.

Once the crop is growing, cultivation close to the crops is achieved with a variety of implements including torsion weeders, spring hoe blades, knives, finger weeders or spyders, and flame. These tools need to be adjusted carefully to allow close cultivation without damaging the crop or its roots. Tool bars can be guided by using bed sleds or cone guide wheels that align the cultivation tool accurately over the bed and reduce "cultivation blight," a term used to describe tractor error resulting in cultivating-out crops. Flame cultivators are arranged to flame weeds in-the-row. Obviously, some crops are intolerant of this practice, and the speed and adjustment of the direction of flame are critical. However, flame cultivation is used very effectively in sweet corn, onions, and garlic, whose growing points are well protected from flame.

The other two ways to control weeds with cultivation are to bury them or to cut the root from the above ground plant part. Once the crop is up and growing (about 8-10 inches tall), more aggressive implements can be used to bury seedlings that escaped the initial blind cultivation.

When mechanical cultivation fails to produce a weed-free field, hand hoeing and hand weeding are required, and used at great expense. Hand weeding can cost $1,200– $2,000 per acre, and, unfortunately, does not guarantee a weed-free field. Weeding crews that are paid on piece rate may rush their work and either miss weeds, or fail to cut the larger weeds below soil level—resulting in weed re-growth. Crews that are paid by the hour may do very thorough work, but spend an inordinate amount of time on the job. Crews should be well trained and supervised to achieve desired results. A good management practice is for the manager to weed a few sections in the field him/herself to become acquainted with the task at hand and to determine how much time should be expected to complete the job, and then communicate this to the weeding crew. At some point, benefits from weeding may be outweighed by the cost of the task, and some degree of weed tolerance is accepted. However, weeds should never be allowed to set seed.

Cultivation tool description

Rod weeders (Figure 2.6) consist of a square rod that runs just below the soil surface, perpendicular to the direction of the tractor travel. The rod spins in the opposite direction of tractor travel, uprooting anything in its path. Rod weeders are also used to undercut dry beans and shallow root crops such as onions for harvest. For weed control, rod weeders are used to blind cultivate bed tops before planting. If vine weeds are present in the field (e.g., field bindweed), the vines will quickly wrap around the rod, making it ineffective.

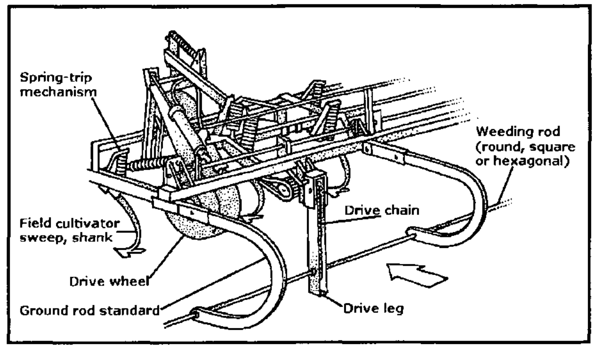


Figure 2.6 Rod weeder. Illustration from Bowman (2002).

Spring toothed or flex tine weeders can be used for blind cultivation and row cultivation of germinating weeds. Several gangs of closely spaced spring steel tines (Figure 2.7) drag through the soil, vibrating and dislodging small weeds. The degree of action that the light weight tines produce depends on the angle they are set. Some tines are smooth, round spring steel, and other styles are flattened at the tips or bent perpendicular to increase the surface they cultivate. Individual tines can be lifted to allow for row cultivation. This is a very lightweight tool that is used at high speed.

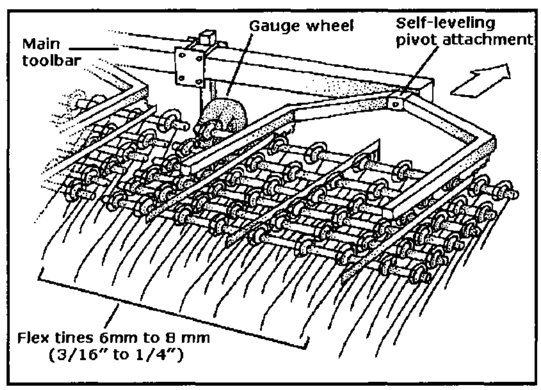


Figure 2.7 Flex tine weeder. Illustration by Bowman (2002).

Rotary hoes are more aggressive than tine weeders but are used in much the same way. They consist of a series of closely spaced spyder wheels (Figure 2.8). Each wheel rolls independently and digs shallowly into the soil as it rolls over it, breaking up crust and dislodging germinating weeds. Depth can be managed by gauge wheels in lighter soils, but generally run on their own weight in heavy soils. Spoon shaped tips are available, to increase their soil moving action. These cultivators are also used at high speeds. Rotary hoes are also very helpful in breaking up crusts that develop after a driving rain or under impact of sprinkler irrigation.

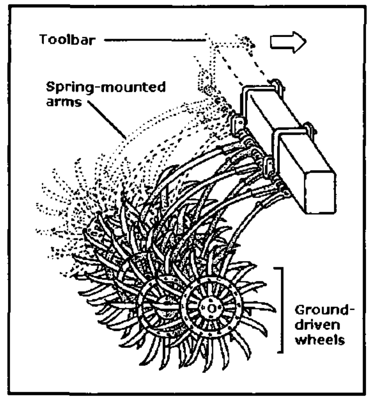


Figure 2.8 Rotary hoe. Illustration by Bowman (2002).

Basket weeders roll on top of the soil, dislodging tiny weeds. When used in two gangs, the forward gang drives the rear gang with a chain, so that the rear gang spins faster than the front gang – increasing the action of the tool (Figure 2.9). Soil is not moved sideways, so basket weeders can be used on crops such as lettuce that do not tolerate soil being thrown into their leafy centers. Some rollers can be turned so that a higher degree of action is achieved. Baskets range from 3–14 inches wide, accommodating a variety of row widths. This tool is used at high travel speed on soil free of stones. This tool is also useful for breaking up crusted soil surfaces.

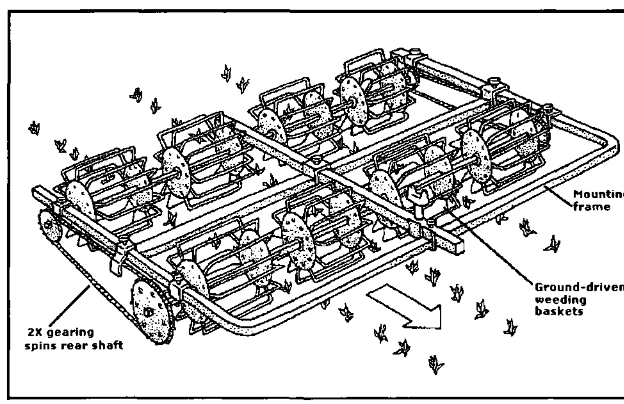


Figure 2.9 Basket weeder. Illustration from Bowman (2002).

Spring steel, or hoe blade weeders use flat spring steel bands (Figure 2.10) running parallel to the ground, and in the opposite direction of tractor travel. These scrape the soil surface adjacent to the crop; a rounded end on the band slides past the crop plant without damaging it.

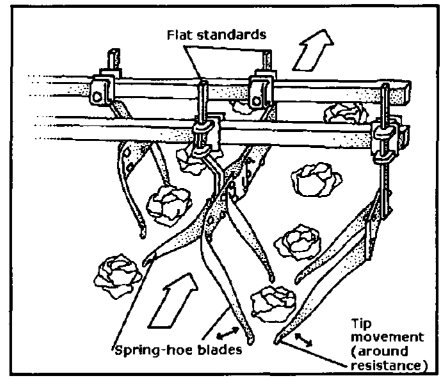


Figure 2.10 Spring hoe blade cultivator. Illustration from Bowman (2002).

Torsion weeders use tines similar to those used in spring tine blind cultivators, but are arranged to cultivate very close to the crop, providing cultivation with a minimal amount of soil movement.

C shanks and S tines connect the cultivator main frame (Figure 2.11) to the tool working in the soil. C and S shaped tines are flexible to some degree, resulting in vibration that helps shatter clods and dislodge soil from weed roots. The flexibility also provides a degree of protection against breakage when a stone or other buried obstruction is hit. Field cultivators may have multiple gangs of S or C tines with cultivating tips that slice through every inch of soil behind the tractor.

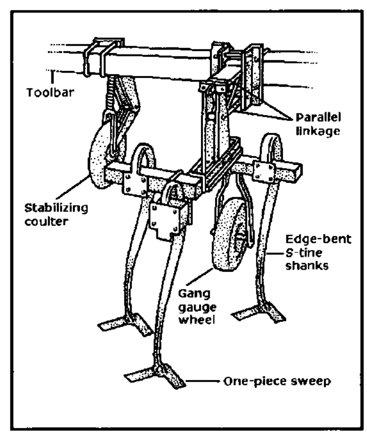


Figure 2.11 S-tine shank and sweep cultivator. Illustration from Bowman (2002).

Knives, shovels, and sweeps are cutting tools that actually cut the roots of weeds; they come in a wide array of shapes for a number of specific uses and specific soil types. Their names suggest their shape and use: knives are straight and undercut the plant just below the soil; half knives or sweeps work only on one side of the shank, and are used to cultivate close to the crop. Sweeps are V-shaped knives, cutting on both sides of the shank. Shovels dig and move soil and generally are used to create furrows or to throw soil to the base of the crop (Figure 2.12). The angle at which any of these tools is set determines how it performs, and how much soil is moved. Most of these tools are used after the crop is established and escaped weeds need to be chopped down by more aggressive means.

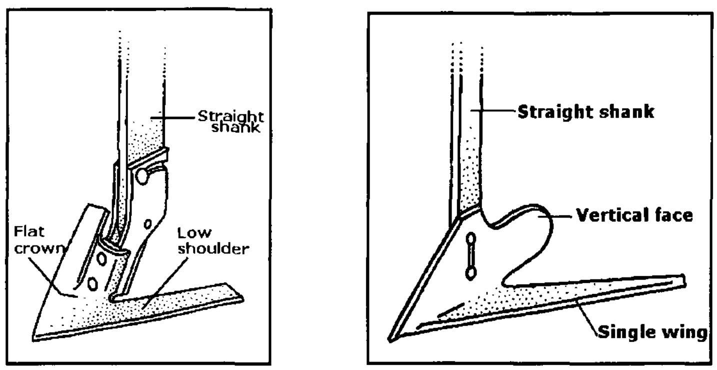


Figure 2.12 Examples of cultivation sweeps (left) and knives (or half-sweep) (right) attached to straight shanks. Illustrations from Bowman (2002).

Spyders are wheels of curved teeth (Figure 2.13) which, depending on the angle at which they are set, may provide minimal or very aggressive tillage very close to the crop, and move soil away from or up against the base of the crop, effectively burying small seedlings. These are generally placed next to the crop row, accompanied by sweep cultivators between the rows.

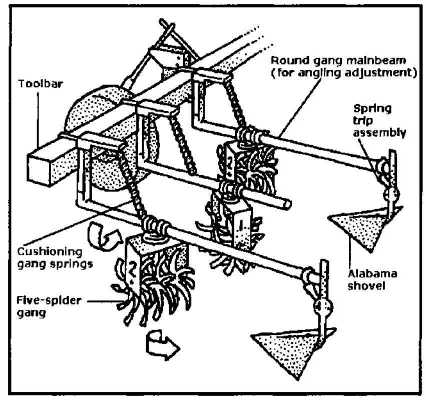


Figure 2.13 Spyder and shovel cultivation tools. Illustration from Bowman (2002).

Finger weeders, also known as Buddingh 'C' cultivators (Figure 2.14), have a series of rubber-coated fingers that gently work the soil in the row. The crop needs to be sturdy enough to take some battering from the rubber fingers.

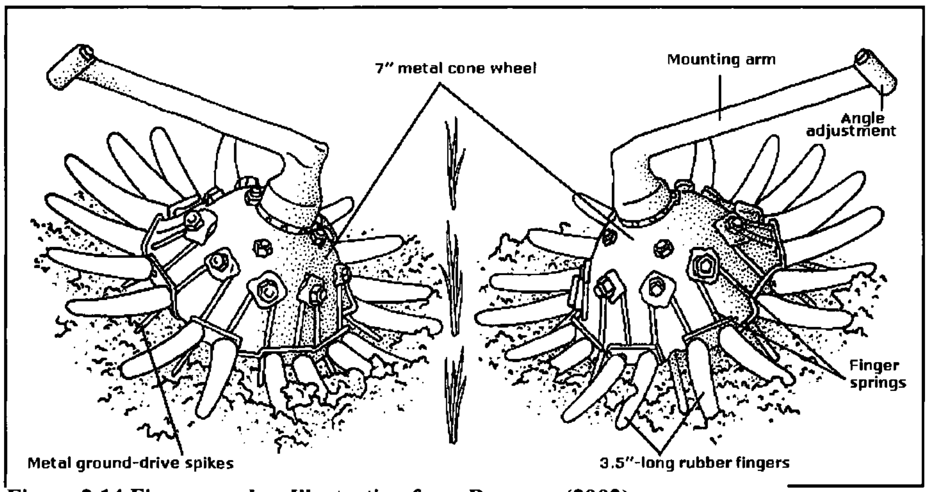


Figure 2.14 Finger weeder. Illustration from Bowman (2002).

Flamers (Figure 2.15) generally use liquefied petroleum and are either hand-held or tractor-mounted. Gas is delivered from the tank to a burner via hoses or pipes. Shields are placed on some machines to direct and concentrate the heat, as well as to protect growing crops or the operator.

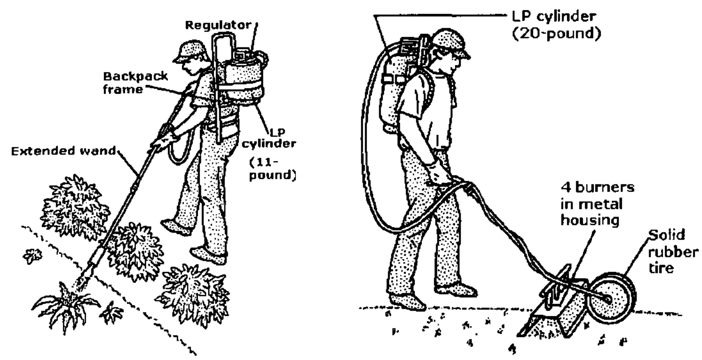


Figure 2.15 Hand held flaming tools. Illustration from Bowman (2002).

Specialized cultivation tractors, such as the Allis Chalmers G and Saukville provide a high degree of visibility from the driver seat, and have cultivation tools belly-mounted for best visibility. These are very lightweight tractors and used almost exclusively for planting and cultivation. The Allis Chalmers G has not been manufactured since the 1950s, but they are still in service and are quite popular among small vegetable farmers. The Huguenot Street Farm electric Allis Chalmers G is shown in Figure 2.16. The Saukville is of the same design, but has a hydrostatic transmission that allows it to creep at very low speed. A diesel engine is also offered. The Farmall Cub is another small, lightweight cultivating tractor with an open front platform.

Figure 2.16 Allis Chalmer G cultivating tractor (photo from www.holmcolmfarmcsa.org).

Hand cultivation tools

Among efficient and widely used hand cultivation tools is the wheel hoe, with a stirrup style hoe that can be used very efficiently in small plots when weeds are still small. Stirrup hoes slice just under the surface of the soil, require a fraction of the effort of a flat bladed hoe, and do not stir up the soil as much. Hand-held flamers (Figures 2.15 and 2.17) can also be very efficient relative to hand weeding. In comparisons of time and efficacy of cultivation of organic garlic over the entire growing season at CSU RMSOFP (2004), flame cultivation (back pack tank unit) required 14.5 hrs/ac versus 40.7 hrs/ac when cultivation was done by hoe and hand (standard error = 0.1). There was not any significant difference in yield between the treatments.

Figure 2.17 Flame cultivation of organic garlic at CSU HFRC, 2004.

Hand operated rototillers are used by many small-scale farmers for light cultivation and seedbed preparation. As mentioned earlier, field bindweed and Canada thistle are propagated effectively by the chopping action of the rototiller, so this machine should be used with caution where vegetatively propagated weeds are present.

Farmer Survey; Weed Management

Among farmers surveyed for this project, weed management was mentioned the most often as a major challenge faced in their operations. Thirty three percent of the respondents noted weed control, which is largely done by hand on the small farms, required an inordinate amount of the farmers' time. Bindweed and Canada thistle were the two most common perennial weeds, and red root pigweed, lambsquarters, and purslane were the most common annual weeds reported (Figure 2.18).

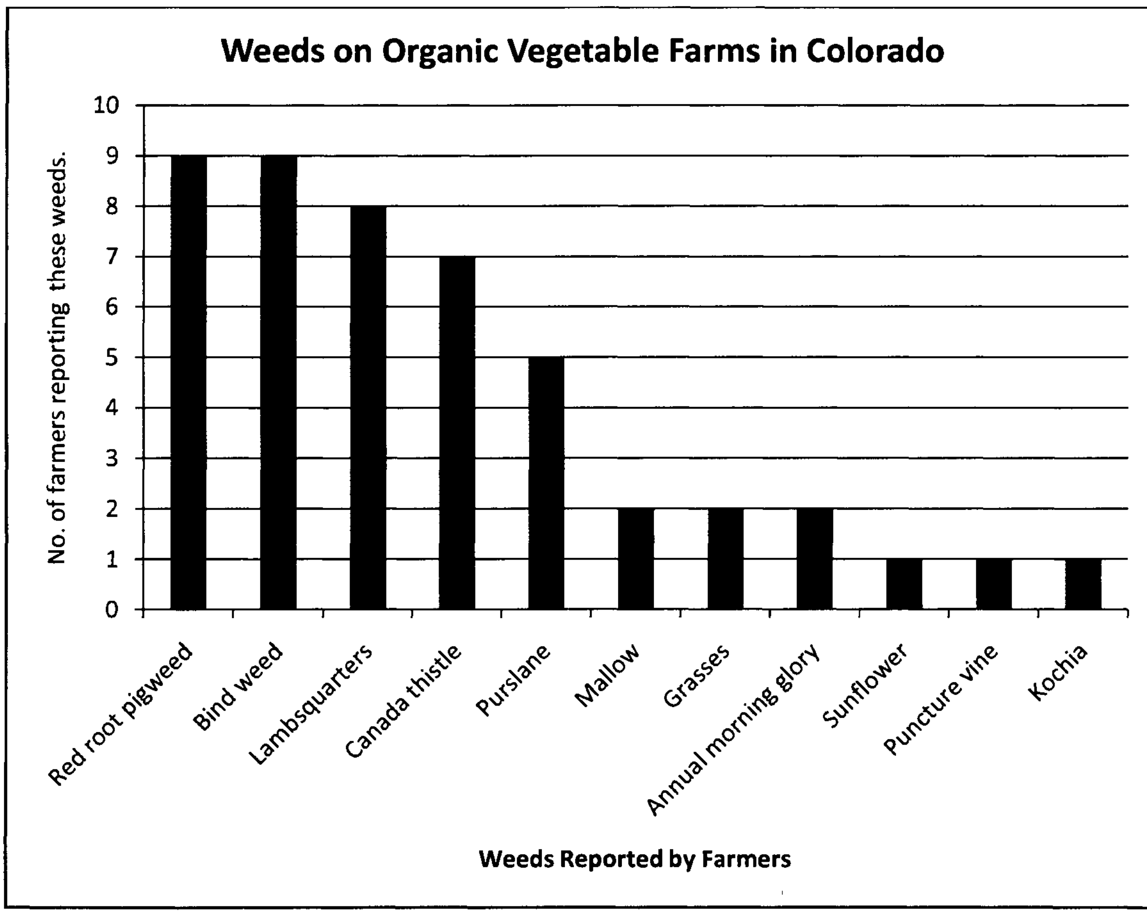


Figure 2.18 Frequency of reported common weeds on organic vegetable farms in Colorado as reported by 15 farm survey participants from across the state; December 2008.

Weed management reported by the farmers included cultivation by tractor, rototiller, hoe, hand weeding, flame, and plastic mulch (figure 2.19). None of the farmers uses any of the organically allowed herbicides and did not indicate any interest in using them; high price and reported poor efficacy were the reasons mentioned.

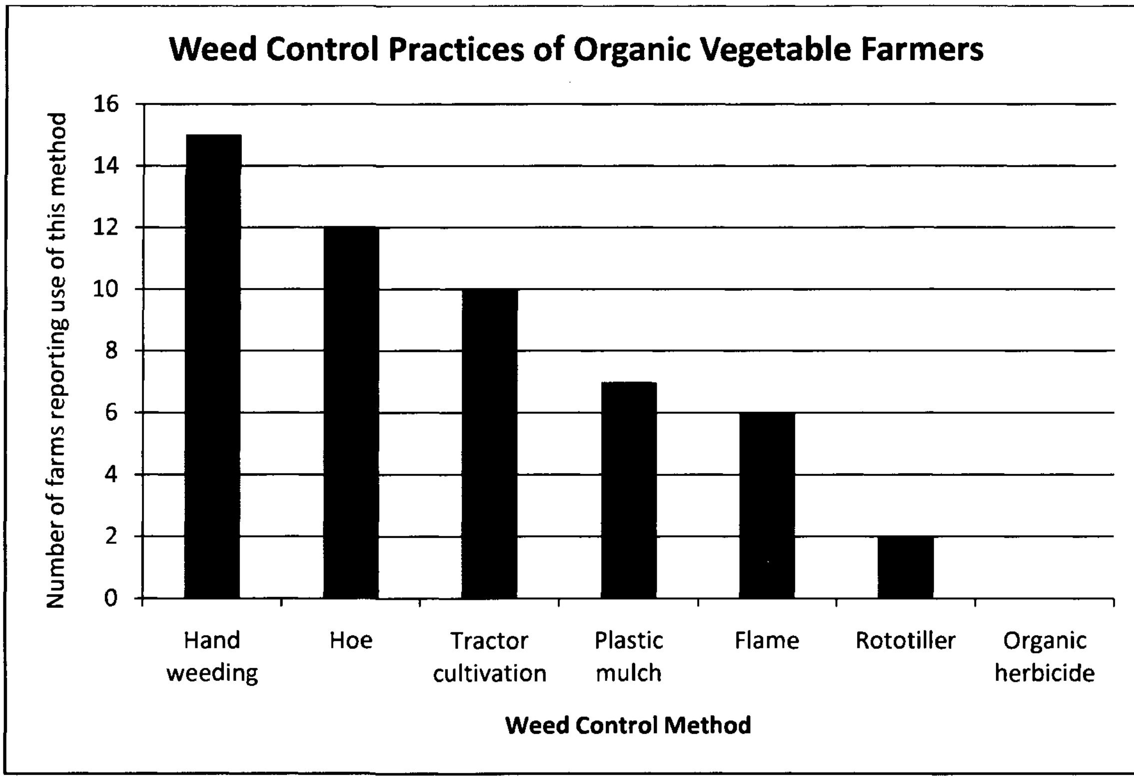


Figure 2.19 Weed control methods reported by 15 Colorado organic vegetable farmers surveyed; December 2008.

Other weed management practices mentioned by farmers included crop rotation. Two farmers use long-term fallow (all summer) with deep chisel plowing to control bindweed and Canada thistle with some success.

Chapter 3 Irrigation

Colorado's arid climate provides an ideal environment for producing a wide variety of organic vegetable crops. High light conditions optimize photosynthesis, dry weather reduces the opportunity for diseases associated with high humidity, and large swings in day/night temperatures increase sugar storage in plants. Coupled with its well developed irrigation projects, Colorado is able to produce excellent vegetable crops, and ranks in the top 7% of the nation's potato, onion, lettuce, sweet corn , cantaloupe, and cabbage production (CASS, 2005).

There are, of course, significant challenges regarding irrigation, including the seasonality of available surface water and water quality. The suitability of water for irrigation is based on the concentration and make up of soluble salts in the water. High concentrations of salts in the soil solution restrict the plants' ability to take up water, and inhibit germination of many vegetable seeds. High salt concentrations of water in the Colorado and Arkansas River drainages of western and southern Colorado and irrigation wells in some parts of the state restrict some vegetable production, or require special management. Water quantity is becoming a greater concern in the face of rapid and thirsty urban growth in Colorado as well as downstream user claims of waters that flow through Colorado.

CSU has been on the forefront of irrigation research for many years, and is responsible for many excellent sources of information regarding best management practices for agricultural irrigation. Irrigation best management practices (BMPs) for organic vegetable production do not differ from those used in conventional agriculture, so limited discussion is presented here beyond providing references that will be useful for small-scale organic vegetable producers. Issues that relate specifically to organic production practices include how irrigation impacts organic soil fertility management, organic weed management, and food safety.

In organic systems, where nitrogen may be the primary limiting nutritional element, special attention to preserve and conserve soil moisture is critical. Preventing leaching of nitrogen out of the root zone by over-irrigation is an important objective. Fortunately, mineralization rates of N from organic sources slow the release of N over an extended period of time, reducing the chance of losing a large percentage of N during any single irrigation event. Adequate moisture levels are also important for microbial activity involved in the decomposition of organic matter into mineral N. Efficient N sequestration by green manure crops is dependent on sufficient and properly timed irrigation to germinate and establish the green manure crop. This requirement may be a determining factor regarding what kind of irrigation system (sprinkler, furrow, etc.) is most appropriate for the farm. This will be addressed in the section "Irrigation Decision Making".

Another concern that is of special relevance in organic systems relating to irrigation is weed control. In the absence of precipitation, timely irrigation is usually required for effective stale bed cultivation, one of the foundations of weed management. Irrigation water can also be a significant source of weed seed which, in practical terms, is difficult to effectively remove unless using a high degree of filtration such as that required for drip irrigation systems.

Irrigation water can also be a source of contamination and is a focus of concern regarding food borne illness on conventional as well as organic farms. Farmers probably have minimal control over activities upstream that result in contaminated irrigation water, but their irrigation practices can help reduce the risks of producing tainted foods.

Water quality – crop requirements

Water quality varies greatly around the state, depending on its source. Many of the state's oldest surface water irrigation systems distribute very high quality water originating from snow melt that is low in mineral content and of nearly neutral pH. Many subsurface sources also provide excellent quality water. However, there are drainages and aquifers that carry higher concentrations of salts than desirable for vegetable crop production (Miyamoto et al., 1985; Shannon and Grieve, 1999). Those waters that carry agricultural contaminants (primarily nitrates and phosphates) may provide farmers using this water with a free source of these plant nutrients. For this reason it is very important that irrigation water be tested; it may be too salty for use on sensitive crops, and the nitrate levels may need to be factored into soil fertility calculations. Tables 3.1 and 3.2 present the relative salt tolerance of several species of vegetable crops and irrigation quality parameters.

Table 3.1. Relative salt tolerance of vegetables.

Degree of tolerance	Vegetable	Threshold of soil salinity without yield loss (dS/m)	Estimated yield loss above salinity threshold (% per dS/m)
Sensitive	Bean, carrot, strawberry, onion	1.0-1.2	14-33
Moderately sensitive	Turnip, radish, lettuce, pepper,	0.9-1.5	9-15
	Sweet corn, potato, cabbage, celery,	1.6-2.0	6-10
	Spinach, cucumber, tomato	2.0-2.5	8-10
	Broccoli	2.5-3.0	9-16
Moderately tolerant	Beet, squash, Swiss chard	4.0-4.7	9

Adapted from Knott's Handbook for Vegetable Growers (Maynard and Hochmuth, 1997).

Table 3.2 Water quality guidelines for irrigation and problems associated with elevated concentrations of specific ions.

Type of problem	None	Moderate	Severe
Salinity			
EC (dS/m)	Less than 0.75	0.75-3.0	Greater than 3.0
Toxicity of specific ions to sensitive crops			
Sodium (evaluated by Sodium Adsorption Ratio (SAR))	SAR less than 3.0	SAR 3.0-9.0	SAR greater than 9.0
Chloride (meq/liter)	Less than 2.0	2.0 -10.0	Greater than 10.0
Boron (mg/liter)	1.0	1.0 -2.0	2.0 -10.0
NH4 and NO3-N (mg/liter)	Less than 5	5-30	Greater than 30
pH	6.5 – 8.3	Greater than 8.3	-

Adapted from Maynard and Hochmuth (1997)

Where drip or micro-irrigation is used, mineral and biological content as well as particulates need to be evaluated so that appropriate filtration methods are employed to mitigate drip system plugging (Nakayama and Bucks, 1991). Water high in salts can be injurious to sensitive crops where sprinkler irrigation is used because of salt accumulation on leaves (Bernstein and Francois, 1975). Early stages of crop development are especially sensitive to salt levels in the root zone (Miyamoto et al., 1985).

Where manures or composted manures are used extensively, their contribution of chloride and sodium salts can exacerbate salt issues arising from salty irrigation water. Organic growers should be aware of this possibility and avoid over-application of composts and manures high in salts. Generally, Na should should make up less than 25% of the total salts in animal manure composts (Alexander, 1994; Rocky Mountain Organics Council (RMOC), 2006).

Irrigation water quality and food safety

As mentioned previously, Colorado has uniquely clean waters. The state has the headwaters of major drainages on both sides of the Continental Divide, and surface water coming directly from snow melt in many cases has been exposed to little contamination relative to downstream neighbors. However, food-borne illness has been linked to tainted irrigation water very recently (luckily, not in Colorado), and vegetable producers need to be ever vigilant to reduce this risk. This concern is for conventional and organic producers alike, and it is worth noting that the outbreaks of *E. coli* in California grown mesclun mix and spinach, and *Salmonella* outbreaks traced to Mexican hot peppers in 2006 and 2007, respectively, originated on conventional and not organic farms (Ackers et al., 1998; USFDA, 2006; USFDA, 2008). The stringent rules regarding manure and compost use on certified organic farms do not exist on conventional farms; for this reason it can be argued that organic farms are no more likely than conventional farms to pose bacterial contamination risks, and the record to date bears this out. Complete protection of surface irrigation waters from bacterial contamination is impossible; however, irrigation practices that reduce the opportunity for contaminated water to contaminate produce directly can and should be employed.

Drip irrigation would seem to provide an obvious solution to the concern of applying fecal-contaminated water to edible leaf surfaces. Drip irrigation supplies all of the crop's irrigation water directly to the soil, and in many cases the drip irrigation lines are buried in the soil, providing no opportunity for tainted water to come in contact with edible vegetable leaves and fruits. Unfortunately, it has been found that *E. coli* is able to enter edible portions of lettuce systemically via roots, making complete security of foods grown in the soil susceptible at some level to contamination (Kim and Harrison, 2008; Solomon et al., 2002). Switching from furrow or sprinkler to drip irrigation incurs considerable upfront costs, making conversion a cost-sensitive decision. The additional benefits of drip irrigation include water savings, reduced energy (pumping) costs, reduced weed pressure resulting from a dry soil surface, continuous field accessibility and highly efficient water use, all good arguments for conversion.

Crop water use requirements and soil moisture measurement

Water use for vegetable production in Colorado ranges considerably depending on the irrigation method, soil type, crop, and the region. Sandy soils that drain quickly and have little water holding capacity require different irrigation practices than heavy clay soils. High elevation, cool valleys, such as in the San Luis Valley, where evapotranspiration (ET) is lower and the growing season is relatively short, utilize considerably less water than the lower elevation Arkansas Valley, where temperatures are among the highest in the state and the growing seasons are more extended. Short season crops, such as lettuce, while being intolerant of drought, are in the field for short periods of time, and have correspondingly low total water consumption rates. The rooting depth of the crop has a major impact on how and when irrigation water is applied.

Colorado vegetable irrigation requirements historically range from 11.5 inches/year in the San Luis Valley, 17.7 inches near Greeley, and to 27.7 inches near Rocky Ford (Soil Conservation Service (SCS), 1988), illustrating the differences associated with climatic and soil properties.

There are several practical methods a farmer may use to establish when and how much irrigation needs to be applied to the crop. These include direct measurement of moisture in the soil and calculation of the amount of water that needs to be replaced in the soil after evaporation and transpiration deplete soil moisture. ET refers to the combined water loss from evaporation from the soil surface and the plants' transpiration. The calculated ET allows the grower to schedule irrigation based on balancing ET, precipitation, and irrigation. Irrigation scheduling enables growers to optimize irrigation usage and minimize the risk of reducing yields associated with under-irrigation and leaching nutrients from the root zone by over-irrigation. Different crops and different stages of crop development have varying transpiration rates, just as evaporation rates change through the season based on day length, temperature, wind speed, ambient humidity, and canopy cover.

Irrigation scheduling based on ET for a set of local weather conditions uses reference crops (usually grass or alfalfa) at specific growth stages that have known ET rates. A conversion formula uses a "crop coefficient" (K_c) to provide the appropriate ET for a given vegetable crop during a given crop developmental stage (ET of alfalfa X K_c of a given crop at a given developmental stage).

Crop coefficients for a few vegetables are established for Colorado conditions, but for other species reasonable estimates can be made based on data developed elsewhere. Figure 3.1 illustrates a generic crop coefficient changing over time relative to the stages of crop development and percent canopy.

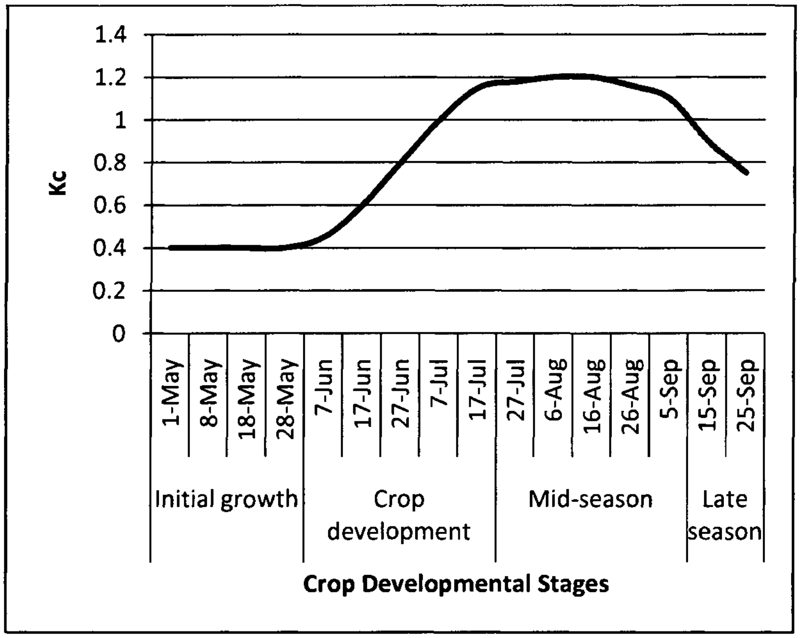


Figure 3.1 Generic vegetable crop coefficient curve (adapted from Allen et al., 1998; Hanson and May, 2006).

Initial growth stages of most vegetable crops fall in the K_c range of 0.3–0.7 range. During crop development and mid-season most vegetable crops fall into the 0.9–1.15 range, and during late season K_c drops to 0.75–0.9. Use of plastic mulches may reduce the K_c from 5% to 15% during the initial and crop development stages before the crop canopy is fully developed (Allen et al., 1998).

There are several reliable sources of ET data in Colorado, many within the major vegetable production regions of the state, that base their ET on local weather station information. In Colorado the CoAgMet network of weather stations provides these data, and can be accessed on the internet at www.CoAgMet.com. This site does not provide ET data for vegetable crops other than onion and potato, but vegetable crop coefficients listed in Table 3.3 can be multiplied by the published daily ET data for alfalfa. When using the CoAgMet network, it is important to check where the weather station is placed, and whether it is in a similar microclimate to that where the data will be used. For example, a weather station located in the middle of an irrigated alfalfa field will have different readings than one in a dryland wheat field. A list of participating weather stations is listed in Appendix C.

Table 3.3. Crop evapotranspiration (ET) coefficients for a variety of vegetable crops.

	Crop growth stages		
Crop	(K_{c1}) Initial growth stages	(K_{c2}) Rapid growth to mid-season growth stages	(K_{c3}) Late season to harvest growth stages
Alfalfa	0.40–0.50	1.00–1.40	0.95–1.35
Asparagus	0.25–0.30	0.95	0.25
Bean (green)	0.30–0.40	0.95–1.05	0.85–0.95
Beets (table)	0.24–0.40	1.05–1.20	0.25–0.30
Cabbage (and other brassicas)	0.30–0.50	0.95–1.10	0.80–0.95
Cantaloupe	0.15–0.40	1.00–1.10	0.30–0.90
Carrot	0.40–0.50	1.05	0.75
Celery	0.25–0.35	1.00–1.15	0.90–1.05
Corn (sweet)	0.20–0.50	1.05–1.20	0.70–0.80
Cucumber	0.20–0.40	0.90–1.00	0.70–0.80
Eggplant	0.25–0.50	0.95–1.10	0.80–0.90
Lettuce	0.20–0.30	0.85–1.05	0.45
Onion	0.40–0.60	0.95–1.10	0.75–0.85
Peas (fresh)	0.40–0.50	1.05–1.20	0.95–1.10
Pepper	0.30–0.40	0.95–1.10	0.80–0.90
Potato	0.40–0.55	1.10–1.20	0.40–0.75
Spinach	0.20–0.30	0.95–1.05	0.90–1.00
Squash	0.20–0.40	0.90–1.00	0.70–0.80
Tomato	0.25–0.50	1.05–1.25	0.60–0.85
Watermelon	0.25–0.50	1.00–1.10	0.20–0.70

Adapted from (Hargreaves and Merkley, 1998)

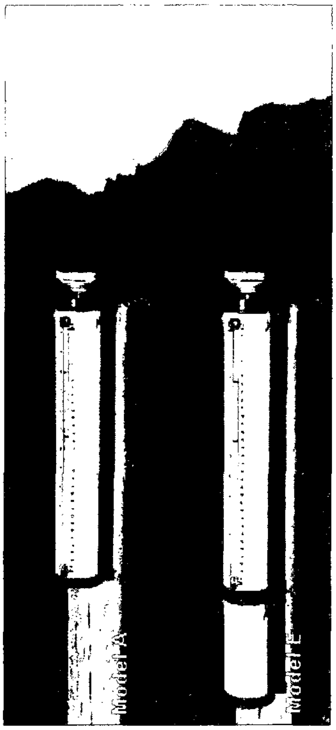


Figure 3.2 ETgage®
Atmometer

Another instrument that provides accurate, on-farm ET data is the atmometer (commercially known as ETgage®, Figure 3.2). It uses an evaporative ceramic material that simulates a plant leaf. The water evaporated from the device is measured through a sight tube, and indicates ET. These instruments are convenient and useful because they provide local ET information and are quite accurate. They must be taken indoors during freezing weather. They cost about $200, and coefficients are available to correct for differing species and crop canopies.

Another method for estimating soil moisture is the tactile hand method; with some practice it can be used to estimate the amount of water that is available in the soil for plants. Most vegetable crops are not limited in soil moisture when the soils are between 50%–75% of field capacity (FC), therefore irrigation should be applied when soil moisture is depleted beyond this range. Many authors have described the process of firmly squeezing soil from the root zone into a ball to observe how well it holds together, a function of moisture level and soil characteristics. For example, at 25%–50% FC, a loamy sand will fail to form a ball, a sandy loam will form a ball but not hold together, a loam or a silty loam will form a plastic ball, and a clay loam or clay will form a ball and ribbon when soil is squeezed between the thumb and forefinger (Table 3.4). To bring these soils back to FC, approximately 0.7–1.7 inches of water would need to be applied to the loamy sand, 1.3–2.6 inches to the sandy loam, 1.7–2.3 inches to the loam or silty loam, and 2.0–4.0 inches to the clay loam or clay (Maynard and Hochmuth, 1997).

Table 3.4. Soil moisture interpretation using tactile and visual cues.

Available water	Sands	Sandy loam	Clay loam	Clay	General comment
Wilting point at or near 0%	Dry, loose, flows through fingers	Dry, loose, flows through fingers	Dry clods break down into powder	Hard clods are hard to break, with fine crumbs on soil surface	Little or no moisture is available
<50%	Appears to be dry; will not form a ball under pressure	Appears dry; will not form a ball	Crumbly, but will hold together with pressure	Somewhat pliable, will ball under pressure	Nearing time for irrigation
Depth of water (inches) required to bring soil to field capacity	0.7–1.6	1.3–2.6	1.7–3.3	2.0–4.0	
50%–75%	Appears to be dry; will not form a ball under pressure	Will form a ball, but not hold together	Forms a somewhat plastic ball	Will form a ball, and ribbon between thumb and forefinger	Enough moisture is available
75% to field capacity	Sticks together weakly and makes a weak ball under pressure	Forms a weak ball; breaks easily; does not become slick	Forms a pliable ball; becomes slick if high in clay content	Slick; forms a ribbon easily	Plenty of available moisture
100 % (field capacity)	Upon squeezing no free water appears and a wet outline is left on hand	Same as sand	Same as sand	Same as sand	Any additional water will drain out
Above field capacity	On bouncing on hand, free water appears	Free water appears when kneading	Can squeeze out free water	Free water puddles on surface	Soil waterlogged; no air can get to the roots

Adapted from Knott's Handbook for Vegetable Growers (Maynard and Hochmuth, 1997 and (Hargreaves and Merkley, 1998).

Irrigation methods

Furrow irrigation

Furrow irrigation is widely used in Colorado, and requires relatively little capital investment. Water supplied in a ditch, flexible polyethylene pipe, gated PVC, or aluminum pipe is applied to the fields in furrows. This method generally applies 3–4 inches of water to the field per irrigation, saturating the field. Soil texture determines the rate of water infiltration into the soil and the length of fields that can be efficiently furrow irrigated; course or sandy soils are limited to 330 feet, loam soils to 660 feet, and clay soils to 1320 feet (Maynard and Hochmuth, 1997). Clay soils that seal up as the wetted clay particles expand may require "surge irrigation," a technique that applies irrigation water in a series of short bursts at the frequency and intervals that allow water to infiltrate the soil rather than run off the end of the field. Furrow irrigation is one way to flush salts out of the root zone and into the subsoil. Conversely, if managed incorrectly, furrow irrigation can accumulate salts in the root zone as the wetting front concentrates salts at its margin (Waskom, 1994). Furrow irrigation is best suited to flat or gently sloping land where flow rate or stream size is limited by the slope of the field. The Soil Conservation Service's Colorado Irrigation Guide (1988) recommendations for maximum slope and stream size to avoid erosion are in Table 3.5.

Table 3.5 Maximum furrow stream size for various slopes

Slope (%)	Stream size (GPM)
0.20	50
0.40	30
0.75	17
1.25	10

Furrow irrigation is labor intensive, and requires vigilance to avoid waste and soil erosion. For many shallow-rooted vegetable crops it also uses a great deal more water than required by the crop. The Specialty Crops Program at Colorado State University conducted research on hardneck garlic (*Allium sativum ophioscorodon*) production on certified organic land at the Horticulture Field Research Center (HFRC) northeast of Fort Collins, Colorado, during the garlic growing seasons of 2002–2003 and 2003–2004. Irrigation treatments were compared using furrow, sprinkler, and drip irrigation methods. Because furrow irrigation requires that a high volume of water be applied to reach the end of the field, the minimum amount used to reach the end of the field may be considerably more water than the crop needs on the top of the field. Sprinkler and drip irrigation allow more control over how much water is applied. In this trial, irrigation water was applied on the same dates, by each method with the objective of applying enough water to fill the root zone to field capacity using tensiometers to monitor soil moisture levels. Because of erratic readings from the tensiometers, manual soil moisture assessment was used to determine when irrigation should be applied. Yields from sprinkler and furrow irrigation were essentially the same; however, furrow irrigation used 24% more water than sprinkler irrigation and 34% more than drip (Figures 3.3 and 3.4).

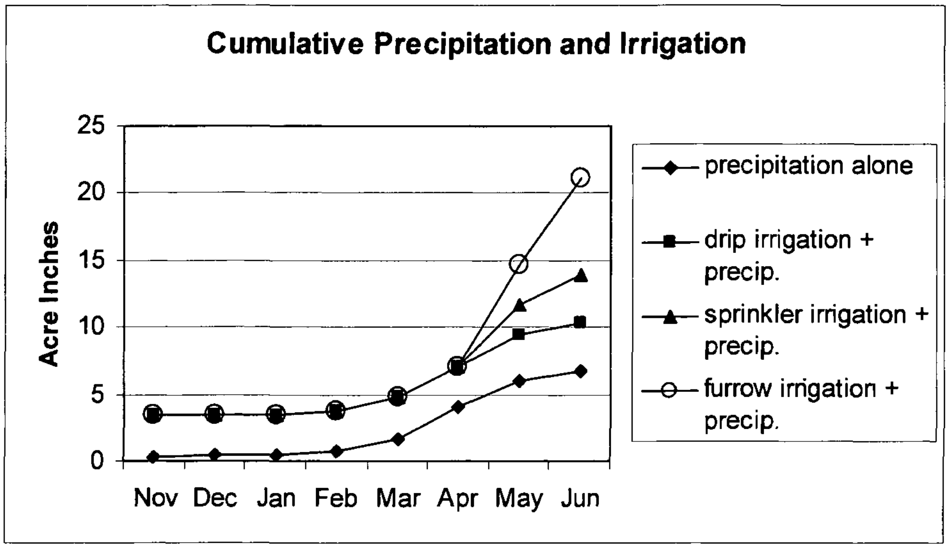


Figure 3.3 Comparison of drip, sprinkler, and furrow irrigation rates to maintain soil moisture at 75% field capacity on hard necked garlic grown at CSU's HFRC in 2003.

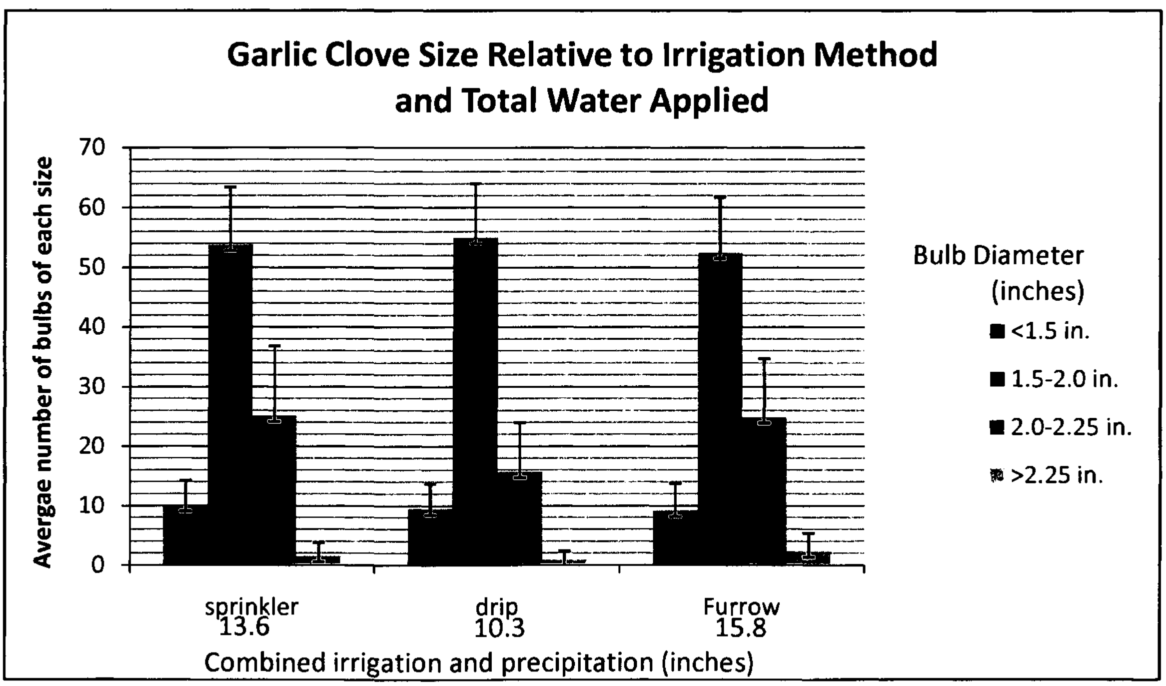


Figure 3.4 Garlic bulb diameter relative to irrigation method and combined precipitation and irrigation applied to hard necked garlic at CSU's HFRC in 2003. Error bars represent one standard deviation.

Sprinkler irrigation

Sprinkler irrigation provides efficient distribution of water and allows for production on fields that are not suited to furrow irrigation due to the field shape or slope. Additionally, sprinkler irrigation may be used to mitigate frost damage under some conditions. A variety of systems are used in sprinkler irrigation, including solid set and traveling systems such as side roll, traveling guns, and center pivot. Center pivots, which are generally used on large acreages, are also designed for use on fields as small as a few acres. Sprinkler systems are used in conjunction with furrow or drip irrigation in some areas, especially where initial establishment of the crop benefits from a moist soil surface. For example, in shallow-seeded lettuce sprinkler irrigation can facilitate seedling emergence, and the cooling effect reduces high temperature seed dormancy. However, duplicate systems carry additional capital investment that must be weighed.

Infiltration rates of soils are also important where sprinkler irrigation is used. Infiltration rates that are slower than application rates lead to run-off and potential erosion. As in furrow irrigated fields, clay soils have slower infiltration rates than sandy and loamy soils (Table 3.6). Sprinkler head and nozzle design determines the droplet size, the throw distance, and application rates, and should be matched with water pressure. An irrigation engineer should be consulted in designing sprinkler irrigation systems.

Table 3.6. Irrigation water infiltration rates of different soil types and different crop canopies.

Soil type	Infiltration rate with full crop canopy (inches per hour)	Infiltration rate with bare soil (inches per hour)
Sand	2.0	1.0
Loamy sand	1.8	0.9
Sandy loam	1.5	0.7
Loam	1.0	0.5
Silt and clay loam	0.5	0.25
Clay	0.2	0.1

Adapted from Maynard and Hochmuth (1997).

Sprinkler irrigation systems are used by organic farmers to apply a variety of foliar fertilizers such as solubolized fish and kelp products, compost teas, and pesticides such as *Bacillus thuringiensis* (*B.t.*). When any of these additives are used, backflow protection is required to protect the source water from contamination. As with all irrigation systems water quality is an important consideration when sprinkler irrigation is used. Light application rates are possible with sprinklers, allowing salts to be deposited in the root zone, assuming that not enough water is applied to leach the salts below the root zone. Salty water applied to leaf surfaces can result in phytotoxicity of some crops, such as pepper (Bernstein and Francois, 1975).

In organic production, where prevention of disease is the primary defense, wet leaf surfaces and high relative humidity in the crop microclimate (especially during cool weather) may promote certain leaf diseases, such as downy mildew (*Pernospora parasitica*) on spinach. Splashing of soil from water droplets also increases the opportunity for soil-borne diseases (such as the leaf spot disease caused by *Alternaria spp.*, *Pseudomonas spp.*, *Cercospora spp.*, Gummy stem blight caused by *Phoma spp.* on cucurbits, *Stemphylium spp.* on spinach, and *Phytophthera spp.* on solanaceous crops) to spread and infect crops (Roberts et al., 2006). On the other hand, relatively high humidity may be used to the advantage of some beneficial biocontrol organisms such as entomophagous fungi that are applied for control of several insect pests (see Chapter 4). Sprinkler irrigation can also increase micro-environmental humidity, thereby reducing water vapor pressure deficits, and reduce crop stress related to high temperature.

Drip irrigation

Drip irrigation is now widely used in vegetable production because of the many benefits it provides in terms of efficient, even water distribution and water savings. The water is distributed through plastic tubes or thin walled tubing that is designed with orifices that regulate the discharge rate. Drip systems work under low pressure, allowing producers to use relatively small pumps or gravity pressurized systems, reducing operating costs.

In addition to providing highly efficient water distribution, advantages of drip irrigation include:

- Provides flexibility to spoon feed crops directly to the root zone using soluble fertilizers, based on crop needs;
- Allows access to the field for cultivation and harvest during irrigation,
- Lessens soil compaction caused by traffic on wet soils;
- Maintains dry crop foliage, reducing foliar disease pressure;
- Reduces weed emergence by virtue of dry soil surfaces between rows (and in-row when drip tape is buried);
- Allows isolation of water application to specific rows or partial rows in highly diversified plantings;
- Allows easy automation of irrigation scheduling and application rates.

A major disadvantage of drip irrigation is the need to maintain very effective filtration. When surface water is used, it is difficult to eliminate silt and organic contaminants (algae, slime molds), but a well maintained sand media filter generally provides adequate filtration. Sand media filters are relatively expensive, and require regular back-flushing to keep the media from becoming plugged. When water is heavily burdened with clay and silt, a settling pond ahead of the filter is recommended, and when large organic debris is in the water, a series of screen filters are used to reduce plugging of the filter intakes. Well water requires some filtration because sand is commonly carried in well water. Screen, spin, or disk filters provide inexpensive and effective filtration of sand-laden well water. A comprehensive review of causes of drip irrigation system clogging has been published by Nakayama and Bucks (1991).

Surface placement of drip tape allows for quick inspection of wetting patterns and clogging. It also allows surface wetting required for germination of shallowly planted crops such as lettuce. However, the tape must be anchored so that wind does not move it when it is not filled with water, and before the growing crop can hold the tape in position. Surface placed tape is also prone to puncturing by errant hoes and field cultivation equipment. Occasionally birds and rodents will peck or chew on exposed tape, puncturing it. For these reasons, many growers prefer to bury drip tape.

Drip tape may be buried to a shallow depth of 2 to 3 inches, or deep-buried to below plowing depth. Shallow-buried tape requires annual removal for primary tillage, but with care can be lifted and stored for subsequent use. Deep-buried tape is not removed, and is intended for multi-year use. Deep burying of tape requires a good understanding of the wetting patterns in different soil types. Clays and loam soils will generally allow some upward capillary movement. Provided long enough irrigation cycles, water may move all the way to the soil surface, providing seeds with adequate moisture for germination. If soils do not wick moisture upward, then a duplicate method such as sprinkler irrigation may be needed for seed germination or to establish shallow rooted transplants. Very shallow rooted crops may not be well suited to deep-buried drip irrigation.

Wetting patterns are determined by the soil type, and may be managed by using different flow rate tapes and orifice spacing. Clays provide the greatest capillary movement of water in all directions away from the drip tape, and sands provide the least. Silts and loams provide intermediate degrees of capillarity. Orifices should be spaced close enough to provide continuous wetting within the row. While closely spaced orifices provide the quickest closing of wetting patterns, they also require more water per linear foot of tape, thereby shortening the possible run lengths and increasing the required pump delivery capacity. Smaller intervals between orifices are preferred for small-seeded crops planted closely together. For wider spaced crops, the orifice spacing is commonly half the distance of the plant spacing. To facilitate design and installation, tape with 6–8 inch spacing is an acceptable compromise on heavier soils, while 4–6 inch spacing may be required on courser soils (Larson, 2006).

Drip tape is available in a variety of thicknesses: from 4 mil "disposable single crop tape," which is lifted and discarded after a single crop, to very heavy 15 mil tapes that withstand abrasion and abuse for many years. Lighter weight, less expensive tape is often used where clogging is anticipated after a single season due to inadequate filtration or slime mold problems. Investment in longer lived tape merits extra attention to filtration and maintenance. A variety of orifice spacing options allow for different plant spacing and soil types.

Common maintenance recommendations for drip tape include chlorination of the water either on a regular or continuous basis to prevent algae, fungi, and protozoa build-up in the tubing which contributes to clogging of drip irrigation orifices (Nakayama and Bucks, 1991).In research using a variety of drip irrigation tapes, (Dehghanisanij et al., 2005) showed that discharge from orifices was reduced 10%–25% over a six-month period by algae, fungi, and protozoa clogging in untreated water, while chlorinated water maintained discharge rates that were at least 90% of their initial flow rate. Nakayama and Bucks (1991) pointed out that chlorination is most effective in waters with $pH < 7$ (this would require acidification of water in many areas of Colorado).

The National Organic Program (NOP) rules state that the use of sodium hypochlorite as a disinfectant is restricted to uses where soil, water, or crop contamination will not occur, and residual chlorine levels will not exceed the maximum residual disinfectant limit established under the Safe Water Drinking Act (USDA, 2002a). It may be argued that these requirements could be met, but careful monitoring and provision for accidental spills may make the use of sodium hypochlorite impractical and risky, if not simply objectionable for the organic grower. Efficacy of alternative, organically allowed disinfectants has not been reviewed in the literature, but these materials are available commercially (PeacefulValleyFarmSupply, 2008).

Disposal of used drip tape presents a variety of economic and environmental challenges. Recycling programs for used drip irrigation tape and tubing exist in California, Arizona, Oregon, and Washington, but at present the market for many recyclable plastics has been dramatically reduced. At the time of writing, no recyclers in the Colorado region were accepting recyclable agricultural plastics (Eco-Cycle, 2008).

Irrigation model for three crops: anticipated irrigation requirements for garlic, tomato, and spinach

Garlic irrigation

Garlic is generally fall planted, and harvested in mid-summer. According to research conducted by the author at the CSU Horticulture Field Research Center (HFRC) in 2002–2003 (Figure 3.3), fall-planted garlic requires sufficient irrigation for establishment in the fall (2–4 inches), and approximately 12 inches of combined precipitation and irrigation during the following spring and summer. These volumes are approximations based on clay soils. This is consistent with reported optimal total irrigation for garlic that ranges from 13.7 to 19.3 inches on loam soils in California and Spain (Hanson et al., 2003; Villalobos et al., 2004) as presented in Table 3.7.

Table 3.7. Estimated water requirement for garlic based on evapotranspiration (ET) of alfalfa using a crop coefficient (K_c) for garlic.

Days after planting	**Crop developmental stage**	**K_c**	**ET alfalfa**	**Irrigation requirement (inches)**
0–30 (Fall planted) soil profile is filled	Establishment	n/a	n/a	3.00
150–180	Development	1.0	7.40	7.40
200–240	Late	0.7	8.21	5.75
Est. combined irrigation and precipitation requirement				16.15

Source: (NCWCD, 2008; Villalobos et al., 2004)

Tomato irrigation

Tomatoes are generally transplanted in Colorado, and irrigated by furrow or drip irrigation. In order to avoid blossom end rot, which is associated with insufficient water uptake during and shortly after flower pollination, even soil moisture approaching field capacity is recommended. If using drip irrigation this is easily achieved with frequent, light irrigation, especially under plastic or organic mulches that conserve moisture. Maintaining a moist root zone during harvest and field operations with furrow irrigation poses greater challenges. Over-irrigation on poorly drained, heavy soils often results in fruit cracking and russeting. Under-irrigation during fruit set often results in blossom end rot, especially in the early season before transplants have developed healthy root systems. In Colorado, and other short season areas, shutting off late season irrigation helps to encourage fruit ripening.

Tomato ET rates have been well documented, providing predictable results in Colorado. Using predicted ET and a tomato crop coefficient (K_c), irrigation requirements for tomatoes can be estimated as illustrated in Table 3.8.

Table 3.8. Estimated water requirement for tomato based on evapotranspiration (ET) of alfalfa and a crop coefficient (Kc) for tomato.

Date	K_c tomato[1]	ET Alfalfa[2]	Inches water required[3]
1–May	0.10	7.5	0.175
1–Jun	0.20	8.9	1.78
1–Jul	0.45	9.0	4.05
1–Aug	0.90	6.7	6.03
1–Sep	1.05	5.0	5.25
Total			17.29

[1] (Hanson and May, 2006)
[2] NCWCD. 2008. Northern Colorado Water Conservation District - daily evapotranspiration summary report, 2008. Berthoud, Colorado.
[3] (K_c X ET alfalfa X #days)

Spinach irrigation

Spinach is direct-seeded throughout the growing season in Colorado as well as fall-sown for over-wintering. The crop is grown for approximately 45–80 days depending on the season. Spinach is shallow rooted and requires continuously moist soil for optimum production. Soil surfaces are maintained moist during and shortly after germination to insure good crop emergence. Furrow, sprinkler, and drip irrigation are used; where available, sprinkler irrigation is used for crop establishment and furrow or drip irrigation is used thereafter. During establishment, bare moist soil increases the evaporative loss of water and figure heavily in K_C for spinach. Leskovar and Piccinni (2005) found that deficit irrigation of 75% of ET could be used without detrimental effects to yield or quality of spinach, providing significant water savings. They did not, however, consider the additional time requirement for crop completion under deficit irrigation.

Fresh market spinach in northern Colorado requires approximately 12 inches of irrigation depending on how many days the crop is in the field. Adequate fertilization and irrigation minimizes the time (and irrigation water) required to bring the crop to a harvestable size. Organic growers may need to supplement N if mineralization of organic N is too slow. Table 3.9 estimates irrigation requirements using ET, and provides three possible harvest time frames. Understanding seasonal ET differences allows the farmer to estimate irrigation requirements throughout production cycles and plan accordingly.

Table 3.9. Estimated water requirement of spinach based on evapotranspiration (ET). Note the difference in application requirements depending on the number of days after planting to harvest.

	Days after planting from May 1	Average K_c spinach[1]	ET Alfalfa[2]	Inches water required[3]	Total est. water (in.) requirement based on time to harvest
May	0–15	0.2	3.8	0.8	
	15–30	0.4	3.8	1.5	
June	30–45	0.9	4.5	4.0	6.3
	45–60	0.9	4.5	4.0	10.3
July	60–75	0.9	4.5	4.1	14.3

[1] Allen, 1998.
[2] NCWCD, 2008.
[3] (K_c X ET alf X #days)

Farmer Survey: Irrigation

All of the 15 organic vegetable farmers that were surveyed used irrigation to grow their crops (see survey description in Chapter 1 and in Appendix D). Forty-six percent of the respondents use furrow irrigation, 73% use sprinkler irrigation, and 53% use drip irrigation. Fifty-three percent of the growers used more than one method to irrigate. Only one of the fifteen farms had access to both well and ditch irrigation; all others used ditch irrigation exclusively. Seasonality of water is a major issue for all of the farmers using ditch water, and this was mentioned as a reason for a lack of using green manure crops to a greater extent. Only one of the farms used formal irrigation scheduling based on ET, all of the others relied on experience.

Irrigation systems appropriate for the small organic farm

Determination of what sort of irrigation practices are best suited for any individual farm requires consideration of a number of factors discussed in previous sections. The following outline highlights these considerations. Remember, the saying goes in Colorado that, "whiskey is for drinkin' and water is for fightin.'" Your rights and obligations as an agricultural water user in Colorado are well worth investigating before any irrigation plans are made. Never assume that you have the right to use water flowing across or under your land. Someone owns it, and you need to know if and how you may access that scarce and precious resource. Start by calling the local Colorado State University extension office, Soil Conservation Service, and visiting with neighboring farmers.

Factors determining the appropriate irrigation system for a farm

What water is available?

If you have well water:

1. What is the quality?
    a. Submit seasonal water samples. Changes in water tables and recharge sources affect water quality through the season. See Appendix C for a list of regional water testing labs.
    b. Determine if water is fit for your production plans, Appendix Table C.1 provides general guidelines for irrigation water quality.
    c. If quality is marginal or unfit, evaluate management choices to correct conditions.

2. What quantity is available?
    a. Establish the well yield.
    b. Determine this by having an irrigation well service run a pumping test.

If you have surface water:

1. When is the water available during the year?
    a. Different ditch companies deliver irrigation water on different schedules, and have different levels of seniority regarding available waters. It is imperative that the grower understand the duration of an average season, and when the irrigation generally begins and ends. Some very early or very late season crops may be poor choices if ditch water is not available during those periods.

   b. If seasonality limits production options, investigate the possibility of developing on-farm water storage. Contact your local extension agent or SCS advisor for information.

2. Is there enough irrigation water?
   a. Shares of ditch water vary in terms of volume from supply company to supply company and from year to year depending largely on snow pack. For example, a share of Cache La Poudre Irrigation Company water has averaged 12.5 acre feet per year, but with ranges of less than 5 to over 27 acre feet per share since 1960 (The New Cache La Poudre Irrigating Company, 2008).

3. Is water quality sufficient for intended crops?
   a. Surface water quality often varies through the irrigation season. This depends on whether the water is coming directly from river sources to the farm, or the water has a high percentage of tail water from upstream farms. High silt loads need to be factored into filtration for drip irrigation. Salts should be measured during different times in the season to establish if they are within crop tolerance ranges (see Table 3.2.)

4. How does the water get to the farm?
   a. Lateral canals that convey water from the ditch company's headgate to the farm require regular maintenance and are the responsibility of those using the water. Maintenance is generally done cooperatively among neighboring farmers. These responsibilities need to be well understood and implemented in order to avoid conflicts. Concrete lined ditches, or piped conveyances reduce maintenance. Piped conveyances eliminate the need for weed control, which is an important consideration where neighboring, non-organic farmers spray herbicides on ditch banks that carry water to an organic operation.
   b. Headgates from the ditch company canal to individual farms may be quite distant, and prone to a great deal of water loss due to rodent burrows, tree and weed consumption, and infiltration into the soil. Shrinkage must be taken into consideration when calculating irrigation requirements. Robert Hill (Utah State University) reports that water loss in earthen conveyance ditches ranges from 20% to over 50% (Barta et al., 2004).
   c. On-farm ditches at tops of fields are best formed with tractor-drawn ditchers that build a strong, well-packed bank. Siphon pipes carry the water from the ditch to the field. Alternatively, gated pipe or flexible poly-pipe can be used to deliver the water from the source to the field.

What crops can be grown based on irrigation water availability and quality?

1. Is water quality suitable for the crop?
   a. See Tables 3.1 and 3.2 for vegetable crop tolerance ranges to salinity.

b. Evaluate the feasibility of mitigation or corrective measures for salty water. Discuss options with the local extension agent or SCS officer.

2. When is irrigation needed for the crop?
    a. For planning purposes, it should be assumed that irrigation will be needed during all periods of active crop growth.
    b. Very early direct-seeded crops such as onions may need irrigation as early as late February, and over-wintered vegetable and green manure crops require water into October. Availability of water for specific cropping plans and budgeting water requirements are important considerations.

3. How much water is needed for the crop?
    a. Crop water needs vary by species and developmental stage. Comparison of generic evapotranspiration graphs and tables (see Table 3.3) will assist in irrigation budgeting.

Which irrigation method is appropriate?

1. Furrow irrigation
    a. Furrow irrigation requires even field grades of <0.5% and the ability to drain the field once the water is applied so that puddling and saturated soils do not drown-out crops.
    b. Single irrigations generally result in applications of 3–4 acre inches, requiring a relatively large volume of water. The larger volume of water applied requires that traffic on the field be postponed until the surface is dry in order to avoid compaction. Deep infiltration fills the soil profile and requires less frequent irrigations once crops have established deeper roots, however, shallow seeded crops may need frequent irrigation for germination and emergence.
    c. Furrow making equipment (generally tractor drawn) is required, but this can be done with rototiller attachments or by hand on small plots.
    d. Salts and nutrients can be leached from the soil with furrow irrigation, however, alternate row irrigation can also concentrate salts at the soil wetting face which can cause problems if sensitive crops are growing in that position on the bed.
    e. Furrow irrigation is not easily automated, and requires vigilance.

2. Sprinkler irrigation
    a. Water infiltration rates need to be known to determine the appropriate nozzle sizing and application rates to avoid run-off.
    b. Steeply sloping or rolling fields are better irrigated with sprinklers than furrow irrigation.
    c. Sprinklers are a good option for maintaining a moist surface for crop germination and emergence.
    d. Wind may influence the irrigation patterns resulting in uneven application of water to the field. Water loss to evaporation is also greater than drip or furrow irrigation.

e. Smaller areas may best be irrigated with solid set, or hand moved sprinkler lines. Larger fields may be more efficiently irrigated with side roll, center pivot, or linear traveling systems.
f. Where surface water is the source for sprinkler irrigation, filtration is required to reduce plugging of lines and nozzles.
    i. Commonly a holding pond is required to insure a steady supply of water is available to the pump.
g. Because the entire soil surface is wetted weed seeds are allowed to germinate throughout the irrigation season.
h. Splashing of soil particles onto leaves and stems of plants may increase the incidence of plant disease, and higher canopy humidities can also promote diseases associated with wet leaf surfaces. Conversely, higher humidities in the crop canopy benefit many beneficial insects.
i. Splashing of soil particles may require additional cleaning of leafy vegetables such as spinach and lettuce.
j. Application of pesticides and fertilizer through sprinklers is efficient, but requires anti-siphon protection to keep products from contaminating the water source.
k. Leaching of salts may be achieved with high enough volumes of water.
l. Application of saline water to sensitive crop leaves may be phytotoxic.
m. Most sprinkler systems are easily automated with timers and section valves.

3. Drip irrigation
    a. Drip irrigation is the most efficient type of irrigation in terms of water use.
    b. Systems are easily automated with timers and section valves.
    c. Because drip irrigation requires only low pumping pressure and low flow volumes, the pumping capacity requirement is relatively small.
    d. Excellent filtration and filtration maintenance is required to avoid plugging of the tiny orifices. Surface water sources generally require sand media filters, however well water is filtered with screen or disc filters.
    e. Water savings relative to cost of materials needs to be weighed.
    f. Because most of the field's the soil surface remains dry under drip irrigation there are fewer weed seeds germinating and reduced weed pressure should be a result.
    g. The application of water directly in the bed allows continuous field access which is convenient for the vegetable farmer that has continuous harvest and crop culture requirements.
    h. Disposal of drip tape is costly, and recycling of used drip tape has been limited recently by a glut of plastic in the recycling market. Hopefully this will improve in the future. Thicker walled tape with longer field life is available, and provides an alternative to single year use tapes commonly used. Good water filtration and flushing with anti-algal biocides prolongs the useable life of thick walled drip tape.

Chapter 4 Pest and Disease Management

Organic production is based on integrated, biological systems including a wide array of organisms that can benefit and/or detract from profitable crop production. Conversely, "conventional agricultural production" has been characterized as a system that minimizes the risk of crop loss by reducing biological challenges. The development of synthetic pesticides in the 1940s and 1950s promised to be a boon for agriculture; however, environmental and health calamities soon became evident in the aftermath of widespread misuse. In a relatively short period of time a great deal of research in biological control of pests that predated synthetic pesticides was forgotten or cast aside. During the early 1960s, as evidence mounted of environmental damage caused by agricultural pesticide misuse, Rachel Carson's Silent Spring brought these issues into the public discourse, and fueled a movement that has helped reshape how we now manage pests. One of the results has been renewed interest in the integration of biological and cultural management of pests, which is one of the fundamentals of organic production practices.

Pest management in organic production systems relies on integrated pest management approaches, integrating all appropriate technologies in a coordinated manner. This includes biological control, crop resistance, and cultural management, with the judicious use of allowed pesticides when all else fails. The small-scale farmer, with highly diversified and continuous production, is quite likely better aligned with ecosystems that are complemented by an array of natural enemies, than larger, monocrop systems that are inherently fragile and susceptible to pest and disease outbreaks due to their lack of diversity.

The definition of "pests" can be very broad and inclusive. In this discussion it will include the main arthropods (insects and mites), mollusks (slugs and snails), and plant diseases affecting Colorado vegetable production. Nematodes have been omitted because Colorado growers are relatively untroubled by them. Weeds are addressed in Chapter 2.

Integrated Pest Management in Organic Systems

Pest management in organic systems relies on a truly integrated pest management (IPM) approach using host crop resistance, cultural management, biological control, and, as a last resort, the use of pesticides allowed under NOP rules (USDA, 2002a). IPM begins in the production planning phase by identifying probable pest and disease issues and developing a farm plan that enhances the appropriate defenses. Timely and accurate monitoring and identification of pests and diseases is the next step. In a perfect world, pest monitoring and identification would be coupled with knowledge of pest density and damage thresholds which, in turn, will determine subsequent management actions.

There was a range of sensitivity among the farmers surveyed for this project regarding tolerance of pest damage to crops sold. Farmers selling produce to grocers noted that stores had very low tolerance for pest damage. Farmers selling directly to consumers commented that they had more tolerance for pest damaged products they sold directly to consumers because their customers were likely to accept some damage if they were told by the farmer why it occurred. All of the surveyed growers said that they believed the general public expected organic products to meet similar standards of quality (cosmetic and free of pest damage) as what is offered in conventional grocery store offerings. However, they all also thought that consumers accepted more damage when they bought directly from the farmer than from a grocer.

Without well established tolerance thresholds, on either the production or market demand side, much is left for the farmer to ponder in terms of action decisions Monitoring pests, natural enemies, disease and damage in the crop provides the information necessary deciding upon for appropriate action.

Monitoring

The objective of a monitoring program is to find and manage a small problem before it becomes a big problem. Farmers need accurate monitoring information to make appropriate management decisions.

A formal monitoring or scouting program provides information about the presence of pests and disease in the crop and trends that develop over time. Pest management in organic systems that rely heavily on biological control evaluates trends of pest and natural enemy populations as they develop and interact. Maintaining a regular scouting effort also provides invaluable observation of changes that may otherwise be overlooked during day-to- day operations. Monitoring methods range from the very narrow and specific (scouting a single pest at a specific developmental stage of the crop) to very broad in approach (randomly selecting plants for inspection throughout the field).

Publications that describe field scouting techniques, insect identification, and record-keeping methods that enable the scout or farmer to assess the pest/disease situation are listed in Appendix B. Extension agents, private consultants, and diagnostic labs also provide pest monitoring services. A list of companies supplying monitoring tools is also listed in Appendix B. The following discussion describes monitoring methods that are appropriate for a small, diverse cropping system.

Arthropod monitoring

To begin the monitoring process, it is very helpful to have an idea of what needs to be recorded. This includes abiotic information (such as date, weather, and cultural practices) and biotic information (such as crop developmental stage, crop condition, and weed presence). It is important to know what to expect to see in the field, at any given time on any given crop. Table 4.1 lists most of the common insects and mites found in vegetable crops in Colorado.

1. Visual inspection of individual plants

Thorough **visual inspection** of several randomly selected plants within a planting will indicate the presence or absence of a pest or crop damage, and the presence or absence of natural enemies of a specific pest. Whole-plant inspection is especially important for locating mites and colonies of relatively stationary pests like aphids. In addition to checking randomly selected plants, it is very useful to identify specific plants that are monitored regularly for the presence of pests and/or natural enemy populations and the degree of biocontrol achieved. If pesticides are used, this method can help in assessing the degree of control achieved and the impact of the pesticide on natural enemies.

Often the damage produced by the pest is more evident than the pest itself, in which case diagnostics of damage help identify the problem. The most common vegetable pests in Colorado can be classified into three general categories based on the type of feeding damage they cause.

Chewing Insects

The chewing insects bite through portions of the leaf or stem, leaving notches, jagged edges, or shot holes in leaves, or stems that are cut through. Among the chewing insects of concern in Colorado vegetables are several species of caterpillars, beetles, and grasshoppers. Earwigs and slugs also fall into this category. Earwigs and some caterpillars skeletonize leaves, leaving a lacelike pattern of veins.

Direct damage caused by chewing insects is the most visually recognizable and objectionable to consumers. Holey cabbage or spinach, or sweet corn with the tip damaged by caterpillar feeding are common types of direct damage that are not acceptable. On the other hand, broccoli can tolerate a great deal of leaf damage without sacrificing yield (Cranshaw and Default, 1985). Once the head forms, however, caterpillar feeding on the florets is unacceptable; not only is the floret damaged, but frass (insect excrement) and caterpillars end up in the harvested product. Some bacterial diseases are spread by chewing insects; bacterial wilt of cucurbits is commonly diagnostic of this insect vector.

Piercing and sucking insects

Piercing and sucking insects pierce plant cells ranging from epidermal to vascular cells, removing cell contents and leaving behind plant tissue that may be stippled, puckered, chlorotic, or covered with honeydew. Among the piercing and sucking insects of concern in Colorado vegetables are aphids, leafhoppers, psyllids, true bugs and mites. Thrips use mouthparts that rasp and suck, leaving behind characteristic shiny damage. Most piercing and sucking damage to crops is less noticeable, and consumer tolerance may be higher than for chewing damage. Heavy feeding, deposits of honeydew on the product, and in the case of aphids, the presence of the aphids themselves or their cast skins are serious problems for consumer acceptance.

Piercing and sucking insects spread many viruses. Symptoms of viral infection such as leaf distortion and/or discoloration may be diagnostic of thrips, aphids or leafhoppers.

Mining insects

Miners also have chewing mouthparts, but their feeding pattern is distinct in that they tunnel within leaves between the upper and lower layers of the leaf, leaving winding trails filled with air and frass. Among the leaf mining insects of concern in Colorado vegetables, there is a two fly species whose larvae cause this damage. Leaves affected by mining are unsightly and they break down quickly, requiring removal of damaged leaves during harvest. Where mining is widespread the crop may not be harvested at all.

Other easily recognizable diagnostics

In addition to feeding damage, frass is diagnostic of pests. Potato psyllids produce a distinct white granule which is often seen before the insects are visible in the crop. Aphids produce copious amounts of honey dew, that is sticky to the touch and shiny, until a black, sooty mold begins growing on it. Grasshoppers excrete small, rice grain-like pellets and horn worms excrete large, block-shaped pellets. Large flights of loopers may speckle a crop with orange streaks of frass (easily confused at first glance with rust or fungus), tipping off the grower that a hatch of caterpillars is soon to follow.

2. ***Trapping***

Trapping methods vary depending on the target pest. Nocturnal moths may be difficult to locate during daytime inspection but can be trapped at night in **light traps,** indicating when a flight occurs and how large a population is present. This information can be used to predict egg laying and caterpillar emergence. **Pheromone traps** can specifically target many species. **Pitfall traps,** placed at soil level, are used to track ground-dwelling insects, and are especially useful for monitoring the activity of predaceous beetles. **Colored sticky traps**, suspended in or slightly above the crop canopy, are available in a variety of colors, and have some degree of specificity for insects visually attracted to a particular color. Sticky traps are especially useful for monitoring insects at low densities, before they are easily found during random plant inspection. The arrival of disease vectoring insects such as the potato psyllid, western flower thrips, and western beet leafhopper may indicate the need for preventative crop protection actions.

3. ***Sweeping***

Sweeping with nets can be done in crops that are not damaged by the action, capturing a sample of everything in the path of the net at that moment in time. This method is useful for establishing the initial arrival and relative density of a pest or beneficial insect. We generally look above ground for insects, but some damaging pests dwell in or at the soil level where pitfall traps or soil sample collection is required.

4. Timing

In addition to looking above and below ground, time of day—or night—when monitoring is carried out will provide very different results. Entomologist John Strayer frequently told his students "insects, like students, like to sleep-in in the morning and stay up late at night."

Scouting very early in the morning may be pleasant, but is probably not as productive as later in the day, after the insects warm up and become more active. Many soil-dwelling insects emerge during the night, so night-time scouting with a bright headlamp generally provides a great number of surprises: cutworms, earwigs, and slugs, all relatively shy in full light are out at night, along with a compliment of predaceous ground beetles, spiders, toads, and even some vertebrates on patrol.

Disease monitoring

Monitoring for plant diseases should begin in the preceding seasons to avoid problems in future plantings, especially with regard to soil-borne diseases. In-season, **direct monitoring** for diseases, that is, inspecting plants for disease symptoms, is easily combined with arthropod monitoring. The premise of this approach is that once the disease is found efforts are made to contain the disease. Regular monitoring and record-keeping allow the farmer to track the extent and spread of the disease, and determine if it is correlated to abiotic factors (such as weather, crop nutrition, soil compaction, irrigation problems, etc). Symptoms of disease may be similar to those caused by abiotic factors, and correct identification of the disease in the field is often impossible. Proper identification of diseased plants is generally best left to expert diagnostics provided by plant diagnostic laboratories (see Appendix B for a list of laboratories in Colorado).

To improve the chance of early detection of disease, sections of the field that are most susceptible should be monitored. Poorly drained areas or areas of especially dense foliage with poor air circulation are often the first to become infected. Insect vectored diseases may first appear near weedy or uncultivated border land where vectors habituate when crop hosts are unavailable.

Indirect monitoring involves two different approaches. One is the identification of insect vectors that introduce disease to the crop. The other is the use of in-field weather stations to collect climatic data that can assist in predicting the likelihood of disease outbreak based on such factors as temperature, relative humidity, and resulting leaf wetness. Computerized predictive models are used successfully on certain crops, but highly diversified growers are unlikely to benefit from these tools since they are designed for monocrop systems. These methods are also largely based on the premise of disease management by pesticides, which is a marginally reliable option for organic producers.

Table 4.1 Vegetable arthropod pests in Colorado.

Common name	Scientific name	Onion and other Alliums	Cole crops	Beet	Carrot	Chard	Spinach	Cucurbits	Sweet corn	Lettuce	Beans	Peas	Pepper	Tomato	Eggplant	Potato
APHIDS & OTHER SAP SUCKERS																
Aster leafhopper	*Macrosteles quadrilineatus*		X		X				X	X			X	X	X	
Bean aphid	*Aphis fabae*									X	X	X				
Beet leafhopper	*Eutettix tenellus*			X		X	X	X		X	X			X		
Cabbage aphid	*Brevicoryne brassicae*		X							X						
Green peach aphid	*Myzus persicae*		X		X	X	X		X	X	X		X	X		
Greenhouse whitefly	*Trialeurodes vaporariorum*		X					X					X	X	X	X
Melon/cotton aphid	*Aphis gossypii*				X	X	X	X			X		X	X		
Pea aphid	*Acyrthosiphon pisum*									X	X					
Potato aphid	*Macrosiphum euphorbiae*									X			X	X	X	X
Potato/tomato psyllid	*Paratrioza cockerelli*												X	X	X	X
Red lettuce aphid	*Nosonovia ribisnigri*									X						
BEETLES																
Banded cucumber beetle	*Diabrotica balteata*	X						X	X	X	X					
Cabbage flea beetle	*Phylotretta cruciferae*		X													
Colorado potato beetle	*Leptinotarsa decimlineata*													X	X	X
Dusky sap beetle	*Carpophilus lugubris*								X							
Mexican bean beetle	*Epilachna varivestis*										X					
Pale striped flea beetle	*Systena blanda*		X	X	X			X	X	X	X		X	X	X	X
Potato flea beetle	*Epitrix cucumeris*												X	X	X	X
Spinach flea beetle	*Disonycha xanthomelas*		X	X			X									
Spotted cucumber beetle	*Diabrotica undecimpunctata*							X			X					
Striped cucumber beetle	*Acalymma vittata*		X					X	X	X	X			X		
Western black flea beetle	*Phylotretta pusilla*		X					X		X			X	X	X	X
Western corn rootworm	*Diabrotica virgifera virgifera*								X							
Western striped flea beetle	*Phylotretta ramosa*															
Wireworms								X								X
BUGS																
False chinch bug	*Nysius raphanus*		X	X		X	X			X						
Harlequin stink bug	*Murgantia histrionica*		X													
Say stink bug	*Chlorochroa sayi*		X								X			X		
Squash bug	*Anasa tristis*							X								
CATERPILLARS																
Alfalfa looper	*Autographa californica*		X			X	X			X	X					
Army cutworm	*Euxoa auxiliaris*															
Beet armyworm	*Spodoptera frugiperda*	X	X	X	X	X	X		X	X			X	X		
Black cutworm	*Agrotis ipsilon*		X						X	X			X	X	X	X
Cabbage looper	*Trichoplusia ni*		X	X		X	X			X	X			X		
Corn earworm	*Helicoverpa zea*								X	X	X		X	X		
Diamondback moth	*Plutella xylostella*		X													
Dingy cutworm	*Feltia spp.*															
European corn borer	*Ostrinia nubilalis*								X		X		X			
Imported cabbage butterfly	*Pieris rapae*		X													
Tobacco hornworm	*Manduca sexta*												X	X		X
Tomato hornworm	*Manduca quinquemaculata*												X	X		X
Variegated cutworm	*Peridroma saucia*		X							X		X	X	X		X
EARWIGS																
European earwig	*Forficula auricularia*							X	X	X					X	
FLIES																
Serpentine leaf miner	*Liriomyza sativae*	X			X			X		X	X		X	X	X	X
Spinach and beet leafminer	*Pegomya hyscyami, P. betae*			X		X	X									
Seed corn maggot	*Delia platura*	X	X	X		X	X	X	X		X	X				
GRASSHOPPERS																
Differential grasshopper	*Melanopus differntialis*															
Migratory grasshopper	*Melanopus sanguinipes*		X					X	X	X				X		X
Redlegged grasshopper	*Melanopus femurrubrum*		X					X	X	X			X	X	X	X
MITES																
Two-spotted spider mite	*Tetranychus urticae*							X	X		X	X	X	X	X	
SLUGS																
Garden slug	*Deroceras reticulatum*		X	X		X	X			X		X		X		
THRIPS																
Onion thrips	*Thrips tabaci*	X	X					X			X		X			
Western flower thrips	*Frankliniella occidentalis*	X						X			X	X	X	X	X	X

Farm Survey; Primary Pests

A survey of 15 organic farmers was conducted by telephone in December 2008 to ascertain common practices used around the state by organic vegetable producers (see Chapter 1 and Appendix D for background on the survey). Questions were asked about pest and disease problems and management tools used to control these problems. It was interesting to hear that they had relatively few insect and disease problems. Table 4.2 lists the insects reported by the farmers as most damaging to organic crops on their farms. Flea beetle was mentioned by half of the respondents as being a predictable problem. One-third of the farmers reported that they regularly used floating row cover (FRC) to exclude flea beetles from a variety of crops, but especially brassicas and salad mixes that included arugula or mustard greens. Cucumber beetle was the next most commonly mentioned pest (40% of those surveyed), with damage to cucurbit seedlings being the primary concern, although one grower noted having serious root damage to mature melon crops due to cucumber beetle in 2007. Caterpillars, including imported cabbage butterflies, loopers, and corn earworm (there was some confusion on the part of the growers about which species of caterpillars were eating the crops) were mentioned by 26% of the respondents use *Bacillus thuringiensis* (B.t.) occasionally for caterpillar control, and one grower stated that European paper wasp now provides complete control of all of the caterpillar problems she used to spray for. Aphids were mentioned by one third of the respondents, all of whom experienced sporadic outbreaks in brassicas, especially on Brussels sprouts. Only two growers had trouble with lettuce aphid. Squash bug was considered to be a regular pest by 26% of the growers, all of whom said it was difficult to control but that damage was limited to a relatively small portion of their crop. One grower pointed out that the real damage observed came when hard squash was in storage and the feeding sites of the insects began breaking down soon after harvest, resulting in rot problems. Thrips and psyllids were only recognized as serious pests by two farmers.

Table 4.2. Survey results of 15 organic vegetable farmers in Colorado regarding their most common insect pests; December 2008.

Most commonly mentioned insect pests	Respondents considering this a serious pest (%)
Flea beetles	53%
Cucumber beetle	40%
Caterpillars	26%
Aphid	33%
Squash bug	26%
Thrips	6%
Psyllid	6%

Table 4.3 Diseases of vegetables in Colorado.

Disease	Causal organism(s)	Alliums	Cole crops	Beet	Chard	Spinach	Cucurbits	Sweet corn	Lettuce	Beans	Peas	Pepper	Tomato	Eggplant	Potato
Alternaria leaf spot	*Alternaria spp.*		X				X								
Angular leaf spot	*Pseudomonas spp.*						X								
Anthracnose	*Colletotrichum spp.*						X			X		X	X	X	
Aster yellows	Virus								X						
Bacterial blight	*Xanthomonas spp.*							X		X					
Bacterial Brown Spot	*Pseudomonas syringae* pv. *syringae*									X					
Bacterial speck	*Pseudomonas syringae*														
Bacterial spot	*Xanthomonas spp.*											X	X		
Beet curly top virus	Virus						X								
Big vein	Mirafiori lettuce virus								X						
Black leg	*Phoma lingam*		X												
Black rot	*Alternaria spp.*, *Xanthomonas spp.*		X				X								
Botrytis	*Botrytis spp.*	X											X		
Cucumber mosaic virus	Virus			X	X	X	X			X		X	X		X
Damping off	*Fungi and Bacteria complex*			X	X		X			X	X	X	X	X	
Downy mildew	*Peronospora spp., Pseudoperonospora spp., Bremia spp.*	X	X	X	X	X	X		X						
Early blight	*Alternaria spp.*												X		X
Fusarium wilt	*Fusarium spp.*		X				X				X		X		
Gray mold	*Botrytis spp.*														
Gummy stem blight	*Didymella bryoniae, Phoma spp.*						X								
Halo Blight	*Pseudomonas syringae* pv. *phaseolicola*									X					
High Plains Disease	Virus							X							
Iris yellow streak virus	Virus	X													
Late blight	*Phytophthora spp.*												X		X
Lettuce drop	Sclerotinia spp.								X						
Mosaic	Virus						X		X	X		X	X		
Pink rot	*Phoma spp.*	X													
Powdery mildew	*Erysiphe polygoni, Sphaerotheca spp.*				X		X			X	X				
Psyllid yellows	Insect toxin												X		X
Purple blotch	*Alternaria porri, Stemphylium vesicarium*	X													
Rust	*Puccinia spp., Uromyces spp.*					X				X					
Seed rot	Bacterial and fungal complexes						X	X		X	X				
Smut	*Ustilago maydis*	X						X							
Soft rots	*Erwinia spp., Pseudomonas spp., Enterobacter spp.*	X													
Spinach rust	*Puccinia aristidae*					X									
Sudden wilt	*Acremonium spp., Pythium spp. Rhizopycnis spp.*						X								
Target speck	*Corynespora cassiicola*														
Tipburn	Calcium deficiency								X						
Tobacco mosaic virus	Virus														
Tomato spotted wilt virus	Virus	X										X	X	X	
Verticillium wilt	*Verticillium dahliae*								X				X	X	
White mold	*Sclerotinia spp.*									X					

Table 4.4 Common diseases transmitted by insects and other arthropods to vegetable crops grown in Colorado.

Disease	Vector	Host
Viruses		
Alfalfa mosaic	Aphid; *Myzus persicae*, *Acyrthoshipon pisum* and others	Beans
Bean common mosaic	Aphids	Bean
Beet curly top virus	Leafhopper; *Circulifer tenellus*	Beet, spinach, tomato, squash, bean
Cucumber mosaic	Aphids: *Myzus persiciae*, *Aphis gossypii*, *A. fabae* and others	Cucumber
Iris yellow spot virus	Western flower thrips	Onion, garlic
Lettuce necrotic yellows	Aphid; *Hyperomyzus lactucae*	Lettuce
Potato Y virus	Aphis	Potato, tomato,
Sugar beet yellows	Aphid; *M. persicae*	lettuce, spinach
Tomato spotted wilt virus	Thrips, *Thrips frankiniella*	Tomato
Wheat streak mosaic	Eriophyiid mite; *Eriophyes tulipae*	Corn, wheat
Mollicute diseases (phytoplasms)		
Aster yellows	Leaf hopper; several spp.	Celery, squash, cucumber, carrot, lettuce
Toxin responses		
Psyllid yellows	Potato psyllid *Paratrioza cockerelii*	Solanaceous crops
Bacterial diseases		
Cucumber wilt (bacterial wilt)	Cucumber beetle; *Acalymma vittatum, Diabrotica undeimpunctata, D. balteata,*	Cucurbits
Various bacterial rot associates	Root maggots	Various

Sources: Borrer, 1989; Cranshaw, 2004; Davidson, 1979.

Pest management options

Insect management options—cultural practices

Cultural practices that disrupt the survival or success of pest species are among the oldest management methods and require a good understanding of the crop, pest, and natural enemy interactions. Crop rotation, good soil fertility, and diversification of crop species provide the foundation of a healthy cropping system that breaks the cycle of pests and diseases, and strengthen the defenses of crops.

Cultural practices are preventative measures including:

- Rotation of plant families
- Establishment of habitat for beneficial organisms
- Use of trap crops
- Use of mulches
- Exclusion of pests
- Sanitation (mowing and removal of pest host plants and/or pest harboring sites)
- Use of clean seed
- Appropriate cultivation, irrigation, and soil fertility

Crop rotation is fundamental for organic soil fertility and disease management since it interrupts insect and disease life cycles that overlap from crop to crop and season to season. For example, corn rootworm beetle is easily managed by rotating fields out of corn. Many soil-borne diseases have obligate crop hosts, and are unable to survive without them. A **diversity** of species and cultivars that are sequentially planted help disrupt pest and disease life cycles on the small organic farm.

The integration of green manures and cover crops provide ideal habitat for a variety of predators and parasites and reduce the opportunity for large populations of pests to develop, as occurs in large monocrop plantings. **Intercropping** and/or planting **beneficial insect habitat,** where predators and parasites are provided with nectar and pollen unavailable in the crop, is an efficient way to attract and **conserve natural enemies**. The variety of plants that offer excellent nectar and pollen sources for predaceous and parasitic arthropods is great; a few commonly used and easily integrated species are listed in Table 4.5. The umbelliferus (carrot, dill, cilantro, parsley) species are especially well recognized to provide excellent nectar and pollen sources for a wide range of parasitic wasps, predaceous syrphid flies, and lacewings.

Table 4.5. Commonly grown plants that are easily integrated into cropping systems providing nectar and pollen for beneficial insects .

Common name	Scientific name
Common yarrow	*Achillea filipendulina*
Dill	*Anethum graveolens*
Chamomile	*Anthemis tinctoria*
Cilantro (coriander)	*Coriandrum sativum*
Fennel	*Foeniculum vulgare*
Sweet alyssum	*Labularia maritima*
Sunflower	*Helianthus annuus*

Permanent planting of grass strips known as "**beetle banks**" in and around the field provides important habitat and cover for predaceous ground beetles that do not thrive in cultivated lands. Interplanting of crops also masks and disrupts contiguous cues used by insects for finding their preferred hosts. Cole crops interplanted with potato, for example, are less susceptible to diamondback moth and crucifer flea beetle (Altieri and Letourneau, 1982).

Trap crops are used to preferentially attract pests away from crops (for example, the flea beetle is attracted to radishes) where they can be killed with targeted pesticide applications or allowed to feed instead of on other crops. Maintaining alfalfa strips will provide preferred habitat for the occasional false chinch bug outbreaks in Colorado which may otherwise attack a wide range of crops. Alfalfa allowed to flower is a favored host of blister beetles, whose larva prey on grasshopper egg pods. Another successful **trap/banker** method used on the Inch by Inch Farm (Fort Collins, CO) was to grow an early sacrificial lettuce planting that was reliably infested with high populations of aphids. The aphids in turn attracted convergent ladybird beetles as they emerged from the foothills in the spring, establishing an excellent bank of predators for the remainder of the season.

The **destruction of overwintering sites** is important for reducing subsequent pest populations. For example, cucumber beetle adults overwinter in squash cull piles and other squash plant litter left in the field. Grant Family Farms (Wellington, CO) has found that **midwinter discing** exposes and kills overwintering adults very effectively. Leaf hoppers that overwinter on growing grasses can be reduced by **low mowing** of grasses in border lands in the late fall.

Mulches, both plastic and organic, provide cover for the squash bug. The soil moisture conservation and weed control provided by mulches are trade-offs in this respect. However, bright straw mulches have been found to reduce thrips damage on onion in Colorado, presumably by providing cover for thrips predators (Gent et al., 2006; Schwartz, 2006).

Exclusion of pests offers protection from disease vectors as well as the direct damage caused by some pests. In Colorado, feeding by flea beetles and cucumber beetles often reduce or wipe-out direct-seeded brassicas and cucurbits respectively. **Floating row** covers applied before direct-seeded crops emerge or directly after transplanting provide very good protection from

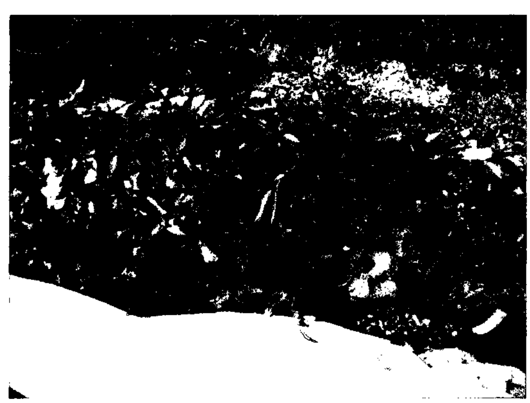


Figure 4.1 Weeds flourish under uncultivated floating row cover. Here, broccoli was direct-seeded and covered to avoid attack from flea beetle. (Photo by Stonaker, CSU HFRC, 2005.)

these insects, as well as from egg-laying lepidopterans (moths and butterflies). Direct-seeding into bare soil and covering with floating row covers, however, present a significant challenge for subsequent weed management. Weeds flourish under the cover, and removal of the cover for cultivation is time-consuming and exposes the seedling crop to the previously excluded pests (Figure 4.1). The use of mulch to eliminate the weed emergence under the floating row cover is one solution, and the use of larger transplants that will compete with the weeds until they are large enough to survive herbivory is an alternative to the use of floating row cover. The cost of floating row covers, and their application and removal must be economically justified.

The use of **high tunnels** covered with insect screening provides excellent exclusion of disease-vectoring potato psyllids and cucumber beetles, allowing good production of tomatoes, melons, cucumbers, and greens that are normally subject to attack along the front range of Colorado. Additionally, a degree of frost protection and hail protection is afforded (Stonaker, 2007).

Insect biocontrol

Conservation of natural enemies is perhaps the easiest and most obvious solution to many insect pest problems. Pests native to this region are well counter-balanced by a diverse group of natural enemies and if allowed to survive provide a high degree of control. As Carl Huffacker wrote "when we kill the natural enemies, we inherit their work." Conversely, when we enhance the environment with beneficial habitat, natural enemies take care of much of that work. The small, organic vegetable farm is well suited for successful biological control of many pests because of the diversity of crops commonly grown and the simple integration of additional flowering nectar and pollen sources critical for many species of predators and parasites alike. The diversity inherent in this system reduces the probable need for augmentative releases of beneficial organisms.

Biological control of arthropods includes the use of predaceous and parasitic arthropods and nematodes, entomopathogens (fungi, bacteria, and viruses that attack insects), as well as vertebrates that prey on insects (a list of many common biocontrol agents is found in Table 4.6). Many biocontrol agents--especially the parasites--are highly specialized, parasitizing only one or perhaps a few species in the same family of insects, and have evolved to survive in the environment in which their hosts live. They also tend to attack specific stages of development in the target. Many predators are less specific opportunists, and are termed "generalists" because they prey on a wide variety of arthropods and/or life stages.

Entomopathogens are generally applied in agronomic and horticultural arenas as biopesticides; they are discussed in the section on organic pesticides. Biocontrol in this section is limited to discussion of the macro-organisms, with the exception of predaceous nematodes.

Of the common arthropod pests listed in Table 4.1, all are endemic in Colorado, and to some extent are subject to naturally occurring biological control. The degree of control provided needs to be monitored to insure that pest damage remains below acceptable levels. As stated earlier, it is difficult to determine action thresholds for pest management action in diverse cropping systems with a multitude of variables that impact both pest population growth rates and the efficacy of natural enemies. Knowing when biological control is providing sufficient control is an art; it requires good observational skills and knowledge of pest and natural enemy life cycles and interactions.

Broccoli is an example of a crop with numerous pests and management options that integrate biocontrol, cultural management, and biopesticides. Broccoli is transplanted rather than direct-seeded in Colorado because Western black flea beetles will kill young seedlings (especially in the early summer). Biological control impacts on flea beetles are not well known, but presumably predaceous nematodes, rove beetles and predaceous mites exert pressure on the soil-dwelling larvae. Nevertheless, populations of flea beetles reliably cause significant injury to cole crop seedlings. During subsequent development, broccoli is grazed by caterpillars (imported cabbage butterfly, diamond back moth, cabbage looper), is often attacked by aphids (cabbage aphid), and occasionally harlequin stink bug. All lepidopteran eggs are subject to egg parasites and generalist predators, but, these alone generally do not provide sufficient control and it is common to see several caterpillars feeding on unsprayed broccoli at any given time.

There are a variety of larval parasites and predaceous bugs that attack caterpillars on broccoli. In some years, the European paper wasp will be seen patrolling cole crops, providing complete caterpillar control. Later in the season, when parasitic wasps and predaceous syrphids and midges are less active, cabbage aphids occasionally build to damaging levels. In the absence of sufficient predaceous wasps, supplemental control of caterpillars such as application of *Bacillus thuringiensis (B.t.)* is likely to be required during head formation. Otherwise this very "buggy" crop is suitable for growing using biological control of pests almost exclusively. Regular scouting easily establishes the need for additional control efforts during the critical head-forming stage of broccoli.

Provision for European paper wasp nesting sites in or near the broccoli fields has been experimented with by Whitney Cranshaw at CSU. Helen Atthowe in Montana found that preservation of natural enemies of the imported cabbage butterfly by spraying *B.t.*, or not spraying at all, resulted in marketable broccoli levels at 88% (Atthowe, 2007).

Of the pests reported in the farmer survey, flea beetle, cucumber beetle, and squash bug are among the most challenging for growers to control. None of these insects are adequately controlled with natural enemies, so the damage is either tolerated or pesticide applications are used. The choice of pesticides used, and when and how frequently they are applied, will impact natural enemies that may be providing control of other pests in the crop.

Transplants grown in greenhouses may be infested with insects (such as whitefly and some mite species) that are not generally problems in field production, so their primary complement of natural enemies may not be present in the field without introduction. Because most pests are challenged by a wide array of naturally occurring enemies augmentative (adding more natural enemies to the environment) or innundative (flooding the environment with natural enemies) introductions are seldom used in the field. However, transplants grown in the greenhouse are often good candidates for either augmentative or innundative introductions of biocontrol agents.

It is important for the practitioner to understand that biological control may produce excellent results; however, many environmental and cultural limitations may render the degree of control unsatisfactory. Biocontrol requires patience and attention, and when it fails to yield the desired results the grower should be prepared to take more aggressive actions, including the use of pesticides which may aid or hinder subsequent biological control. The number of natural enemies exerting pressure on arthropod pests of vegetables is impressive. A summary list of these families is in the following tables (Tables 4.6– 4.12).

Table 4.6 Natural enemies of pests in Colorado

Order/ Family	*Common name*	Order/ Family	*Common name*
Coleoptera	*Beetles*	**Araneae**	*Spiders*
Coccinellidae	*Ladybird beetles*	Thomisidae	*Crab spiders*
Carabidae	*Ground beetles*	Salticidae	*Jumping spders*
Cantheridae	*Soldier beetles*	Lycosidae	*Wolf spiders*
Staphylinidae	*Rove beetles*	Tetragnathidae	*Orb-weaver spiders*
Lampyridae	*Fireflies*	Agelenidae	*Funnel weaver spiders*
Melyridae	*Collops beetles*		
		Opilones	*Daddy longlegs*
Neuroptera	*Lacewings*	Phalangida	
Chrysopidae	*Green lacewings*		
Hemerobiidae	*brown lacewings*	**Acari**	*mites*
		Phytoseiidae	*predatory mites*
Diptera	*Flies*		
Syrphidae	*Syrphid flies*	**Parasites**	
Cecidomyiidae	*Midges*	**Diptera**	*Flies*
Dolichopodidiae	*Long legged flies*	Tachinidae	*Tachinid flies*
Thysanoptera	*predatory thrips*	**Hymenoptera**	*Wasps*
		Braconidae	*Braconids*
Hemiptera	*Predatory bugs*	Ichneumonidae	*ichneumons*
Pentatomidae	*predatory stink bugs*	Aphidiidae	*Aphid parasites*
Reduviidae	*Assassin bugs*	Encyrtidae	*Encyrtids*
Nabidae	*Damsel bugs*	Chalcidae	*Chalcids*
Miridae	*Plant bugs*	Eulophidae	*Eulophids*
Lygaeidae	*Big eyed bugs*	Trichogrammatidae	
Anthocoridae	*Minute pirate bugs*		
		Entomopathogens	
Mantodea	*Mantids*	Viruses Polyhedrosis, Bacteria, Bacillus Fungi, Beuveria, Metarhizium	
Dermaptera	*Earwigs*		
Forficulidae			
Labiduridae		**Protozoa**	
		Nosema locustae	*Nosema locustae*
Hymenoptera	*Wasps and ants*		
Formicidae	*Ants*	**Nematodes**	
Vespidae	*Paper wasps, hornets, yellowjackets*	Steinernema	*entomopathogenic nematodes*
		Heterohabditis	*entomopathogenic nematodes*
Sphecidae	*Hunting wasps*		

Table 4.7 Plant-sucking vegetable pests in Colorado; their natural enemies and cultural practices used to manage them.

Common name	Scientific name	Ladybird beetles	Ground beetles	Lacewings	Syrphid flies	Predatory bugs	Vespid wasps	Midges	Predaceous mites	Parasitic flies and wasps	Egg parasites	Entomopathogens	Beneficial nematodes	Spiders	Floating row covers	Cultural practices and notes
APHIDS & OTHER SAP SUCKERS																
Bean aphid	*Aphis fabae*	X		X	X	X		X		X		X		X	X	
Cabbage aphid	*Brevicoryne brassicae*	X		X	X	X		X		X		X		X	X	
Green peach aphid	*Myzus persicae*	X		X	X	X		X		X		X		X	X	
Melon/cotton aphid	*Aphis gossypii*	X		X	X	X		X		X		X		X	X	
Pea aphid	*Acyrthosiphon pisum*	X		X	X	X		X		X		X		X	X	
Potato aphid	*Macrosiphum euphorbiae*	X		X	X	X		X		X		X		X	X	
Red lettuce aphid	*Nosonovia ribisnigri*	X		X	X	X		X		X		X		X	X	
Greenhouse whitefly	*Trialeurodes vaporariorum*	X		X	X	X		X		X		X		X	X	Buy or grow clean transplants
Aster leafhopper	*Macrosteles quadrilineatus*	X		X	X	X		X		X				X	X	
Beet leafhopper	*Eutettix tenellus*	X		X	X	X		X		X				X	X	
Potato/tomato psyllid	*Paratrioza cockerelli*	X		X	X	X		X		X				X	X	

Table 4.8 Beetle vegetable pests in Colorado; their natural enemies and cultural practices used to manage them.

Common name	Scientific name	Ladybird beetles	Ground beetles	Lacewings	Syrphid flies	Predatory bugs	Vespid wasps	Midges	Predaceous mites	Parasitic flies and wasps	Egg parasites	Entomopathogens	Beneficial nematodes	Spiders	Floating row covers	Cultural practices and notes
BEETLES																
Colorado potato beetle	*Leptinotarsa decimlineata*	X		X	X	X	X				X	X			X	
Cabbage flea beetle	*Phylotretta cruciferae*								X			X	X		X	Plant strong transplants, apply floating row cover immediately after planting. Plant radish trap crops.
Western black flea beetle	*Phylotretta pusilla*								X			X	X		X	
Pale striped flea beetle	*Systena blanda*								X			X	X		X	Plant strong transplants, apply floating row cover immediately after planting.
Potato flea beetle	*Epitrix cucumeris*						X		X			X	X		X	
Western striped flea beetle	*Phylotretta ramosa*								X			X	X		X	
Spinach flea beetle	*Disonycha xanthomelas*						X		X			X	X		X	Larval feeding damage may be confused with that of caterpillars.
Banded cucumber beetle	*Diabrotica balteata*		X							X	X		X		X	
Corn rootworm beetle	*Diabrotica virgifera virgifera*		X							X	X		X		X	
Spotted cucumber beetle	*Diabrotica undecimpunctata*		X							X	X		X		X	
Striped cucumber beetle	*Acalymma vittata*		X							X	X		X		X	
Mexican bean beetle	*Epilachna varivestis*	X		X	X		X			X	X				X	
Wireworms			X										X			Avoid planting susceptible crops on recently plowed sod.
Dusky sap beetle	*Carpophilus lugubris*		P						P				P			Destroy cull products, corn cultivars with good wrapper leaves (*P* denotes probable natural enemy).

Table 4.9 Hemipteran (true bugs) vegetable pests in Colorado; their natural enemies and cultural practices used to manage them.

Common name	Scientific name	Ladybird beetles	Ground beetles	Lacewings	Syrphid flies	Predatory bugs	Vespid wasps	Midges	Predaceous mites	Parasitic flies and wasps	Egg parasites	Entomopathogens	Beneficial nematodes	Spiders	Floating row covers	Cultural practices and notes
BUGS																
False chinch bug	*Nysius raphanus*			X										X	X	Provide alternative hosts such as alfalfa in June, when large populations peak. Floating row cover.
Harlequin stink bug	*Murgantia histrionica*			X		X				X	X			X	X	Floating row cover
Say's stink bug	*Chlorochroa sayi*			X		X				X	X			X	X	
Squash bug	*Anasa tristis*			X		X					X			X	X	Some cultivars offer a degree of resistance; avoid mulches if squash bug is a recurring problem. Floating row cover.

Table 4.10. Caterpillar vegetable pests in Colorado; their natural enemies and cultural practices used to manage them.

Common name	Scientific name	Ladybird beetles	Ground beetles	Lacewings	Syrphid flies	Predatory bugs	Vespid wasps	Midges	Predaceous mites	Parasitic flies and wasps	Egg parasites	Entomopathogens	Beneficial nematodes	Spiders	Floating row covers	Cultural practices and notes
CATERPILLARS																
Alfalfa looper	*Autographa californica*			X		X	X			X	X	X		X	X	
Army cutworm	*Euxoa auxiliaris*		X	X		X	X			X	X	X	X	X		
Beet armyworm	*Spodoptera frugiperda*		X	X		X	X			X	X	X		X		
Black cutworm	*Agrotis ipsilon*		X	X		X	X			X	X	X	X	X		
Cabbage looper	*Trichoplusia ni*			X		X	X			X	X	X		X	X	
Corn earworm	*Helicoverpa zea*			X		X	X			X	X	X		X		
Diamondback moth	*Plutella xylostella*			X		X	X			X	X	X		X	X	
Dingy cutworm	*Feltia spp.*		X	X		X	X			X	X	X	X	X		
European corn borer	*Ostrinia nubilalis*		X	X		X				X	X	X		X		
Imported cabbage butterfly	*Pieris rapae*			X		X	X			X	X	X		X	X	
Tomato hornworm	*Manduca sexta*			X		X	X			X	X	X			X	
Variegated cutworm	*Peridroma saucia*		X	X		X	X			X	X	X	X	X		

Table 4.11. Earwig, fly, and grasshopper vegetable pests in Colorado; their natural enemies and cultural practices used to manage them.

Common name	Scientific name	Ladybird beetles	Ground beetles	Lacewings	Syrphid flies	Predatory bugs	Vespid wasps	Midges	Predaceous mites	Parasitic flies and wasps	Egg parasites	Entomopathogens	Beneficial nematodes	Spiders	Floating row covers	Cultural practices and notes
EARWIGS																
European earwig	*Forficula auricularia*		X						X				X	X		Pit trap with soy sauce and oil, or in rolled up paper or cardboard.
FLIES																
Serpentine leaf miner	*Liriomyza sativae*									X				X	X	
Spinach and beet leafminer	*Pegomya hyscyami, P. betae*		X						X				X	X	X	
Seed corn maggot	*Delia platura*		X						X				X	X		Avoid planting large seeded crops in cool soil immediately after plow down of green manures or heavy application of manures.
GRASSHOPPERS																
Differential grasshopper	*Melanopus differntialis*		X									X			X	Avoid planting adjacent to undisturbed weedy land where grasshoppers lay eggs. Turkeys and Guinea fowl are excellent grasshopper predators.
Migratory grasshopper	*Melanopus sanguinipes*		X									X			X	
Redlegged grasshopper	*Melanopus femurrubrum*		X									X			X	

Table 4.12. Mites, slugs, and thrips vegetable pests in Colorado; their natural enemies and cultural practices used to manage them.

Common name	Scientific name	ladybird beetles	ground beetles	lacewings	syrphid flies	predatory bugs	vespid wasps	midges	predaceous mites	parasitic flies and wasps	egg parasites	entomopathogens	beneficial nematodes	spiders	floating row covers	cultural practices and notes
MITES																
Two-spotted spider mite	*Tetranychus urticae*	X		X		X		X	X							Overhead irrigation or strong blast of water.
SLUGS																
Garden slug	*Deroceras reticulatum*		X						X	X			X			Avoid heavy, moist mulches. Ducks are good predators of snails and slugs.
THRIPS																
Onion thrips	*Thrips tabaci*	X	X	X	X	X		X	X			X	X	X	X	Use bright straw mulch
Western flower thrips	*Frankliniella occidentalis*	X	X	X	X	X		X	X			X	X	X	X	

Pesticides

A subset of registered pesticides is allowed in organic production. The use of these materials falls within the broader IPM approach applied in organic pest management that includes judicious use of pesticides. Ideally, appropriate cultural practices and conservation and enhancement of the environment to encourage healthy crop production suffice. The use of pesticides is generally considered to be a last line of defense only to be used when other options fail to provide the required level of control. It is generally agreed that optimizing agricultural productivity often requires some crop protection technology, i.e., use of pesticides. It should be noted that many of the organically allowed pesticides are broad-spectrum pesticides that impact beneficial organisms as well as pests, and repeated use can have deleterious effects on biocontrol efforts.

All pesticides, organic or not, undergo regulatory evaluation by the U.S. Environmental Protection Agency registration approval process, which, among other things, evaluates certain environmental impacts and health and safety issues. Pesticide use in certified organic fields is limited by regulations of the USDA National Organic Program (NOP). The NOP National List of Allowed and Prohibited Substances (USDA, 2002a) includes both synthetic and non-synthetic materials. A list of types of materials and biological formulations that are allowed and commonly used for pest and disease management is presented in Table 4.13. A complete list of allowed materials is available on the USDA/NOP National List of Allowed and Prohibited Substances and the Organic Materials Review Institute (OMRI) websites (Organic Materials Research Institute, 2008; USDA, 2008).

OMRI is an independent organization and serves as the Technical Advisory Board (TAB) to the National Organic Standards Board (NOSB) which evaluates materials submitted for allowance under the NOP rules. The list of products that OMRI certifies and publishes is the defacto approval that most producers use when considering whether or not to apply a product. This is not to say that *only* OMRI certified materials are allowed under NOP rules. As of December 2008, OMRI listed 333 "crop, pest, weed and disease control" products that may be used on certified organic land. Regulated materials may only be used under certain circumstances, and only after preferred methods were used and documented in the organic certification farm plan. Prohibited materials may not be used within three years of certification. OMRI ratings are based largely on origin of material rather than safety profiles or environmental impacts (Cleveland, 2007), which is a topic of concern and continued debate.

The main categories of insecticides and miticides, are described below.

Entomopathogens

This group of insecticides includes formulations containing insect pathogens. They are generally applied as a pesticide in sprays.

- *Bacillus thuringiensis (B.t.)* is a widely used bacterium which, when ingested, releases a toxin that kills the pest. There are many strains of *B.t.* that are toxic to specific orders or sometimes species of pests. For example, *B.t. var. kurstaki* and *B.t. var. aizawai* are toxic to lepidopteran larvae, and *B.t. israelensis* is toxic to certain dipterans (mosquitoes, flies, and gnats). Transgenic *B.t.* products are not OMRI listed (for example, transgenic strains of *B.t. var San Diego* and *B.t. var. tenebrionis).*
- Other entomopathogens include fungi such as *Beauveria bassiana*, which has a broad host range and is infective topically.
- Protozoans such as *Nosema locusta* is used against grass hoppers and crickets.
- Viruses such as nuclear polyhedrosis virus (NPV) is used against corn earworm and beet armyworm. Granulosis virus is used against codling moth.

Botanically derived pesticides include products that are either "allowed" or "restricted" by NOSB depending upon how they are manufactured and other ingredients in the product.

Natural pyrethrum and pyrethrins derived from chrysanthemum are allowed and are toxic to a wide range of insects. These have no PBO (piperonyl butoxide) synergist added. Products containing a combination of pyrethrum and other ingredients (including soaps) fall into the restricted class.

Non-synthetic oils are used on a wide range of insects. These oils are derived from fish and plant seeds and include fish, neem (without insecticidal azadirachtin), garlic, soybean, cottonseed, canola, and jojoba oils. They act on insects by breaking down the cuticle, blocking respiratory function, and suffocating eggs. Stylet oils also inhibit virus transmission by aphids (Davidson et al., 1991).

Synthetic mineral oils, derived from petroleum sources, are used primarily as dormant oils (applied to tree crops when leafless). However, they also act on mites, aphids, leafhoppers, and mealybugs in the ways described for non-synthetic oils above. Stylet oils also inhibit virus transmission by aphids (Davidson et al., 1991). Both synthetic and non-synthetic oils are often used as adjuvants to improve the efficacy of other pesticide solutions, even though they act as pesticides themselves.

Soaps are potassium salts of fatty acids and are used on a wide range of pests, especially soft-bodied insects such as aphids. Activity includes the break-down of cuticle and blockage of respiratory organs.

Spinosad is derived from a soil actinomycete that produces insecticidal spynosin. It is used primarily to control thrips, caterpillars, and some beetles.

Mineral dusts include sulfur, diatomaceous earth, and kaolin clay and are used against a variety of insects. Sulfur is used against psyllids and mites, but also has fungicidal and bactericidal properties. Diatomaceous earth is an abrasive that desiccates insects. Kaolin is used as a repellent and visual and tactile deterrent to a variety of pests.

Pheromones are used for mating disruption by confusing male insects searching for mates; aggregation pheromones are used to attract insects into a poison bait or other trap.

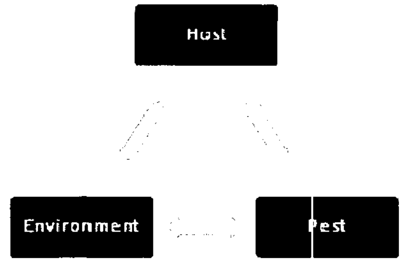
Table 4.13 Common organic pesticides used to control vegetable pests

Common name	Scientific name	Bacillus thurengiensis (B.t.)	B.t. San Diego	Beauveria bassiana	Nosema locustae	Diatomaceous earth + pyrethrins	Insecticidal oils	Insecticidal soaps	Iron phosphate (sluggo)	Kaolin clay	Neem oil	Pyrethrum (cube)	Spinosad	Sulfur
APHIDS & OTHER SAP SUCKERS														
Bean aphid	*Aphis fabae*			X		X		X			X	X		
Cabbage aphid	*Brevicoryne brassicae*			X		X		X			X	X		
Green peach aphid	*Myzus persicae*			X		X		X			X	X		
Melon/cotton aphid	*Aphis gossypii*			X		X		X			X	X		
Pea aphid	*Acyrthosiphon pisum*			X		X		X			X	X		
Potato aphid	*Macrosiphum euphorbiae*			X		X		X			X	X		
Red lettuce aphid	*Nosonovia ribisnigri*			X		X		X			X	X		
Greenhouse whitefly	*Trialeurodes vaporariorum*					X		X				X		
Aster leafhopper	*Macrosteles quadrilineatus*					X		X		X		X		
Beet leafhopper	*Eutettix tenellus*					X		X		X		X		
Potato/tomato psyllid	*Paratrioza cockerelli*					X		X			X	X	X	X
BEETLES														
Colorado potato beetle	*Leptinotarsa decimlineata*		X	X		X					X	X	X	
Cabbage flea beetle	*Phylotretta cruciferae*					X					X	X	X	
Pale striped flea beetle	*Systena blanda*					X					X	X	X	
Potato flea beetle	*Epitrix cucumeris*					X					X	X	X	
Western black flea beetle	*Phylotretta pusilla*					X					X	X	X	
Western striped flea beetle	*Phylotretta ramosa*					X					X	X	X	
Spinach flea beetle	*Disonycha xanthomelas*					X					X	X	X	
Banded cucumber beetle	*Diabrotica balteata*					X						X		
Wetern corn rootworm	*Diabrotica virgifera*					X				X		X		
Spotted cucumber beetle	*Diabrotica undecimpunctata*					X				X		X		
Striped cucumber beetle	*Acalymma vittata*					X				X		X		
Mexican bean beetle	*Epilachna varivestis*					X						X		
Wireworms														
Dusky sap beetle	*Carpophilus lugubris*											X		
BUGS														
False chinch bug	*Nysius raphanus*											X		
Harlequin stink bug	*Murgantia histrionica*					X								
Say's stink bug	*Chlorochroa sayi*					X								
Squash bug	*Anasa tristis*					X								

Table 4.13 continued.

Common name	Scientific name	Bacillus thurengiensis (B.t.)	B.t. San Diego	Beauveria bassiana	Nosema locustae	Diatomaceous earth + pyrethrins	Insecticidal oils	Insecticidal soaps	Iron phosphate (sluggo)	Kaolin clay	Neem oil	Pyrethrum (cube)	Spinosad	Sulfur
CATERPILLARS														
Alfalfa looper	*Autographa californica*	X				X							X	
Army cutworm	*Euxoa auxiliaris*	X				X							X	
Beet armyworm	*Spodoptera frugiperda*	X				X							X	
Black cutworm	*Agrotis ipsilon*	X				X							X	
Cabbage looper	*Trichoplusia ni*	X				X							X	
Corn earworm	*Helicoverpa zea*	X				X							X	
Diamondback moth	*Plutella xylostella*	X				X							X	
Dingy cutworm	*Feltia spp.*	X				X							X	
European corn borer	*Ostrinia nubilalis*	X				X							X	
Imported cabbage butterfly	*Pieris rapae*	X				X							X	
Tobacco hornworm	*Manduca sexta*	X				X							X	
Tomato hornworm	*Manduca*	X				X							X	
Variegated cutworm	*Peridroma saucia*	X				X							X	
EARWIGS														
European earwig	*Forficula auricularia*							X				X		
FLIES														
Serpentine leaf miner	*Liriomyza sativae*					X	X	X				X	X	
Spinach and beet leafminer	*Pegomya hyscyami, P.*					X	X	X				X	X	
Seed corn maggot	*Delia platura*													
GRASSHOPPERS														
Differential grasshopper	*Melanopus differntialis*				X							X		
Migratory grasshopper	*Melanopus sanguinipes*				X							X		
Redlegged grasshopper	*M. femurrubrum*				X							X		
MITES														
Two-spotted spider mite	*Tetranychus urticae*					X	X	X			X			X
SLUGS														
Garden slug	*Deroceras reticulatum*								X					
THRIPS														
Onion thrips	*Thrips tabaci*			X		X		X		X	X	X	X	
Western flower thrips	*Frankliniella*			X		X		X		X	X	X	X	

Management options for disease control



Avoiding disease problems begins with a comprehensive approach to disease management. Plant pathologists commonly use the "disease triangle" to identify the three critical components in disease management. The triangle consists of interacting aspects involved in plant disease: the host, environment, and pest. In Colorado, our dry climate reduces many of the challenges that other parts of the country must contend with, but the fundamentals are the same.

Starting with disease-resistant cultivars of plants reduces the opportunity for the disease to increase, and reduces the opportunity for inoculum loads to build up in the field. Planting into soil that is not loaded with disease inoculum and providing the crop with proper nutrition and water, thus reducing stress, are all important aspects in disease management.

High density plantings that trap moisture and reduce air movement provide a good environment for disease organisms to survive. Adjusting crop density and irrigation frequency are techniques that keep leaves drier and reduce the likelihood of many diseases. Using certified, disease-free seed and clean transplant stock are obvious but often overlooked details. Additionally, the value of minimizing transplant shock and getting plants off to a healthy start cannot be overstated in avoiding disease.

Harvest and post-harvest handling present another set of opportunities for a beautifully grown crop to go to waste. Careful handling to reduce bruising, puncturing, abrading, or other abuse reduces the chance of bacterial infection. Clean boxes, clean wash water, and appropriate storage temperatures and humidity help insure that the crop is delivered in peak condition.

Small-scale growers practicing intensive production may not be able to rotate families of crops out of the same field frequently enough to break disease cycles that persist on a wide range of hosts. In such cases, reliance on disease resistance becomes more important. Also, by increasing the biodiversity of the rhizosphere, through application of composts and incorporation of organic material, pathogenic organisms will be challenged by beneficial organisms. It is well established that composts are an excellent source of phytopathogen antagonists. Additional beneficial fungi and bacteria are introduced by some growers; however the benefit is probably nominal relative to what a healthy soil contains. Specific examples of disease management tools are listed in Table 4.14.

Table 4.14 Disease management options for organic vegetable growers.

																Management options		Pesticides (biological)								Pesticides (mineral)				
Disease	Cause	Onion and other Alliums	Cole crops	Beet	Chard	Spinach	Cucurbits	Sweet corn	Lettuce	Beans	Peas	Pepper	Tomato	Eggplant	Potato	Use resistant varieties	Cultural management	*Ampelomyces quisqualis (AQ10)*	*Bacillus subtilis*	*Bacillus pumilus*	*Burkholderia cepacia*	*Coniothyrium minitans*	*Gliocaldium spp.*	*Streptomyces lydicus*	*Trichoderma harzianum*	Bicarbonates	Copper materials	Oils	Peroxides	Sulfur materials
Alternaria leaf spot	*Alterneria spp.*		X				X										Use disease-free seed		X					x		X	X	X	X	
Angular leaf spot	*Pseudomonas spp.*						X									X											X	X	X	
Anthracnose	*Colletotrichum spp.*						X			X		X	X	X			Use disease-free seed, do not cultivate when wet										X	X	X	X
Aster yellows	Virus								X								Exlude leafhopper vectors													
Bacterial blight	*Xanthomonas spp.*							X		X							Rotate out of crop for 3 years		X								X	X		
Bacterial brown spot	*Pseudomonas syringae* pv. syringae									X							Rotate out of crop for 3 years										X			
Bacterial speck	*Pseudomonas syringae*																		X										X	
Bacterial spot	*Xanthomonas spp.*											X	X			X	Hot-water treat seed, long rotation		X								X	X	X	X
Beet curly top virus	Virus			x	x	x	X						x				Exclude leafhopper vectors													
Big vein	Mirafiori lettuce virus								X							X	Crop rotation is not effective													
Black leg	*Phoma lingam*		X														Hot-water treat seed, long rotation													
Black rot	*Alterneria spp.*, *Xanthomonas spp.*		X				X									X	Crop rotation, weed management, disease-free seed		X								X			
Botrytis	*Botryts spp.*	x							x	x			x				Minimize physical damage to plants, harvest alliums when dry, cure well before storage.		X				X	x	X	X	X	X	X	
Cucumber mosaic virus	Virus			X	X	X	X			X		X	X		X	X	Exclude aphid vectors													
Damping off	*Fungi and Bacteria complex*			X	X		X			X	X	X	X	X			Avoid planting in cool wet conditions				X			X						
Downy mildew	*Peronospora spp.*, *Pseudoperonospora spp.*, *Bremia spp.*	X	X	X	X	X	X		X							X			X	X				x		X	X	X	X	
Early blight	*Alterneria spp.*												X		X		Bury cull potatoes		X	X							X	X	X	
Fusarium wilt	*Fusarium spp.*		X				X				X		X			X	Avoid planting susceptible families in infected ground for several years				x		X	x	X				X	
Gray mold	*Botryts spp.*																Harvest dry, sound fruit		X											
Gummy stem blight	*Didymella bryoniae, Phoma spp.*						X									X	Use disease-free seed		X								X			

Table 4.14 Disease management options for organic vegetable growers (continued).

																Management options		Pesticides (biological)								Pesticides (mineral)				
Disease	Cause	Onion and other Alliums	Cole crops	Beet	Chard	Spinach	Cucurbits	Sweet corn	Lettuce	Beans	Peas	Pepper	Tomato	Eggplant	Potato	Use resistant varieties	Cultural management	*Ampelomyces quisqualis (AQ10)*	*Bacillus subtilis*	*Bacillus pumilus*	*Burkholderia cepacia*	*Coniothyrium minitans*	*Gliocaldium spp.*	*Streptomyces lydicus*	*Trichoderma harzianum*	Bicarbonates	Copper materials	Oils	Peroxides	Sulfur materials
Halo Blight	*Pseudomonas syringae* pv. *Phaseolicola*									X							Rotate out of crop for 3 years										X			
High Plains Disease	Virus							X									Control grass hosts of wheat curl mite (*Aceria tosciella*) before crop emerges													
Iris yellow streak virus	Virus	X															Exclude *Thrips tabaci*, maintain good fertility and avoid stress													
Late blight	*Phytophthora spp.*												X		X		Bury cull potatoes, provide good drainage, allow field to dry between irrigations		X	X				x			X	X	X	
Lettuce drop	Sclerotinia spp.								X								Crop rotation, deep plowing, raised beds, avoid alternative hosts		X			X		x					X	
Mosaic	Virus						X		X	X		X	X			X	Exclude insect vectors													
Pink rot	*Phoma spp.*	X															Long rotation, flood 4-8 weeks		X											
Powdery mildew	*Erysiphe polygoni, Sphaerotheca spp.*				X		X			X	X					X		X	X	X				x		X	X		X	X
Psyllid yellows	Virus												X		X		Exclude psyllids													x
Purple blotch	*Alternaria porri, Stemphylium vesicarium*	X																	X								X			

Table 4.14 Disease management options for organic vegetable growers (continued).

Disease	Cause	Onion and other Alliums	Cole crops	Beet	Chard	Spinach	Cucurbits	Sweet corn	Lettuce	Beans	Peas	Pepper	Tomato	Eggplant	Potato	Management options		Pesticides (biological)								Pesticides (mineral)				
																Use resistant varieties	Cultural management	*Ampelomyces quisqualis (AQ10)*	*Bacillus subtilis*	*Bacillus pumilus*	*Burkholderia cepacia*	*Coniothyrium minitans*	*Gliocladium spp.*	*Streptomyces lydicus*	*Trichoderma harzianum*	Bicarbonates	Copper materials	Oils	Peroxides	Sulfur materials
Rust	*Puccinia spp., Uromyces spp.*					X				X						x	Crop rotation 2+ years, bury residue, dry foliage after irrigation, before evening.		X	X								X	X	X
Seed rot	Bacterial and fungal complexes						X	X		X	X						Avoid planting into cold wet soils													
Smut	*Ustilago maydis*	X						X								X														
Soft rots	*Erwinia spp., Pseudomonas spp., Enterobacter spp.*	X															Avoid overhead irrigation after bulbing. Dry and cure quickly before storage													
Sudden wilt	*Acremonium spp., Pythium spp. Rhizopycnis spp.*						X										Exclude cucumber beetle vectors				x			x					X	
Target speck	*Corynespora cassiicola*																		X											
Tipburn	Calcium deficiency								X							X	Avoid moisture stress													
Tobacco mosaic virus	Virus															X	Mechanical transmission is easy;, tobacco users can transmit this virus													
Tomato spotted wilt virus	Virus	X										X	X	X		X	Exclude thrips													
Verticillium wilt	*Verticillium dahliae*								X				X	X		X	Long rotation							x						
White mold	*Sclerotinia spp.*									X							See above		X			X							X	

Management options- resistance

Plant resistance to pests and diseases is most often associated with disease management; however, resistance to insect pests is an objective of many plant breeding efforts (Eigenbrode and Trumble, 1994; Khush and Brar, 1991; Selvanarayanan and Narayanasamy, 2006; Srinivasan and Uthamasamy, 2005). With the advent of transgenic engineering, much of the focus has been on engineering crop genomes that exhibit insect toxins (such as *B.t.* toxins). Since the use of genetically engineered organisms is strictly prohibited in organic production, breeding efforts for disease and insect resistance continue to follow classical breeding techniques.

Plant resistance is especially important for managing insect-borne diseases because disease transmission may only require a brief feeding exposure. Very low densities of disease vectoring insects can have significant impacts, and are the subject of important resistance breeding research.

Physical characteristics or chemical cues may serve as deterrents to insect vectors of disease. These include a high density of tricombs, very pubescent leaves, or semiochemicals that deter or repel potential herbivores.

There are varying degrees of resistance or tolerance expressed by plants to pests, and these may provide enough protection for the crop to survive and produce a reasonable crop. Scientific literature may show statistically significant differences in the susceptibility of a specific plant cultivar to attack or to an insect-borne disease, but translation of those results to business decisions may be problematic if profit margins tight.

Seed catalogues generally list disease resistance for specific strains or races of disease. Development of resistance in the tomato to a number of common diseases is noteworthy. Big Beef tomato, for example, is listed in the Cornell Tomato Disease resistance table as being resistant to:

Alternaria stem canker, Fusarium wilt races 1 and 2, root knot nematodes, Stemphylium, tobacco mosaic virus, tomato mosaic virus, and verticillium wilt races 1 and 2 (Zitter and Mcgrath, 2006).

Resistance to one race may provide no resistance to the next. New races of the same disease continue to emerge in response to narrow, selective, vertical resistance breeding that identifies and relies on resistance exhibited by a single gene that disables the pathogen or herbivore. However, when the pathogen evolves an alternative pathway around that single gene defense, the resistance is lost. Horizontal resistance is more commonly found in nature and is derived from many genes working in unison, developing "good constitution" (Navazio, 2002). This form of resistance is durable and less susceptible to single mutations that allow a pathogen to bypass a single gene line of defense. Horizontal disease resistance is promoted by organic plant breeders as a more comprehensive and holistic approach (Robinson, 1995).

Grafting provides another option for disease resistance. Grafting rootstock of disease-resistant lines of tomatoes, eggplant, and cucurbits is commercially available. The technique is widely used in commercial greenhouse vegetable production elsewhere in the world, and is becoming a more common practice in the US for high value crops. Most uses are against fungal and bacterial diseases (King et al., 2008), but resistant rootstock is also used for prevention of some viruses (Rivero, 2003), nematodes (Giannakou and Karpouzas, 2003, Siguenza et al., 2005, Ioannou, 2001), and spider mites (Edelstein et al., 2000). Table 4.15 presents an array of resistances to diseases, nematodes and mites provided by grafting.

Table 4.15 Vegetable crops and diseases, nematodes and mites controlled by grafting.

Crop	Disease	Organism
Cucumber	Fusarium wilt	*Fusarium oxysporum*
	Phytopthora blight	*Phytopthora capsici*
	Root-knot nematodes	*Meloidogyne spp.*
	Verticillium wilt	*Verticillium dahliae*
	Target leaf spot	*Corynespora cassicola*
	Black root rot	*Phomopsis sclerotiodes*
	Melon Fusarium wilt	*Fusarium oxysporum*
	Vine decline	*Monosporascus cannonballus*
	Root-knot nematodes	*Meloidogyne spp.*
	Gummy stem blight	*Didymela bryoniae*
	Verticillium wilt	*Verticillium dahliae*
	Black root rot	*Phomopsis sclerotiodes*
Cucurbita sp.	Spider mites	*Tetranychus cinnabarinus*
Watermelon	Fusarium wilt	*Fusarium oxysporum*
	Root-knot nematodes	*Meloidogyne spp.*
	Verticillium wilt	*Verticillium dahliae*
	Virus complexes	*CMV, ZYMV, PRSV, WMV-II*
Eggplant	Verticillium wilt	*Verticillium dahliae*
	Corky root	*Pyrenochaeta lycopersici*
	Root-knot nematodes	*Meloidogyne spp.*
Tomato	Bacterial wilt	*Ralstonia solanacearum*
	Fusarium wilt	*Fusarium oxysporum*
	Corky root	*Pyrenochaeta lycopersici*
	Root-knot nematodes	*Meloidogyne spp.*
	Verticillium wilt	*Verticillium dahliae*
	Tomato yellow leaf curl	*ToYLCV*

Source: (King et al., 2008)

Disease biocontrol

Biological control of diseases has received a great deal of attention in the last several years, particularly due to the prohibition of the soil fumigant methyl bromide. Biological control targeting soil-borne diseases includes the use of bacteria and fungi that compete with, antagonize, displace, prey upon and kill pathogenic organisms, or induce host resistance. A few of the myriad organisms involved in natural control of phytopathogens have been identified and successfully formulated for use as biocontrol agents of diseases (Friberg et al., 2005). Included are bacteria of the genera *Bacillus, Pseudomonas, Streptomyces, Agrobacterium* and fungi of the genera *Trichoderma, Gliocladium, Ampelomyces, Candida* and *Coniothyrium* (USEPA, 2008). A partial list of commercially available biocontrol products is listed in table 4.16.

Table 4.16 Biofungicides used in organic disease management.

Organism	***Product name***
Bacteria	
Bacillus spp.:	Companion, Serenade
Burkholderia cepacia	Deny, Intercept
Streptomyces spp.	Actinovate, Mycostop
Fungi	
Ampelomyces quisqualis	AQ10
Coniothyrium minitans	Contans WG, Intercept WG
Trichoderma spp./ *Gliocaldium* spp.	Plantshield, Rootshield, T-22 Planter box Soilgard, Primastop
Plant activators	
Bacteria	Serenade, YieldShield

Source: Friberg, Lagerlof et al. 2005.

Note that some of these products contain a biocontrol agent as part of the formulation which would otherwise be prohibited for use in organic production, so use of the product should be verified with the organic certifier before application. The OMRI Product List is a good source of information regarding allowed products (OMRI, 2008).

Because of the cost of these products, their use against soil diseases is generally limited to greenhouse and transplant production. Before field planting transplants, a common practice is to drench the seedlings with a cocktail of beneficial fungi and bacteria to provide added protection from any soil-borne pathogens the new transplant might encounter. Another practice is to introduce beneficial organisms in seed box treatments which is similar to inoculation of legumes with rhizobia at planting. Seeds are inoculated at planting, effectively introducing the organism into the root zone at planting.

The use of foliar and soil applied compost tea (CT) and other compost derived extracts has received considerable attention in the past several years because of reported plant benefits and disease suppression. The disease suppression aspect is of special interest to organic growers with limited plant disease protection technology, and is of interest to conventional producers as a tool in fungicide resistance management. Most of the information available about CTs has come from practitioners' experiences, while scientifically based research has been limited (Duffy et al., 2004; Scheuerell and Mahaffee, 2002).

Compost teas are produced using aerated (ACT) and nonaerated (NCT) suspensions of compost in water with a variety of additives. The objective is to first increase populations of beneficial organisms in the suspension and, second, to extract the beneficial organisms and metabolites from compost for efficient application to crops and fields through irrigation systems or sprayers. There are a number of ways in which CTs are produced, with varying results depending upon the ingredients used, the fermentation and filtration processes involved, application method, and field environmental conditions. Compost tea as a disease suppression tool has been successful only to a limited degree. Improved success depends on gaining a better understanding of the mechanisms involved in CT disease suppression, as well as CT production and application methods (Duffy et al., 2004; Scheuerell and Mahaffee, 2002).

Pesticide options for disease

Fungicides and bactericides are used to kill or suppress the development of pathogens. Some of these pesticides are effective on both fungal and bacterial diseases, and have been used for centuries. Aside from the biofungicides (discussed in the previous section), most of the fungi/bactericides allowed in organic production fall into either mineral or oil-based formulations. Sulfur, Bordeaux mixture, copper, and bicarbonate compounds fall into the former, and the highly refined horticultural oils of petroleum source and plant oils (most commonly neem oil) fall into the latter category. Peroxides represent another group of fungicides/bactericides. All of these materials require reapplication to provide continuous protection during the plant's growth. Complete leaf surface coverage is also critical.

Elemental **sulfur**, which was used by the Greeks over 2000 years ago to control rust on wheat, is still used to prevent fungal spore germination of powdery and downy mildew and rusts. It is applied as a preventative measure and requires regular applications during periods of crop susceptibility. During high temperatures it can be phytotoxic to a range of crops, and should never be applied following an oil spray. Because it is also used to control mites and psyllids, it probably has some deleterious impacts on beneficial organisms as well.

Bordeaux mixture (a mixture of copper sulfate and lime) has been used for over 150 years to provide protection from fungi and bacteria. The lime reduces the phytotoxic effect of the acidic copper sulfate on the plant. Bordeaux mixture is not listed by OMRI for use in plant disease control (OMRI, 2008), but the ingredients are included in the NOP allowed products list (USDA, 2002a).

Copper-based fungicides/bactericides are effective because of their capacity to de-synthesize cellular proteins in bacteria and fungi. They are classified as synthetics, and are allowed, with restrictions, by NOP. Fixed coppers such as copper hydroxide, copper oxide, and copper oxychloride are allowed for disease control provided that there is minimal accumulation in the soil. Copper sulfate is also allowed with the same restrictions. When copper sulfate is mixed with calcium hydroxide (hydrated lime) Bordeaux mixture results, which has a longer period of efficacy on the plant, and is less phytotoxic than the fixed copper materials. Continued protection requires reapplication to emerging plant leaves. Copper-based products are restricted because of potential accumulation in the soil and environmental concerns relating to runoff into bodies of water where it is toxic to a variety of aquatic organisms. This concern is amplified when plastic mulches are used, which concentrates runoff (Rice et al., 2007). Trials with organically approved copper products were found to provide poor to fair control of fungal and bacterial diseases by Cornell University researchers (Caldwell et al., 2005).

Oils include those derived from plants, fish, and petroleum. These highly refined oils not only control some insects and mites, but also disrupt fungal development. The mode of action is not clear, but it appears that adhesion of the fungal spore is prevented, and fungal membranes are compromised (Davidson et al., 1991).

Bicarbonates of sodium ($NaHCO_3$) and potassium $KHCO_3$) are classified as allowed synthetics by the NOP and are used to control fungi (botrytis, mildews, and alternaria leaf spot). Efficacy is enhanced by mixing the bicarbonates with oils. The mode of action is apparently the development of an ion imbalance which causes fungal cell walls to collapse.

Hydrogen peroxide is a broad-spectrum fungicide and bactericide. It is classified as an allowed synthetic that may be applied to crop foliage and as a post-harvest protectant. It is a strong oxidizer and is reported to be involved in fungal and bacterial cell wall degradation. It breaks down quickly in the environment and is not considered to pose negative environmental impacts.

Farm Survey of Plant Diseases

During a 2008 fall survey, 15 organic vegetable farmers were asked to discuss the greatest disease issues in their crops. It was interesting to learn that plant disease is a relatively small problem for the farmers that were surveyed. Forty-six percent of the respondents reported having no disease problems on the crops. Fifty-four percent responded that they had some disease issues, but they were not major. Of those who mentioned having crop diseases, 13% identified western beet curly top virus and one respondent said that downy mildew is a recurring problem on early plantings of savoy spinach. None of them used any measures to control disease aside from incidental management with the use of floating row cover.

Chapter 5 What to Grow and How to Grow it.

The decision of what crops to grow and the cultivars of each crop are important decisions for the small-scale organic farmer. Colorado's climatic conditions dictate to some degree what can be grown, but that can be expanded considerably with the use of season extension techniques. Colorado's climate can be extreme, and the growing season ranges from about 100–150 days depending on the region of the state. Growers in the mountains and in high valleys can grow excellent, cool-season crops that will suffer at lower elevations in the middle of the summer. Long- and warm-season vegetables like tomatoes and melons are generally limited to the lower elevations and at least 120 days of frost-free weather.

Some small-scale growers are highly specialized, and prefer to produce a single crop or two, while others prefer to produce a wide variety of crops. The decision to either specialize or diversify depends on a variety of things, such as the marketing direction a farmer chooses to pursue, the availability of labor during times of peak labor requirement, the desire or ability to mechanize production operations, post-harvest storage capacity, distance from market, irrigation water availability (seasonality and quantity), soil types, microclimatic opportunities and challenges, and just plain passion or interest in a specific crop. Specializing in one or two crops reduces the need for the variety of tools and skills needed to produce a wider range of crops. Specialization, however, also carries a higher degree of risk of total crop loss due to a single, destructive weather event, or a shift on market demand. The highly diversified farmer is likely to experience some degree of crop loss or failure each year, but total loss is unlikely because of the variety of crops and planting periods in use. Part-time farmers, with limited available time, may find that specialization in a single crop is a good option—this is frequently seen at the farmers' market. A highly diversified small farm reduces the risk of total crop loss in any one season and the returns per acre can provide a reasonable living, but it does require full-time attention. A farmer growing a variety of crops over a long season has a range of marketing options, including farmers markets, on-farm sales, CSA, and local restaurant and, to a limited degree, local grocer trade. The extended season of a highly diversified farm allows the farmer to maintain a presence in the market, and establish a long-term rapport with customers, which by nature is limited if one specializes and appears in market for a short period of time. Retail outlets buying from local producers especially like to have continuity of supply, and a known quality.

Crop scheduling for the diversified small farm can be quite challenging, and requires the flexibility to adjust to seasonal differences, whether driven by the weather, production, or market. Ideally, a steady of supply of many different items will provide customers with everything they expect to find. CSAs especially need to plan their production based on the weekly diet of their members. Lettuce and salad greens are perhaps easiest to grow in the early and late season, but consumers want to have salad greens in the heat of the summer as well, when producing a high quality product is more challenging.

Farmer Survey: Organic Certification

In addition to determining what crop to grow, many organic farmers question the need to have their farm certified organic per NOP regulations. Currently, Colorado Department of Agriculture's (CDA) tiered certification fee is $750 for a small organic farm; an additional inspection fee is variable, but is in the range of $100. In years when funds are available, partial reimbursement (depending upon the size and type of operation) of the certification fee has been available. Clearly, if a farmer is contracting with a grocer or other food retailer and the products are to be labeled "organic", they are required by law to be certified by an accredited organic certification agency.

Among the organic farmers that participated in the survey for this project, 40% are not certified; all of them had been certified previously. Of those that are certified, only one is certified by an agency other than CDA. The reasons cited for not certifying included: no need to certify because of their farm's marketing design, inordinate amount of paper work, cost, and dislike of "big-brother government intervention in my livelihood". Reasons that farmers cited for certification included: credibility in the market place, advocacy of the program that supports organic farmers, premium prices, contractual agreements with buyers, philosophical and environmental statement about food production. The breakdown of how the farmers sold their products followed the same lines:

- Farmers selling < 30% of their products directly to consumers, were all certified organic;
- Farmers selling > 30% of their products directly to consumers with a small amount (< 5% of their business) to restaurants were split 50:50, certified and not certified.

Specific crop production requirements

Crop production requirements vary considerably from crop to crop, however there are also a number of similarities with crop types, Vegetable crops are commonly divided into cool season and warm season crops, representing basic differences in climatic requirements. Colorado's relatively short growing season with springs and falls that are characteristically short represents additional challenges for some cool season crops which prefer long cool. However there are high valleys in Colorado, which do provide good cool season crop conditions while never really getting warm enough to grow warm season crops. The following sections will highlight production methods of crops representing both cool and warm season requirements, and some of the production techniques specific to each. Tomatoes and melons are warm season crops, while spinach and lettuce represent cool season crops.

Tomatoes

This section will provide the small-scale organic grower with practical information for successful field production of tomatoes in most agricultural regions in Colorado. These production requirements are similar to those of other warm season crops such as melon, pepper, and eggplant, and can be applied with minor modification.

Small-scale production of tomatoes in Colorado certainly presents some challenges, but it can be quite rewarding as well. Locally grown, vine-ripened tomatoes are popular and can be sold for top dollar at farmers' markets, discriminating restaurants, and specialty grocers. Tomatoes also represent the second highest consumption of fresh vegetables after lettuce in the U.S., with annual per capita consumption of fresh tomatoes exceeding 20 lb (ERS, 2008). The variety of types and unique flavors offer a range of options for specialty growers. Tomato production is labor intensive, but good yields and reliable market demand can make tomatoes one of the higher profit crops grown by small organic farmers.

Cultural requirements and practices

Temperature

Tomatoes are considered to be a "warm season" crop, with optimal daytime temperatures between 77˚F and 86˚F and nighttime temperatures between 60˚F and 68˚F. Temperatures over 95˚F or under 53˚F stress tomatoes, and temperatures over 85˚F, especially with low relative humidity, reduce pollen viability; warm night temperatures (>70˚F) also result in reduced fruit set (Swiader and Ware, 2002).

Tomatoes are intolerant of frost, and temperatures below 50˚F are generally considered to be damaging and may be responsible for inferior fruit quality (Nonnecke, 1989). However, the large swings in day and night temperatures--common in many parts of Colorado--have also been credited with higher concentrations of sugars in fruit. Protection from cool temperatures after transplanting may be achieved by the use of plastic row covers or floating row covers. These materials provide a few degrees of protection against low temperatures and also protect plants from wind, which can be damaging to newly transplanted tomatoes.

Soil fertility

Tomatoes do well in a variety of soil types, preferring well drained soils with good water holding capacity and pH in the 5.5 – 7.5 range. They are also relatively tolerant of moderately saline conditions, and have been shown to produce higher brix (soluble solids) under saline conditions (Maynard and Hochmuth, 1997). Tomatoes are probably the most responsive of any vegetable crop to soil fertility (Swiader and Ware, 2002). Over-fertilization with nitrogen is a common mistake, resulting in excessive vegetative production, especially when indeterminate cultivars are grown. High N levels also result in slower ripening of fruit. Available nitrogen early in the season is important to establish a strong plant and encourage early fruit set. In organic production this may require top dressing with compost or supplemental N application through the irrigation water if soil N levels are low, or if organic sources such as green manures are not fully mineralized. Mid- and late-season N supplementation is generally not needed where the soil is of moderate fertility, and may actually delay ripening of fruit.

Tomatoes take up 75-100 lbs of N per acre (Maynard and Hochmuth, 1997), which is easily supplied through green manures and rotation with legumes. Application of animal manures and composts to fulfill the P requirement of the crop (200 lbs/ac) will supply the N requirement as well. Other nutrients are generally sufficient if animal and green manures are used to provide N and P. Additional potassium is rarely needed in Colorado. Iron and zinc in high pH soils may need to be supplemented where soil testing indicates deficiencies. Table 5.1 shows expected responses of tomato when soil micronutrients levels are deficient. Soil testing should be done to provide accurate assessment of fertility.

Table 5.1.Relative responses of tomato to micronutrient applications

Micro-nutrient	Critical levels in the soil below which crop will respond to application	Degree of response expected
B	0.1–0.7 ppm	Med
Cu	0.75 ppm (EDTA extraction)	High
Zn	0.5–1.0ppm (DTPA method)	Med
Mo	0.04–0.2 ppm	Med
Fe	2.5–4.5 ppm (DTPA extraction)	High

Source: Maynard 1997; Swiader 2002.

Crop establishment

Tomatoes are generally transplanted in Colorado, allowing several weeks of growth in the greenhouse, when outdoor temperatures would be too cold for good growth. Transplanting is done after the danger of frost has past, which is mid-May in most agricultural production regions of the state. Some growers direct-seed tomatoes in southern Colorado, after soil temperatures reach 55°F and adequate moisture is available. However, the relatively slow growth of tomato seedlings is challenged by fast-growing weeds during the crop's establishment stages. Direct-seeding is generally done for processing tomatoes where input costs of transplants are too high.

Mulching

Mulching in the row reduces moisture evaporation and keeps annual weeds from emerging. It also acts as a barrier between fruit and soil--reducing or eliminating the need to wash fruit, and reducing some diseases and insect damage associated with soil/fruit contact. Mulching with opaque plastic or paper mulches provide the added benefit of warming the soil in early season. The use of organic mulches, such as straw or hay, have the advantage of being produced on-farm, or locally, and can be reincorporated into the field, thereby increasing soil organic matter. Organic mulches have been demonstrated to keep soil temperatures slightly lower than plastic or paper mulched plots (Atthowe, 2007) in a climate similar to Colorado. However, Abdul-Baki et al. (2002) have shown that tomatoes grown on vetch mulches surpass the yield of black plastic mulched plots in spite of the initially cooler soil temperatures. Brown et al. (1992) has found black plastic to be inconsistent in providing superior yields reported earlier by Lamont (Abdul-Baki et al., 2002; Brown et al., 1992; Brown et al., 1991; Diaz-Perez and Batal, 2002; Lamont et al., 1991).

In spite of the variable crop responses to plasticulture, it continues to be used widely, and the reduction in weed pressure it affords has many organic growers enthusiastic about being able to use it. The costs of materials (table 5.2), labor, plastic disposal, weed suppression, and sustainability of these choices all deserve consideration when determining which type, if any, mulch is used.

Plastic mulch is best laid in the field with a tractor-drawn mechanical layer that applies the plastic tightly and well secured on the bed. A well leveled and prepared field is critical for plastic laying. Cloddy rough surfaces do not allow the plastic to be laid tight and well stretched over the surface, which is required to keep the plastic from flapping in the wind. Flapping plastic results in plant damage and increases the likelihood of the mulch blowing away. Drip tape is laid in the same operation, directly ahead of the plastic, either on the soil surface, or buried shallowly in the center, or slightly off center of the bed. Plastic mulch is generally laid several days before planting, allowing time to pre-irrigate the field (using drip irrigation under the mulch). Laying the plastic much earlier than the transplanting date may be risky because wind can lift the plastic, or mice will take up residence under the protection of the plastic.

Drip irrigation is generally used under plastic mulch. It provides good distribution of water and, if properly timed, and very uniform soil water content over time, which is critical for tomato production. Furrow or sprinkler irrigation may be used in conjunction with plastic mulch, but the advantages of drip irrigation easily outweigh the advantages of furrow and sprinkler irrigation (see Chapter 3.).

Disadvantages of using plastic mulches are the issues of plastic production, transport, and ultimately, disposal. Recycling of mulches is not widely done because the films are usually very dirty when removed from the field; at the time of writing the market for recycled plastic is nonexistent (Eco-Cycle, 2008). True costs and benefits of plastic mulches should be considered relative to other options.

Mulching with organic mulches, such as hay or straw, is a commonly used strategy to maintain soil moisture, reduce germinating weed pressure, and keep the fruit off of the soil. Advantages of using organic mulches on an organic farm are that there are no disposal problems (as with plastic mulches) and the mulch can be produced on the farm, and when turning the mulch into the soil it returns organic matter to the soil. The cost of materials (Table 5.2), application labor, keeping the mulch in place in a windy environment, and the possibility of introducing weed seed into the field are common drawbacks of using organic mulches. Application of the mulch early in the season provides superior weed suppression, but cooler soil temperatures resulting from shaded surfaces slows initial crop development, and delays harvest (Lamont, 2005). Mulching with straw also makes hoeing and tractor cultivation extremely difficult when weeds manage to grow through the mulch.

Mulching with biodegradable paper or plastics such as those used widely in Europe offers another option., These materials, however, have not been fully evaluated under Colorado climatic conditions. Initial evaluation at the CSU Rocky Mountain Small Organic Farm Project (RMSOFP) of performance of paper mulches manufactured in Colorado by Sunshine Paper Co. have been promising (Thomas and Mink, 1998). Currently, biodegradable films are much more expensive than plastic mulches, and durability of the materials over an entire cropping season is reportedly limited (Ngouajio et al., 2008).

Table 5.2 Estimated costs of plastic, straw, and biodegradable films for mulching tomatoes.

	Material cost/ac ($)	Application cost/ac ($)	Removal cost/ac ($)	Total cost/ac ($)
Black plastic mulch [1]	194	50	85	329
Straw [2]	201	181	0	382
Planters paper [3]	1,960	50	0	2,010
Biobag ® biodegradable film [4]	524	50	0	574

[1] Prices from Robert Marvel Plastic Mulch LLC http://www.robertmarvel.com/ 1-800-478-2214
[2] Straw prices local market, Ft Collins, CO.
[3] Prices from Johnny's Selected Seed, http://www.johnnyseeds.com; 877-564-6697.
[4] Prices from Biobag USA, http://www.biobagusa.com; 1-800-959-2247.

Transplanting to the field

Many growers prefer to produce their own transplants because they can grow transplants of a specific variety in small quantities on a schedule that is appropriate for their operation. Alternatively, farmers may have transplants grown by a local (or distant) custom grower that grows the specified cultivar to the farmer's requirements. The decision to grow one's own, or have transplants grown by someone else depends on the farmer's ability to grow transplants (greenhouse facility, and the time available to dedicate to the task) and the cost of buying relative to producing one's own. Actual production costs of growing transplants can be misconceived savings, relative to the cost of buying plants from an efficient, specialized producer whose scale permits considerable cost savings.

Tomatoes are commonly grown on beds 5–6 feet apart, with plants 18–24 inches between each other in the row, resulting in plant populations of 3600–5800 plants per acre. Spacing depends on the plant type (determinate or indeterminate) and whether or not they will be staked or trellised.

Every effort should be made to minimize transplant shock when going from the greenhouse to the field, allowing the plant to continue its growth without stopping. Reducing their water (without allowing them to wilt excessively) and exposing them to the elements (indirect light and cool temperatures [45–60 °F]) while still in their cell trays for a few days prior to planting helps harden the plants. Stocky, well-hardened plants will stand up to the wind and direct sun, but spindly, stretched plants will often be unable to support themselves, resulting in stems breaking, or the plant laying on hot plastic mulch or hot soil surfaces. The field should have been pre-irrigated, and moist enough to work efficiently, but not soggy. The transplant should be placed deep enough to cover the root ball completely, but deeper planting of taller plants allows the stem to develop adventitious roots and become well-established quickly. The transplants should go into the soil wet, being watered before going to the field. Irrigation immediately after planting is needed to fill in air spaces around the root ball. Some transplanting machines have watering lines that do this after each transplant is placed--otherwise a worker follows the transplanting crew and waters individual plants. A fertilizer solution aids in establishment and quick growth. Transplanting late in the afternoon may not be possible, but, when possible, it affords a cool evening to acclimatize the plants.

When transplanting onto plastic mulched beds it is important that the plastic lays tightly stretched on the soil. If there is a gap between soil and plastic, the transplants often end up under the mulch, are battered by wind flapping the plastic, and exposed to high temperatures underneath the plastic. Soil can be placed on top of the plastic surrounding the holes to avoid this.

A number of transplanting machines are available, each with different attributes. For the small farmer with limited labor a transplanting machine can speed the process. Most transplanting machines require at least three people to operate: a tractor driver and two planters. Tractors with a creeper gear or hydrostatic transmission allow operation at speeds slow enough for the planters to keep up.

If floating row covers or plastic row covers are used, hoops made of 12-gauge wire or plastic hoops made of poly-irrigation pipe or other materials are inserted firmly into the soil just off of the bed, or on top of the bed. Slitted plastic row covers should be white pigmented, or white-washed to keep the plants from overheating in Colorado's intense sunshine. When using slitted row cover, the sides must be lifted and held open with clothes pins on warm, sunny days or temperatures can rise to well over 100°F, stressing the plants. These covers are pulled very tight from the end of the row, and soil placed along the entire edge to hold them in place. This is a very labor intensive operation, but warm season crops respond well to the protection from wind and cold--although only a few degrees of frost protection is afforded. Bumble bees are able to find their way in and out of slitted row covers, as are insect pests.

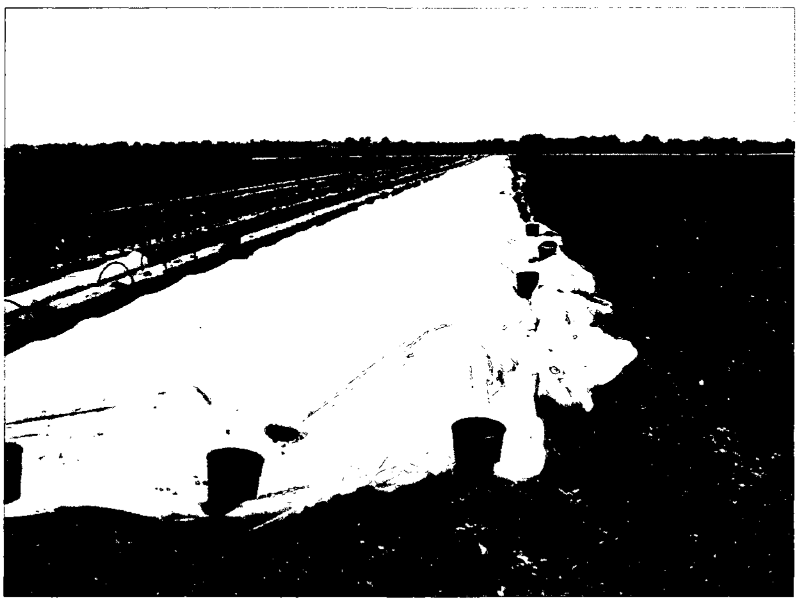


Figure 5.1 Floating row cover applied over hoops in a tomato and pepper trial at CSU HFRC in 2005, Photo by Stonaker.

Floating row covers also require support over tomatoes (Figure 5.1) and other non-vining crops, but can be held in place with much less soil. Floating row covers offer a number of advantages over slitted or perforated plastic row covers. They are made of spunbonded polyester and similar porous fabrics,, resulting in less lift by wind. They are available in a variety of widths, allowing the farmer to cover multiple rows at once, with a fraction of the labor. The exclusion of flying insects is nearly complete, and the porosity allows the cover to be left in place without the need to ventilate. Large areas can be covered very quickly with a minimum of labor, and if properly anchored with piles of soil, sand bags, or nursery pots filled with soil, the covers stay in place in winds in excess of 70 mph.

Irrigation

On a per-acre basis, tomatoes are not high water users because they are planted at low densities (< 6000 plants/ac). Tomatoes will develop relatively deep root systems in search of water, but stressing tomatoes during fruit set has dire consequences in fruit quality and fruit set. Irrigation should be sufficient during the entire season to keep the plants from wilting. Calcium is transported into the developing fruit cells as water is transpired, so any irrigation stress will likely result in blossom end rot, which is common in tomatoes, and almost always related to inadequate irrigation or diseased roots that are unable to take up enough water, especially in Colorado where most soils have abundant calcium. Over-irrigating is wasteful of water, it leaches nutrients out of the root zone, and can result in fruit splitting and root rots. See Chapter 3 for more detail on irrigation practices and methods for monitoring soil moisture.

Staking and trellising

In regions where high humidity results in disease pressure, tomatoes are trellised or staked to increase air circulation around the plant and reduce the likelihood of leaf diseases. Staking also reduces damage to crops from foot or tractor traffic, and allows for good penetration and coverage of pesticide applications. One of the main advantages is keeping the fruit off of the soil, reducing disease and some pest damage. Another benefit is the ability to see the fruit and efficiently pick it. Considerable cost and effort, however, are also involved. Some determinate cultivars with short, compact growth habit are poorly suited to staking or trellising.

There are a number of methods that are used for staking and trellising, based on farmer preference, plant type, and cost. Some growers use cages, which are expensive, but require relatively little labor once installed in the field. Short stakes are used on medium-sized indeterminate or large determinate plants. Weave trellising has worked well in trials at the CSU RMSOFP where stakes are driven between every other plant (being careful to not damage the drip irrigation tape). Twine is then woven between plants and stakes along the length of the row, twine is wrapped around each stake and woven in and out of the plants; at each stake, the string is pulled taut. The worker carries a ball of twine on his/her belt, and a piece of pipe or a stringing tool allows the worker to quickly weave the twine between plants and around the stakes (Figure 5.2). Weekly or biweekly weaving of twine between the plants and stakes plants holds the tomatoes in a hedge fashion, allowing easy field access for inspection of the crop, pest control, weeding, and harvest. High winds on very heavily fruited trellises can result in trellises breaking and falling over if stakes are not strong enough. Wooden stakes 1.5–2 inches thick, pounded into the soil at a depth of 12 inches works well, with T-posts placed at the row ends to anchor the trellis.

Care should be taken when trellising to minimize damage to fruit trusses. Considerable scarring and dislodged fruit can result from careless handling. In the weave system, string tension needs to be great enough to hold the plant up, but not so tight that stems or fruit are constricted and damaged. Strings are added when the crop has grown 8–10 inches in height, or about every 10–12 days.

Very vegetative indeterminate cultivars (especially some of the heirloom types) require some pruning in order to keep them trained in a hedge. Trellising can be done on any frame that holds the plant up and is strong enough to support a fruit-laden crop and wind loads. Trellises should allow good access to the fruit for harvest, and, of course, be made of reasonably priced materials.

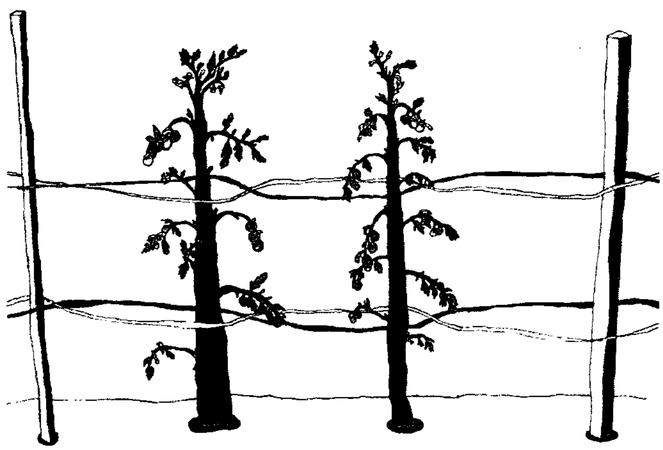


Figure 5.2 Weave trellising (drawing by Elena Stonaker).

Pest and disease management

Pests and diseases that are common problems in Colorado tomato production were outlined in the previous chapter. Insect-vectored diseases are probably the greatest threat, and ones for which organic growers have the fewest management options. In particular, tomato spotted wilt virus (TSWV), beet curly top virus, and psyllid yellows cause regular and significant damage in Colorado. In western Colorado, beet curly top virus has been responsible for field losses in excess of 70% (Swift and Hammon, 2007). Because these diseases are potentially transmitted at low pest density, preventative efforts may provide some protection. TSWV infection is likely to occur in the greenhouse where transplants are grown and thrips are present. The best deterrent is the use of resistant cultivars, but cultivars developed with TSWV resistance are limited (Thomas and Mink, 1998; Wehner, 1999). If contracting with a greenhouse grower to produce transplants, it is a important to ensure that the greenhouse is making good efforts to reduce the risk of infection with TSWV and other viruses. Once transplanted to the field, covering the crop with floating row cover offers a degree of protection. Removing plants that show early signs of TSWV infection can reduce the inoculum in the field. Aggressive trapping of thrips with rolls of sticky tape may provide some protection.

Curly top virus is vectored by Western beet leafhopper (WBLH) and is more likely to be seen in the field than the greenhouse. Dr R. Hammon (CSU Tri-River Area Cooperative Extension, Grand Junction) has evaluated a number of cultivars for curly top virus resistance in western Colorado, and found a few to be resistant. Evaluation of different color mulches have been trialed as well, with reflective mulch resulting in significantly less infection of tomatoes (12.4% infection on red mulch v 2.4% on reflective mulch) (Hammon, 2008). Otherwise, exclusion by floating row cover and trapping with sticky tape may provide some degree of protection.

Lastly, potato psyllid is occasionally found in greenhouses, but field infestation and psyllid yellows are not uncommon and can be fairly destructive. The exclusion methods mentioned above are options for psyllid as well.

Preventative pesticide application to organic crops is not advised, because materials are not especially effective against these pests, and damage to potential predators and parasites of these pests and other potential secondary pests is likely to result in unintended secondary pest outbreaks.

Disease management of tomato pests is covered in Chapter 4. Prevention by crop rotation and use of disease resistant cultivars are the best options for common diseases in organic production. Lists of pests and diseases of tomatoes and management practices are in Tables 4.1 – 4.18.

Harvest and post-harvest practices

Field grown tomato harvest in Colorado begins about 8 weeks after transplanting, depending on the cultivar grown. Cardboard and plastic picking trays and boxes are used for picking as well as for transporting tomatoes. Red-ripe tomatoes should be packed single layer deep; if the calyx is left on the fruit it should be placed pointing up to avoid damaging other fruit in the box. Single layer tomato boxes generally weigh 15 lbs. Less ripe tomatoes may be packed two or three layers deep, and the calyx should be removed at picking to reduce the chance of puncturing adjacent fruit. Double-layer packing in standard tomato boxes or lugs weigh about 22 lbs.

Tomatoes should not be stored below 50˚F; the preferred storage temperature is 55˚F – 70˚F at 90%–95% RH (Maynard and Hochmuth, 1997). Field heat of tomatoes is slow to dissipate if fruit is picked and packed when warm and placed in boxes and stacked closed. Closed containers also concentrate ethylene, which is produced by the fruit and speeds ripening and spoilage. To avoid premature spoilage fruit should be picked early in the day when cool, or subsequently cooled.

Complete immersion of fruit in cooling water effectively removes field heat, but with some risks. Pathogens responsible for food-borne illness and organisms responsible for post-harvest fruit decay may be concentrated in bath water with repeated use, so hydro-cooling water should be replaced frequently or sanitized using NOP allowed sanitizers. Reducing the time of immersion reduces the chance of fruit absorption of bath water sourced pathogens that enter through skin abrasion and calyx scars. For these reasons, immersion cooling may not be the best option for tomatoes. Picking in the morning when the fruit is cool is a simple solution and probably the best option. When selling directly to consumers at farmers markets or through CSAs, size grading is not required, but sales to stores usually require sizing to USDA standards. Fruit size and grade is used for pricing, and should be established and agreed upon with the store before delivery.

Cultivar selection

Cultivar selection for specific climatic conditions and desired production and quality attributes is an important decision.Results of varietal evaluations done by the author in 2006–2008 are reported below. Neighboring states with vegetable research stations are resources for information about cultivars that have performed consistently well in similar climatic conditions. Seed company representatives are often excellent sources of information about new cultivars. CSU field days provide information and allow growers to see the crops standing. In selecting cultivars there are several criteria to consider, including:

- Days to maturity
- Pest and disease resistance
- Yield
- Fruit quality
- Quality market acceptability
- Pest and disease resistance
- Vigor
- Suitability for organic production

Days to maturity

Days to maturity reflects the earliness of the crop, an important factor in a region that commonly has only 120 days of frost-free production period. There are many cultivars of tomatoes that produce early fruit, but trade-offs exist in quality, fruit size, or yield, which tend to be better in later cultivars. Very early determinate cultivars also tend to produce for a short period, running out of fruit before the season runs out. However, they may work well in very short season areas in Colorado. Days to maturity advertised in catalogues can be used for reference, but often these figures represent a production region quite different than Colorado's, and should be used as relative references only.

Pest and disease resistance

Pest and disease resistance was discussed in the previous chapter, in terms of what diseases and insects commonly trouble tomatoes. Grafting of tomatoes was mentioned as a possibility for enhancing susceptible cultivars scions with resistant root stock. Cornell University has documented resistance of a wide range of vegetable crops to a wide range of diseases as well (see http://vegetablemdonline.ppath.cornell.edu/Home.htm). Most seed catalogues offer information on cultivar resistance to diseases and some insects.

Yield potential

Average fresh market tomato yields across the country are in the range of 31,000 lb/ac (ERS, 2008). National averages are heavily weighted by production areas where conditions are ideal and most of the production occurs, but this information is useful in making general comparisons with local production. Fluctuations of yield within a cultivar from year to year can also be quite significant, so multi-year trials should provide the most reliable information about yield potential of a region and specific cultivars. Trials at CSU RMSOFP between 2005 and 2008, using identical production techniques and cultivars, have demonstrated the difference a year can make see (Figures 5.14, 5.15).

The cultivar selected should have good yield potential, and good pack-out potential. There is a tendency of many specialty market growers to overlook yield when searching for top quality in a cultivar. A low yielding, flavorful tomato should demand a higher price to make up the difference in returns, so marketing adjustments may need to be made. There often is a tradeoff between quality and yield, and these should be considered carefully. This is especially true for some of the heirloom cultivars that have enjoyed resurgence in popularity due to their excellent flavor and unique shapes and colors. Farmers excited at the prospect of receiving double the price for these gourmet fruits should be aware that yields may be considerably lower than many of the standard hybrid cultivars.

Quality

Quality and market acceptability are paramount in cultivar choice. Consumers expect flavor of a locally "home-grown" tomato to surpass that of what has become the standard flavorless type found in the grocery store. This is largely a function of cultivar, although some flavor enhancement may be possible with production technique and growing temperatures. There has been renewed interest from breeders in recovering the flavor of cultivars that was lost when shipping characteristics and high yields overshadowed good flavor. For example, the New Jersey Agricultural Experiment Station at Rutgers University has an initiative titled "rediscovering the Jersey tomato" to identify old cultivars with solid production credentials and flavor. As a result the Ramapa cultivar has been reintroduced into public breeding programs.

Plant vigor

Seedling vigor is important; not only does it produce a transplant in less time that will stand up to the rigors of going from the protected greenhouse environment to the field, but it continues to grow steadily once moved to the field. Very vigorous "vegetative" types that produce a great deal of leaf and stem do not, however, do not always produce high yields, especially if supplied with an excess of fertilizer. Very vigorous cultivars that produce too much leaf and canopy can be difficult to harvest because fruit is hidden, and may require some pruning to keep under control-- especially if they are grown on a trellis.

Plant habit

Tomatoes are characterized as being of three different growth habits: indeterminate, semi-determinate, and determinate. Indeterminate cultivars will continue to produce vegetative growth and flowering trusses until the crop is killed--in Colorado field production this is generally a killing frost. They produce 3–4 leaves between each flowering truss. A main shoot dominates side shoot development, but side shoots are continuously produced. Indeterminate cultivars often produce a great deal of foliage, which helps protect the fruit from sunscald, but can pose difficulty in harvest and cultural practices that are impeded by the luxuriant growth. Over-fertilization with nitrogen can amplify this problem. Most heirloom cultivars are indeterminate, as are the cherry types.

Determinate tomato cultivars grow stems that produce fruiting trusses with only one or two leaves between them. Several fruiting trusses are formed before the stem terminates in a flowering truss. Side shoots develop above each leaf, and they also produce flowering trusses. Side shoots terminate at approximately the same distance from the crown of the plant as the main stem, resulting in an erect, bush-type plant. Determinate crops produce all of their fruit within a determined period of time, and then quit growing. Early, short-season tomatoes tend to be determinate, and produce relatively less vegetative growth. Semi-determinate cultivars are characterized by intermediate growth patterns, including several lateral side shoots that terminate in flowering clusters.

Suitability for organic production

Cultivars that are well suited to organic production have not been effectively evaluated, but it is fair to say that disease resistance, seedling vigor, and possibly less requirement of high levels of soil fertility are likely to be better suited to organic production. Following good cultural practices is probably as important as finding a cultivar that is "well suited" to organic production. Cultivar trials at CSU RMSOFP comparing conventional and organic production failed to show significant differences in yield or quality (see the section in this chapter "Cultivar Trials 2006–2008; tomato, melon, and spinach").

Melons

Melons represent another iconic summer treat that growers and consumers alike look forward to. The grower can choose from a great diversity of types of melons, ranging from crisp, sweet, light-fleshed honeydew melons to the deep salmon-colored flesh and musky aroma of the Charentais melons. Southern Colorado has long been known for its delicious "cantaloupe" and watermelon, but Rocky Ford is now sharing some of the melon production market with growers all the way up the front range and on the western slope. This is due in part to growers' determination to grow this heat-loving crop in areas previously considered to be too cool or short seasoned for good melon production.

Melons (other than watermelons) are of the *Cucumis melo* species, which crosses freely, resulting in a wide variety of types. The major types of melons are classified as "cantaloupe", casaba, Persian, and crenshaw. Within the *C. melo* are the Reticulatus (netted types), Inodorus (smooth skinned with hard rinds), and Cantalupensis group. The Cantalupensis group has hard, rough, warty rinds without netting (the true cantaloupes), which are not grown here in spite of what is commonly known as a "Colorado Rocky Ford cantaloupe".

Temperature

Melons, like tomatoes, do well in warm climates, preferring day temperatures in the 65 ˚F to 75 ˚F average temperature range, and a low temperature threshold of 60˚F. High temperatures are less stressful to melons than to tomatoes, but the upper temperature threshold of growth is 90˚F. Germination of melon seed is best between 75˚F –95˚F.

Soil fertility

Melons have deep-reaching roots that are able to access nutrients out-of-reach to many other shallow-rooted crops. However, many of the feeder roots are shallow, especially when plasticulture is used and the soil directly under the plastic is moist and warm. Melons are moderate feeders, with N, P, and K requirements of approximately 120 lbs, 150 lbs, and 25 lbs/ac, respectively (Maynard and Hochmuth, 1997). Green manures are able to provide enough N, but P is probably best supplied by animal manures in high pH soils. Melon is responsive to micronutrient application when levels of zinc are below 1.0 ppm (see Table 5.3).

Table 5.3. Relative responses of melon to micronutrient applications

Micro nutrient	Critical levels in the soil below which crop will respond to application	Degree of response expected
B	0.1-0.7 ppm	Low
Cu	0.75 ppm (EDTA extraction)	Low
Zn	0.5-1.0ppm (DTPA method)	Med
Mo	0.04-0.2 ppm	Low
Fe	2.5-4.5 ppm (DTPA extraction)	Low

Sources: Maynard, 1997; Swiader, 2002.

Crop establishment

Melons are transplanted and direct-seeded. Transplants are used to achieve early production, often in conjunction with row covers. Many growers prefer to grow melons in peat pots that are planted directly in the soil, thereby avoiding disturbing the roots that are believed to be more sensitive than other vegetables. Melons are planted after the danger of frost has passed, when soil temperatures reach at least 60˚F.This is, however, the lower limit for germination;

optimal germination occurs between 75˚F and 95˚F. Direct-seeded crops emerge quickly in warm and moist soils, but soil temperatures that dip below 60˚F may result in permanently stunted plants. Mice are serious pests where melons (and other cucurbit crops) are direct-seeded, digging the seed out of the soil and eating the germ. This alone may require growers to transplant rather than direct-seed melons and other cucurbits if field or field margins are home for mice. A labor intensive alternative to transplanting is placing a plastic or paper cup over the sown seeds, with the lip buried in the soil. A careful watch is required to remove or open the cup as the seedling emerges so that it does not develop into a spindly, light-starved seedling. Cucumber beetles are also very destructive to cucurbit seedlings, but can be deterred with floating row covers (Mueller et al., 2006).

Melons are insect-pollinated, and honey bee hives are commonly placed in fields for this purpose. It is estimated that one bee will pollinate 100 flowers, so a strong hive will effectively pollinate an acre of melons (Nonnecke, 1989). A number of other native pollinators also visit melons, including bumble bees, leafcutter bees, sweat bees, and squash bees, not to mention the butterflies and moths, flies, and beetles that visit the flowers for nectar and pollen (Shepherd et al., 2003).

Melons grow quickly, and the first fruit is often set at the two-leaf stage. Subsequent flowering axils are aborted until the 8^{th} to 10^{th} axil. Melons will continue to set fruit if the first fruit are removed when ripe, otherwise the plant will abort subsequent flowers (Nonnecke, 1989). For this reason we often see distinct flushes of fruit forming--with the first two flushes ripening before frost, and the last flush often maturing too late. Sequential planting of the same cultivar, or planting cultivars with different maturation periods, provides the grower with a continuous supply of fruit from the end of July until frost along the front range. Harvest generally begins in southern Colorado by the middle of July.

Mulching

Plasticulture has become the norm for melon production in much of Colorado, providing superior yields, clean fruit, and ease of access to the field, since drip irrigation confines moisture to the planted row. The use of plastic mulch, as mentioned previously, presents a number of environmental concerns including disposal and reliance on off-farm inputs. Alternatively, bare soil production or organic mulches are used successfully. Minimum and no-till melon production are options that are being evaluated at CSU's Arkansas Valley research Center, and results have been promising.

Irrigation

Melons have deep roots that allow them to search greater depths for moisture. They can be produced with as little as 15 inches of water per acre, however, for maximum production irrigation is applied in the 18–24 in/ac range using flood irrigation, and approximately 50%–75% of that with drip irrigation. Consistent moisture through the vegetative and fruit development stage is required. For higher quality and when harvest is not to extend over a long period of time, irrigation is reduced or discontinued 10–15 days before harvest. Some cultivars of melons are prone to splitting if irrigation is continued into the ripening stages or when a heavy rain falls during ripening.

Pest and disease management

A number of viral, fungal, and bacterial diseases infect cucurbits, including melons (see Tables 4.3 and 4.4). The insect-vectored diseases can be reduced by excluding vectors with floating row covers. However, melons are insect pollinated, requiring the covers to be off in time for pollination to occur. Bees can be used under row covers if they are provided with flight space (this is done where seed production requires isolation), but this is probably not practical for general application. Cucumber beetles have become an increasingly important pest in melons, attacking seedlings and in some years severely scarring fruit, as shown in Figure 5.3.

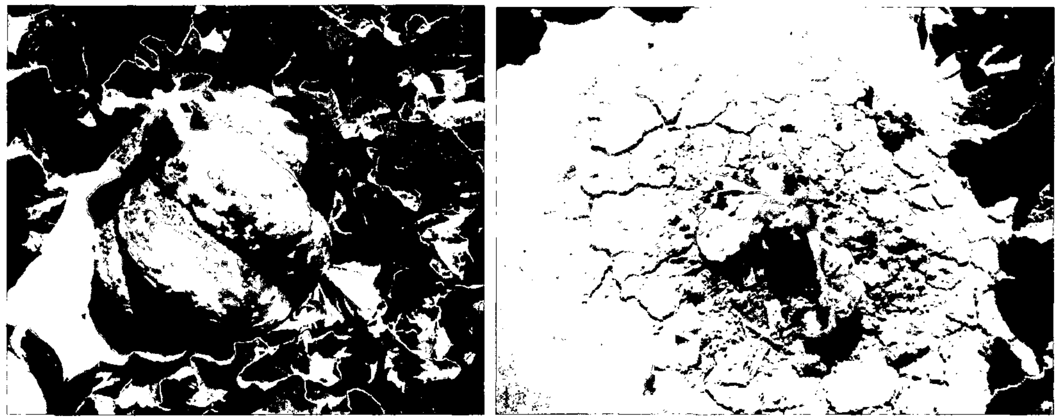


Figure 5.3 Scarred fruit and seedling damage caused by cucumber beetle at CSU RMSOFP in 2004. Photos by Stonaker.

Pyrethrins appear to suppress cucumber beetle long enough for seedlings to become established and withstand attack, but larval damage to roots can also be serious. Predacious nematodes injected in the drip irrigation water may provide some protection(Kaya et al., 1995), however this has not been established. More research is needed to establish effective organic methods of managing this pest.

Harvest and post- harvest handling

Melons harvested for local market may be left on the vine until fully ripe, when they are at their peak of aroma and flavor. Determining when a melon is ripe varies a good deal from type to type and even from cultivar to cultivar, but is primarily based on color changes that occur on the rind. Most of the dark fleshed, netted types (muskmelon, Charentais) become somewhat golden colored. The Reticulatus group develops an abscission layer between the pedicel and fruit that releases the fruit with a gentle tug--this is known as the "full-slip stage"; if harvested earlier, and the abscission layer is less well established, the melons may be at "half" or "quarter-slip" stage. Some of the Inodorus group will also slip (eventually) but often after their ripeness has peaked, and they are on the verge of being over-ripe. Some melons whose color change is difficult to detect can be gauged by the leaf and tendril closest to the fruit beginning to dry, or senesce. Others begin producing droplets of wine-red exudate at the pedicel/fruit interface(referred to as "weeping"). Table 5.4 lists four cues used to determine when different types of melons are ripe.

Table 5.4 Cues of ripeness of types and some melon cultivars.

	Rind color	Slip	Tendril/first leaf senescent	Weeping stem
Reticulatus group				
Charentais	Turning gold	When over-ripe	Yes	Yes
Muskmelon	Turning gold	Full	-	-
Persian	Turning green to gold	Part	-	-
Inodorus group				
Asian	Turning gold	Full	-	-
Casaba	Turning gold	Part	-	-
Galia	Turning gold	Full	-	-
Haogan	Turning speckled gold	Full	-	-
Honey dew	Turning white to yellow	Half	-	-
Sweetie #6	Turning green to aqua	When over ripe	-	Yes
Winter	Yellow spot under fruit	Part	-	-

Melon harvest is labor intensive, requiring the field to be walked every few days during the harvest period, and carefully placing the fruit in harvest totes to avoid bruising. Small-scale farmers often toss fruit from person to person across the field and to a person loading totes on a truck or field wagon. Larger operations often use field conveyors that move fruit from the picker to the truck.

Like tomatoes, melons absorb a good deal of field heat that can be trapped in harvesting totes. Hydro-cooling melons is practiced by commercial scale melon producers that must harvest continuously during the heat of the day; however, if early morning harvest is possible then cooling may not be needed. Conventional practice is to cool and store muskmelons at 32˚F –41˚F, and other types at 45˚F –50˚F (Maynard and Hochmuth, 1997), but it has been mentioned that superior flavor is maintained if melons are stored at room temperature. Heather Troxel, as part of her graduate work at CSU, evaluated sensory quality of melons stored at different temperatures. She concluded that storage of Haogan var. melons at 50˚F received higher scores than melon stored at ambient 68˚F among an untrained sensory panel (Troxell et al., 2008). It is likely that different types or cultivars respond differently in terms of sensory attributes.

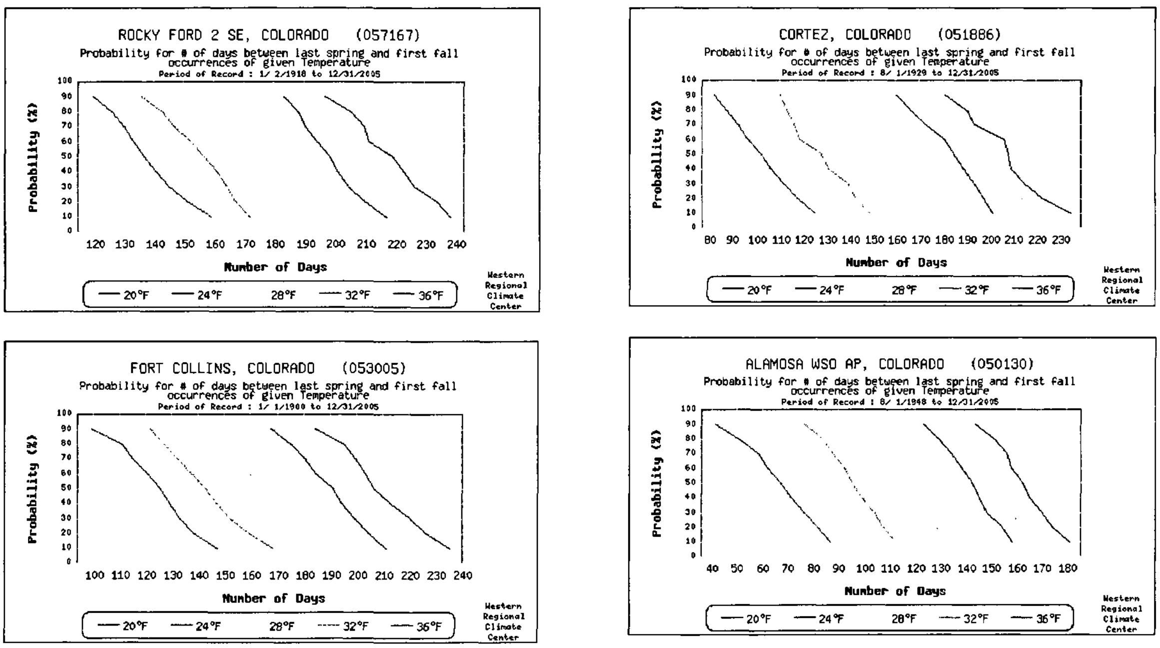
Cultivar selection

The small grower often needs a product that uniquely identifies her/him in the marketplace, and melons provide this opportunity. A wide variety of aromas, textures, colors, sizes, and flavors are available in different cultivars of melons. Larger producers selling in regional markets may be limited to producing melons fitting into regional market preferences--as determined by grocery chains and centralized marketing channels. Selection of cultivars that have outstanding sensory attributes need to be matched with good yields and relative ease of production. Colorado's favorable climatic conditions allow a great deal more latitude in cultivar selection than the eastern part of the country where disease resistance is a primary consideration. However, the shorter season areas in our state require close attention to the number of days needed by the melon to ripen. Many of the large fruited melons require a longer season than can be reliably planned on.

Days to maturity

The earliest Asian and small crisp melons may be ripe 65 days after transplanting but many muskmelons require 76 days from transplanting, and larger honeydew and winter melons require 103 days. By choosing cultivars that overlap harvest periods, a grower can provide continuous harvest of melons from the latter part of July through frost, with a variety of types. Alternatively, sequential planting can extend a harvest period that starts in late July through frost with the same cultivar. The use of frost probability tables (Figure 5.4) for production planning reduces the risk of losing frost sensitive crops such as melons.

Figure 5.4 Probability of frost-free days of four areas in Colorado.



Source: WRCC, 2008.

Pest and disease resistance

Disease resistance to soil-borne diseases is especially important where small acreage results in short interval rotations and disease life cycles are not broken. Resistance to Fusarium wilt may be a requirement in fields that are infected with this fungal disease. The most common diseases of melons are listed in Table 4.3, and biological and common disease management approaches are presented in Table 4.14.

Cucumber beetle has become a major pest of cucurbits in Colorado, and is difficult to control in organic systems. Cucumber beetle has been reported to prefer cucurbits with higher concentration of cucurbitecin, a feeding stimulant for cucumber beetle. Screening of cultivars within the *C. melo* species for resistance to this pest, and breeding cultivars with lower cucurbitecin content is needed. Protection of the crop through the 3 leaf stage is reported to increase survival of the plant, but does not reduce the chance of infection of plants with bacterial wilt, which is caused by *Erwinia tracheiphia* and transmitted by about 10% of the beetles. Other than cucumber beetle, few insects are serious pests of melons in Colorado.

Yield potential

The national average of muskmelon yield is 186 cwt/ac, honey dew yield slightly less, and water melon slightly more (ERS, 2008). There is a wide range of yield potential among the specialty melons, as demonstrated in the cultivar trials conducted at RMSOFP in 2005-2007 (see Figures 5.5 and 5.10). Larger melons produce fewer per plant. Melon size is also correlated to planting density (Brandenberger and Wiedenfeld, 1997).

Quality

Melon quality is based on texture, sweetness, and aromatic sensory perception. Eating quality is a combination of cultivar and ripeness at harvest. Under-ripe melons lack sweetness and can be tough, while overripe melons become mealy and may even begin to ferment. Texture quality is quite variable among different types, with honeydews producing crisper flesh than other types. Some of the western shipping melons that have been bred for long hauling can actually be rather tough textured. Brix measurements measure the sweetness (soluble solids), but aroma is another important sensory experience that is important, and difficult to measure. There has been some research that indicates soil type may impact sensory attributes of melons as well (Bett-Garber et al., 2005).

Plant vigor

Plant vigor is especially important for seedlings when challenged by heavy herbivory of cucumber beetles. Quick vine growth that quickly covers the ground reduces weed competition. Overly vigorous vine development hinders harvest somewhat, and can be managed with fertility and irrigation practices in the weeks preceding harvest.

Lettuce

Lettuce is the most consumed fresh vegetable in the U.S., and Colorado is the third largest producer in the country (Colorado Agricultural Statistics Service, 2005; ERS, 2008). Most of Colorado's lettuce production is in the San Luis Valley, where cool summer temperatures provide ideal production conditions for this cool season crop. However, lettuce can be produced in most areas of the state in spite of less than ideal temperatures. Varietal choice and production methods allow lettuce to be grown even during Colorado's hot summer months. Season extension using high tunnels is another production option for the small organic grower interested in maintaining market presence throughout a good portion of the year.

Lettuce is classified as crisp head, loose leaf, romaine, and butter types. The crisp head types, such as the widely used iceberg lettuce, are characterized by tightly wrapped heads of blanched leaves. Another crisp leafed lettuce is the Batavian type, with an open leaf habit, a variety of colors, and excellent eating qualities. Loose leaf lettuces produce open rosettes rather than true heads, and a wide array of leaf texture, color, and shape. The butterhead types produce small tight heads of thick leaves that possess a unique buttery, sensory quality when eaten. Romaine lettuce (also known as cos) produces a strong upright plant habit, with crisp texture. Leaf texture varies from smooth to savoyed. Romaine hearts are popular in food service, where a sturdy, crisp alternative to iceberg lettuce is desired.

Leaf color of lettuces range from wine red to dark green to very light green. Some cultivars are speckled with a range of colors. Textures range from smooth and buttery, to crisp and almost leathery. Flavors range from mild and sweet to somewhat bitter.

Outside of the cool mountain valleys, spring and late summer production in Colorado produces high quality lettuce. However, midsummer production becomes more of a challenge. Finding cultivars that resist bolting during hot weather is a major challenge when growing full-sized heads. To avoid the danger of losing a crop to bolting, one approach is to grow it as a baby lettuce crop, harvesting it before the weather is too hot.

Cultural requirements and practices

Some but not all cultivars of lettuce require light to germinate. Seed may fail to germinate if exposed to temperatures above 77°F for 24 hours. This high temperature dormancy can be broken by exposing it to cool temperatures, but in field conditions this may result in very uneven and poor stands. Combined effects of temperature and light are complex, and some seed companies treat seed with a variety of plant hormones to “prime” seed, insuring germination under adverse conditions.

Temperature

Lettuce is a cool-season crop, best grown when daytime temperatures are between 66˚F – 73˚F and evening temperatures drop to 45˚F –52˚F. Higher temperatures encourage most cultivars to bolt (develop a seed stalk), resulting in bitter, unpalatable leaves. Lettuce is quite tolerant of cold temperatures, especially in the younger stages of development. Published material reports that well-hardened lettuce will tolerate temperatures as low as 22˚F (Swiader and Ware, 2002). However, in the fall and winter of 2008, lettuce trials in high tunnels at CSU RMSOFP continued to grow after temperatures dropped to –17 ˚F! Growth during cold weather becomes very slow, and frost damaged epidermal cells do predispose the plant to bacterial infection and soft rots, presenting challenges for winter high tunnel production.

Soil fertility

Lettuce is not a heavy feeder, but its shallow root systems and intolerance of drought requires regular irrigation. These irrigation practices result in N being lost to leaching (Dabney et al., 2001). Lettuce will remove about 100 lb/ac nitrogen, which is the most limiting nutrient for lettuce growth. Lettuce also requires about 150 lb/ac P_2O_5 and 170 lb K_2O per acre(Maynard and Hochmuth, 1997). To avoid losing excessive N to leaching, conventional lettuce production relies on side dressing nitrogen to sustain rapid growth of the later stages of development. Timing of N nutrition in organic systems is, as mentioned in Chapter 1, difficult because of the many variables that affect the rate of mineralization of organic N. Side dressing with compost and/or pelletized organic fertilizer, or injection of high N fertilizer in irrigation water are options for spoon-feeding lettuce when the crop most needs it. Micronutrient deficiencies are not common in lettuce, but lettuce does respond to supplementation when low soil concentrations of manganese, copper, and molybdenum exist (Table 5.5).

Table 5.5. Relative responses of lettuce to micronutrient applications

Micro nutrient	Critical levels in the soil below which crop will respond to application	Degree of response expected
B	0.1–0.7 ppm	Med
Cu	0.75 ppm (EDTA extraction)	High
Zn	0.5–1.0ppm (DTPA method)	Med
Mo	0.04–0.2 ppm	High
Fe	2.5–4.5 ppm (DTPA extraction)	Low

Source: Maynard 1997; Swiader 2002

Crop establishment

Lettuce is usually direct-seeded, because it germinates and emerges very easily and quickly, provided that high temperature dormancy is not a factor, and some moisture is available. During midsummer, when soil temperatures can be quite high, irrigation helps reduce the soil surface temperature, aiding in germination. During the early spring, germination may occur at temperatures as low as 33˚F, but emergence is quite slow. Some farmers will sow lettuce in the middle of the winter, and allow the seasonal weather patterns to determine when the crop will emerge. The advantage of this strategy is very early establishment of the crop before weed competition becomes an issue. Two other strategies used to avoid weed competition during crop establishment are to use stale bed technique (see Chapter2) before sowing or before transplanting the crop. Transplanting lettuce is not widely practiced, but is advantageous in terms of weed management and producing a crop during a short period of time. Also, transplanting eliminates the need for thinning a direct-seeded crop, which is tedious and time consuming. Where high temperature seed dormancy results in poor stands in the middle of the summer, transplants provide an alternative. A transplanted field also produces a perfectly spaced and populated field. The cost of growing the transplant and placing it should be compared to the expense of thinning, crop maintenance incurred in a longer standing crop, and the opportunity costs of tying-up land in a crop that takes longer to reach harvest time. Vacuum seeders accurately space seed, so little thinning is required later; vacuum planters are expensive, however, and are used by few small producers.

For full size lettuce, plants are spaced 8–12 inches in the row, and commonly planted on beds of two or three rows. Baby lettuce is drill seeded with rows spaced 4–6 inches apart, or broadcast on the bed top and lightly cultivated to cover the seed. Bed configuration in organic production is often determined by the cultivation tools and methods used, since no herbicides are used.

Irrigation

Irrigation of lettuce is needed to keep the soil from drying out throughout the growth period. Because lettuce is a shallow rooted crop, frequent, light irrigation with sprinkler or drip irrigation is efficient. Furrow irrigation requires narrow bed widths and shallow furrows, so that the root zone can be wetted quickly with a minimum of water applied. Sprinkler irrigation should be designed so that water droplets are small and do not splash too much soil into the developing head, to lessen the need for subsequent washing. Irrigation of about 0.5 inches per week is applied during establishment, and 1 inch per week the final few weeks of growth, for a total ranging from 10–20 inches depending on the type of lettuce, soils, and weather conditions. Irrigation scheduling options are discussed in Chapter 3.

Pest and disease management

Lettuce is attacked by a variety of pests (see Tables 4.1–4.18), most of which can be well controlled with organic management techniques. Lettuce aphid is probably the most difficult arthropod pest to control in lettuce, because it establishes deeply in the head, making it difficult for biocontrol agents or contact pesticides (soaps and pyrethrins) to access. It becomes a more serious pest late in the season when some of the natural enemies become less active. Very early season and very late season lettuce crops are under the greatest aphid pressure, probably because of the lack of active populations of natural controls.

A number of caterpillar species feed on lettuce, resulting in holey leaves and frass contaminated heads. Fortunately, caterpillars are easily controlled with B.t. insecticides when natural enemies fail to provide sufficient control.

Diseases in lettuce are somewhat limited in Colorado, however, curly top virus is occasionally a serious problem, as is aster yellows virus. The leafhopper-vectored diseases can be reduced by using floating row covers.

Palestriped flea beetle can be a problem in some years, and has been observed to be especially problematic midsummer on the Batavian crisp leaf lettuces and red leafed lettuces, where feeding damage is noticeable.

Harvest and post- harvest handling

Lettuce is very perishable, and must be handled properly to maintain its quality. Immediately after harvest it should be chilled and kept moist. Large lettuce growers generally harvest and field-pack the lettuce into cartons and take it immediately to a packing shed, where it is either vacuum-cooled or hydro-cooled, and stored at 32˚F with high humidity. Well-chilled and hydrated lettuce can be kept in good condition for 3 weeks after harvest. On the small farm, where facilities such as hydro-coolers and vacuum coolers do not exist, lettuce is often harvested into field totes, taken to a dunking tank where any field soil is washed off, and cooled to the lowest temperature possible. Wet plants can then be packed into totes or waxed boxes and are stored in coolers or taken directly to market. Storage at 37˚F rather than the recommended 32˚F decreases storage life of loose leaf lettuces by about 50% (Nonnecke, 1989). Higher than optimal storage temperatures result in soft rot and other bacterial degradation. If lettuce is stored with ethylene producing fruits such as apples or melons, russet spotting (red spotting along the midribs and veins of the outer leaves) is a common problem.

Washing lettuce, which is a common practice, has received attention recently because of the possibility of contamination with enterobacteria. Wash water must come from a clean source known to be free of these pathogens, and replacement and/or sanitation of the wash water are important management practices.

Cultivar selection

Cultivar selection of lettuces is based on the grower's market demand and what grows well in a particular area. A mixture of types and colors of lettuces is a common approach. During the cooler parts of the year, growers can successfully produce almost any type of lettuce; however, during the summer months selection of cultivars may be dependent upon resistance to bolting. Another disorder that is commonly associated with specific cultivars is tip burn. This physiological disorder results from a failure of the plant to take up enough calcium during rapid leaf development and results in necrosis along the leaf margins.

Days to maturity

The number of days from sowing to maturity is quite variable among types of lettuce. Bibb or butter types mature quite quickly, and romaines and crisp head types are the slowest to reach full size. Loose head types are intermediate. From seed to a harvestable stage, bibb lettuce may take as little as 45 days under ideal conditions, and be harvestable over a period of 1–2 weeks. Loose leaf lettuces generally take about 60–85 days to reach full size from seed, and romaine and head types may require 75–90 days to reach full size from seed. Transplanted lettuce is grown in cells for 3–4 weeks before planting in the field. Within another 4–6 weeks the crop reaches full harvestable size. Baby lettuce is commonly harvested in less than a month from sowing, and can be harvested again in 10–15 day intervals for a couple of times if the quality remains good.

Pest and disease resistance

Several insects enjoy feeding on lettuce (see Tables 4.1–4.18), and plant resistance to insect attack is not especially successful. Among the pests that are especially troubling in Colorado is the red lettuce aphid, for which some cultivars are claimed to provide resistance. However, field trials of these cultivars in 2005 at Grant Family Farms in Wellington, Colorado, (GFF)[11] failed to indicate any difference in resistance with other lines of the same types of lettuce.

Many cultivars of lettuce express resistance to downy mildew (caused by *Pernospora farinosa*, a common late season disease in Colorado). Resistance to physiological disorders including tip burn and bolting are also expressed in a number of cultivars, however good irrigation practices mitigate this issue in most cases. Cornell University has produced a comprehensive list of lettuce cultivars and their resistance to a variety of diseases and physiological disorders (Zitter and Mcgrath, 2006).

Yield potential

Because lettuce is sold by the count (generally 24 heads/case) the objective is to maximize the number of harvestable heads per acre. Therefore, cultivar selection for yield potential is a function of the crop's ability to complete development. Cultivars that reach size in the expected amount of time and resist disease, bolting, and tip burn are likely to make the grade. It is not uncommon for a planting of lettuce to go unharvested because of one or more environmental challenges. Sequential planting reduces the risk of losing every planting and increases the chance that some of the plantings will produce a good crop.

[11] Grant Family Farms, 1020 WCR 72,Wellington, CO 80549 (970) 568-7654

Suited to organic/ Colorado conditions

The high, cool valleys of Colorado provide good growing conditions for lettuce during the summer months; any cultivars of lettuce can be grown there. Occasional uncharacteristic hot spells in these areas impact lettuce as in the lower hotter regions with bolting, and possibly tip burn. Cultivars suited for midsummer production where temperatures regularly reach the upper 80s°F are limited; however, some of the Batavian cultivars, many of the butter types, and several green loose leaf and green romaine may be grown successfully with adequate irrigation. All of the red-leafed cultivars are prone to bolting except for the red Batavian cultivars which have been successfully grown during hot summer weather at CSU RMSOFP. Because disease issues are not major concerns for lettuce in Colorado, we have the benefit of being able to grow a wider variety than other regions, where greater disease pressure exists. Aside from the physiological challenges of bolting and tip burn that challenge conventional and organic growers alike, there does not appear to be a great need for lettuce suited to conditions or practices unique to organic production.

Spinach

Spinach is well recognized as one of the "functional foods" thanks to its high mineral content and phytochemicals. Spinach is the most important vegetable green grown in the U.S., and is produced on a large scale organically because of its popularity as a frozen and processed baby food. Colorado is the third largest spinach producer in the country, and most of the production occurs in the San Luis Valley.

For the small-scale organic grower, spinach is a valuable crop for a number of reasons. It is relatively easy to grow, has few pests, and is a quick crop that fits into short time slots during the summer. It can also be sown in the fall to overwinter for an early crop, providing income in the spring before most other crops are available. It is well recognized as a nutritious vegetable and is a good complement to any mixture of vegetables being grown.

There are three main types of spinach: smooth leaf, semi-savoy, and savoy leaf. Spinach is also classified by seed type: round and prickly-seeded. Traditionally the prickly seed types were used for over wintering; however, round seeded types prevail now. The flat leaf types are grown mainly for processing because they are easier to clean, and the savoyed and semi-savoy types are grown mainly for fresh market. However, all types are seen in the fresh market.

Cultural requirements and practices

Spinach is a hardy, cool season crop, preferring temperatures in the range of 60˚F; however, many cultivars are tolerant of higher temperatures if supplied with adequate irrigation. Like lettuce, it is a short-season crop, reaching harvestable size in 45-65 days.

Spinach does reasonably well on alkaline soils, but manganese deficiency can be a problem. It is among the most tolerant of vegetable crops of salty conditions. Spinach nutrient requirements are relatively high for the amount of time it is the field. It removes about 100 lb/ac N. 120 lb/ac, and 100 lbs/ac K_2O (Maynard and Hochmuth, 1997). Early season nitrogen, when soils are cool and mineralization of organic N is slow, may require supplemental N applications through the irrigation water if soil analysis is low. Spinach responds well to micronutrient fertilization when levels are below those noted in the Table 5.6. Composted manure is a good source of these nutrients.

Table 5.6. Relative response of spinach to micronutrient applications

Micronutrient	Critical levels in the soil below which crop will respond to application	Degree of response expected
B	0.1–0.7 ppm	Med
Cu	0.75 ppm (EDTA extraction)	High
Zn	0.5–1.0ppm (DTPA method)	High
Mo	0.04–0.2 ppm	High
Fe	2.5–4.5 ppm (DTPA extraction)	High

Source: Maynard 1997; Swiader 2002.

Crop establishment

Spinach is always direct-seeded, often on beds with three rows to a bed. Cultivation equipment configuration is a determining factor for organic spinach spacing. Spacing is close in-row, and between rows spacing is generally 8–12 inches. Some growers plant on very wide beds (80 inches) with 6 rows of spinach on a bed. Germination of spinach seed will occur at very low temperatures (35˚F) but the optimum is between 45˚F and 75˚F. As soil temperatures rise, germination speed increases, but germination rates decrease. Choice of cultivars that germinate and emerge at higher temperatures is an attribute that is very beneficial for midsummer planting. Midsummer plantings in warmer parts of the state require higher seeding rates to achieve equivalent stands as early or late fall seeded crops. Thinner stands result in less intercrop competition and moisture stress resulting in less bolting (LeStrange et al., 2006). For overwintering, spinach is planted in mid-September, giving it time to emerge and become well established before winter.

Irrigation

As with lettuce, spinach is shallow rooted and intolerant of dry conditions. Furrow and sprinkler irrigation is common, and as with lettuce, sprinkler nozzles should be sized to reduce splashing of soil onto the leaves. Where available, growers use sprinkler irrigation for crop establishment, with short and frequent applications to overcome soil crusting, and then switch to furrow irrigation for the remainder of the production. Fresh market spinach production (with a shorter growing period than processing spinach) may require application of about 8–12 inches of irrigation water (LeStrange et al., 2006). Savoy spinach, with its characteristic puckered leaves, catches and holds sand and soil particles very effectively, making furrow irrigation preferred. Drip irrigation on short season crops such as spinach is less commonly applied because of the expense and effort it requires for installation and removal of drip tape for the short period of time it is used. On the other hand, the convenience and flexibility of being able to irrigate at the same time as doing other field operations may be worth the extra expense.

Weed management

Weed management with spinach is important not only because of competition but also because of contamination of the spinach with weed leaves when harvesting. Because spinach is such a short-season crop, cultivation and crop removal in a short period of time effectively disrupts weed life cycles. Timing of cultivations is critical, because the closely spaced rows close over with crop foliage, and leaves are damaged by late cultivation.

Pest and disease management

Most of the spinach grown in the major production areas of California is the flat-leaf type. Because of its popularity, flat-leaf spinach receives the greatest attention in spinach breeding programs. Colorado has historically served the east-coast fresh spinach market and its taste for the thick-leafed savoy spinach has kept much of Colorado's production in this type. The savoyed spinach, while much superior in flavor, is not grown as widely, and consequently has received less attention by plant breeders focusing on disease resistance breeding. Savoy spinach remains susceptible to more diseases than many of the improved lines of flat leaf spinach that are bred with single gene resistance to downy mildew, caused by *Pernospora farinose spinaciae.*

In addition to downy mildew, damping off disease (a fungal bacterial complex) is more common under warm conditions, especially when the soil is kept very wet and where spinach has been produced repeatedly. Good soil drainage, care to not over-irrigate, and crop rotation are effective deterrents to this disease. Organically approved fungicides and their use is covered in Chapter 4.

Small-scale farmers, selling directly to consumers and desiring the highest culinary quality of spinach, prefer to grow the savoyed cultivars, but need to pay extra attention to managing disease problems. Susceptibility of so-called resistant cultivars is now common, and positive identification of the strain will probably require that a sample be sent to the USDA spinach diagnostic lab in Salinas, California.

Pests that attack spinach are listed in Tables 4.1 and 4.7–4.12. Leaf miner and spinach flea beetle are the most elusive and difficult to control of the spinach pests, but if beneficial habitat is provided on the farm, they have a relatively minor impact. One of the famers surveyed for this project noted that corn rootworm beetle larvae have been a serious problem on his farm when spinach is planted on land that was previously in corn production, indicating that rotation of spinach following corn is ill advised.

Beet curly top virus (BCTV) has been a serious problem on plantings at the RMSOFP. Other common viruses on spinach include cucumber mosaic virus (CMV) and beet western yellows virus (BWYV). All of these diseases are insect vectored (aphid and leafhopper). Floating row cover can be used to exclude the vectors if this is a recurring and serious problem. A drawback of using floating row covers is the need to remove and replace it every time cultivation is needed.

Harvest and post-harvest handling

Harvesting of spinach on the small farm is generally done into totes when the leaf is about 8 inches long. When harvested for bulk packing, the crop is cut about 4 inches above the soil line, and leaves and stems are packed in totes. This method of harvest allows a field to be harvested multiple times until the plants begin bolting or weed contamination becomes an issue. Alternatively the crop can be bunched, in which case the plant is cut just below the soil surface, and several plants are bundled together and field-packed with 24 bunches to a carton, with a minimum weight of 20 lbs per carton. Baby spinach is bulk harvested as soon as the leaves are 2–3 inches long and packed into 10 or 20 lb. boxes. Multiple harvests of baby spinach are common, but quality of the crop is compromised as time proceeds. Much of the conventionally grown processing spinach is machine harvested; however, organic spinach is more commonly hand harvested.

Once harvested, spinach is highly perishable; it needs to be washed and iced or cooled immediately. Cooling methods include vacuum cooling, forced-air cooling, and hydro-cooling. Small farms are probably limited to improvised hydro-cooling where spinach is immersed in cold water, and then taken to cold storage. The need to use clean water for washing and hydro cooling to reduce the risk of contamination by enterobacteria cannot be over emphasized. Early morning harvest greatly reduces the amount of cooling required to maintain high quality. Storage should be at 32˚F with high humidity.

Cultivar selection

In addition to selecting cultivars for yield, disease, and bolt resistance, there are some physical characteristics that are important if spinach is bunched, such as the length and pliability of the stem. Stems and leaves that withstand breakage when the crop is handled is also an attribute that improves the appearance and shelf life of bunched spinach.

Cultivar trials 2006–2008: tomato, melon and spinach

Regional vegetable cultivar trials provide valuable information to farmers about the suitability of different cultivars grown under environmental conditions similar to their own. A common complaint among organic producers has been that cultivars available to them have been bred with the assumption that conventional practices regarding fertility and pest and disease management would be used to grow them. There is also an assumption that without the use of synthetic fertilizers or effective pesticides, cultivars that are highly productive under conventional management may not be well suited to the rigors challenging organically grown crops.

Since 2003, a number of demonstration plantings, cultivar trials and research evaluating nutritional differences of different cultivars have been performed at RMSOFP. Some of the most pertinent results (primarily cultivar yield comparisons) for organic growers are reported here.

As part of a USDA/CSREES/NRI research project titled "Differentiating Small Farm Produce Offerings through Nutritionally Superior Cultivars, Marketing, and Extension Programs"[12] led by Dr. C. Stushnoff[13], tomatoes, melons, spinach, broccoli, lettuce, and garlic were grown and evaluated for their phytochemical properties, sensory acceptability to consumers, and varietal performance under conventional and organic production practices. Melon and tomato yields from this study are reported here, and are of special interest to growers. Included here are results from cultivar trials of tomatoes and melons carried out for Seeds of Change (SOC), a seed company in New Mexico that specializes in organic seed, and spinach trials conducted for Grant Family Farms (GFF), one of the country's preeminent organic vegetable farms whose operations are near Wellington, Colorado. The phytochemical

[12] USDA/CSREES/NRI grant #2005-55618-15634, "Differentiating Small Farm Produce Offerings through Nutritionally Superior Cultivars, Marketing, and Extension Programs"; C. Stushnoff (Principal Investigator), P. Kendal, D. Thilmany,.M. Bunning, F. Stonaker. (co-PIs), K. Salandanan, H. Troxel, O. Kulen.

[13] Stushnoff (Dept. of Horticulture and Landscape Architecture, CSU.)

composition, sensory evaluations, and potential of marketing advantages of "nutritionally superior" cultivars are not reported here.

All of the trials took place on certified organic land at RMSOFP, using production methods that fit within the guidelines of the USDA NOP rules and are commonly used by organic growers in this region. Spinach trials were conducted at two fields on Grant Family Farms. Spinach bolting resistance is also reported.

Cultivar Trials; Melons

In 2005 and 2006, as part of the NRI research project, 10 cultivars of melons were trialed at the CSU Horticultural Research Center, using both certified organic and conventional growing systems. In 2007, 31 cultivars were trialed at the same research center for Seeds of Change[14] using organic growing methods exclusively. This trial included eight of the cultivars represented in the NRI projects, providing an additional year of data.

Methods: Melon 2005-2006

The organic/conventional trials were run at the Rocky Mountain Small Organic Farm Project (RMSOFP) on paired plots of land situated within 100 feet of one another with nearly identical soil characteristics (Nunn clay, pH 7.8), however organic matter content of the plots differed by 0.32%, with the organic plots being higher at 2.46%. Both organic and conventional plots had been soil tested and analyzed by CSU's Soil Testing Laboratory in the preceding fall, and compost or synthetic fertilizers were applied to each plot in quantities so that the treatments provided equivalent soil fertility. Based on these soil tests, 9.8 ton/ac poultry compost (A-1 Organic[15]) was applied to the organic block and immediately incorporated by rototiller. To match nutrient levels in the organic block, 346 lbs/ac of urea (45 - 0 -0) and 785 lbs/ac of triple

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[14] Seeds of Change. Santa Fe, NM

[15] A-1 Organics, Eaton, CO

superphosphate (0 - 20.1 - 0) were applied to the conventional block using a broadcast spreader. Subsequent soil analysis and tissue analysis was made in order to determine if any nutrient differences existed during the production season.

Transplants were grown in greenhouses at CSU, following organic production methods for all transplants. Seeds were sown into 3 inch, round Jiffy peat pots and filled with organic potting mix (Sunshine[16]). The plants were grown in the greenhouse with bottom heat maintained at 65 °F for 3 weeks, and transplanted to the field on May 21 of each year. 'Rootshield®' (BioWorks,[17] *Trichoderma harzianum*, Strain T-22 #9462) was drenched into the pots immediately before transplanting.

The plots had black plastic mulch and drip tape (Chapin twin-wall[18]) applied by machine one week before planting. Melons were transplanted into black plastic mulched beds at 24 inches spacing between plants and 6 feet between beds. The field plots measured 146 feet long and 36 feet wide. Plots were pre-irrigated, and two Watermark granular matrix sensors (Irrometer [19]) were installed in each plot to monitor soil moisture.

Drip irrigation with domestic water was applied at 0.5 gal/min/100ft, and application varied during the season from 0.5 hours/2 days to 2 hours/day in order to maintain water tension below 100 KPa. During the production period, crops were not permitted to suffer from water stress based on data from the 'Watermark' soil sensors.

[16] Sun Gro Horticulture Ltd. Canada
[17] BioWorks Inc., Geneva, NY
[18] Chapin Watermatics Inc., Watertown, NY
[19] Irrometer Company Inc., Riverside, CA

Permethrin (Loveland Products[20]) was applied in conventional plots and pyrethrin (Pyganic EC 5.0®, MGK [21]) was used in the organic plots both in 2005 and in 2006 to control cucumber beetle (*Acalymma vittatum*) on the seedlings.

All production methods for the organic and the conventional plots of melons were the same with the exception of insect pest management.

The plots were completely randomized in a split plot design with the whole plots arranged as a completely randomized design. Three blocks in each production system served as replications. Ten cultivars were planted in each block of the organic and conventional production plots. Melons were harvested at physiological maturity.

The melon cultivars grown in the trial were:

Charentais type:
Edonis, Savor

Galia type:
Arava

Honeydew type:
Honey Orange

Muskmelon type:
Burpee Hybrid, Early queen

Persian type:
Rayan

Specialty type:
Swan Lake, Haogan, Sweetie#6

[20] Loveland Products Inc., Loveland, CO
[21] McLaughlin Gormley King Company, Golden Valley, MN

Methods: Melon 2007

All production methods were the same for the Seeds of Change cultivar trials in 2007 except that no conventional trials were run. Three replications of each cultivar were randomly planted in blocks of 8 plants. Thirty-one cultivars of melons were grown, eight of which had been grown in the NRI trials. The cultivars grown were:

Asian type:
Sun jewel

Canary type:
Lilly

Casaba Type:
San Juan

Charentais type:
Edonis, Savor, Charentais, Sivian

Galia type:
Arava, Galia, Passport

Honeydew type:
Early brew, Honey orange, Honey pearl, Honey yellow, Megabrew, Snowmass, Sugarnut

Muskmelon type:
Early queen, Gold coast, Halona, Strike, Sweet granite, Western express, Western king, Wrangler

Persian type:
Sharlyn, Eindor

Specialty type:
Eel river, Haogan, Swan lake, Sweetie #6

Results

Yield data from 2006 were incomplete; however other parameters were measured in that year. The data collected for all three years have been combined to include the melon count per plant (2005 and 2007), weight per melon (pounds) and total yield per plant (pounds) (2005 and 2007). The data are being reported in this manner so that multiple years of results can be directly compared. In addition, a limited amount of data on the dissolved solids (sugar to water mass ratio, Brix) were collected for 2007.

The year specific data graphs include all cultivars listed in descending order beginning with the cultivar producing the largest fruit in that year. For each year, that hierarchy of cultivars changed. To assess that variability, cultivars planted in all three years were compared across years to evaluate the effect of three distinct growing seasons.

Results of trials in 2005

Yields for 2005 reported as weight per melon are first presented in Figure 5.5 to assess the difference between organic and conventional treatments. Tests of significance between the different cultivars can be assessed by comparing the error bars. Overlapping error bars between treatments (organic vs. conventional) and cultivars indicate that the differences were not statistically significant. The data show that there was no difference in individual melon weight between the two cropping systems. The difference between melons is represented by the letters located at the base of the conventional treatment column. Mean weights per melon for the combined treatments were assessed through t-tests. Cultivars with the same letter are not significantly different.

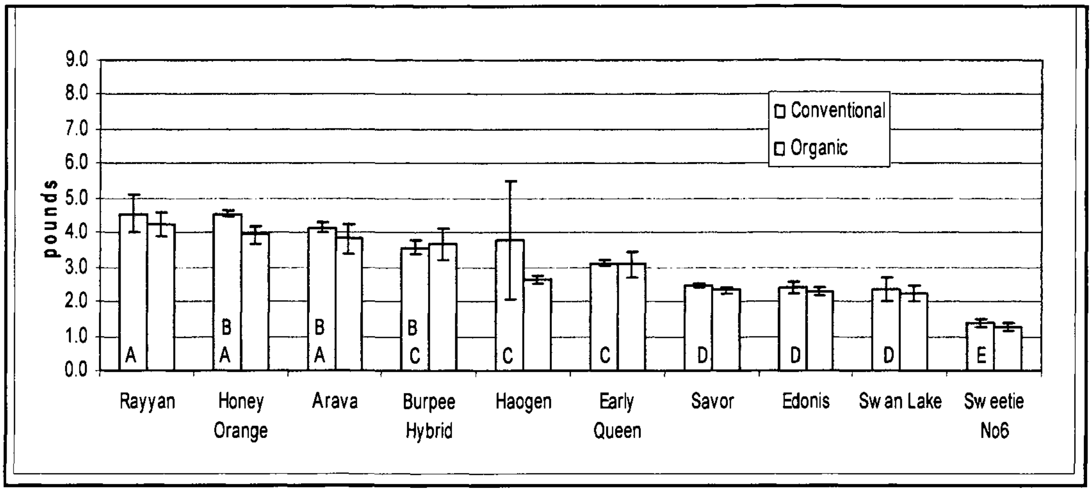


Figure 5.5. Conventional and organic melon weights of 10 cultivars in 2005 NRI trials. Cultivars with the same letter are not significantly different.

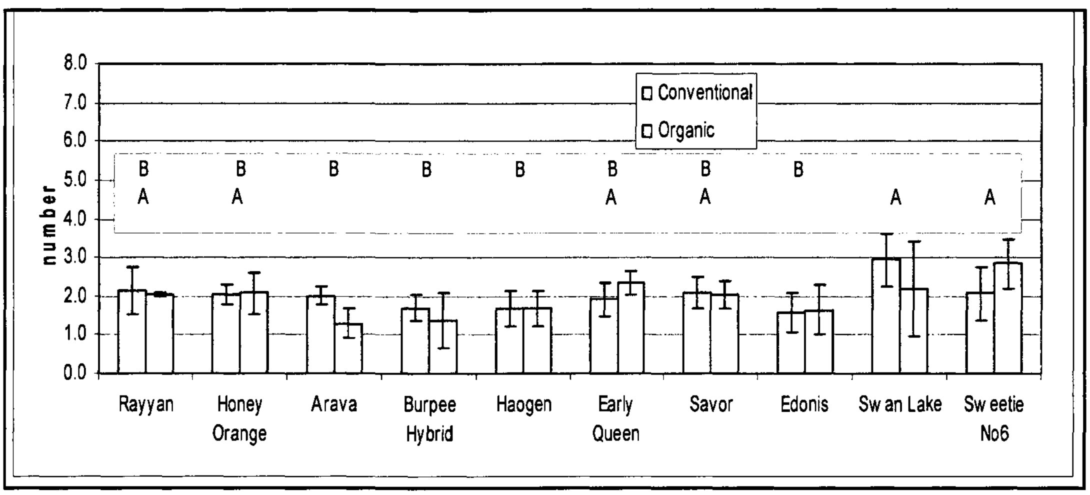


Figure 5.6. Melon count per plant of ten cultivars in 2005 NRI trials. Cultivars with the same letter are not significantly different.

Figure 5.6 presents the melon count per plant with the cultivars in the same order as Figure 5.5. As with Figure 5.5 there was no significant difference between the organic and conventional cropping systems. This is shown by the overlapping error bars. Differences between cultivars using the pooled data from treatments are shown by the letter bar positioned above the columns; cultivars with the same letter are not significantly different.

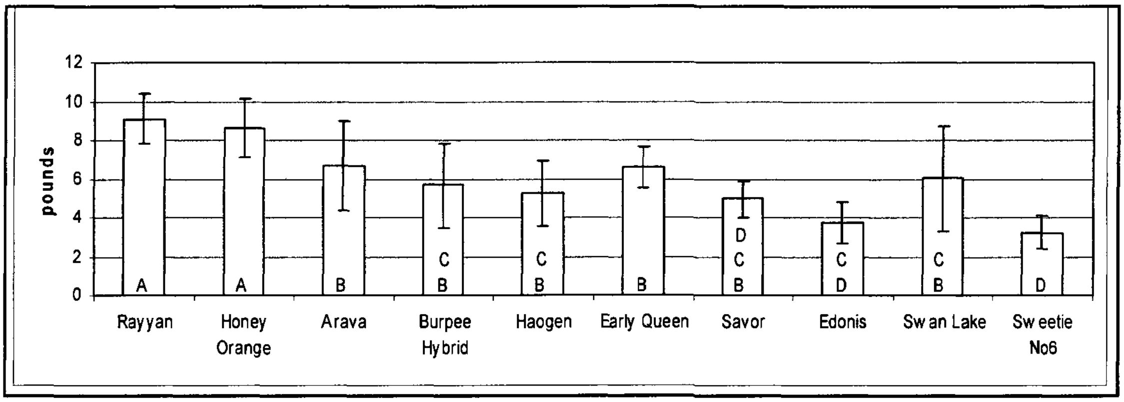


Figure 5.7. Total melon fruit production (lbs) per plant of 10 cultivars in 2005 NRI trials.

Figure 5.7 presents a combination of the data presented in Figure 5.5 and 5.6. Overall plant production was calculated by multiplying melon size by melon count per plant. The single column represents the combination of organic and conventional treatment data. As with Figures 5.5 and 5.4, cultivars with the same letter are not significantly different. From the data we can see that total fruit production is controlled, to a greater degree, by fruit weight than by fruit count. Total plant productivity was the highest for Rayan, Honey Orange, and Arava, the three cultivars with greatest fruit size. The cultivar with the lowest total plant productivity was Sweetie No. 6, which was the cultivar with the smallest fruit size. However, total plant productivity for Sweetie No. 6 was not significantly different from cultivars Edonis or Savor.

Results of trials in 2007

In 2007, 31 cultivars were tested including eight of the cultivars trialed in 2005 and 2006. Rayan and Burpee Hybrid were the two cultivars not included. Figure 5.8 presents the weight per melon in descending order. Orange highlighted bars identify cultivars that were grown in all three years of this study. Corresponding Brix measurements for selected cultivars are included. The variability in Brix measurements is a function of many factors, including: harvest date, sunlight penetration through the canopy, and gradients of sugar within the fruit. All fruits were harvested when they were ripe, as determined by parameters presented earlier, including rind color, senescence of the tendril and leaf adjacent to the fruit, and weeping exudates at the pedicel. The Brix values provide a quantitative assessment of those qualitative traits.

The added cultivars in 2007 produced a much broader range of fruit sizes, from Mega Brew (8 lbs) to Sweetie No. 6 (2 lbs). Figure 5.9 presents the melon count per plant in the same order as Figure 5.8. While Sun Jewel and Sweetie No. 6 show an inverse relationship between small melon size and high fruit count, that relationship is quite variable among the other cultivars. A high crop load often translates into smaller fruit so that total fruit production by weight approximates the total photosynthetic activity across the growing season. That relationship is not very strong in 2007. A regression of fruit count on fruit size shows significance $P = 0.029$, but only explains 15% of the variability ($R^2 = 15.5$).

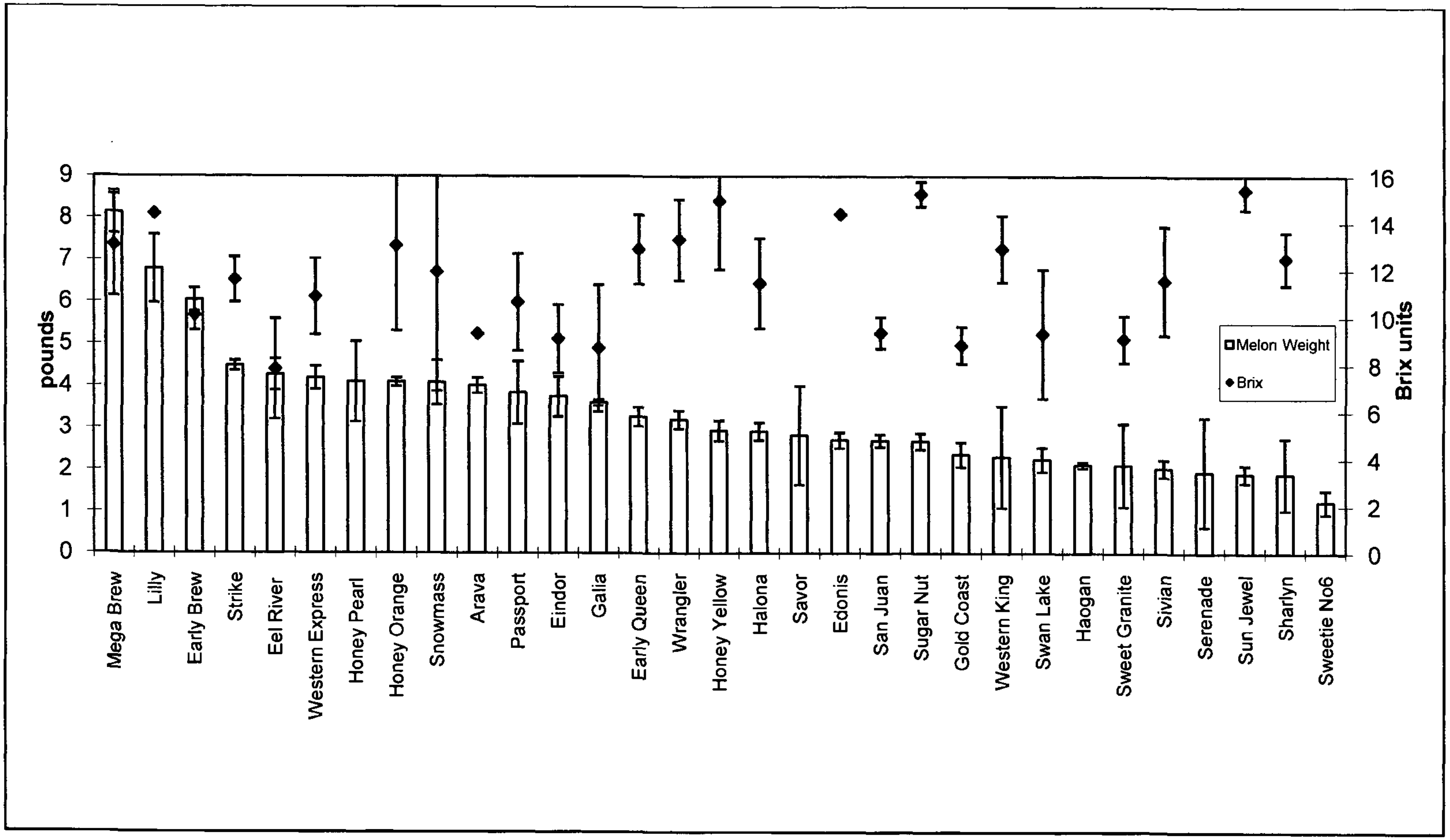


Figure 5.8 Weight per melon (lbs.) is identified by vertical bars and Brix is identified by blue diamonds. Orange bars identify cultivars that were grown in 2005, 2006 and 2007. Tan bars identify cultivars grown only in 2007.

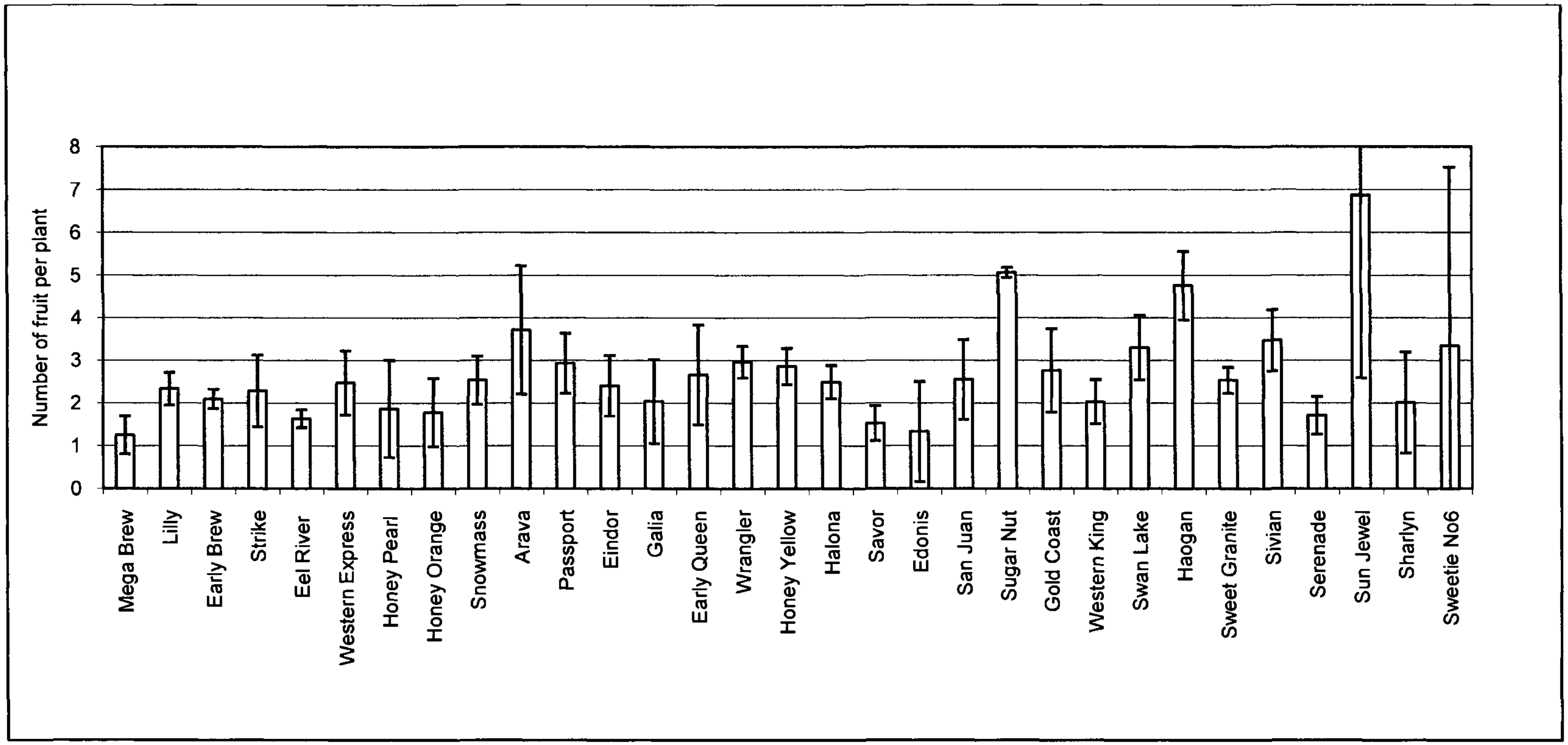


Figure 5.9. Melon count per plant. Orange bars identify cultivars that were grown in 2005, 2006 and 2007. Tan bars identify cultivars grown only in 2007.

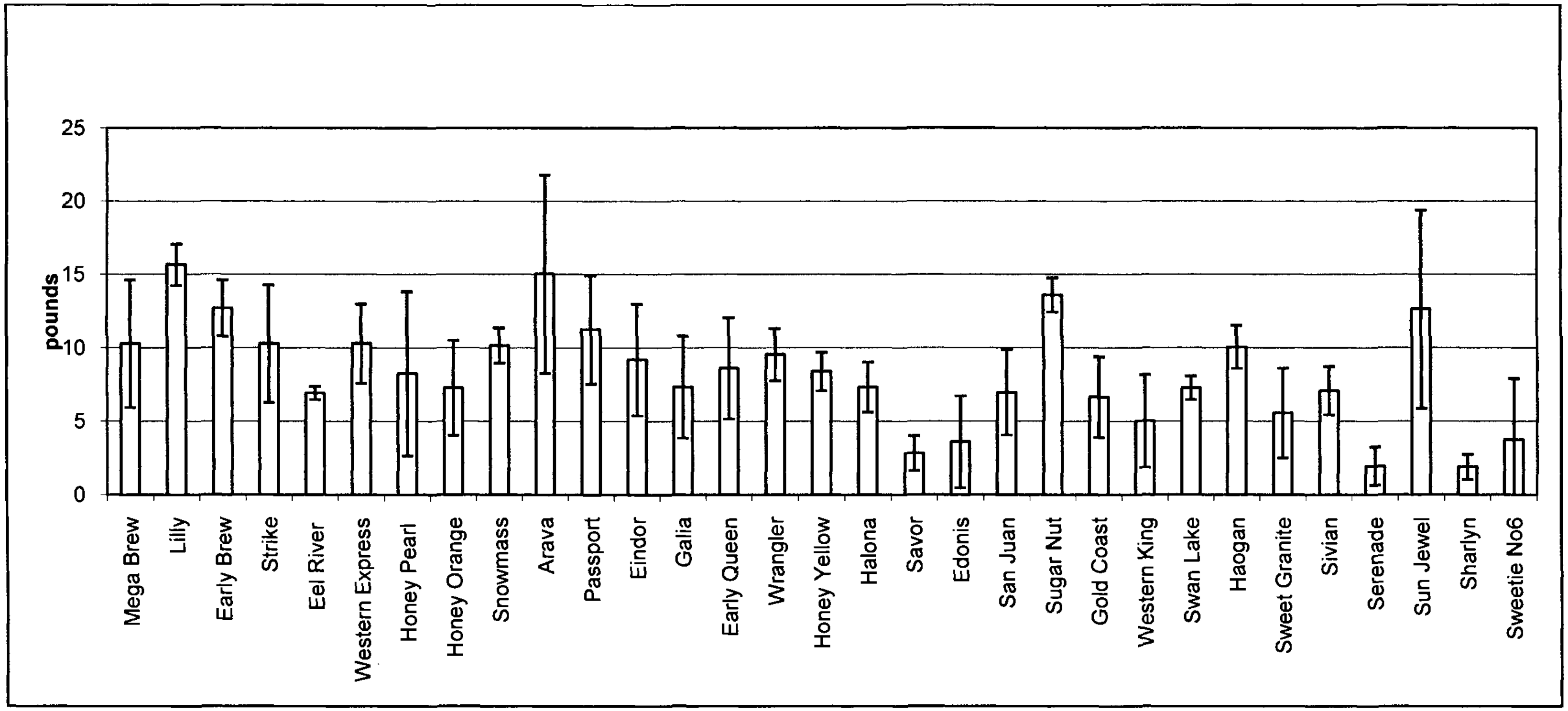


Figure 5.10. Total fruit production per plant (lbs.). Orange bars identify cultivars that were also grown in 2005, 2006 and 2007. Tan bars identify cultivars grown only in 2007.

Figure 5.10 presents the total fruit harvest weight for 2007; the order of cultivars is based on weight per fruit and the relationship is highly variable.

For a better understanding of the highly variable relationship between weight per fruit and fruit count, Figure 5.11 plots these values along with a regression line for each year and treatment of those cultivars that were grown in 2005 and 2007..

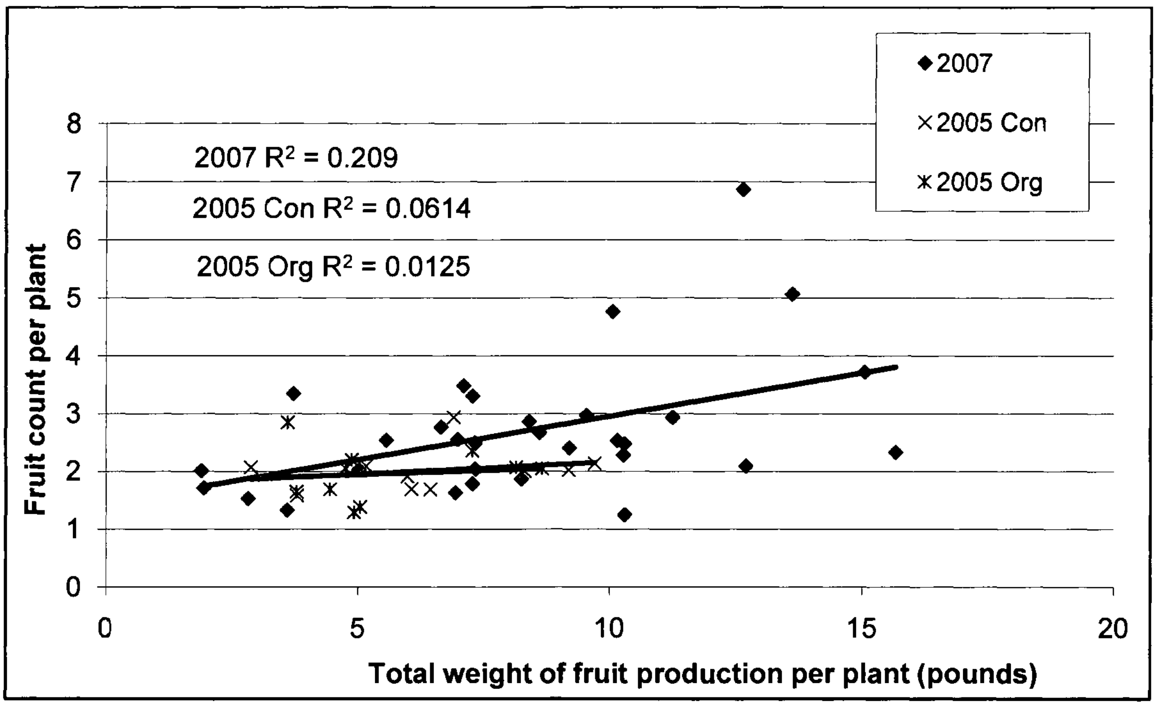


Figure 5.11 Regression analysis of the number of melons per plant; total weight (lbs) of fruit per plant in 2005 and 2007 trials.

Figures 5.12 and 5.13 present multiple year data for the eight cultivars grown in all three years. Honey Orange and Arava had the heaviest average fruit weight in all three years and Sweetie No. 6 had the lightest. The other five cultivars fell between these endpoints and varied year to year. Fruit count for all cultivars was quite variable and showed no trends from year to year.

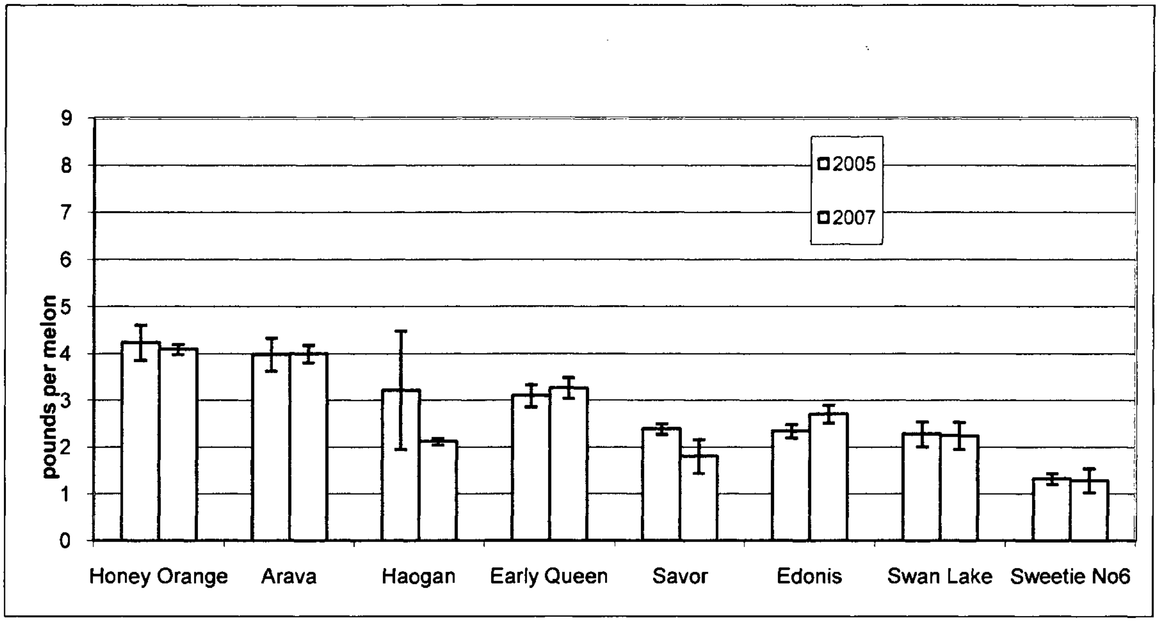


Figure 5.12 Yearly comparison by specific cultivar; weight (lbs.) per melon.

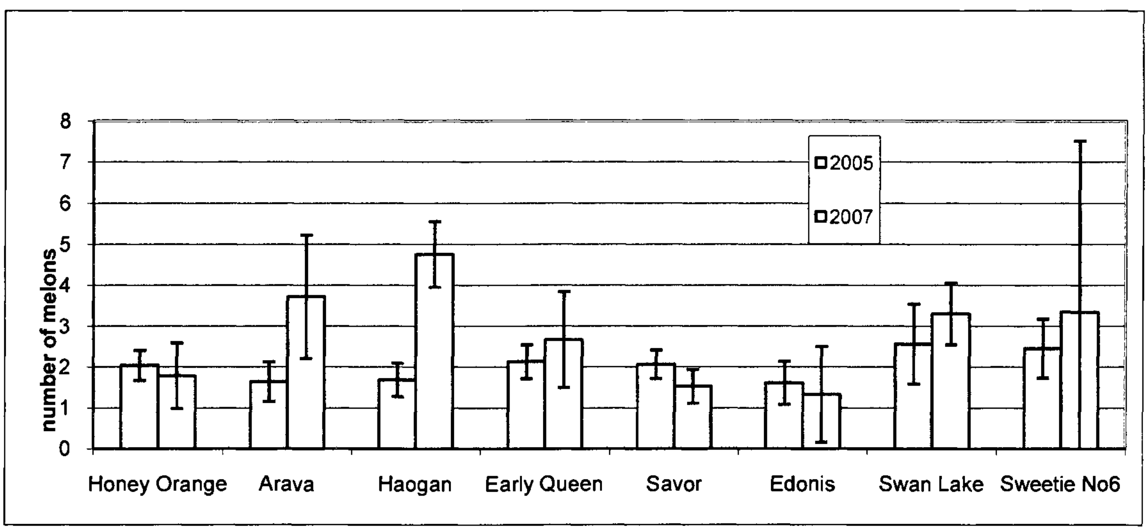


Figure 5.13 Yearly comparison by specific cultivar; melon count per plant.

Conclusions: melon trials

Melon is a well proven crop in the Rocky Ford area, where a high standard of quality muskmelons and watermelon has established a national name in the market. As small organic farmers from other parts of the state experiment with melon production it is becoming evident that this crop can be grown well under a wide range of conditions. The CSU cultivar trials in northern Colorado have indicated yield potential of several cultivars (see Figure 5.10) to be well above the national average yields 186 cwt/ac (Maynard and Hochmuth, 1997). For the small-scale organic farmer marketing directly to the consumer, melon quality may be more important than yield. More subjective qualities such as aroma, texture and eye appeal become very important in the choice of what cultivar to grow. More research in consumer preference, coupled with yield data presented here will be useful in the choice of cultivar grown by the small organic farmer. The high-yielding melons from each type represented in the CSU RMSOFP trials and include:

- Honeydew type - Sugar nut, yielding equivalent of 471 cwt/ac
- Muskmelon type- Early queen, yielding equivalent of 270 cwt/ac
- Canary type - Lilly, yielding equivalent of 508 cwt/ac
- Specialty melon type - Haogan; yielding equivalent of 363 cwt/ac

This list offers an excellent array of unique choices and excellent yields for the Colorado farmer.

Cultivar trials: tomatoes

As described in the introduction to the section on cultivar trials, tomatoes were evaluated as part of the larger program of NRI research. In addition, in 2007 a larger assortment of tomato cultivars was tested for Seeds of Change (SOC) using organic growing methods exclusively. Data from NRI research in 2006 and SOC research in 2007 are included and compared below.

Methods

Transplants for all tomato trials were grown in greenhouses at CSU in 48 cell plastic trays filled with organic potting medium. Seeds were planted two to a cell, covered with vermiculite, and placed under automatic misting. At the first true leaf stage, seedlings were thinned to one plant per cell by pinching off the second seedling. The tomato seedlings were grown with bottom heat (68˚F) for six weeks, during which time they were fertilized twice with Omega 6-6-6 using a concentration of 200 ppm N. The plants were hardened in the greenhouse by withholding water and applying wind with an oscillating fan. The transplants were somewhat stretched when taken to the field, and required support with bamboo skewers and a tomato clip. The tomato seedlings were drenched with Rootshield® and transplanted onto black plastic mulched beds on May 15 of each year into pre-irrigated beds and watered in with clear water. The plants were spaced 18 inches apart on the bed, and the rows were 6 feet apart. Five-foot wooden stakes were pounded 1 foot deep in between every other plant for subsequent trellising. When the plants were approximately 1 foot tall trellising was initiated, using a Florida weave technique. The plants were subsequently tied-up after approximately 1 foot of growth had occurred until the tomatoes (indeterminate cultivars) reached the top of the stakes. Irrigation during the season followed the protocol presented for melon trials, as described above.

In the NRI project, the only variable that was different for the organic and conventional plots was insect pest management. Potato psyllids were the only pests requiring control. Pyrethrin (Pyganic EC 5.0) was applied to the organic plots, and imidacloprid (Provado 1.6F)[22] applied to the conventional plots. Three applications were made to each treatment.

Harvest of all fully ripe fruit began in July and continued through frost (mid-September in 2006 and mid-October in 2007), with biweekly harvests. All fruit was counted and weighed.

Results

The yield data collected for both NRI and SOC trials have been reduced for this report to include the fruit weight (pounds), total fruit count per plant, and total fruit production per plant (pounds). However, 2006 data consisted of only total fruit production per plant, so multi-year comparisons are limited. The suite of cultivars in each year differed with only five cultivars comparable between 2006 and 2007.

Figure 5.14 presents 2006 total fruit production per plant for both conventional and organic cropping treatments. Although there was a trend of greater production in the conventional treatment, t-tests of the treatment means show that only Red Sun had significantly greater conventional tomato production. When comparing the conventional cropping treatment of each cultivar we find that only Red Sun and Early Girl have greater total fruit production than the five lowest producing cultivars. Figure 5.15 presents 2007 total fruit production per plant in descending order of productivity. Error bars represent one standard deviation and cultivars also trialed in 2006 and 2008 are highlighted with different colors.

[22] Provado 1.6F, Bayer Crop Science, Research Triangle Park, NC.

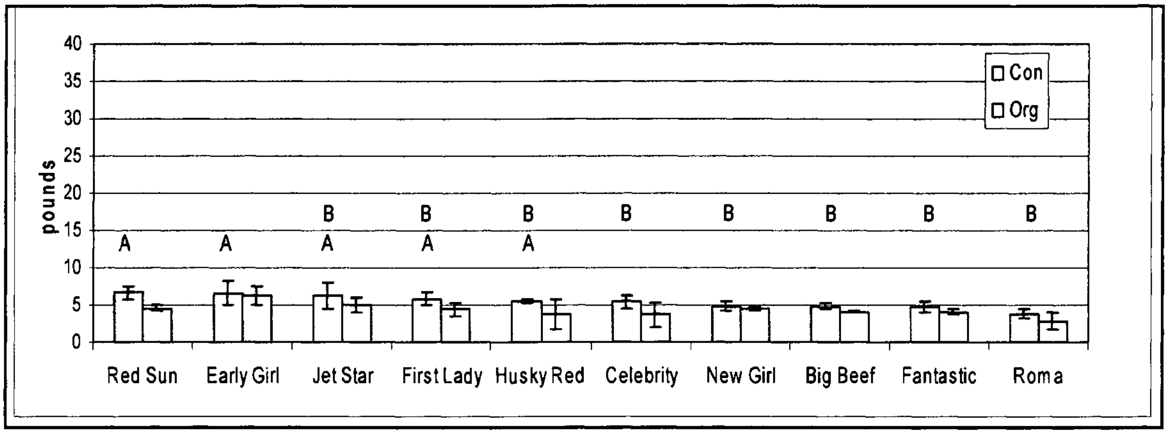


Figure 5.14. Total tomato production per plant (lbs) in 2006 NRI trial.

The obvious difference in 2007 is the dramatic increase in production over 2006 due to ideal growing conditions in 2007. Figures 5.16 and 5.17 present the fruit count per plant and individual fruit weight for 2007. These data were not comparable to 2006 because of the lack of fruit count data.

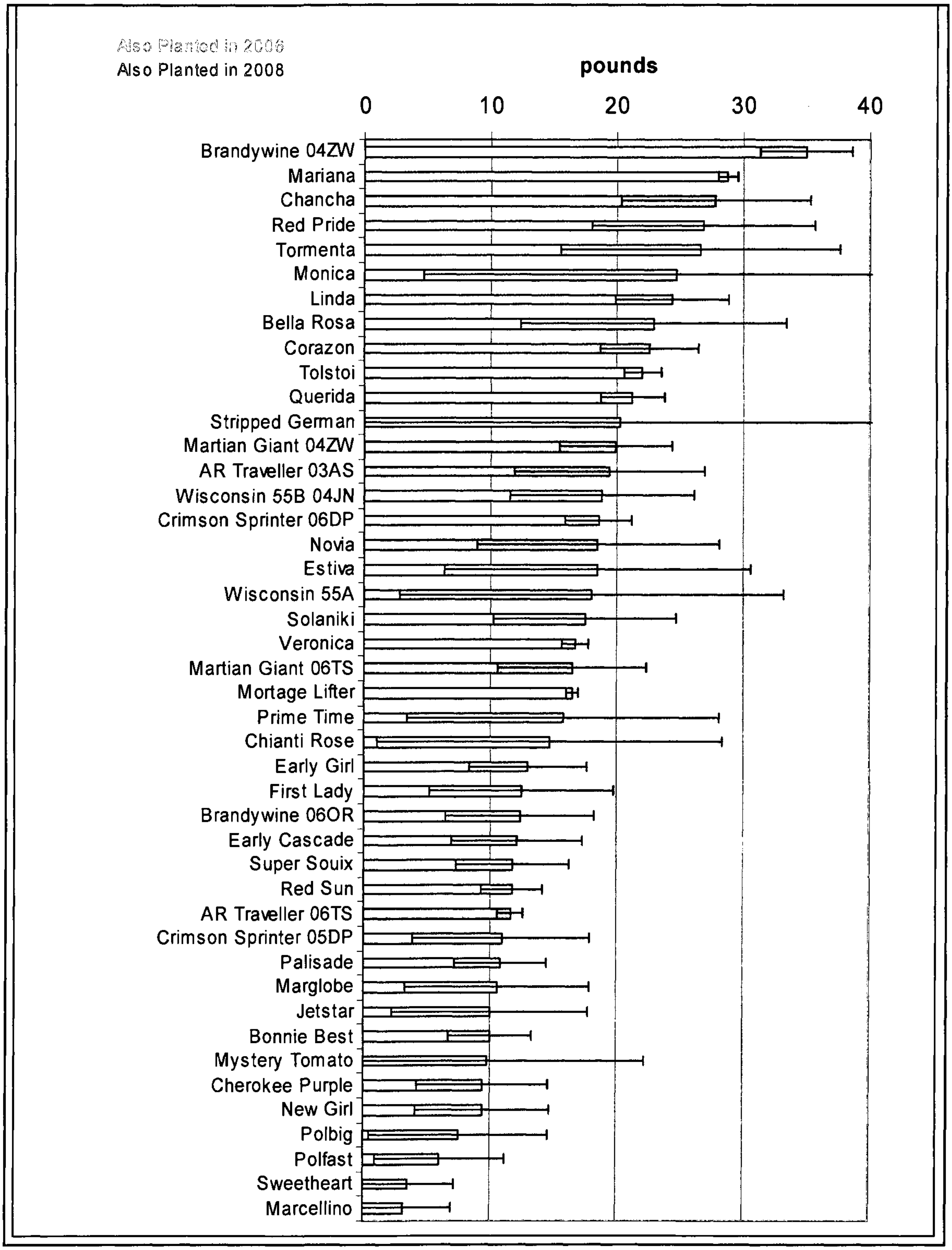


Figure 5.15. Total tomato production per plant. Blue bars indicate cultivars only grown in 2007. Red bars indicate cultivars grown in 2007 and 2008. Gold bars indicate cultivars grown in 2006 and 2007.

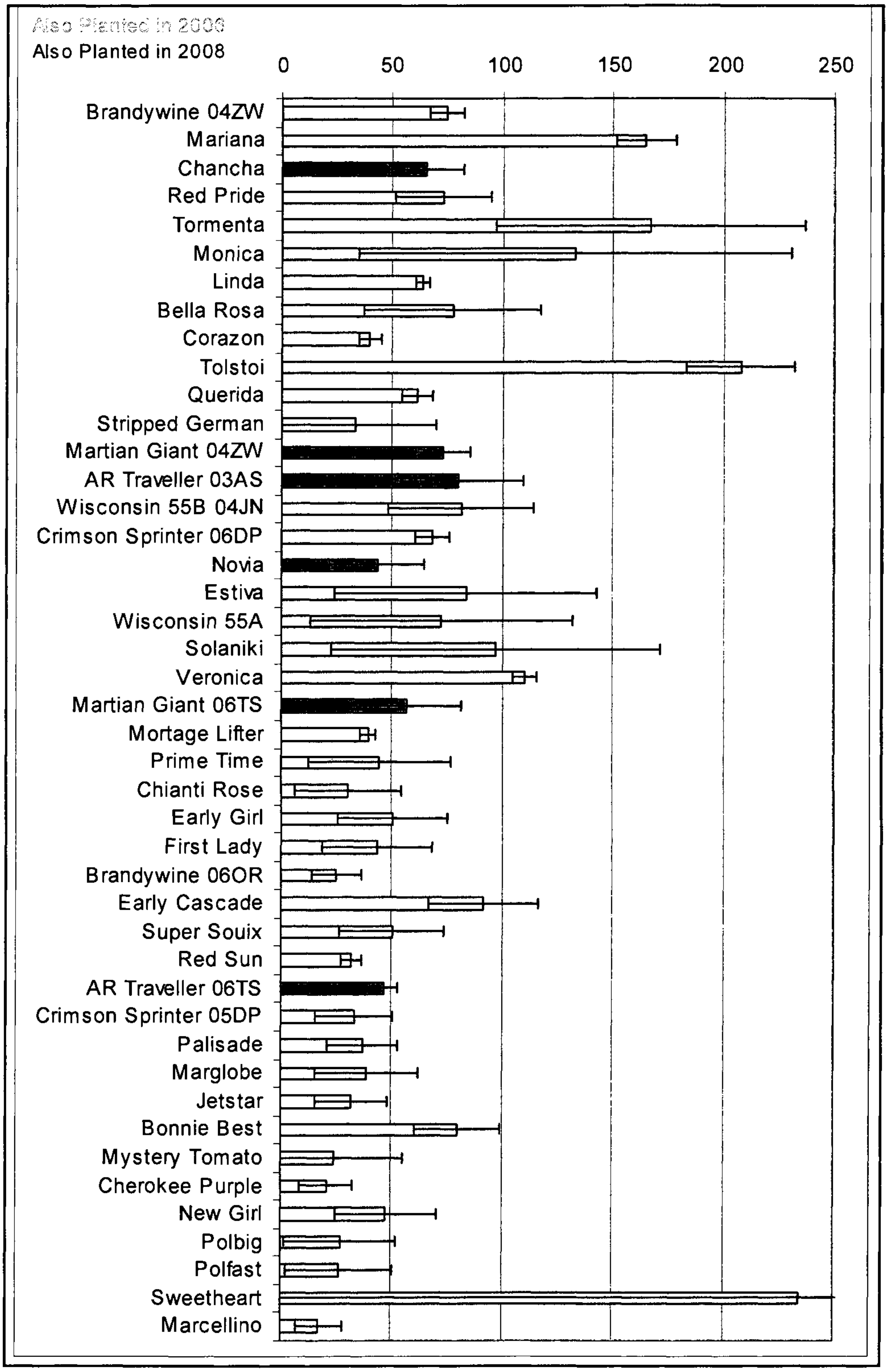


Figure 5.16 Tomato fruit count per plant. Blue bars indicate cultivars only grown in 2007. Red bars indicate cultivars grown in 2007 and 2008. Gold bars indicate cultivars grown in 2006 and 2007.

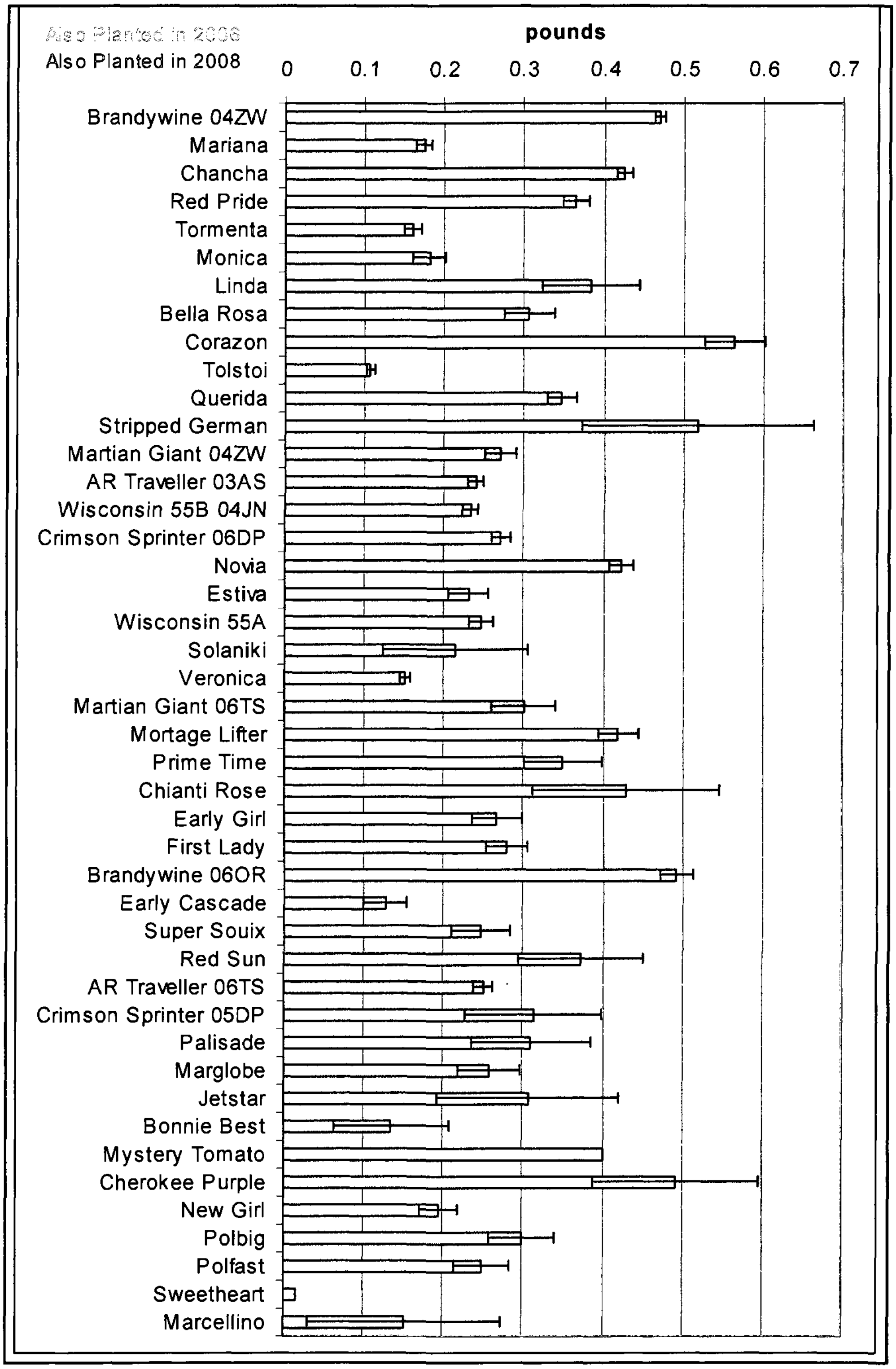


Figure 5.17 Weight per tomato fruit (lbs.). Blue bars indicate cultivars only grown in 2007. Red bars indicate cultivars grown in 2007 and 2008. Gold bars indicate cultivars grown in 2006 and 2007.

Figure 5.18 compares total fruit production between common cultivars grown in both 2006 and 2007. Data from both the conventional and organic growing treatments in 2006 are included but, in 2007, the tomatoes were exclusively organically grown. This subset of cultivars shows the dramatic increases in 2007 evident from comparison of Figures 5.14 and 5.15.

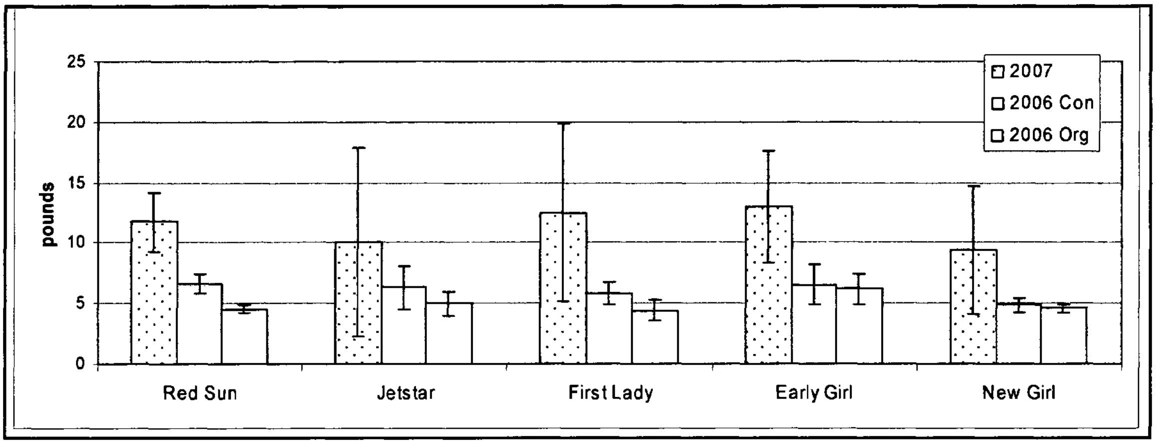


Figure 5.18 Total tomato fruit weight per plant of organic and conventionally grown crops in 2006 and organic production in 2007.

Conclusions: tomato cultivar trials

These cultivar trials will contribute to a database of information that the small-scale organic farmer should be able to use to help determine which cultivars are suitable for production in Colorado. Besides the complex qualitative characteristics that determine what makes a tomato delicious and highly desirable to the consumer, yield is important for the farmer. We saw that there is not a significant difference in yield between conventional and organic production. There is a great deal of difference from cultivar to cultivar and from year to year (Figures 5.14, 5.15 and 5.18). Even when following controlled production practices yields were nearly doubled in 2007. Total yield was not clearly correlated to fruit size or the number of fruit produced.

Although yield is not the end-all for the small farmer whose market may be more dependent on fruit quality and flavor, these findings help narrow the choices of cultivars to consider growing based on total yield and fruit size.

Cultivar trials: spinach

Two evaluations of spinach cultivars were conducted by the CSU Specialty Crops Program at Grant Family Farms (GFF) during the summer of 2005. The first planting was sown on April 26, 2005, at GFF field P1 and harvested on June 28, 2005: it represented a spring planting slot and including 42 cultivars of spinach. The second planting of 54 cultivars was planted June 20, on field S1; harvest took place August 17, 2005, representing a midsummer planting slot. The main objective of this trial was to evaluate a wide number of cultivars for spring and summer production.

Ironically, the spring crop was exposed to summer-like stress immediately before harvest when temperatures in the upper 80s to lower 90s (˚F) coincided with an irrigation system breakdown that left the crop dry for several days at its peak ET. These early summer spikes in temperature are not uncommon in northern Colorado, and provided useful information about the tolerance of cultivars under less than ideal production climate.

Performance of the cultivars was evaluated using parameters set by the owner, Andy Grant, and by the farm's spinach production manager, Felipe Muñoz. Parameters included a wide range of subjective measurements of interest to their specific market objectives as well as some parameters that are more readily quantifiable and less subjective. Included in this report are yield and bolting resistance; two parameters that are important to Colorado spinach growers.

Methods

The trials were conducted on certified organic land operated by Grant Family Farms (GFF). Both fields had received dairy manure applications of approximately 20 t/ac in the late fall of the previous year, and soil fertility was reported by the operators as "good". Both fields were irrigated by center pivot, using surface water. Irrigation scheduling at GFF is based on ET; however, immediately prior to harvest the first trial underwent severe stress due to high temperatures concurrently with a breakdown of the irrigation equipment. These stresses may have initiated premature bolting, and reduced leaf size and yields.

No pesticides or additional inputs were applied to the crops once sown. The fields were blind cultivated immediately before planting. After crop emergence the fields were tractor cultivated once and hoed twice; however, weed pressure was very light.

Three replications of each cultivar were randomly assigned in a split-plot design. Each replication was five feet long, and had two rows per bed spaced 10 inches between rows. Beds were spaced 40 inches apart. A Planet Junior planter was used to plant the seed, providing in-row spacing of approximately 3 inches between plants. The fields were irrigated immediately after seeding, and maintained moist until emergence, at which time ET-based irrigation scheduling was used. The plots were placed within spinach production fields, replicating production field environmental conditions and cultural practices.

An experienced field harvest crew from GFF hand harvested the trials, bunching the plants for fresh market per industry standards. Immediately before harvest, each plot was inspected for bolting plants. Blocks that had many bolting plants were not harvested. Resistance to bolting was scored 0 to 5: 0 represented a replication whose plants were nearly all bolting and 5 represented a replication that had no plants bolting; intermediate scores were represented relative degrees of plants bolting. After being bunched, the yield of each cultivar was weighed and recorded. The first planting of 42 cultivars was sown on April 26, 2005, at GFF field P1, and harvested on June 28, 2005. The second planting of 54 cultivars was planted June 20, on field S1, and harvested August 17, 2005. Table 5.7 presents the cultivars grown, sorted by leaf type.

Table 5.7 Spinach cultivars trialed at Grant Family Farms in 2005; sorted by type.

Savoy Type	*Semi-savoy type*		*Flat leaf*
#268	#3665	Lombardia	Bordeaux
Brutus	51-71 FI Osborne	PV-0172	Falcon
C1-601	51-72 rz fl Osborne	Rembrandt	Mig
Cultivar	7-GREEN	Renegade	Tarpy
FY0268	Avenger	RX2028	
FY0284	c1-602	SPACE	
Indian summer	C2-607	Spalding	
Regiment	Cherokee	Spiros	
Remington	CI604	Springfield	
Spargo	Correnta	Tiger Cat	
SPD411	Cultivar	TYEE	
SPD413	Emelio	Umbria	
Spinner	F123	Veneto	
Springer	Hal Cat	Venger	
Unipak 151	Hector	Whale	
XSPC403	Interceptor	Whale 756	
	Lazio	XSPC005	

Results

The cultivars were separated into three categories based on leaf type: flat leaf, semi-savoy, and savoy. Within each of these categories the cultivars were scored per the parameters defined by Mr. Grant above. Differences within cultivar were more evident in some cultivars than others, and there was a yield difference as well. However, there were few statistically significant differences in yield. There were differences of characteristics between the two planting dates; this was probably due to the high level of stress the early planting experienced the week preceding harvest.

Observations on bolting resistance:

6/28 harvest date

Flat leaf types:

- Mig resisted bolting.
- Tarpy, Bordeaux and Falcon were completely bolted at time of harvest.

Savoy types:

- Tyee, Unipak 151, Regiment, Spargo, Spinner, and Springer all showed good resistance to bolting.
- Brutus and XSPC403 showed bolting in at least one rep.
- FY0268, FY0284 all bolted.

Semi-savoy types:

- F123, 3665, XSPC005, 7-Green, 51-71 FI Osborne all bolted
- Space and Tiger cat bolted in at least one rep.
- No bolting occurred in these semi-savoys: Renegade, Correnta, 51-72 rz fl Osborne, RX2028, Cherokee, Interceptor, Spalding, Springfield, Spiros, Venger, CI604, Whale, Lazio, Umbria, Veneto, PV-0172, Lombardia, Emelio, Hector, Hal Cat, Avenger

8/17 harvest date:

Flat leaf types:

- Mig, Tarpy and, to a lesser degree, Falcon all resisted bolting.
- Bordeaux was completely bolted at time of harvest.

Savoy types:

- Indian Summer, Regiment, Spargo, Spinner, and Springer all showed good resistance to bolting.
- Brutus, C1-601, Remington, SPD411, 268, showed bolting in at least one rep.
- FY0268, SPD413, XSPC403, FY0284, Unipak 151 all bolted.

Semi-savoy types:

- 51-71 Osborne, Hal Cat, C2-607, Emelio, 7-Green, RX2028, F123 were beginning to bolt in at least one rep.
- C2-608, Samish, SPD416, XSPC005, 3665 all bolted.
-

All other semi-savoy cultivars were free of bolting plants.

The following three graphs (Figures 5.19, 5.20, 5.21) report the resistance to bolting of spinach by savoy, semi-savoy, and flat leaf spinach planted on two dates. Resistance to bolting was scored as follows: 0=most plants bolting, 5= no plants bolting. Error bars represent standard deviation.

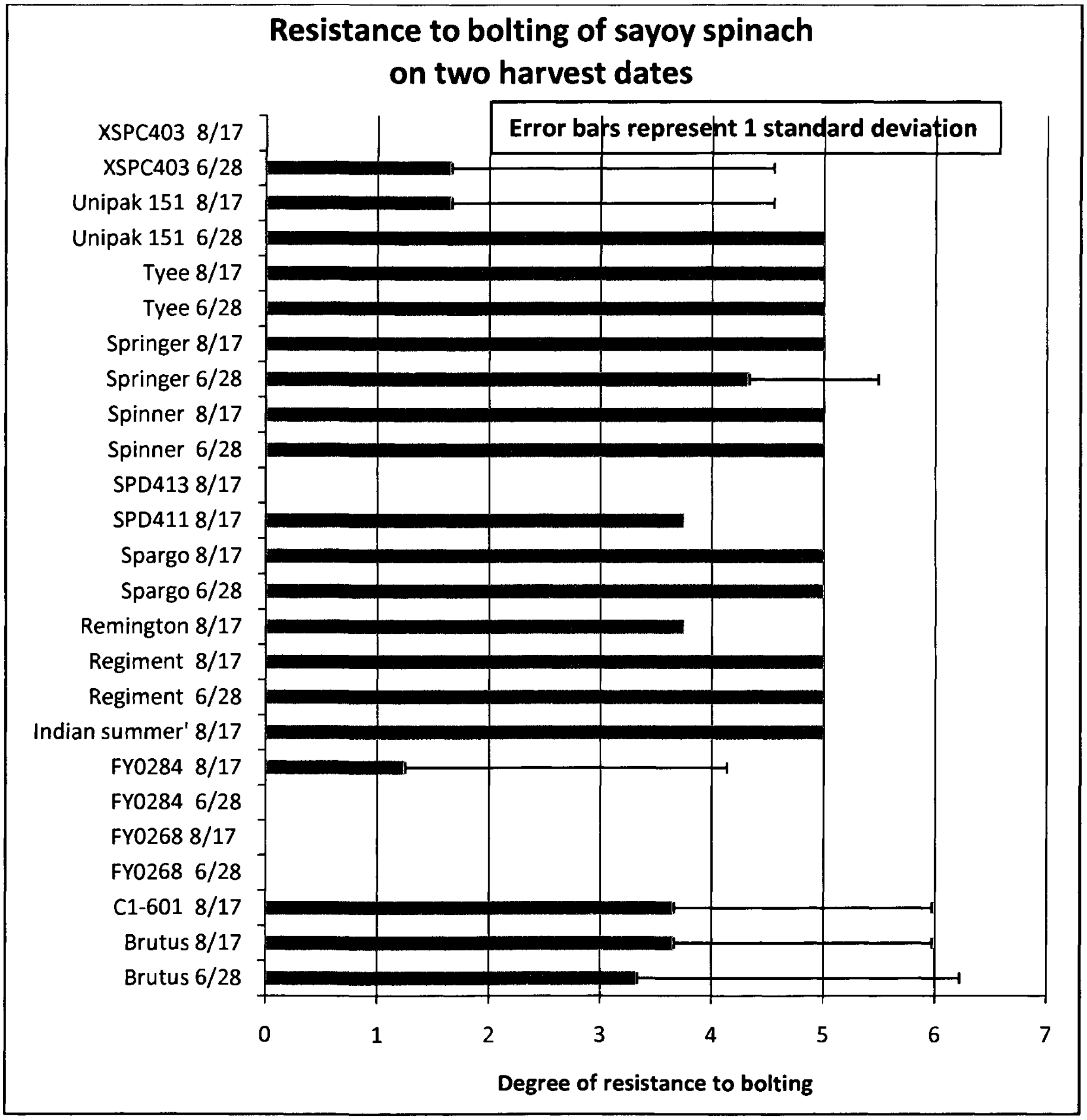


Figure 5.19. Resistance to bolting of savoy types of spinach sown on 6/28/2005 and 8/17/2005. 0=most plants bolting, 5= no plants bolting. Error bars represent 1 standard deviation.

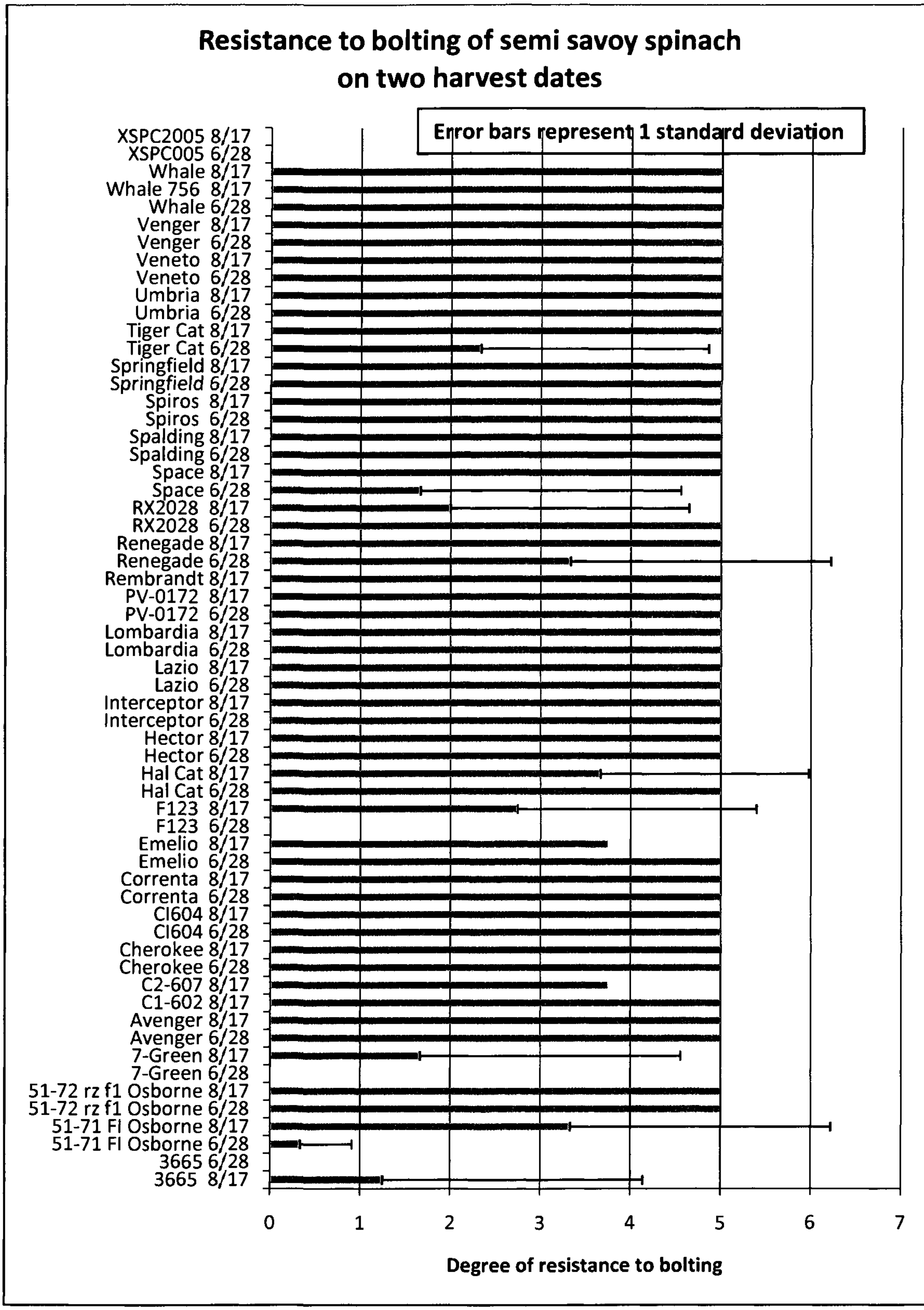


Figure 5.20. Resistance to bolting of semi-savoy spinach planted on 6/28/05 and 8/17/05. 0=most plants bolting, 5= no plants bolting. Error bars represent standard deviation.

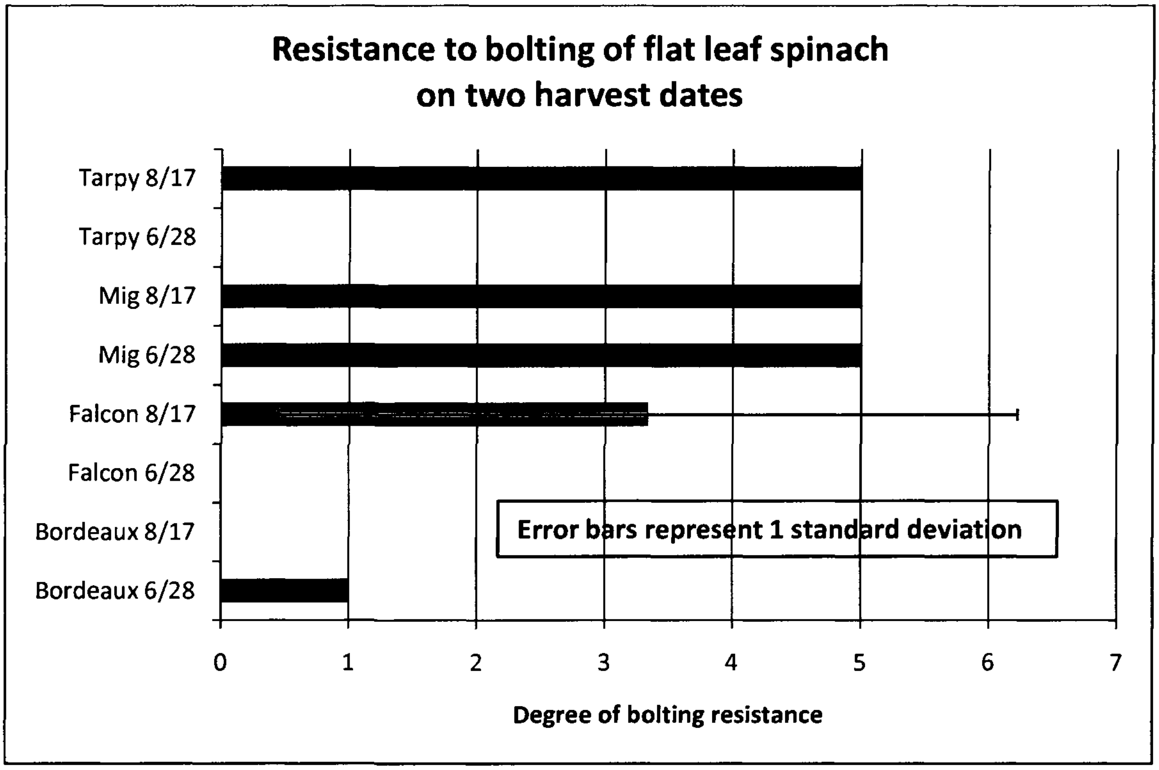


Figure 5.21 Resistance to bolting of flat leaf types of spinach planted on 6/28/05 and 8/17/05. 0=most plants bolting, 5= no plants bolting. Error bars represent standard deviation.

Yield

Felipe Muñoz supervised a GFF spinach harvest crew which harvested each replication using standard harvest techniques. The number of bunches and weights were recorded on a mobile electronic scale. Only saleable spinach was harvested per GFF market standards.

The following (figures 5.22 and 5.23) show pounds harvested per replication of each cultivar from a 4 foot bed length. Figure 5.22 presents all cultivars harvested on 6/28/05, and figure 5.23 presents cultivars harvested on 8/17/05. The error bars indicate the standard deviation of that cultivar. Caution should be used in extrapolation of these small plot yields to field scale estimates; these plots represent only 0.0003 acre.

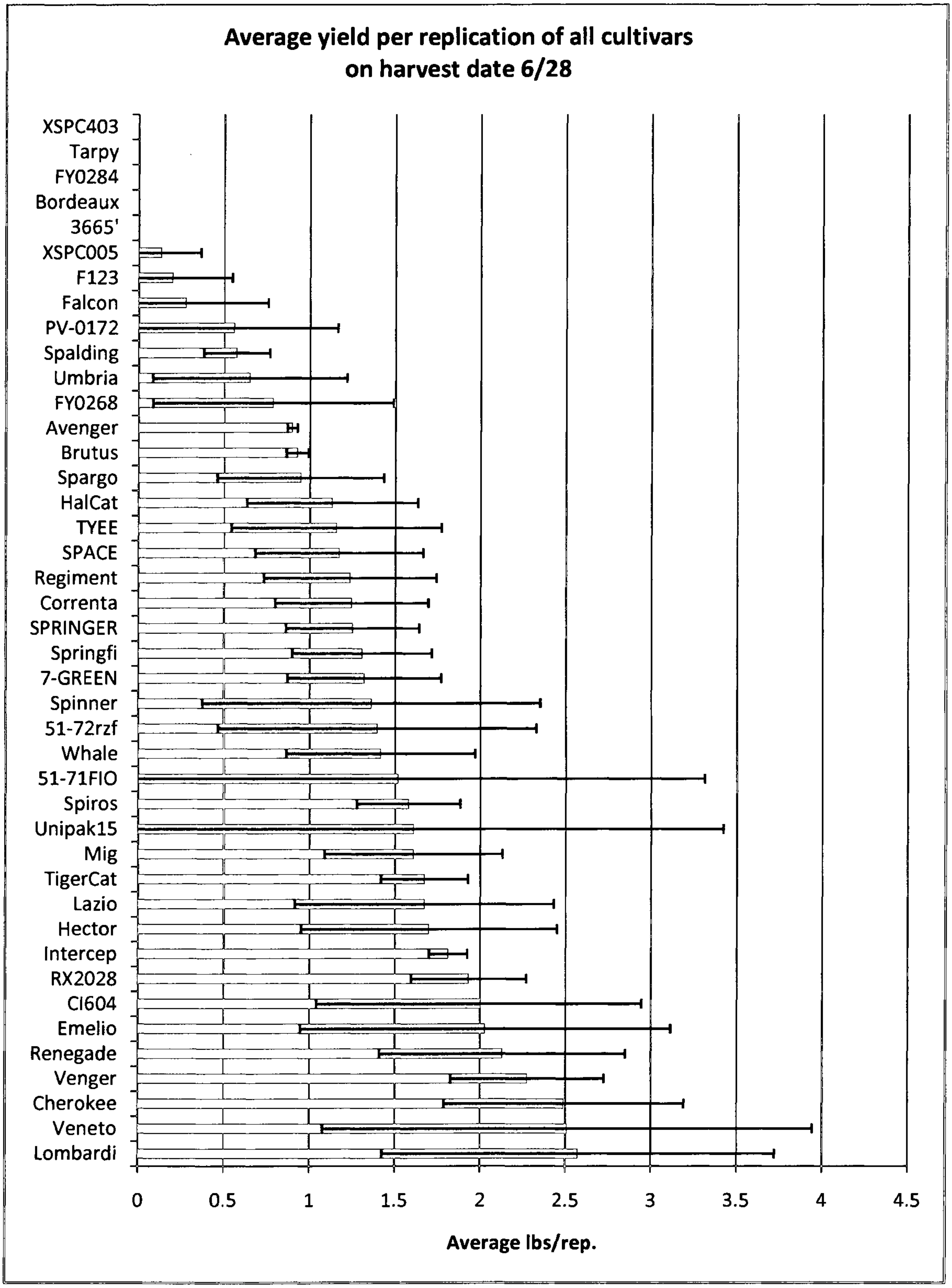


Figure 5.22. Average yield per replication of 42 cultivars of spinach harvested on 6/28/05. Each replication was a double row per bed, and 4 feet long.

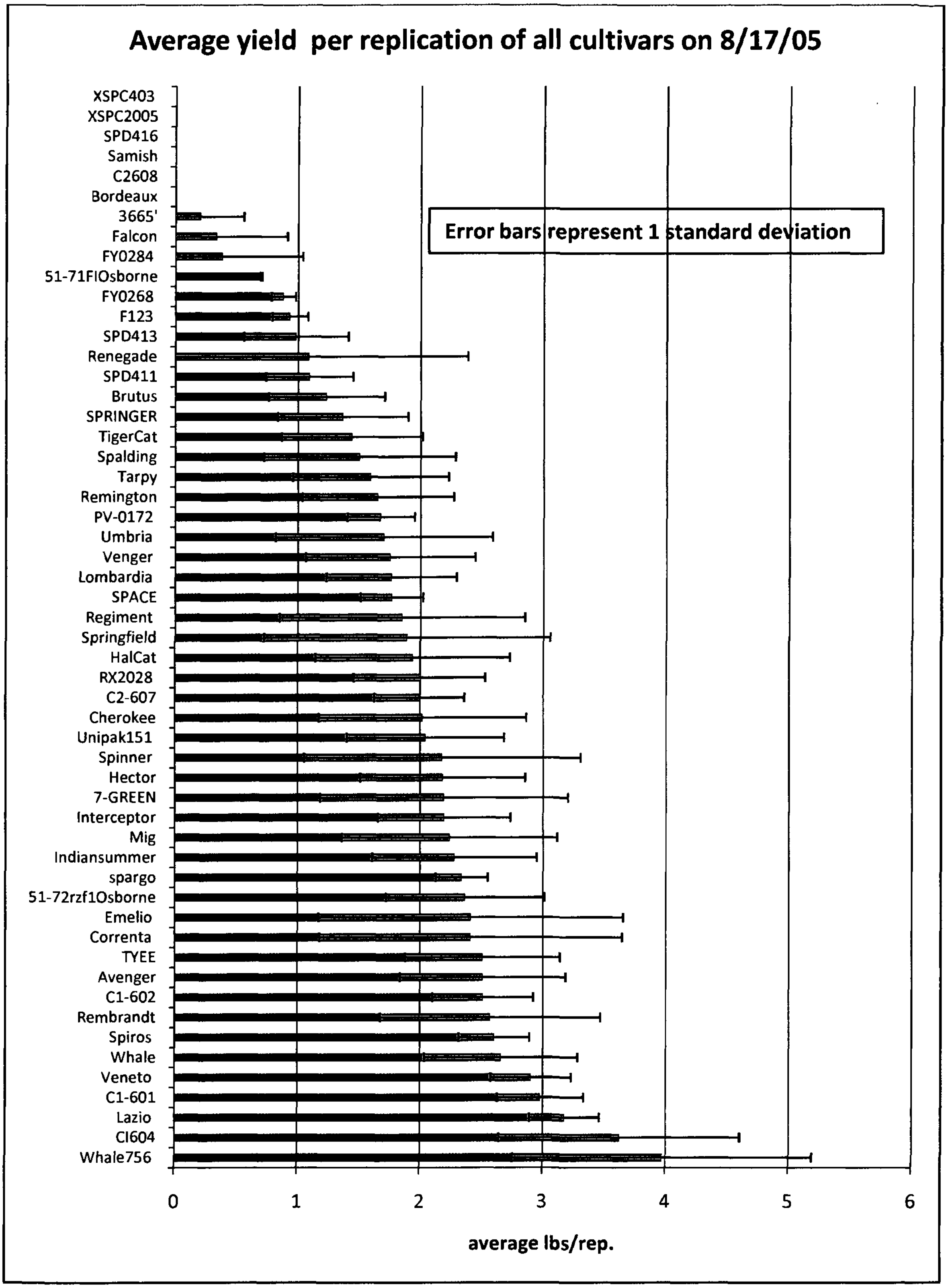


Figure 5.23. Average yield per replication of 54 cultivars of spinach harvested 8/17/05. Each replication was a double row per bed, and 4 feet long.

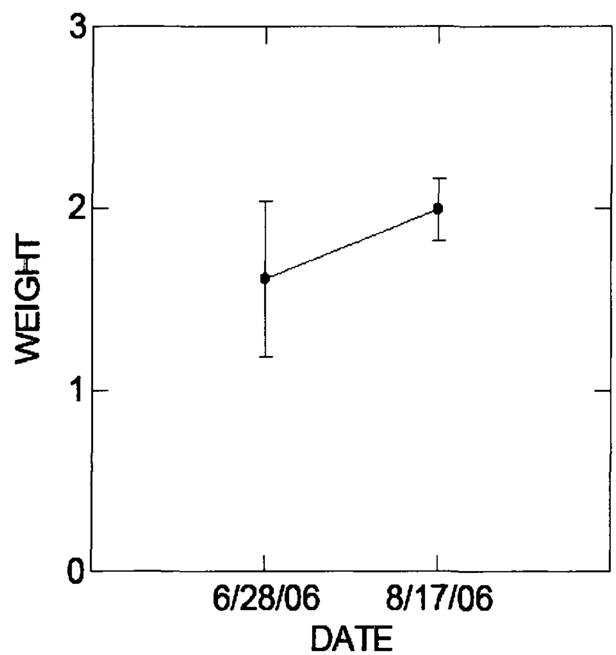


Figure 5.24. Least square means, showing overall spinach yields of 8/17/05 harvest to be insignificantly higher than 6/28/05 harvest date.

Conclusions: spinach cultivar trials

The hot, dry period preceding the first harvest impacted the performance of the trials, and a yield difference trend is suggested (Figure 5.24). However, statistical differences across all cultivar yields are absent. Yield is likely the most important factor once other market demanded attributes are met. The small plots and degree of variability within cultivars make it impossible to estimate yield potentials accurately, however, the top and bottom performers are indicated in Figures 5.22 and 5.23.

Summary of spinach yields identified by leaf type.
Flat leaf type yields:

Mig yielded the highest of the flat leaf cultivars, with a *mean* of 2.54lbs/rep followed by Tarpy and Falcon. No statistical difference exists.

Semi-savoy type yields:

Semi-savoy spinaches yield means per rep ranged from 3.97 lbs per rep (cv. Whale 756) to 0.61 lb (cv3665).

Savoy type yields:

Savoy spinaches yield means per rep ranged from 2.98 lbs per rep (cvC1-601) to 0.72 lb (cv268).

Notes on specific cultivar attributes:

Bolting:

All types had cultivars that bolted and some cultivars expressed a range of resistance to bolting. Those with the highest probability of bolting included Bordeaux, FYO0268, FY0284, SPD413, XSPC403, XSPC005, f123, 7Green, 51-71, 3665, and Brutus. UNIPAK 151 had very good attributes, but was susceptible to bolting.

Stature:

Stature may facilitate harvest, but the high degree of variability within cultivars (especially semi-savoys) suggests only the shortest should be avoided unless those cultivars offer other significant advantages such as disease resistance (not evaluated this season). Among the shortest were XSPC403, Space, and Brutus. Among the tallest were SPD413, SPD411, 268, F123, Hal Cat, Interceptor, and Renegade.

Among the standouts in the field for overall good appearance for the savoy leaf fresh market were C1-601, Spinner, and Tyee (Tyee is considered to be a savoy, although in these trials it appeared more as a semi-savoy type). For processing, when maximum yield is the objective, the larger leafed flat to semi-savoy leaf types including Whale756, Mig, and Spiros performed well.

Chapter 6 Production scheduling for the small organic farm

Production scheduling of a small organic farm requires a good knowledge of what the market demands are for specific crops and what the likely production will be for that crop during different times of the season. On small acreages, where sequencing of crops is required to produce the cash flow necessary for the enterprise to succeed, production scheduling is fundamental.

In this section, a hypothetical CSA farm will be used to illustrate the scheduling of production required to supply the CSA members with a diverse range of products for a 20 week period – which is fairly typical for Colorado CSA operations. A CSA model also has the advantage of providing a known market price, and a known demand. Before the season starts, it is known how much must be produced to supply the members.

A spreadsheet has been prepared that estimates the amount of each crop a household of four normally consumes in a week, paired with crops that are grown in Colorado and the time frames in which they can be reliably grown. Based on a proposed number of members in the CSA, the amount of land dedicated to each planting is calculated. This spreadsheet provides target dates for seeding and harvest. The spreadsheet is linked to worksheets that determine the number of transplants, and greenhouse space required. This information is based largely on the author's experience of many years growing these crops in Colorado as well as production planning used by the CSU CSA from 2004 to 2008. This spreadsheet allows the user to estimate the gross value for each crop that can be used in a number of analytical business scenarios.

While this production scheduling tool has been developed primarily for the use of CSA product availability, it is also a useful tool for any small farm producing a diversity of crops with the need for succession plantings.

* * * *

This is a view of part of the CSU CSA Planner, showing two crops; spinach and tomato. In the following series of figures, the individual cells that are tagged with a red "comment tag" will be opened to illustrate how the planner works.

Note that across the top of Figure 6.1 are dates that indicate the anticipated CSA delivery dates or harvest dates; these are set up on weekly intervals. Directly below the date lines is a series of cells with "50" entered. This is the number of CSA shares, and drives the equations below. These numbers are linked to the large cell in the corner that can be changed as the CSA membership changes in number.

I22 fx

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	
1					Target harvest date	6/1	6/8	6/15	6/22	6/29	7/5	7/13	7/20	7/27	8/3	8/10	8/17	8/24	8/31	
2					Members=	50	50	50	50	50	50	50	50	50	50	50	50	50	50	
3	Crop	Details		rows/ bed	in row spacing (inch)															
4	spinach	units per member		2	4			0	1	0	1	0	1	0	1	0	1	0	1	
5	spinach	need per week	lbs						50	0	50	0	50	0	50	0	50	0	50	
6	spinach	days to harvest							50	50	50	50	50	50	50	50	50	50	50	
7	spinach	sow date						4/21	5/3	5/10	5/17	5/24	5/31	6/7	6/14	6/21	6/28	7/5	7/12	
8	spinach	y/ft/wk							0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	
9	spinach	sow feet						100		0	0	100	0	0	100	0	0	0		
10	spinach	sow trays																		
11	spinach	$ 2.00	mkt value/lb						$ 100.00	$ -	$ 100.00	$ -	$ 100.00	$ -	$ 100.00	$ -	$ 100.00	$ -	$ 100.00	$
12																				
13	tomato	units per member	each	1	18										3	3	3	3	3	
14	tomato	units total	each			0	0	0	0	0	0	0	0	0	150	150	150	150	150	
15	tomato	days to harvest				130	130	130	130	130	130	130	130	130	130	130	130	130	130	
16	tomato	greenhouse sow date				1/22	1/29	2/5	2/12	2/19	2/26	3/5	3/12	3/19	3/26	4/2	4/9	4/16	4/23	
17	tomato	y/ft/wk				0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	
18	tomato	sow feet				0									900					
19	tomato	sow trays				0	0	0	0	0	0	0	0	0	16.67	0	0	0	0	
20	tomato	$ 2.00	mkt value/ea			$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ 300.00	$ 300.00	$ 300.00	$ 300.00	$ 300.00	$ 3
21																				
22																				

Figure 6.1 CSA planner over view, showing the MS Excel worksheet and planting plans for spinach and tomato for a 50-member CSA.

In Figure 6.2, the screen provides some of the explanatory note tags, showing:

- Where to enter the number of CSA members – row B
- The crop being grown – column A
- The number of rows of plants are grown on a bed – column D
- The spacing of plants in the row – column E

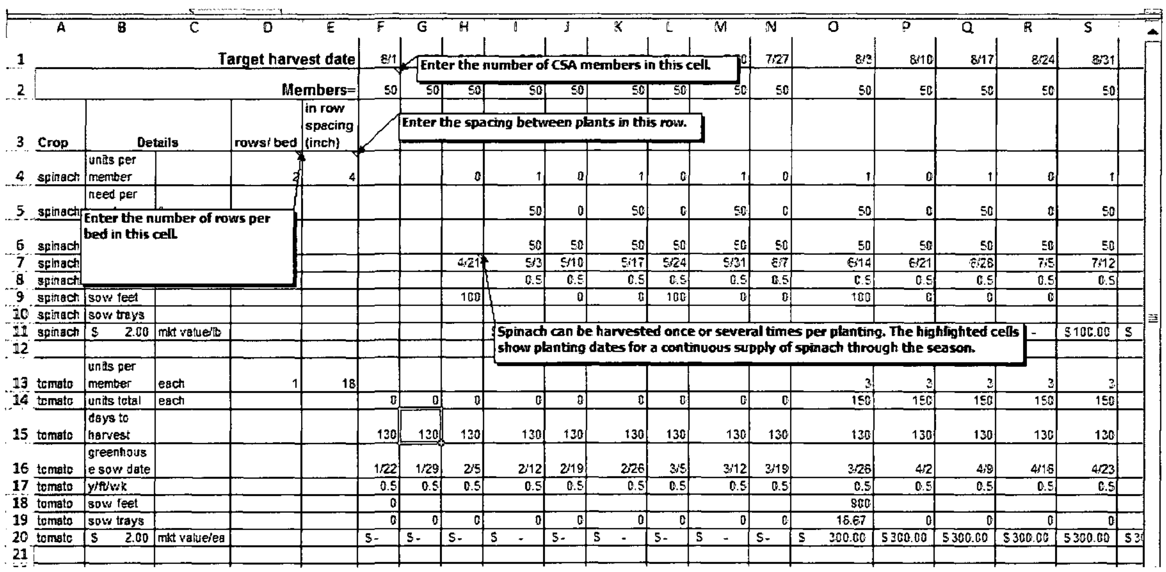


Figure 6.2 CSA planner highlighting program inputs.

In Figure 6.3 the units of a given crop to be delivered establishes production requirements.

1. In the example illustrated, they are receiving 1 unit of spinach every other week.
2. In the next row, 50 shares * 1 unit shows how much product needs to be produced that week.
3. In the next row, an estimation of how long the crop requires from seed to harvest is entered--this is variable with season, cultivar, etc., but is important for establishing sequential planting dates.
4. In the following row is the sow date, which is calculated in the spreadsheet based on when the crop is needed for harvest, and how many days it takes from seed to harvest.
5. In the following row is the estimated yield per linear row foot of production; this is based on field observation and cultivar trials.
6. The following row calculates the number of feet that need to be sown to meet the production requirements.
7. Sowing into trays is sometimes done for braising mixes and baby salad greens, in which case the number of trays would be calculated here.
8. The market value line is useful to understand the value the customer is receiving for any given crop, and also provides insight into gross returns per crop relative to production cost and effort.

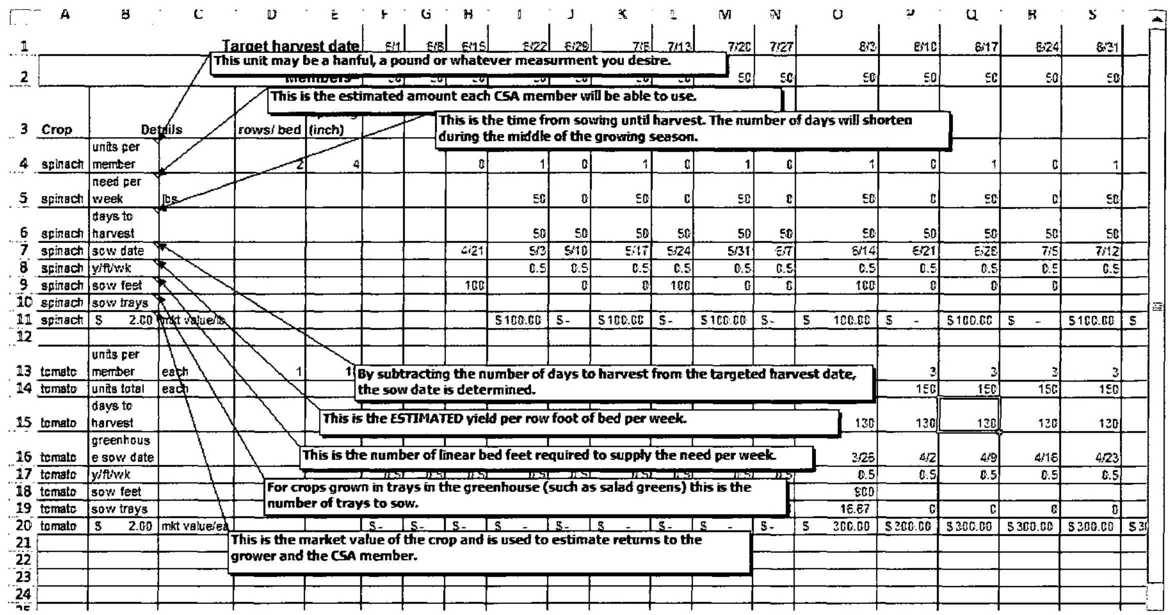
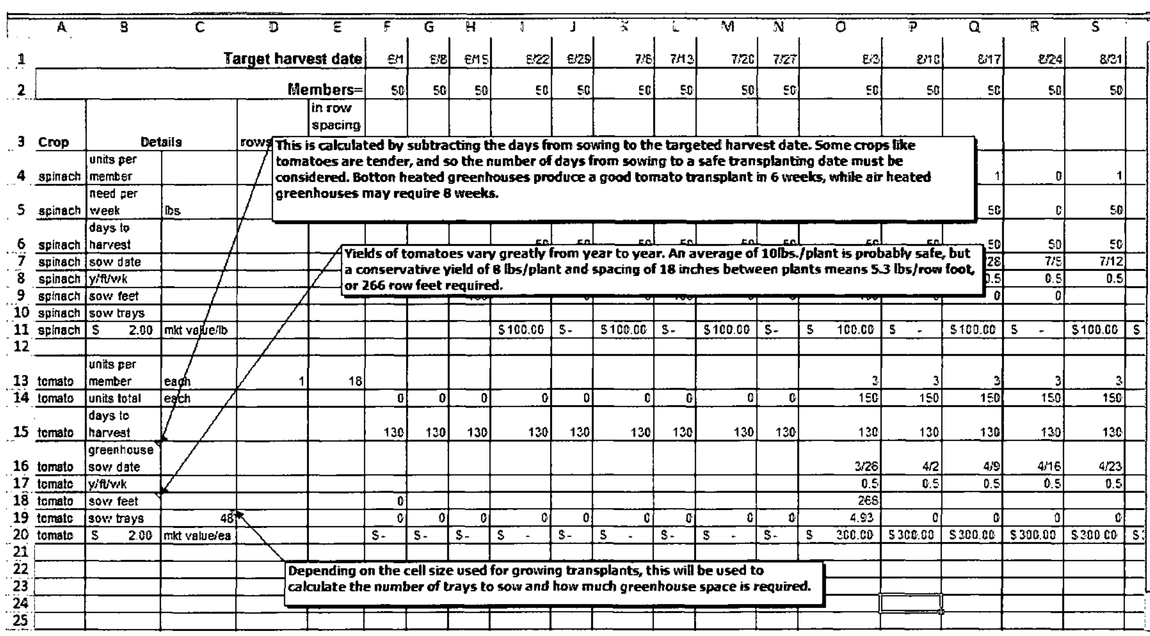


Figure 6.3 CSA planner user inputs showing harvest units, units to be given for each share, days from sowing to harvest, sow date, expected yield per for foot, production area required and market value of the crop.

The following screen (Figure 6.4), which shows tomatoes, requires a few different considerations because it is a long season crop with a single planting date. In row 16 there is a highlighted cell with “3/26” entered. This is a calculated seeding date *in the greenhouse* for field planting 8 weeks later, and beginning harvest 8/3. This is assuming 8 weeks for transplant growing time (this can be reduced to 6 weeks with bottom heat and good fertility) and a frost-free planting date of mid-May. The number of row feet is determined in line 18 and is based on the expected yield of 8 lbs per plant spread over 8 weeks, and an average of 3 lbs of tomatoes to be delivered per customer per week. This is a conservative yield estimate-- in very good years plants will produce three times that amount.

For greenhouse transplants, the number of cells per tray is entered, and the number of trays to plant is calculated, with a 15% overage included to make up for weak plants.



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	
1					Target harvest date	6/1	6/8	6/15	6/22	6/29	7/6	7/13	7/20	7/27	8/3	8/10	8/17	8/24	8/31	
2					Members=	50	50	50	50	50	50	50	50	50	50	50	50	50	50	
3	Crop	Details		rows	in row spacing															
4	spinach	units per member															1	0	1	
5	spinach	need per week	lbs														50	0	50	
6	spinach	days to harvest															50	50	50	
7	spinach	sow date																7/5	7/12	
8	spinach	y/ft/wk																0.5	0.5	
9	spinach	sow feet															0	0		
10	spinach	sow trays																		
11	spinach	$ 2.00	mkt value/lb						$100.00	$-	$100.00	$-	$100.00	$-	$ 100.00	$ -	$100.00	$ -	$100.00	$
12																				
13	tomato	units per member	each	1	18										3	3	3	3	3	
14	tomato	units total	each			0	0	0	0	0	0	0	0	0	150	150	150	150	150	
15	tomato	days to harvest				130	130	130	130	130	130	130	130	130	130	130	130	130	130	
16	tomato	greenhouse sow date													3/26	4/2	4/9	4/16	4/23	
17	tomato	y/ft/wk													0.5	0.5	0.5	0.5	0.5	
18	tomato	sow feet				0									266					
19	tomato	sow trays	48			0	0	0	0	0	0	0	0	0	4.93	0	0	0	0	
20	tomato	$ 2.00	mkt value/ea			$-	$-	$-	$ -	$-	$ -	$-	$ -	$-	$ 300.00	$300.00	$300.00	$300.00	$300.00	$3
21																				
22																				
23																				
24																				
25																				

This is calculated by subtracting the days from sowing to the targeted harvest date. Some crops like tomatoes are tender, and so the number of days from sowing to a safe transplanting date must be considered. Botton heated greenhouses produce a good tomato transplant in 6 weeks, while air heated greenhouses may require 8 weeks.

Yields of tomatoes vary greatly from year to year. An average of 10lbs./plant is probably safe, but a conservative yield of 8 lbs/plant and spacing of 18 inches between plants means 5.3 lbs/row foot, or 266 row feet required.

Depending on the cell size used for growing transplants, this will be used to calculate the number of trays to sow and how much greenhouse space is required.

Figure 6.4 CSA planner inputs showing planting dates, row feet to plant, and transplanting trays to be sown.

Once the data are entered, as you move across the spreadsheet to the right, information is made available on a weekly basis. Cells that are highlighted indicate planting dates for succession planting of crops like spinach, and the number of feet to be planted to fulfill the harvest date indicated at the top of the sheet.

Each farm will have variables affecting the validity of this tool, but with experience and "tweaking" this planning tool can become very well tuned for an individual operation.

Hidden from view in the previous explanations is information at the top of the spreadsheet, which projects the row feet to be planted at either 30 or 60 inches bed spacing. This information is useful for determining supply needs including seed, fertilizer, drip tape, mulching material, and so on. The compiled total estimated market value of individual as well as all the crops grown can be used to estimate the value provided to CSA members, and to input into budget enterprises of specific crops (Figure 6.5).

	A	AI	AJ	AK	AL	AM
1			Acres			
2		Cumulative row feet	30 inch beds	60 inch beds	Gross $ all crops	
3						
4	Crop					
5	spinach					
6	spinach					
7	spinach					
8	spinach					
9	spinach					
10	spinach	300	0.017			
11	spinach					
12	spinach				$ 1,000.00	
13						
14	tomato					
15	tomato					
16	tomato					
17	tomato					
18	tomato					
19	tomato	266		0.0305326		
20	tomato					
21	tomato				$ 3,000.00	
22						

Figure 6.5 CSA planner outputs, showing production area required and gross market values.

Only two crops were highlighted in this explanation, but 32 crops have been detailed, some of them with additional, unique requirements, but most crops follow this general approach.

This tool will be available to growers on-line in 2009 at the CSU Specialty Crops Program website http://www.specialtycrops.colostate.edu.

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Appendices

Appendix A: Soil fertility management

The following tables present common analyses of frequently used manures and composted manures, and give examples of how manure and compost application is calculated. The figures present a range of reported values, illustrating the variability among different manure and compost composition. This underscores the value of and need to use laboratory analysis of manures and composts before application.

Soil sampling and analysis

The Colorado State University Soil Water and Plant Testing Lab recommends using the following procedures to submit soil samples to a testing laboratory:

1. Obtain a spade, trowel, soil tube, or soil auger free of rust and soil.
2. Dig 5-10 samples (depending on the size of the area) from the soil depth where your plants will be rooting.
   a. The samples should represent a uniform area consisting of land that is similar in slope, texture, drainage, or other characteristics that make the soil the same.
   b. A front and back yard would most likely be very similar to each other; however, a garden area may be different from a turf grass area.
3. Place all of the samples into a plastic container and mix well to get your final sample for submittal to the lab.
4. If possible, air dry the sample by spreading it out on paper towels.
5. Remove about 1 ½ - 2 cups of soil from the container and place it in a plastic bag or soil sample bag. If more than one bag is submitted to the lab, the samples will be analyzed and invoiced as separate samples.
6. Seal the bag and label the sample with name, address, and location of the sample.
7. Complete the soil sample information form as completely as possible and include it with the soil sample.
8. Keep the samples cool before mailing. If samples heat-up the nitrogen readings can be dramatically altered (Self, 2004).

A helpful source for choosing a soil testing laboratory is:

Selecting an analytical laboratory. CSU Cooperative Extension Bulletin no. 0.520 by R.M. Waskom, J.G. Davis, and J.R. Self
http://www.mans.edu.eg/projects/heepf/ilppp/cources/12/pdf%20course/31/00520.pdf

Soil analysis results

Table A. 1 An example of a soil analysis report.

Lab	Sample	Paste		Lime	%	AB-DTPA Extract ---- ppm						
#	ID #	pH	EC mmhos/ cm	Estimate	OM	NO_3-N	P	K	Zn	Fe	Mn	Cu
R3111	BRASSICAES	7.8	0.8	High	3	6.9	5.3	373	1.9	8	6.8	3.3

Table A. 2 General soil fertility recommendations for a variety of vegetables.

Nutrient recommendations for a variety of vegetable crops	N (lbs/ac)	P_2O_5 (lbs/ac)	K_2O (lbs/ac)	Zn if <1ppm	Fe if <5ppm (equal to 20t/ac manure)	Mn if <0.5ppm, and pH>7	Cu if <0.2ppm
Sweet corn	230	110	120	10	10	5	5
Non-legume vegetable	210	185	200	10	10	5	5
Legume	75	80	80	10	10	5	5
Potato	240	220	180	10	10	5	5

Sources: (Cooperband, 2002; Ells, 1993; Maynard and Hochmuth, 1997; OMAFRA, 2006; Rosen and Bierman, 2005; Tyler and Lorenz, 1991)

Green manure contribution calculation

Table A. 3 Calculation of green manure contribution to soil fertility.

A biomass sample is collected:	Example		
a) Square feet harvested	10		
b) Lbs total weight of dried sample	1		
c) Lbs dry matter per ft^2 (b/a)=	0.1		
d) Lbs dry matter per acre (c X 43,560)	4356		
	e) Approximate total N contribution (lbs/ac)	Approximate available N contribution (lbs/ac) in 1st year if incorporated =(e/2)	Approximate available N contribution (lbs/ac) in 1st year if left on surface =(e/4)
If GM is leafy legume in bud (d X 4%)	174	87	44
If GM is leafy legume after flower (d X 3.5%)	152	76	38
If GM is a grass before flowering (d X 3%)	131	65	33
If GM is a grass after flowering (d X 2.5%)	109	54	27

Source: (Sarrantonio, 2007)

Table A. 4 Calculations for estimating available nitrogen for a crop.

Example of estimating available nitrogen for a crop.

1st, look at your soil test, which reports the NO3 and NH4 forms of nitrogen, and the soil organic matter (SOM).

A.	***Residual nitrogen in soil***			
	Soil test results - example			
	NO3 (ppm)		15	
	NH4 (ppm)	+	4	
	total N ppm		19	
	multiply by 4 to get lbs/ac		***76 lbs/ac***	
	Nitrogen contribution form SOM			
	SOM contributes about 30 lbs/ac N per 1% SOM			approximate lbs/ac N contribution from SOM
B.	***if SOM = 2%, then 30 X 2=***		***60 lbs/ac***	

2nd, evaluate the contribution of the green manure crop.

1	***Calculate the Dry Matter per Acre***		
	Total weight of dried samples		2
	square feet harvested	÷	10
	lbs dry matter per ft2		0.2
	square feet per acre	X	43,560
	lbs dry matter/ac		***8,712 lbs/ac***

2 ***Calculate N from GM based on type of GM by multiplying dry matter by the % N estimated for type of GM.***

Nitrogen contribution from 8,712 lbs/ac DM			approximate N contribution	N Available in the 1st year: If GM is tilled under immediately (N contribution ÷ 2)	if GM is left on surface (N cotribution ÷ 4)
if GM is a leafy legume in bud	X	4.0% =	348	***174***	87
if GM is legume after flower	X	3.5% =	305	152	76
if GM is a grass before flowering	X	3.0% =	261	131	65
if GM is a grass after flowering	X	2.5% =	218	109	54

3rd, add up all the parts, lets assume the following conditions:

A.	The GM is a leafy legume in bud, and immediately incorporated		174
B.	SOM @ 2%	+	60
C.	residual N @ 19 ppm (per soil test)	+	76
	The total N available from these three sources is:		***310 lbs/ac***

Table A. 5 Soil fertility balance sheet for estimating contributions of residual, green manure and compost/manure to the soil fertility management equation.

Steps		**Explanation**	**lbs/ac** **Total N**	**P_2O_5**	**K_2O**
1.	Determine crop need	Crop nutritional needs (see Table A.2 "crop nutritional requirements")	230	60	100
2.	See soil test results	In soil ppm (from soil test)	6.9	5	373
3.	Convert ppm to lbs/ac: multiply ppm X 4	Conversion of ppm to lbs/ac (in top 12 inches of soil)	27.6	20	1492
4.	Account for organic N from % OM	SOM credit (%OM X 30lb)	90		
5.	Account for nitrates in irrigation water	Irrigation water credit (if water sample is taken: ppm NO_3 X 0.23 X inches water applied = lbs NO_3/ac)	18.4		
6.	**Sub total**	**Total nutrients available in soil and water**	**136**	**20**	**1452**
7.	Account for N contribution from green manure crop	Projected green manure contribution (see green manure contribution Table A.3)	65		
8.	**Sum**	**Additional nutrient needs (crop need - available in soil and water)**	**29**	**40**	**-1352**
9.	Estimate amount of compost or manure needed to supply nutrient deficit	Beginning with P need - because it is the greatest needed (see step 8.)			
		Tons of compost required to meet P needs @ 4lbs/ton		10	
		Nutrients provided from 10 tons dairy compost =	30	40	40
		Balance needed after amendments	-1	0	-1392

Common analysis of manures and composted manures

Table A. 6 Nutrient analysis of composted dairy and poultry manures.

	% Dry Matter	Total N[1]	P_2O_5	K_2O	Reference
Poultry compost	20-45	1.8-2.2	4.2-4.3	2.3-2.6	(A-1Organics, 2008; Chaney, 1992; MidWestPlanService, 1993; Rosen and Bierman, 2005)
Dairy compost	45-76	0.9-1.3	1.2-1.3	2.3- 2.9	

[1]Total N = NH_4 plus organic N

Table A. 7 Composition of animal manures.

SOURCE	Dry Matter (%)	Approximate Composition (% dry weight)			Reference
		Nitrogen	P_2O_5	K_2O	(Chaney, 1992; Hawkes, 1985; Maynard and Hochmuth, 1997; MidWestPlanService, 1993; Reid, 2007)
Dairy	15-25	0.6-2.5	0.2-1.1	0.6-3.6	
Feedlot	20-50	1.0-2.5	0.9-1.6	2.4-3.6	
Horse	15-25	0.7-3.0	0.2-1.2	0.7-2.2	
Poultry	20-30	1.6-4.5	0.9-6.0	0.4-2.4	
Sheep	25-35	1.2-4.0	0.5-1.9	1.2-4.5	
Swine	20-30	0.5-4.0	0.3-2.5	0.5-2.2	

Table A. 8 Approximate availability of organic N from manure and composted manure following 1 year of soil application.

Manure type	Organic N available (%)
Dairy, no bedding	35
Beef, feedlot	35
Horse, with bedding	20
Poultry, with litter	45
Sheep, feedlot	25
Swine, fresh	50
Composted poultry	30
Composted dairy	14

Source: (Rosen and Bierman, 2005)

Table A. 9 Volatilization of N from surface applied manure.

Days until incorporation	% NH_4 lost to volatilization
½-2	20
2-4	40
4-7	60
More than 7 days	80

Sources: (Rosen and Bierman, 2005; Terman, 1979)

Sources for cultivation equipment:

Bartschi-Fobro LLC
P.O. Box 651
Grand Haven, MI 49417
616-847-0300

Bezzerides Bros., Inc
P.O. Box 211
Orosi, CA 93647
559-528-3011

BDi Machinery Sales Co.
430 E. Main St.
Macunie, PA 18062
800-808-0454

Buddingh Weeder Co.
7015 Hammond Ave.
Dutton, MI 49316
616-698-8613

Chauncey Farm
119 Bridle Rd.
Antrim, NH 03440
603-588-2857

HWE Agricultural Technology (Einbock)
B.P. 1515
Embrun, ON K0A 1W0
613-443-3386

Market Farm Implement
257 Fawn Hollow Rd.
Friedens, PA 15541
814-443-1931

Lely Corp.
P.O. Box 1060
Wilson, NC 27894
252- 291-7050

Unverferth Manufacturing
P.O. Box 357
Kalida, OH 45853
800- 322-6301

Wasco Hardfacing Co.
P.O. Box 2476
Fresno, CA 93745
559-485-5860

Appendix B: Pest and Disease Management

Reference Material about the USDA National Organic Program (NOP):

- Rules and list of allowed and prohibited materials:

http://www.ams.usda.gov/AMSv1.0/getfile?dDocName=STELPRDC5068682&acct=nopgeninfo

- Organic Materials Research Institute (OMRI) http://omri.org/index.html

Scouting and monitoring reference materials and products:

Reference material:

The American Phytopathology Society produces an excellent series of compendia of plant diseases for a wide array of crops, with color plates and disease descriptions. The American Phytopathology Society: http://www.shopapspress.org/

Many university web sites also provide diagnostics for a variety of common plant diseases.
Colorado: The VegNet of Colorado State University http://www.colostate.edu/Orgs/VegNet/

Cornell University: http://vegetablemdonline.ppath.cornell.edu/Home.htm

University of California: http://www.ipm.ucdavis.edu/

University of Minnesota: http://www.vegedge.umn.edu/

Iowa State University http://www.ent.iastate.edu/List/directory/153/vid/4

High Plains Integrated Pest Management site: http://highplainsipm.org/

Pesticide label and MSDS database:
Crop Data Management Systems, Inc. http://www.cdms.net/LabelsMsds/

Organic pest management:

An excellent source of reference material can be found at :
http://highplainsipm.org/OrganicPesticidesIndex.html

National Information System for the Regional IPM Centers: http://www.ipmcenters.org

Suppliers of beneficial insects/organisms

There are many suppliers of biological control organisms. A comprehensive list can be found at:
http://highplainsipm.org/HpIPMSearch/Docs/BiologicalOrganisimSuppliers.htm

Scouting supplies:

BioQuip Products: http://www.bioquip.com/default.asp
The Green Spot, Green Methods: http://greenmethods.com/site/

Pheromones:

A comprehensive list of pheromone monitoring and trapping products is provided by: Trécé Inc. :http://www.trece.com/

Misc. Supplies:

Peaceful Valley Farm and Garden Supply
http://groworganic.com/default.html?welcome=T&theses=3899915

Appendix C. Irrigation

The CoAgMet weather station network provides weather data and crop water use calculations across the state. For a complete index of the stationslisted on this map, with interactive internet links visit: http://ccc.atmos.colostate.edu/~coagmet/station_index.php

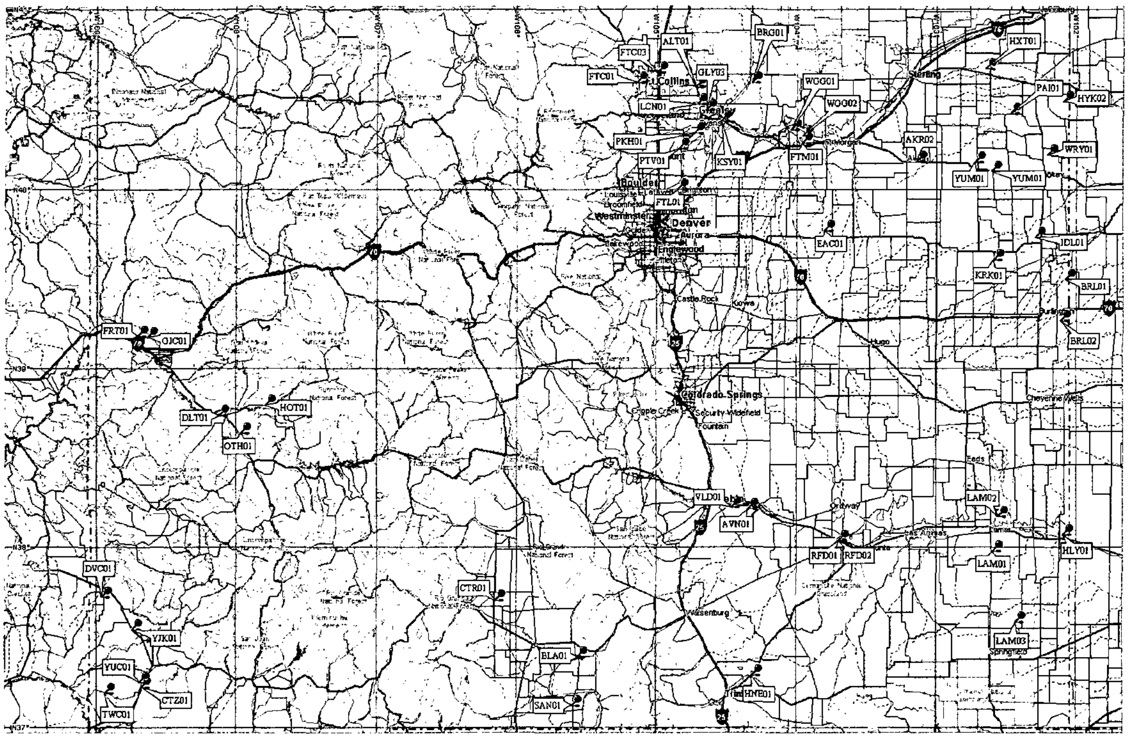

Figure C. 1 Map of CoAgMet stations reporting ET

From Colorado Climate Center (ColoradoClimateCenter)

Appendix D. Farmer survey

Farmer survey questionnaire. Fifteen organic farmers around the state of Colorado were asked the following questions in telephone surveys in the fall of 2008. Responses and discussion are interspersed throughout the text of this dissertation.

Questions about certification

1. Are you certified organic?
2. Why do you certify?
3. Why not?
4. How many acres are in production on your farm?
5. How many of those acres are in vegetable production (including land in rotation)?
6. How many acres are not currently in vegetable crops but used in rotation or non vegetable crops?
7. What organization certifies your farm?
8. What crops do you grow?

Questions about marketing

9. What % of you r market is "direct" market?
10. % farmers market?
11. % stand?
12. % CSA?
13. % PYO (pick your own)?
14. % wholesale to grocers?
15. % restaurant?
16. % other marketing
17. If you sell to grocer, is the grocer more or less accepting than a direct customer? Why?
18. Do you think consumers have a different standard in terms of pest damage on organic produce than on conventional?
19. What do you think consumers perceptions/expectations are about produce quality coming directly from the farm v store bought?
20. What do you think are the public perceptions of organic produce?

Questions about production

21. Do you irrigate?
22. How do you irrigate?
23. What is the irrigation source?

PESTS

List the pests you have trouble with.

24. Do you consider the following pests to be serious?
25. Beet leaf hoppers?

26. Cabbage looper?
27. Cucumber beetle?
28. Flea beetle?
29. Imported cabbage butterfly?
30. Lettuce aphid?
31. Mexican bean beetle?
32. Colorado potato beetle?
33. Squash bug?
34. Thrips?
35. Codling moth?
36. Corn earworm?
37. Cabbage aphid?
38. Nematodes?
39. Psyllids?
40. Vine borer?
41. Grasshopper?
42. Corn rootworm?
43. Do you use insecticides? Please list.
44. B.t.?
45. Spinosad?
46. Soap?
47. Pyrethrin(mix)?
48. Mechanical exclusion? Floating row cover?
49. Do you have other pest problems?
50. What determines whether or not you act on a pest or disease presence in a crop?
51. Rodents?
52. Birds?
53. Deer?
54. Raccoon?
55. Other?
56. Do you have disease problems? Please list

Questions about soil fertility

57. Do you soil test?
58. How often?
59. Do you follow recommendations?
60. Do you use compost?
61. Is the compost it tested?
62. What kind of compost is used?
63. How frequently is it used?
64. Do you use manure
65. Is the manure tested?

66. What kind of manure?
67. How frequently is it applied?
68. Is it from an on-arm source?
69. Is it trucked?
70. How far is it hauled?
71. Do you know the cost/yd delivered?
72. Do you know the cost/ac?
73. How is it spread?
74. Do you use green manures
75. What kind of green manure?
76. How frequently do you grow green manures?
77. Do you use other fertilizers? Please list them.
78. Do you have any soil fertility issues?
79. What are your primary weeds? Please list them.
80. How do you control weeds?
81. By hand?
82. Mechanical?
83. Flame?
84. Herbicide?
85. Do you have any other major production issues?

Miscellaneous

86. How many years have you been farming?
87. How many years have you been farming organically?
88. What is your age?
89. Is this a full time occupation?
90. Do you use plastic mulch?
91. Do you keep bees?

Appendix E. Testing and diagnotic laboratories in Colorado and the region

Table E. 1 Labs providing analysis of soil, water, manure, nitrate, pesticide residue and bacteria.

	Soil Test	Water Analysis	Manure Analysis	Nitrate Analysis	Pesticide Analysis in Soil or Water	Bacteria Analysis
Price Range	\$15-\$80	\$13 - \$74.50	\$28 - \$80	\$6 - \$20	*	\$10 - \$50
Most Quoted Price	\$20	\$40	\$45	\$10		\$20
A & L Laboratories, Inc. P.O. Box 1590 302 34th St. Lubbock, TX 79408-1590 (806) 763-4278 E-mail: allabs@al-labs-plains.com Web: www.al-labs-plains.com	x	x	x	x		x
ACZ Laboratories, Inc. 2773 Downhill Drive Steamboat Springs, CO 80487 (970) 879-6590, (800) 334-5493 E-mail: sales@acz.com Web: www.acz.com	x	x		x	x	x
Analytica Environmental Laboratories, Inc. 12189 Pennsylvania St. Thornton, CO 80241 (303) 469-8868, (800) 873-8707 E-mail: kellysuvada@analyticagroup.com Web: www.analyticagroup.com	x	x		x	x	x
Colorado Analytical Laboratory 240 S. Main St P.O. Drawer 507 Brighton, CO 80601 (303) 659-2313 E-mail: info@coloradolab.com Web: www.coloradolab.com	x	x	x	x		x

	Soil Test	Water Analysis	Manure Analysis	Nitrate Analysis	Pesticide Analysis	Bacteria Analysis
Colorado Dept. of Public Health Laboratory Services Division 8100 Lowry Blvd. P.O. Box 17123 Denver, CO 80230 (303) 692-3048 E-mail: cdphe.lab@state.co.us Web: www.cdphe.state.co.us/lr		x		x	x	x
Colorado State Soil, Water and Plant Testing Laboratory Room A319 NES Building Fort Collins, CO 80523-1120 (970) 491-5061 E-mail: jself@agsci.colostate.edu Web: www.extsoilcrop.colostate.edu/SoilLab/soillab.html	x	x	x	x		
El Paso County Dept. Public Health Env. Laboratory 301 South Union Blvd. Colorado Springs, CO 80910 (719) 578-3120; (719) 575-8636 E-mail: healthinfo@epchealth.org Web: www.elpasocountyhealth.org/environment		x				x
Energy Laboratories, Inc. 2393 Salt Creek Highway P.O. Box 3258 Casper, WY 82602 (888) 235-0515 Voice: (307) 235-0515 Web: www.energylab.com	x	x	x	x	x	x
Evergreen Analytical Inc. 4036 Youngfield St. Wheat Ridge, CO 80033-3862 (303) 425-6021 E-mail: info@evergreenanalytical.com Web: www.evergreenanalytical.com		x		x	x	x

	Soil Test	Water Analysis	Manure Analysis	Nitrate Analysis	Pesticide Analysis	Bacteria Analysis
Kansas State Research and Extension Soil Testing Laboratory Dept. of Agronomy 2004 Throckmorton Manhattan, KS 66506-5501 (785) 532-7897 E-mail: soiltesting@ksu.edu Web: www.oznet.ksu.edu/agronomy/ SoilTesting/research.htm	x	x		x		
MDS Harris 624 Rose St. Lincoln, NE 68502 (402) 476-0300 E-mail: info.ag@agsource.com Web: www.mdsharris.com	x	x	x	x	x	
Midwest Laboratories, Inc. 13611 B St. Omaha, NE 68144-3693 (402) 334-7770 Web: www.midwestlabs.com/index3.html	x	x	x	x	x	x
Northeast Colorado Dept. of Public Health 700 Columbine Sterling, CO 80751-0316 (970) 522-3741 E-mail: juliem@nchd.org Web: www.nchd.org						x
Olsen's Agricultural Laboratory, Inc. 210 East First McCook, NE 69001 (308) 345-3670 E-mail: info@olsenlab.com Web: www.olsenlab.com	x	x	x	x		x
Quality-Water Bio-Lab 9999 Olde Wadsworth Blvd. Broomfield, CO 80021 (303) 466-7055						x

	Soil Test	Water Analysis	Manure Analysis	Nitrate Analysis	Pesticide Analysis	Bacteria Analysis
SDC Laboratory, Inc. Tierra del Sol Industrial Park 2329 Lava Ln. Alamosa, CO 81101 (719) 589-1024 FAX (719) 589-3697 E-mail: ed@sangrelabs.com	x	x	x	x	x	x
Severn-Trent Laboratories 10703 E. Bethany Dr. Aurora, CO 80014 (303) 751-1780 Web: www.stl-inc.com	x	x	x	x	x	x
Servi-Tech Laboratories P.O. Box 1397 1816 E. Wyatt Earp Dodge City, KS 67801 (800) 557-7509 Web: www.servi-techinc.com	x	x	x	x		x
Servi-Tech Laboratories P.O. Box 169 1602 Park West Dr. Hastings, NE 68902 (402) 463-3522, (800) 468-5411 Web: www.servi-techinc.com	x	x	x	x		x
Stewart Environmental 3801 Automation Way, Suite 200 Fort Collins, CO 80525 (970) 226-5500, (800) 373-1348 E-mail: info@stewartenv.com Web: www.stewartenv.com	x	x	x	x		x
Stukenholtz Laboratory P.O. Box 353 2924 Addison Ave. East Twin Falls, ID 83303 (208) 734-3050, (800) 759-3050 E-mail: paul@stukenholtz.com Web: www.stukenholtz.com	x	x	x	x		x

	Soil Test	Water Analysis	Manure Analysis	Nitrate Analysis	Pesticide Analysis	Bacteria Analysis
UNL Soil and Plant Analytical Laboratory 139 Keim Hall Lincoln, NE 68583-0916 (402) 472-1571 FAX: (402) 472-1396 E-mail: spal@unl.edu Web: http://agronomy.unl.edu/spal/	x	x	x	x		
Ward Laboratories, Inc. 4007 Cherry Ave. P.O. Box 788 Kearney, NE 68848 (308) 234-2418, (800) 887-7645 E-mail: Web: www.wardlab.com	x	x	x	x		x
Weld County Department of Public Health and Environment Laboratory 1555 N. 17th Ave. Greeley, CO 80631 (970) 304-6415 Web: www.co.weld.co.us/departments/health/environmental/lab/health_lab.html		x		x		x
Weld Laboratories, Inc. 1527 1st Ave. Greeley, CO 80631 (970) 353-8118 E-mail: info@weldlabs.com Web: www.weldlabs.com	x	x	x	x		x
Western Laboratories P.O. Box 1020 Parma, ID 83660 (208) 722-6564, (800) 658-3858 E-mail: info@westernlaboratories.com Web: www.westernlaboratories.com	x	x	x	x	x	x
x indicates service provided *Cost of analyzing soil or water for pesticides will vary depending on how many and which pesticides.						

Source: (Waskom et al., 2006)

Diagnostic labs

Most state universities support diagnostic labs, a few in this region are found below. Gail Ruhr of Purdue University has compiled a list that is available on line with the following link:

http://www.apsnet.org/directories/pdfs/SoilLabsandPlantClinics1-06.pdf

Colorado State University supports a plant diagnostic clinic in Ft. Collins.
Plant Diagnostic Clinic
E215 Plant Sciences Bldg.
(mail to: Campus Delivery 1177)
Colorado State University
Fort Collins, CO 80523-1177
Phone: 970-491-6950, Fax: 970-491-3862
http://plantclinic.agsci.colostate.edu/

Agdia, Inc. Specializes in ELISA analysis of plant viruses.
30380 County Road 6
Elkhart, IN 46514 USA
Tel.:574-264-2014, 800-622-4342
http://www.agdia.com/testing/

Texas Plant Disease Diagnostic Laboratory (TPDDL) :
http://plantpathology.tamu.edu/extension/tpddl/tpddl.asp

University of Nebraska Plant & Pest Diagnostic Lab:
http://pdc.unl.edu/diagnosticclinics/plantandpest