**Substrates and Fertilizers for Organic Container Production of Herbs, Vegetables, and
Herbaceous Ornamental Plants Grown in Greenhouses in the United States**

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Abstract

The value of organic greenhouse production in the United States is \$112 million, and organic floriculture production has increased 40% in greenhouses since 2008. The U.S. National Organic Program (NOP) guidelines allow organic production in containers. One of the primary concerns for current and potential organic container growers is managing container substrate and plant fertility. This manuscript provides a review of current literature on organic substrates and fertilizers for container grown herbs, vegetables and herbaceous ornamentals according to NOP guidelines. Organic-approved substrates can be purchased from commercial suppliers or produced in house. Many organic substrate components are similar to those used in conventional production (peat moss, pine bark, perlite, vermiculite, rice hulls, and whole pine tree) but lack a synthetic wetting agent. Growers who mix their own substrates often add compost at percentages ranging from 20 to 50%. Compost has high water holding and cation exchange capacity. It is often locally or regionally produced and purchased, which impacts variability and quality. For this reason, growers often need to manage substrates with compost more carefully. Single source or blended organic fertilizers may be incorporated in substrates prior to planting. These are derived from a variety of plant and animal based sources. A small number of mined components may be added to substrate-incorporated fertilizers (i.e. limestone). These fertilizers will typically last for four to five weeks, and are often supplemented with liquid fertilizers for longer-term crops or species with high nitrogen requirements. Liquid fertilizers also tend to be more quickly plant available compared to substrate-incorporated fertilizers. With careful management, it is possible to grow container plants in organic production systems that are comparable to those produced in conventional production systems.

Keywords. compost; liquid organic fertilizer; national organic program; organo-mineral fertilizer; tomatoes; vegetable transplants

Introduction

The increase in consumer demand for organically-grown crops has been recognized by many greenhouse producers in the United States (e.g. Treadwell et al., 2007). As interest in organic greenhouse production increases in the U.S., nutrient management is often cited as a key challenge to the adoption of organic production practices (Burnett and Stack, 2009). Organic substrates typically use a blend of various allowed bulk materials to achieve appropriate physical properties (water and air holding capacity). Organic nutrient management for container production often includes the use of a combination of fertilizers, such as pre-plant amendments with compost or other organic-certified materials to provide an initial nutrient charge that is supplemented with liquid organic fertilizers as the production cycle progresses. Length of the production cycle often dictates the best strategy for using organic nutrient sources: shorter production cycles, such as for vegetable transplants, can often be accomplished solely with nutrients amended to the substrate pre-plant, but longer-term greenhouse crops, such as tomatoes, typically require that liquid organic nutrients be used to supplement pre-plant incorporated nutrients. Ornamental crops are also produced using organic-based nutrient sources, but they are frequently produced solely with liquid organic fertilizers regardless of length of the production cycle.

The objective of this article is to highlight organic greenhouse production methods of containerized plants with a focus on allowable production practices, the size of the industry, and a review of organic substrate and fertilizer practices used in the United States.

1.1 Guidelines for Organic Greenhouse Production in the United States

According to the United States Department of Agriculture (USDA), organic greenhouses and other farms in the United States, ‘Preserve natural resources and biodiversity..., only use

approved materials, and receive annual onsite inspections’ (USDA, 2015). The USDA NOP guides the development of standards for organic greenhouse production (USDA – Agriculture Marketing Service, 2015a). These guidelines were developed in 2000 (Greer and Driver, 2000). While the USDA provides the legal guidelines and definition of organic, accredited certifying agents certify greenhouses and their products. All greenhouse growers who sell more than \$5,000 of product each year are required to go through the certification process (Baier, 2012). There are approximately eighty agents who have the ability to certify greenhouses; they are national and international organizations. Typically, when a grower is becoming certified, they go through a transition process, and an accredited certifying agent assists them as they work through this process. After this initial process, they need to renew their certification each year.

Throughout the United States, there may be minor regional or state differences in the interpretation of the guidelines for the NOP. Growers may choose which accredited certifying agent they work with. However, not all eighty agents work in every state. Some groups, such as Oregon Tilth Certified Organic, are qualified to certify growers in every state, Puerto Rico, and the Virgin Islands. By comparison, some growers work with a regional accredited certifying agent, such as the Maine Organic Farmers and Gardeners Association or the Northeast Organic Farmers Association which certify growers in a limited number of states. The full list of accredited certifying agents is available through the USDA-Agricultural Marketing Service (2015b).

Growers wishing to determine which fertilizers, substrates, or pest management products would be appropriate to use during organic production could check in a few places. One would be the list of allowed products through the USDA NOP Guidelines. Since the interpretation of these guidelines varies slightly according to certifying agent, many growers work closely with

their accredited certifying agent to ensure that they are following appropriate organic greenhouse production procedures. There is also an independent group called the Organic Materials Review Institute (Organic Materials Review Board, 2014) that reviews products for compliance with NOP guidelines and provides a fairly comprehensive list of certified organic products.

The NOP standards in the United States differ from some international organic standards. One difference for greenhouse production is that growers may produce crops either in containers or directly in the soil (Schmutz et al., 2014). Since container production is not prohibited, growers often purchase or produce certified organic container substrates. While these substrates may contain soil or compost, they also usually contain other naturally derived components, such as peat moss. Another difference for organic production in the United States compared to most other countries is that organic production in hydroponic systems is not prohibited.

1.2 Status of Organic Greenhouse Production in the United States

The most recent survey of organic greenhouse production indicated that it is valued at \$112 million (USDA-NASS, 2014). Greenhouse crops are diverse and include food (\$76 million), floriculture crops (\$27.3 million), and propagative material (\$8.8 million). The value of greenhouse crops has increased over time. For example, the economic value of organic floriculture (greenhouse and open field) alone has increased 43% since 2008 (USDA-NASS, 2008 and 2014). There are 2.1 million m² of organic production under protection in approximately 1,785 greenhouses. This has more than doubled compared with 2008 numbers when there were 744 greenhouses covering 0.7 million m² (USDA-NASS, 2008 and 2014).

Our focus in this review will be on the unique industry of organic greenhouse production in containers in the United States. Many growers in cold climates produce vegetable or herb transplants in containers in greenhouses for on-farm use and/or to extend the season. Container-

grown plants are also grown for sale through retail markets to home gardeners. There has been market research to determine consumer interest in organic container-grown plants, however, that information has provided conflicting results. Yue et al. (2011) reported that there was less consumer interest in organically grown container plants, compared to conventional or locally grown plants (2011). By comparison, Hawkins et al. reported that consumers were highly interested in organically grown vegetable/herb and ornamental container grown plants (2012). Both surveys of interest in container-grown plants were regional, rather than national. Yue et al. (2011) surveyed consumers in four states (Indiana, Michigan, Minnesota, and Texas), and Hawkins et al. (2012) surveyed consumers in Maine. Given consumers' diverse interests in organic products throughout various regions in the United States, it would be interesting to provide more national economic and marketing data for growers in the future.

Hawkins et al. (2012) also indicated that consumers would be willing to pay 10 to 15% more for organically grown container plants than conventional plants. Although consumers will pay more for container grown plants, they will pay a greater premium (up to 25% more) for organically grown vegetables (Rippy et al., 2004). The greater price premium that growers receive for food compared to ornamental plants could partly explain why there is more greenhouse production of food compared to container-grown plants. If a 10-15% increase in premium does not cover higher production costs for container grown plants, it would be difficult to justify the adoption of organic production techniques.

There are challenges for organic growers and conventional growers who wish to transition to organic production. Research could remove barriers for these growers. One of the primary challenges for organic growers and those interested in transitioning is managing

substrate and fertility issues (Burnett and Stack, 2009). The remainder of our review will focus on those production areas.

1.3 Organic Substrates

Organic substrates (also referred to by the NOP as growing media, potting media, and soilless media) must use only allowed materials and may not contain prohibited substances such as synthetic wetting agents and fertilizers (Treadwell et al., 2007). Alternatives to synthetically-derived starter fertilizers or wetting agents are available in approved organic forms (Treadwell, 2007). If restricted substances are used they must be used in manner that meets the ingredient restrictions. As in conventional substrates, bulk materials and amendments used for approved organic substrates must be formulated so as to supply proper physical, chemical, and biological properties to support plant growth and be free of diseases and weed seeds. Several commercially available organic substrates formulated for professional growers by potting mix manufacturers are available on the market. These manufacturers' distribution may be regional [including but not limited to: McEnroe (Millerton, NY, U.S.), Vermont Compost Company (Montpelier, VT, U.S.)] or national [including but not limited to: Berger (Saint-Modeste, Quebec, Canada), Lambert Peat Moss (Rivière-Ouelle, Québec, Canada), Premier Tech Horticulture (Quakertown, PA, U.S.), Sun Gro Horticulture (Agawam, MA, U.S.)]. In addition, many growers also choose to prepare their own organic substrates.

Many commonly used bulk components of conventional potting mixes can be used, such as peat, coconut coir, perlite and vermiculite (Treadwell et al., 2007). In addition, many other locally/regionally available bulk components are used such as compost, anaerobic dairy manure digestate (Krucker et al, 2010), rice hulls (Evans and Gachukia), bark (Baumscha et al., 2007), and milled pine bark or whole pine tree (Jackson and Wright, 2009). Many feedstocks are used in

compost for container media and we describe composts in more detail in the next section. The use of locally available components in organic substrates can make it difficult to compare plant performance trials from one region to another. In addition to the bulk components, an organic wetting agent may be used. This is often an extract from *Yucca* spp. containing saponin (Treadwell et al., 2007). Additives to adjust pH include limestone to increase pH and elemental sulfur to decrease pH. Substrate incorporated and liquid applied organic fertilizers are discussed in subsequent sections; this section focuses on bulk components as well as comparisons of different organic substrates.

Numerous different formulations for organic substrates exist in the literature, for example, Kuepper (2010). Some experiments in the scientific literature have directly compared performance of plants where the organic substrate had different bulk components. Zhai et al. (2009) compared yield of greenhouse tomatoes (*Solanum lycopersicum*) with different bulk components: 20% or 40% yard waste compost or 20% swine compost plus 20% yard waste amended to a peat/perlite substrate as compared to a peat/perlite control. In their first experiment, the compost-based substrates with organic fertilizers produced yields that were 18% to 80% of control yields with conventional fertilizer. The 40% yard waste performed better than 20% swine compost plus 20% yard waste. In a subsequent experiment, 50% yard waste or spent mushroom compost was amended to the peat/perlite substrate. Tomatoes with either substrate performed as well as controls so long as they were fertilized continuously with a low concentration (192, 64, and 299 mg·L⁻¹ N, P, and K, respectively) of plant based liquid organic fertilizers (Zhai et al, 2009).

Rippy et al. (2004) compared two organic substrates for greenhouse tomato production in 18.9-L upright plastic bag containers. One mix contained a commercial peat and pine bark blend

and a second mix consisted of a commercial pine bark and coir blend. Both mixes were amended with 15% vermicompost as well as dolomitic limestone, blood meal, bone meal, and potassium sulfate. Plants received one of two different liquid organic fertilizer regimes and these 4 treatments were compared to a conventional substrate with peat, perlite, vermiculite and 50% pine bark and conventional fertilizer. All the organic and conventional fertilizers were formulated to provide the same amount of N, P, and K. Regarding the organic substrates, the peat/pine bark blend led to slightly higher yields than the pine bark/coir blend. While results varied based on growing season, fruit yield of organically grown tomatoes was equal to or greater than the conventional treatment. Surrage et al. (2010) compared growth of tomatoes in 14-L containers with one of 4 different organic substrates, to conventional rockwool tomatoes. The organic substrate formulations were: 1) coconut coir and vermicompost (proportions not given), 2) 70% coconut coir and 30% composted manure, 3) 40% coconut coir, 30% composted manure, 15% perlite, and 15% vermiculite, and 4) aged pine bark, coconut coir, and vermicompost (proportions not given). Granular organic fertilizer was incorporated to supply 165, 66, and 264 mg·L⁻¹ N, P, and K respectively. Elemental sulfur was used to reduce substrate pH to 5.7. The organic substrates received a liquid organic fertilizer formulation while rockwool plants received a conventional fertilizer. Marketable tomato yields were higher in the organic substrate treatments than the conventional treatment with no significant differences between organic substrate treatments. Organic substrate 1 treatment led to significantly less incidence of blossom end rot than substrates 2 and 3, and rockwool.

Succop and Newman (2004) compared three substrates for fresh market sweet basil (*Ocimum basilicum*): rockwool slabs (a conventional substrate not allowed in U.S. organic production), perlite, and an organic commercial sphagnum peat/perlite and compost substrate.

When fertilized with a liquid organic fertilizer, rockwool gave less harvestable yield than the other two substrates in one of the trial years. The authors hypothesized that the low aeration of the rockwool provided insufficient oxygen to foster microbial activity required for mineralization from the organic fertilizer source (Succop and Newman, 2004). Mattson and Beeks (2013) compared several organic substrates for growth of pepper (*Capsicum annuum*) and tomato seedlings (in 20 mL cells) and transplants (in 500 mL pots) without additional liquid fertilizers. Compost-based mixes with several substrate incorporated fertilizer components (McEnroe and Vermont Compost) gave greater plant growth than a Cornell University organic formulation, which performed better than a peat/perlite mix with a relatively small organic starter nutrient charge. The Cornell formulation was 70% peat, 25% coarse perlite and 5% vermicompost (Worm Power LLC, Avon, NY) along with $1.48 \text{ g}\cdot\text{L}^{-1}$ dolomitic limestone, $2.95 \text{ g}\cdot\text{L}^{-1}$ green sand and rock phosphate and $2.07 \text{ g}\cdot\text{L}^{-1}$ dried blood.

Several researchers have studied biological amendments to enhance plant growth in organic substrates. For example, Russo (2006) looked at the impact of commercially available arbuscular mycorrhizal fungi (AMF) and *Sinorhizobium* sp. bacteria species on the growth of pepper transplants in 128-cell (30-mL per cell) trays with an organic peat/perlite based substrate and varying amounts of liquid fish emulsion fertilizer. Plant height and dry weight were promoted by the bacterial amendment across fertilizer treatments, but were generally unaffected by AMF treatment. Carpio et al. (2005) tested two different commercial strains of AMF for growth effects on bush morning glory (*Ipomoea carnea* spp. *fistulosa*) grown in a pine bark:sand (3:1 by volume) substrate. Across three different rates of incorporation of a granular organic fertilizer, both AMF products increased root and shoot dry mass as compared with unamended controls. Depending on fertilizer treatment and AMF species, total plant dry mass was increased

by 30% to 180% with biological amendment (Carpio et al., 2005).

1.4 Compost

Compost is a common ingredient in container substrates in the United States. Compost is produced from various waste products. Organic growers can work to fulfill the organic mission when they use compost since they are reducing environmental damage by using organic waste materials in a productive way. Composted manure is used as a component in container production. It is also necessary to compost certain farm wastes, such as manure, before use in order to kill human pathogens and prevent the spread of food-borne illnesses (Millner, 2008). Compost has a high cation exchange capacity and water holding capacity, which makes it appropriate for a replacement for at least part of peat moss traditionally used in container substrates (Hartz et al., 1996; Stoffella and Kahn, 2001). Compost has been reported to have at least some ability to suppress soil-borne diseases (Raviv, 2008). In addition to using compost as a substrate component, some growers also top-dress with compost to provide additional organic matter and/or fertility later during the production cycle. This is an especially useful production practice for crops with a longer production cycle.

The NOP provides guidance for growers to ensure that appropriate feedstocks are utilized in compost, both for field and greenhouse production. Organic growers are encouraged to protect soil, crops, and water during plant production. Greenhouse growers typically select composts with this guiding principle in mind. For example, manure, leaf matter, and yard waste would be appropriate feedstocks for compost. However, certified organic producers could not use composted sewage sludge.

Throughout the United States, a wide variety of feedstocks are composted, including yard or food waste, cow manure, and seafood and shellfish waste (Burger et al., 1997; DeKalb et al.,

2014; Hartz et al., 1996; Hawkins, 2010; Sanders et al., 2011; Spiers and Fietje, 2000). Often, compost is a regionally sourced material, and the feedstock would be a waste product of industry that is common in a particular state or region. For example, shellfish and seafood waste are frequently used in New England as compost feedstocks because of the large fishing and lobster industry in this region. There are few composts that are available nation-wide because shipping costs tend to be greater for compost compared to other substrate components.

Since compost feedstocks and sources vary regionally, it is important to test chemical and physical properties to ensure quality (Raviv, 2005; Hartz et al., 1996). There are some recommendations that are useful to growers regarding selection of compost for container production. Plants tolerate a range of electrical conductivities (ECs; 0.76 to 4.0 mS•cm⁻¹ measured using saturated-paste extract); generally, levels above this would be considered too high for container production (Nelson, 2011). EC levels well above this range have been measured in compost (Clark and Cavigelli, 2005; Hartz et al., 1996; Hawkins, 2010; Young et al., 2002). For example, substrates containing 33% shellfish compost and composted manure have ECs as high as 4.6 and 4.78 mS•cm⁻¹, respectively (Hawkins, 2010). EC levels as high as 14.7 mS•cm⁻¹ have been measured in green waste compost or 16.1 mS•cm⁻¹ in spent mushroom compost (Clark and Cavigelli, 2005; Hartz et al., 1996). Leaching will reduce salinity to a recommended range (Young et al., 2002). However, this practice will displace water-soluble nutrients that may be present. The C:N ratio in finished compost should be approximately 25:1 in order to insure that the appropriate composition of materials was used in the feedstock (Dresbøll, 2004). Compost pH is generally above 6.0 and can be above 8.0 (Clark and Cavigelli, 2005; DeKalb et al., 2014; Sanders et al., 2011; Spiers and Fietje, 2000; and Young et al., 2002).

Combining compost with acidic substrate components, such as certified organic peat-based substrate, reduces the pH to desirable levels (DeKalb et al., 2014).

One problem some growers have noticed is that using immature compost in container production can result in reduced plant growth (Gouin, 1998; Hawkins, 2010). Poinsettia (*Euphorbia pulcherrima*), bibb lettuce (*Lactuca sativa*), baldhead cabbage (*Brassica oleracea*), sweet william (*Dianthus barbatus*), and pansy (*Viola x wittrockiana*) growth was greater in compost aged for 90, compared to 30 days in windrows (Purman and Gouin, 1992). So, greenhouse growers often work with a private or state lab to test for maturity. Some greenhouse growers utilize on-farm test kits such as the Solvita (Woods End Laboratories, Inc., Mt. Vernon, ME) test kit, which estimates maturity by measuring ammonia and carbon dioxide (Changa et al., 2003).

The total porosity of compost varies depending on the feedstock, but can be too low for compost to be used as the sole ingredient in container substrates (Raviv, 2005). For example, yard-waste compost may be incorporated at 20%; higher amounts reduced growth of basil and increased the amount of time for plants to germinate (DeKalb et al., 2014). Suggestions for the portion of compost to include in a final mix range from 20-50% (Hartz, 1996; Kuepper, 2010). The amount to include will depend on the EC of the compost. The particle size of particular compost will greatly impact porosity. In container production, particle size should be 30-300 μm (Dresbøll, 2004). It is often difficult to obtain the optimum particle size, and many growers use screening to exclude the largest particles ($>1.25\text{ cm}$) from compost-based substrates (Gouin, 1998).

The cost of compost would likely vary regionally due not only to differences in supplier costs nationwide, but also due to large differences in freight charges. However, Clark and

Cavigelli indicated that the price of compost based-substrates is similar or more expensive compared to the cost of a commercial potting mix, depending on the source (2005).

Finally, another thing to consider is that it is rare for compost alone to provide adequate fertility for container plant production (Fitzpatrick et al., 1998; Hawkins, 2010; Keupper, 2010). Nitrogen content of composts may be below 2% (Stofella and Kahn, 2001). The amount of nitrate and ammonium varies depending on source and feedstock. For example, NO_3 ranged from 13.3 (composted yard waste) to 177.3 $\text{mg}\cdot\text{L}^{-1}$ (composted manure); NH_4 varied from 4.8 (composted yard waste) to 19.25 $\text{mg}\cdot\text{L}^{-1}$ (shellfish based compost; Hawkins, 2010). Three shellfish based composts, composted manure, and composted yard waste had lower NO_3 compared to a standard growing substrate (Hawkins, 2010). Shoot dry weight of basil and marigolds grown in compost-based substrates was lower than shoot dry weight of plants grown in a substrate with only starter fertilizer (Hawkins, 2010). This was at least in part due to low nutrient concentration in compost. Further, availability of nitrogen increases with temperature, which can impact management of plants grown in compost-based substrates (Kraus, 2000). Since there is little fertility present in compost-based or other organic substrates, incorporated and/or liquid fertilizers are commonly used in organic container production.

1.5 Substrate-Incorporated Fertilizers

Organic fertilizers may be incorporated into the substrate prior to transplanting or may be added later by top-dressing or side-dressing on or within the substrate surface. In addition, organic water-soluble fertilizers may be added in the irrigation water. Substrate-incorporated fertilizers can be categorized as conventional mineral, organic, or organo-mineral. Organo-mineral sources utilize both organic-based nutrients as well as inorganic sources. Organo-mineral sources cannot be used in certified organic production, but represent a tool for conventional

growers to utilize waste products. Organic nutrient sources may be single source or blended and come from plant or animal by-products or allowable mined sources (Treadwell, 2007). Some plant based substrate incorporated fertilizers include alfalfa (*Medicago sativa*) meal, soybean (*Glycine max*) meal, and kelp (Order Laminariales) (Gaskell and Smith, 2007). Some animal-based substrate incorporated fertilizers include fish meal/powder, pelleted chicken manure, feather meal, seabird or bat guano, bone meal and blood meal (Gaskell and Smith, 2007). The use of organic-waste products as the nutrient source is beneficial as it represents a productive method of using waste products in a manner that conserves nutrients (Williams and Nelson, 1992). Some mined sources of nutrients with low solubility are also allowed by the NOP including limestone and dolomitic limestone, glauconite (i.e. greensand, a source of potassium), magnesium sulfate, rock phosphate, potassium sulfate (if from langbeinite or other nonsynthetic sources) (USGPO, 2015). Some mined materials with high solubility are allowed with restriction such as calcium chloride (CaCl_2) potassium chloride (KCl) and sodium nitrate (i.e. Chilean nitrate, NaNO_3) (USGPO, 2015). Prior to October 2012, a maximum of 20% of a crop's N needs could be supplied with sodium nitrate. After this date, there was not a specific maximum percentage, however "operators using sodium nitrate shall use it in a manner that maintains or improves the natural resources of the operation, including soil and water quality, and comply with crop nutrient and soil fertility requirements" (OMRI, 2012). It is unclear whether the NOP will continue to allow use of Chilean nitrate for much longer.

Unlike inorganic fertilizers, organic nutrients from plant and animal-based residues are often not immediately available to the plant and must be converted into plant available forms by microbes in the substrate (Bi et al., 2010). The rate of microbe mediated mineralization is highly variable and dependent on several factors such as substrate temperature, air porosity, and

moisture content as well as by the nature of the organic fertilizer source (particle size and composition) (Gaskell and Smith, 2007). A difficulty with using organic fertilizers is matching the rate of nutrient release to the plant's nutrient demands (Treadwell, 2007). Other challenges noted with substrate incorporated organic fertilizers are that they may contribute to high substrate pH and EC (Bi et al., 2010) and in some cases, an incubation period is required before plants are sown or transplanted; otherwise, damage can occur from high ammonium (such as from blood meal) or allelopathic compounds from plant-based products such as alfalfa residues (Nair et al, 2011).

Using a laboratory incubation method, Hartz and Johnstone (2006) determined N availability from feather meal, seabird guano, fish powder, and blood meal in soil as a response to temperatures ranging from 10 to 25 °C and across an 8 week period. Temperature influenced early N mineralization of all the materials except fish powder. For example, for blood meal after 1 week, 18% of N had mineralized at 10 °C while 51% had mineralized at 25 °C. By two weeks, across materials, about half or more of all N had mineralized; 47 to 51% of N had mineralized at 10 °C and 57 to 60% had mineralized at 25 °C. Seven organic materials were assessed by Williams and Nelson (1992) for their suitability for providing organic N over a 10 to 12 week crop period for potted chrysanthemums. N release was quickest within the first two weeks and declined until week 6-7. When substrate incorporated prior to planting, two organic N sources, coarse bonemeal (at 1.82 g N·L⁻¹) and *Brevibacterium lactofermentum* in a nonviable state (at 0.97 to 1.45 g N·L⁻¹, depending on strain) produced plants of similar size and quality to inorganic controlled release fertilizer or liquid fertilizer controls.

Because a large proportion of organic nutrients are mineralized within the first few weeks and can leach out of container mixes, substrate incorporated organic fertilizers are typically used

as the sole fertilizer source only for short term crops. An alfalfa-based substrate-incorporated fertilizer, Tasty Tomato 3-1.31-2.49 (N-P-K; Bradfield Organics, Springfield, MO, U.S.) was suitable for producing commercially acceptable 6-week old tomato transplants if a 1-3 week incubation period was used prior to seeding (Nair et al, 2011). Fertilizer incorporation rates were 0, 5.6, 11.2, 16.8, and 22.4 g·L⁻¹. Substrate EC increased with incubation period and incorporation rate. Poor germination was noted if the substrate was incubated for either 0 or 4 weeks or at the highest rates of fertilizer incorporation. Best rates that balanced both high germination percentage and good plant growth were 5.6 and 11.2 g·L⁻¹. The use of two commercially-available pelletized chicken litter (manure plus bedding) materials as a substrate organic fertilizer was studied for marigolds (*Tagetes patula*) grown in 15 cm containers for 28 or 40 days after transplanting (Bi et al., 2010). The two materials were TOP 4-0.87-1.66 (N-P-K) and TOP 3-1.31-2.49 (N-P-K; Organic Growing Systems, Alpharetta, GA, U.S.) and were applied at rates of 0, 259, 518, 1036, and 1555 mg·L⁻¹ N. The products were compared to a synthetic controlled release fertilizer (Osmocote 3-4 month, 14-6.12-11.62, Scotts-Sierra, Horticultural Products, Marysville, OH) incorporated at 0, 139, 277, 554, and 831 mg·L⁻¹ N. Low to intermediate incorporation rates of 4-0.87-1.66 (N-P-K) and 3-1.31-2.49 (N-P-K) resulted in plants with the highest dry weight and similar quality compared to plants that received the highest rates of Osmocote. The highest rates of the poultry litter fertilizers led to symptoms associated with excessive fertilization and reductions in plant growth.

For long-term crops, substrate incorporated fertilizers are typically not enough to supply plant needs for the entire crop cycle and must be supplemented by top-dressing, side-dressing, or use of liquid fertilizers in the irrigation water. Shrimp meal was tested as a substrate fertilizer amendment for pepper transplants grown for 5 or 10 weeks (Gravel et al., 2012). The shrimp

meal was provided at 0, 400, 800, or 1600 mL·m⁻³ in a commercially available organic substrate and was in addition to a three times weekly application of a commercial liquid organic fertilizer. Five weeks after sowing, plants fertilized with 400 and 800 mL·m⁻³ were slightly larger; however shrimp meal impacts were not visible 5 weeks later. In the greenhouse container tomato study by Zhai et al. (2009), tomatoes in 15-L pots with a 20% to 40% compost amended substrate exhibited symptoms of N and P deficiency after 1 month. Plants were subsequently provided with plant-based liquid fertilizers on a routine basis.

Commercially available organic fertilizer blends with a guaranteed nutrient analysis that combine several organic nutrient sources into a granular fertilizer are becoming increasingly used by organic container growers (Treadwell et al., 2007). The use of blended commercial products can allow for several (and potentially all) the necessary plant nutrients to be supplied in one product, rather than the grower combining several materials. In addition the combined materials might use both quick and slowly mineralizable materials so as to have more sustained nutrient release. Four organic fertilizer treatments (including 3 blended materials) were compared to a conventional hydroponic nutrient solution (HNS) for yield of fresh cut basil and spearmint (*Mentha spicata*) (Treadwell et al., 2011). The organic fertilizers were incorporated into growing troughs with an organic substrate prior to transplanting and supplemented with a second application of fertilizer side-dressed into the substrate 58 days after transplanting. This approach was successful in matching HNS yields in several cases. Spearmint yields were similar in year 1 regardless of treatment. In year 2 HNS and poultry litter gave the greatest yields. Basil yield was similar with HNS and poultry litter in year 1; while in year 2, yields from all the organic treatments were significantly lower than HNS.

Performance of bedding plants grown with substrate incorporated organic fertilizers were compared to conventional liquid and controlled release fertilizer (CRF, Osmocote Bloom 12-3.06-14.94, Everris, Dublin, OH, U.S.) regimes (Mattson, 2014). The organic fertilizers were EcoVita 7-2.19-8.30 (N-P-K, derived from hydrolyzed feather meal, fermented sugar beet and sugar cane molasses, bone meal, soybean meal, and cocoa shell meal) (Bioworks, Inc. Victor, NY, U.S.), Microstart 60 plus 7-3.06-1.66 (N-P-K, derived from feather meal and pasteurized poultry litter) (Perdue AgriRecycle, Seaford, DE, U.S.), and Sustane 8-1.75-3.32 (N-P-K, derived from aerobically composted turkey litter, feather meal and sulfate of potash) (Sustane, Cannon Falls, MN, U.S.). The organic fertilizers and CRF were substrate incorporated at 250 mg·L⁻¹ N prior to transplanting coleus (*Plectranthus scutellarioides*), fibrous begonia (*Begonia semperflorens*), pansy and petunia (*Petunia x hybrida*). Plants were evaluated for shoot fresh weight 5-7 weeks after transplanting when they were considered commercially marketable. Liquid fertilized plants were the largest in all cases; however, for coleus, fibrous begonia, and pansy the organic fertilized plants were, in general, of similar size to CRF plants and considered commercially marketable. Petunia produced with organic fertilizers were not marketable, and this was attributed to its higher fertility needs, longer crop production length (7 weeks), and sensitivity to high pH (Mattson, 2014).

1.6 Liquid Fertilizers

Classification of liquid organic fertilizers. Like substrate-incorporated fertilizers, liquid fertilizers can also be categorized as conventional mineral, organic, or organo-mineral. Soluble, conventional mineral fertilizers are comprised of blends of inorganic nutrient salts that are dissolved in concentrates, diluted via fertilizer proportioner, and applied through irrigation lines; these are the current greenhouse industry standard for conventional production.

Liquid organic fertilizers include a variety of materials derived from plant and animal sources, including fish and seaweed emulsions, fish hydrolysates, and oilseed extract. Many fertilizers are derived from waste streams of food processing. Plant essential nutrients are parts of larger molecules with a carbon framework, such as protein fragments, that are degraded by microbial activity before plant uptake. Under U.S. organic standards, organic-certified fertilizers can include soluble nitrate from mined sodium nitrate; an example is Nature's Source 3-1.31-0.83 (N-P-K) with most nutrients derived from soybean oilseed extract and extra nitrogen provided by sodium nitrate. Liquid organic nutrient sources may contain excessive (e.g. micronutrients) or unneeded (e.g. sodium) constituents that necessitate routine ion-specific monitoring.

While fertilizer injectors can be used to deliver some liquid organic fertilizers to crops via the irrigation system, a drawback is that the consistency of some liquid organic fertilizers often clogs irrigation equipment such as drip emitters and screens of pumps used in ebb and flood fertigation. Another challenge with organic fertilizers is that the carbon supports microbial activity, so at diluted rates, microbes grow in nutrient stock and their use supports the development of biofilm in irrigation pipes, ebb and flood benches and greenhouse environments. These problems significantly limit the use of liquid organic fertilizers in production systems such as ebb and flood benches in the U.S.

Organo-mineral fertilizers are liquid organic fertilizers to which solubilized inorganic nutrients have been added for the purpose of increasing nutrient content or balancing ratios of the primary macronutrients. An example is Nature's Source 10-1.75-2.49 (N-P-K; Ball DPF LLC., Sherman, TX, U.S.) which is a soybean oilseed extract supplemented with inorganic salts. Because of the addition of nutrients derived via synthetic processes, these fertilizers are not

available to use for organic-certified production.

Production of liquid organic fertilizers. Liquid organic fertilizers used in U.S. production are produced in a variety of ways. Microbial digestion of animal by-products of blood meal and bone meal, along with mined sulfate of potash, produces complete liquid fertilizers. For example, Chan et al. (2007) describe a process to solubilize blood meal by means of a microwave-hydrogen peroxide oxidation process which breaks down large protein molecules into peptides and amino acids, ammonia and nitrate; intermediate compounds can be easily converted to nitrogen by bacteria.

Fish emulsion is typically derived from acidulated fish tankage; urea, phosphoric acid and potassium chloride may be added, but these additions would result in the material being classified as organo-mineral and not ‘certified organic.’

Nature’s Source is a popular liquid organic fertilizer in the U.S. Non-genetically modified soybean, an oilseed, is processed to yield soybean meal and soybean oil; the seeds are crushed and the oil is extracted with a solvent to remove the entire organic fraction. This crude soybean oil is processed further to remove the natural organic compounds of lecithins, carbohydrates, protein fragments, and mucilaginous substances by addition of a dilute aqueous alkali solution. Through further processing, this solution becomes a liquid organic fertilizer for plant growth (Daniels, 1989).

Nitrogen availability from liquid organic fertilizers. One of the most challenging aspects of using organic nutrient sources is synchronizing nutrient supply, which occurs at least in part by microbial mineralization, with plant demand. Hartz et al. (2010) evaluated N availability from three liquid organic fertilizers: Phytamin 801 (California Organic Fertilizers, Hanford, CA, U.S.), comprised of fishery waste and seabird guano; Phytamin 421 (California Organic

Fertilizers, Hanford, CA, U.S.), comprised of soybean meal and plant extracts; and Biolyzer (Converted Organics of California, Gonzales, CA, U.S.), derived from grain fermentation. Nitrogen availability from Phytamin 801 ranged from 79% to 93% of total N content after only 1 week, and 83% to 99% after 4 weeks. The fertilizers derived from plant materials had half to 92% of total N mineralized after 4 weeks. Results from this study emphasize that liquid organic fertilizers generally have rapidly-available nitrogen that often makes their use complementary to substrate-incorporated organic nutrient sources.

Transplant production. The demand for commercially-available, organically-grown vegetable and herb transplants is increasing, though transplants are still usually produced on-farm for use by the producer. Larrea (2005) conducted six experiments to study the effect of substrate and amendments, including vermicompost and feather meal, on growth of tomato transplants; she concluded that all substrates tested would require additions of soluble fertilizer to provide sufficient N and K for transplant production. In a study with bell pepper, onion (*Allium cepa*) and watermelon (*Citrullus lanatus*) transplants, Russo (2005) evaluated the use of Sea Tea (2.1-3.3-2.2), which is an organic fertilizer containing compost tea, or the organic fertilizer Rocket Fuel (2-6-1, but not completely soluble; Garden-Ville, San Antonio, TX, U.S.) used in tandem with an organic substrate. He found that watermelon transplants had such a short cropping cycle that it was relatively easy to produce transplants with the organic substrate and fertilizer; bell pepper and onion, on the other hand, had longer transplant production cycles and therefore the organic-fertilized transplants were considered substandard compared to those produced with a conventional fertility regime. However, quality improved as organic fertilizer application rate increased, up to the point that high salt levels negatively affected seedling growth. Finally, Murray and Anderson (2004) compared the use of organic fish emulsion 5-0.44-

0.83 (N-P-K; Safer, Woodstream Corp., Lititz, PA, U.S.) and conventional Peter's 20-4.37-16.6 (N-P-K; Everris NA, Inc., Dublin, OH, U.S.) fertilizers for tomato and pepper transplant production. They found that fish emulsion was an effective organic fertilizer for tomato and pepper transplant production in that its use (4 to 8 applications during an 8 to 9 week production cycle) increased dry weights of the transplants 200% to 300% over unfertilized controls, though transplants were not as large as those fertilized with the conventional Peter's 20-4.37-16.6 soluble fertilizer.

Greenhouse herb production. Organic herb production occurs in a variety of production systems, including in containers with soilless substrate that are produced in recirculating culture. Succop and Newman (2004) evaluated basil production in a propriety blend of sphagnum peat moss/perlite/compost consisting of construction wood waste and poultry manure (Organix, Platteville, CO, U.S.). Conventional and organic liquid fertilizer mixtures were compared: the organic blend was comprised of organic fermented poultry compost, hydrolyzed fish emulsion, kelp extracts, and soft rock phosphate, and the conventional fertilizer was a modified Hoagland's recipe (Hoagland and Arnon, 1950) formulated to match as closely as possible the organic nutrient source. Yield of basil between the two fertilizers was not different. Treadwell et al. (2007) similarly reported that despite the variability within and among experimental trials with organic versus conventional nutrient management, yields and quality of greenhouse-grown herbs are frequently similar to, and occasionally better than, conventionally-fertilized crops.

Greenhouse tomato production. Greenhouse tomatoes in containers are being successfully produced solely with organic nutrient regimes. Rippy et al. (2004) reported on greenhouse tomato production in six organic production systems that included two liquid organic fertilizer regimes: Earth Juice program [several products including 'Grow' (2-0.44-0.83 N-P-K),

‘Bloom’ (0-1.3-0.83 N-P-K), ‘Microburst’, etc., comprised in total components including bat guano, Chilean seabird guano, Norwegian sea kelp, mined sulfate of potash, feather meal, oat bran, blood meal, steamed bone meal, rock phosphate, and other organic materials; Greenfire, Chico, CA, U.S.] and Magna Gro (2-1.3-5 N-P-K; Magna Gro, Lawrence, KS, U.S.) from poultry compost tea, pasteurized blood meal, calcium phosphate, seaweed, and fermented molasses; this product was supplemented with poultry compost tea, pasteurized blood meal, and K-9 (7.47% K from seaweed). These production regimes resulted in tomato plants that were comparable to conventionally-fertilized tomatoes based on nutritional status, plant development and harvest yields. Compared to conventional systems, differences were that salt levels (as measured via electrical conductivity) were exceptionally-high in the organic systems for about the first 4 weeks after transplant, which was attributed to pre-plant amendments and substrate pH was higher in the organic systems, so in subsequent studies, pre-plant limestone rates were reduced and elemental sulfur was added to result in pH levels that were in the recommended range.

Zhai et al. (2009) reported on liquid organic fertilizer use for greenhouse tomato production compared to a hydroponic control. Similar to Rippy et al., they found success with use of an organic pre-plant nutrient source supplemented with liquid organic fertilization in that total tomato yield in the best-performing organic treatment was 80% to 100% of the hydroponic control. The best organic treatment was a substrate heavily-amended with mushroom compost in tandem with a mixture of Pura Vida Grow (6-1.75-3.32 N-P-K), Pura Vida Bloom (2-2.62-4.98 N-P-K) and Thrive Alive (1-0.44-0.83 N-P-K), all liquid organic nutrient sources (Technaflora Plant Products Ltd., Port Coquitlam, B.C., Canada) applied at a ratio of 4.55:4.50:0.50 N-P-K.

Key points of interest from these studies of tomato production with organic liquid

fertilizers is that tomato yield can match that from conventional fertilizer use, but the grower must take care to supply all essential plant nutrients in appropriate quantities over the course of the entire cropping cycle, which can span up to one year. As these studies demonstrate, this is typically accomplished by using a combination of organic pre-plant nutrient sources, such as compost, that is supplemented by a somewhat complex recipe of liquid organic nutrient sources.

Ornamentals production. Ornamental greenhouse crops in containers are being successfully produced with organic nutrient sources. A difference compared to organic transplant and vegetable production is that ornamental crops are more frequently produced solely with liquid organic nutrient sources without pre-plant amendment with a compost or other organic fertilizer.

Eaton et al. (2013) evaluated organic production of calibrachoa (*Calibrachoa xhybrida*) and marigold, both of which had about a 60-day post-transplant production cycle. Plants were fertilized twice per week with 175 mg L^{-1} N during the first 30 d after transplanting and then 225 mg L^{-1} for the remaining 30 d. Liquid organic fertilizer treatments were Nature's Source 3-0.44-0.83 (N-P-K) oilseed extract, Neptune's fish hydrolysate 2.0-0.79-0.66 (N-P-K), and a combination of the two products compared to a conventional control of Plantex 20-0.87-16.6 (N-P-K; Master Plant-Prod Inc., Brampton, ON, Canada) or the organo-mineral Nature's Source 10-1.75-2.49 N-P-K. The treatment that resulted in the poorest calibrachoa quality was Nature's Source 3-0.44-0.83 which might be attributed to high pH-induced iron chlorosis. The best quality marigolds resulted from fertilization with fish hydrolysate or the conventional control; again, the Nature's Source oilseed extract resulted in a pH of 6.9 and higher EC.

Nelson et al. (2010a and 2010b) have also evaluated the use of Nature's Source organo-mineral fertilizer (10-1.8-2.5 N-P-K) from oilseed extract for bedding plant production. They

found that petunia (*Petunia xhybrida*; 26 d production cycle fertilized with 49, 98 and 196 mg·L⁻¹ N) produced with the Nature's Source fertilizer were taller, flowered in less time, and did not differ in plant dry weight from a conventional control of the same N rate and 40% NH₄-N. Similarly, cyclamen (*Cyclamen persicum*; 78 d production cycle fertilized with 126 mg·L⁻¹ followed by 175 mg·L⁻¹ N) had similar plant growth and formed 47% more flowers than the 40% NH₄-N control (2010b). In both the petunia and cyclamen experiments, conventional fertilizer treatments were designed to match the N-P-K concentrations supplied by the organo-mineral fertilizer, but N form and concentrations of other essential elements were not matched across treatments. As also observed by Eaton et al. (2013), the substrate pH from the oilseed extract fertilizer was higher or similar to the control for both species. Nelson et al. (2010a) also evaluated the use of Nature's Source 10N-1.8P-2.5K for pansy, petunia, salvia (*Salvia farinacea*) and vinca (*Catharanthus roseus*) production, specifically studying ammonium impact and whether the low K was adequate for plant growth. They found that ammonium toxicity did not occur in any treatments with a standard lime rate and that the K content of the fertilizer, though a lower N:K ratio than typically considered necessary for floral crops, was adequate to meet the requirement of these four bedding plant species.

In a study with wax begonia (*Begonia xsemperflorens-cultorum*) and Surfinia petunia, Rochefort et al. (2013) used three liquid organic or organo-mineral fertilizers: General Purpose 15-1.31-9.13 (BioFert Manufacturing Inc., B.C., Canada), Nature's Source 10-1.75-2.49, and Solo-Tek Grow 8-1.75-1.66 (Growtek Manufacturing Inc., B.C., Canada). Plants received 200 mg·L⁻¹ N for two weeks, then the rate was increased to 300 mg·L⁻¹ N. Though some growth differences were observed, the organic fertilizers performed well compared to the conventional control and all plants from each fertilizer treatment achieved market standards for quality.

Organic fertilizers have also been used for longer-term greenhouse crops like potted poinsettias. Williams et al. (2009) reported performance of poinsettias grown with Ferti-lome fish emulsion (5-0.44-0.83 N-P-K; Bonham, TX, U.S.), Drammatic fish hydrolysate (2-2.19-0.0.17 N-P-K; Dramm Corp., Manitowoc, WI, U.S.), and Nature's Source soybean oilseed extract (10-1.75-2.49 N-P-K) compared to a conventional control, all at rates of 200 mgL⁻¹ N. The researchers noted differences in substrate salt levels (such as higher EC levels from fish emulsion) and plant architecture (such as taller and narrower plants from fish emulsion) between the treatments, but plants all achieved standards of commercial quality.

Future Prospects and Research

The size of the organic greenhouse industry in the United States has doubled since 2008. Container grown plants allow growers to reach the retail market and provide season extension for vegetable growers in cold climates. Continued growth in this area would benefit from research support, particularly to remove barriers for current and potential organic greenhouse growers. Fertility and substrate management in organic greenhouse production were identified as challenges in publications spanning decades of organic research in the United States. Growers utilize a variety of regionally or nationally sourced substrates and fertilizers. The diversity of materials and high level of management involved in organic compared to conventional production creates a steeper learning curve for new growers interested in entering the industry. It would be helpful to provide better strategies to assist new growers in finding appropriate fertilizers, substrates and composts in this diverse market. Further, many growers find it more challenging to produce longer-term, high fertility requiring crops using organic practices compared to short-term, low fertility requiring crops. Developing organic fertilizers that slowly release nutrients over longer periods for pre-plant incorporation would abate some of the

challenges and increase the diversity of crops that could be produced organically in container production systems.

Organic hydroponic production was recently approved in the United States. However, there are numerous challenges (Williams and Nelson, 2016) and few recommendations in the literature for growers interested in producing plants using organic fertilizers in liquid culture. Further research on which liquid nutrient blends are compatible for hydroponic production and developing strategies to aid growers in overcoming challenging of pH and nutrient management in these systems would be useful.

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References

- Baier, A.H. 2012. Organic certification of farms and businesses producing agricultural products. United States Department of Agriculture. 21 May 2015.
<http://www.ams.usda.gov/AMSV1.0/getfile?dDocName=STELPRDC5101547/>
- Bi, G., W.B. Evans, J.M. Spiers and A.L. Witcher. 2010. Effects of organic and inorganic fertilizers on marigold growth and flowering. *HortScience*. 45:1373-1377.
- Burger, D.W., T.K. Hartz, and G.W. Forister. 1997. Composted green waste as a container medium amendment for the production of ornamental plants. *HortScience* 32:57-60.
- Burnett, S.E. and L.B. Stack. 2009. Survey of the research needs of the potential organic ornamental bedding plant industry in Maine. *HortTechnology* 19:743-747.
- Carpio, L.A., F.T., Davies Jr. and M.A. Arnold. 2005. Arbuscular mycorrhizal fungi, organic and inorganic controlled-release fertilizers: effect on growth and leachate of container-grown bush morning glory (*Ipomoea carnea* ssp. *fistulosa*) under high production temperatures. *J. Amer. Soc. Hort. Sci.* 130:131-139.
- Chan, W.I., K.W. Lo and P.H. Liao. 2007. Solubilization of blood meal to be used as a liquid fertilizer. *J. Env. Sci. Health, Part B: Pesticides, Food Contaminants, and Agricultural Wastes*. 42(4):417-422.
- Changa, C.M., P. Wang, M.E. Watson, H.A.J. Hoitink, and F.C. Michel Jr. 2003. Assessment of the reliability of a commercial maturity test kit for composted manures. *Compost Sci. Util.* 11:125-143.
- Clark, S. and M. Cavigelli. 2005. Suitability of composts as potting media for production of organic vegetable transplants. *Compost Sci. Util.* 13:150-156.
- Daniels, R.S. 1989. Fertilizer process. U.S. Patent 4,836,843.

DeKalb, C.D., B.A. Kahn, B.L. Dunn, M.E. Peyton, and A.V. Barker. 2014. Substitution of a soilless medium with yard waste compost for basil transplant production. *HortTechnology* 24:668-675.

Eaton, T.E., D.A. Cox, and A.V. Barker. 2013. Sustainable production of marigold and calibrachoa with organic fertilizers. *HortScience* 48(5):637-644.

Fitzpatrick, G.E., E.R. Duke, and K.A. Klock-Moore. 1998. Use of compost products for ornamental crop production: research and grower experience. *HortScience* 33:941-944.

Gaskell, M. and Smith, R. 2007. Nitrogen sources for organic vegetable crops. *HortTechnology* 17:431-441.

Gouin, F.R. 1998. Using compost in the ornamental horticulture industry, p. 131-137. In: S. Brown, J.S. Angle, & L. Jacobs (eds.). *Beneficial co-utilization of agricultural, municipal, and industrial by-products*. Springer Science & Business Media, B.V., Dordrecht, Netherlands.

Gravel, V., M. Dorais and C. Ménard. 2012. Organic fertilization and its effect on development of sweet pepper transplants. *HortScience*. 74:198-204.

Greer, L. and Diver, S. 2000. Organic greenhouse vegetable production. ATTRA. 20 May 2015. <http://attra.ncat.org/attra-pub/ghveg.html>.

Hartz, T.K., F.J. Costa, and W.L. Schrader. 1996. Suitability of composted green waste for horticultural uses. *HortScience* 31:961-964.

Hartz, T.K. and P.R. Johnstone. 2006. Nitrogen availability from high-nitrogen containing organic fertilizers. *HortTechnology* 16:39-42.

Hartz, T.K., R. Smith, and M. Gaskell. 2010. Nitrogen availability from liquid organic fertilizers. *HortTechnology* 20(1):169-172.

- Hawkins, G. 2010. Consumer interest and compost substrate management of organic and sustainable plants. Univ. Maine. Thesis Abstr. HOR2010-001.
- Hawkins, G., S.E. Burnett, and L.B. Stack. 2012. Survey of consumer interest in organic, sustainable, and local container-grown plants in Maine. *HortTechnology* 22:817-825.
- Hoagland, D.R. and D.I. Arnon. 1950. The water-culture method for growing plants without soil. Calif. Agr. Expt. Sta. Circ. 347.
- Kraus, H.T., R.L. Mikkelsen, and S.L. Warren. 2000. Container substrate temperatures affect mineralization of composts. *HortScience* 35:16-18.
- Kuepper, G. 2010. Potting mixes for certified organic production. ATTRA publ. #IP112. 25 May 2015. <https://attra.ncat.org/attra-pub/viewhtml.php?id=47/>.
- Larrea, E.S. 2005. Optimizing substrates for organic tomato transplant production. M.S. Thesis. North Carolina State University.
- Mattson, N. 2014. Comparing substrate fertilizer amendments for spring bedding plants. *Greenhouse Grower Magazine*. 32(13):48-54.
- Mattson, N.S. and S.A. Beeks. 2013. Extensive soil mix studies for greenhouse production of seedlings and transplants. New England Fruit and Vegetable Conference 2013 Proceedings. 18 June 2015. http://www.newenglandvfc.org/2013_conference/proceedings2013/Mattson_NEFVC2013_soilmix_studies.pdf.
- Millner, P., S. Reynolds, X. Nou, and D. Krizek. 2009. High tunnel and organic horticulture: Compost, food safety, and crop quality. *HortScience* 44:242-245.
- Murray, R. and R.G. Anderson. 2004. Organic fertilizers and composts for vegetable transplant

production. University of Kentucky Agricultural Experiment Station. Floriculture Research Report 17-04.

Nair, A., M. Ngouajio and J. Biernbaum. 2011. Alfalfa-based organic amendment in peat-compost growing medium for organic tomato transplant production. *HortScience*. 46:253-259.

Nelson, P.V. 2011. *Greenhouse operation and management*, 7th ed. Prentice, Upper Saddle River, N.J.

Nelson, P.V., C.E. Niedziela, D.S. Pitchay, and N.C. Mingis. 2010a. Effectiveness, ammonium impact and potassium adequacy of soybean-base liquid fertilizer on bedding plants. *J. Plant Nutrition* 33:724-735.

Nelson, P.V., D.S. Pitchay, C.E. Niedziela, and N.C. Mingis. 2010b. Efficacy of soybean-base liquid fertilizer for greenhouse crops. *J. Plant Nutrition* 33:351-361.

Organic Materials Review Board. 2012. NOP notice regarding sodium nitrate. 18 June 2015. <http://www.omri.org/news/107418/nop-notice-regarding-sodium-nitrate>.

Organic Materials Review Board. 2014. Organic materials review lists. 25 May 2015. <http://www.omri.org/>.

Purman, J.R. and F.R. Gouin. 1992. Influence of compost aging and fertilizer regimes on the growth of bedding plants, transplants and poinsettia. *J. Env. Hort.* 10:52-54.

Raviv, M. 2005. Production of high-quality composts for horticultural purposes: A mini-review. *HortTechnology* 15:52-57.

Raviv, M. 2008. The use of compost in growing media as suppressive agent against soil-borne diseases. *Acta Hort.* 779:39-49.

Rippy, J.F.M., M.M. Peet, F.J. Louws, P.V. Nelson, D.B. Orr, and K.A. Sorensen. 2004. Plant development and harvest yield of greenhouse tomatoes in six organic growing systems.

HortScience 39(2):223-229.

Rocheffort, S., L. O'Donoghue, N. Authier and M. Delorme. 2013. Evaluation of organic-based fertilizers for the production of ornamental bedding plants. *Acta Hort* 982:53-60.

Russo, V.M. 2005. Organic vegetable transplant production. *HortTechnology* 40(3):623-628.

Russo, V.M. 2006. Biological amendment, fertilizer rate, and irrigation frequency for organic bell pepper transplant production. *HortScience*. 41:1402-1407.

Sanders, J., T.M. Waliczek, and J-M. Gandonou. 2011. An economic analysis of a university educational cafeteria composting program – Bobcat blend. *HortTechnology* 21:639-646.

Schmutz, U., J. Wright, and M. Lennartsson. 2014. Urban horticulture and organic greenhouse standards. *Acta Hort*. 1041:281-286.

Spiers, T.M. and G. Fietje. 2000. Green waste compost as a component in soilless growing media. *Compost Sci. Util.* 8:19-23.

Stofella, P.J. and B.A. Kahn. 2001. *Compost utilization in horticultural cropping systems*. CRC Press, Boca Raton, FL.

Succop, C.E. and S.E. Newman. 2004. Organic fertilization of fresh market basil in a greenhouse. *HortTechnology*. 14:235-239.

Surraige, V.A., C. Lafrenière, M. Dixon, and Y. Zheng. 2010. Benefits of vermicompost as a constituent of growing substrates used in the production of organic greenhouse tomatoes. *HortScience*. 45:1510-1515.

Treadwell, D.D., G.J. Hochmuth, R.C. Hochmuth, E.H. Simonne, L.L. Davis, W.L. Laughlin, Y.

Li, T. Olczyk, R.K. Sprenkel, and L.S. Osborne. 2007. Nutrient management in organic greenhouse herb production: where are we now? *HortTechnology* 17(4):461-466.

Treadwell, D.D., G.J. Hochmuth, R.C. Hochmuth, E.H. Simonne, S.A. Sargent, L.L. Davis, W.L. Laughlin and A. Berry. 2011. Organic fertilization programs for greenhouse fresh-cut basil and spearmint in a soilless media trough system. *HortTechnology* 21:162-169.

United States Department of Agriculture. 2015. Organic Agriculture. 28 May 2015. <http://www.usda.gov/wps/portal/usda/usdahome?contentidonly=true&contentid=organic-agriculture.html/>.

United States Department of Agriculture - Agricultural Marketing Service. 2015a. National Organic Program. 20 May 2015. <http://www.ams.usda.gov/AMSV1.0/nop>.

United States Department of Agriculture –Agricultural Marketing Service 2015b. List of USDA-authorized organic certifying agents by state of operation. National Organic Program. 20 May 2015. <http://www.ams.usda.gov/AMSV1.0/getfile?dDocName=STELPRDC5100383/>.

United States Department of Agriculture – NASS. 2014. 2014 Organic Survey. 30 November 2015. http://www.agcensus.usda.gov/Publications/2012/Online_Resources/Organics/

United States Department of Agriculture –NASS. 2008. 2008 Organic Survey. 21 May 2015. http://www.agcensus.usda.gov/Publications/2007/Online_Highlights/Organics/.

United States Government Publishing Office. 2015. Soil fertility and crop nutrient management practice standard 205.203(d). 18 June 2015. www.gpo.gov/fdsys/pkg/CFR-2011-title7-vol3/pdf/CFR-2011-title7-vol3-sec205-203.pdf.

Young, J.R., E.J. Holcomb, C.W. Heuser. 2002. Greenhouse growth of marigolds in three leached sources of spent mushroom compost over a 3-year period. *HortTechnology* 12:701-705.

Yue, C., J.H. Dennis, B.K. Behe, C.R. Hall, B.L. Campbell, R.G. Lopez. 2011. Investigating consumer preference for organic, local, or sustainable plants. *HortScience* 46:610-615.

Williams, K.A. and J.S. Nelson. 2016. Challenges of using organic fertilizers in hydroponic production systems. *Acta Hort. In press*. [Proceedings from the International Horticulture Congress, Brisbane, August 2014].

Williams, K.A. and P.V. Nelson. 1992. Low, controlled nutrient availability provided by organic waste materials for chrysanthemum. *J. Amer. Soc. Hort. Sci.* 117:422-429.

Williams, K.A., R.G. Lopez, and D.F. Warnock. 2009. Producing poinsettias sustainably. *Greenhouse Grower* 27:66-73.

Zhai, Z., D.L. Ehret, T. Forge, T. Helmer, W. Lin, M. Dorais, and A.P. Papadopoulos. 2009. Organic fertilizers for greenhouse tomatoes: productivity and substrate microbiology. *HortScience* 44(3):800-809.