Developing a Vegetable Fertility Program Using Organic Amendments and Inorganic Fertilizers

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SUMMARY. This review integrates information from common organic amendments used in conventional vegetable production, including 1) cover crops (legumes and nonlegumes), 2) compost generated from yard wastes, biosolids, municipal solid waste (MSW), animal manures, and other biodegradable waste by-products, and 3) raw animal manure (with and without bedding). Environmental monitoring has shown elevated nitrate concentration to be widespread in both surface and groundwater, often occurring in regions with concentrated horticultural production. Therefore, the objective of this review was to calculate the nutrient content from organic amendments, since these are not considered nutrient sources. Common organic amendments affect soil bulk density, water-holding capacity, soil structure, soil carbon content, macro- and micronutrients, pH, soluble salts, cation exchange capacity (CEC), and biological properties (microbial biomass). The first step in building a conventional tomato (*Solanum lycopersicum*) fertility program will be to take a soil sample and send it to a soil laboratory for a nutrient analysis. These results should be compared with the local crop recommendations. Second, select the organic amendments based on local cover crop suitability and availability of compost, raw animal manure, or both. Then, determine the nutrients available from cover crops and other applied organic amendments and use inorganic fertilizer sources to satisfy the crop nutrient requirements not supplied from these other sources.

Vegetable production systems in the United States include plasticulture and open bed. These production systems have been effective for commercial production with resulting economic return. Plasticulture generally includes raised beds, fumigation, polyethylene mulch, irrigation, and soluble fertilizer application; open bed production includes herbicides, irrigation, and soluble fertilizer application. However, conventional vegetable growers rarely add organic amendments because the use of concentrated, relatively inexpensive (compared with the value of the crop), and readily available synthetic fertilizers results in high yields with maximum short-term profits (Kelly, 1990). The most common organic amendments that conventional vegetables growers can use are cover crops, compost, and raw manures (Ozores-Hampton et al., 2012).

Incorporating cover crops into vegetable production may enhance

the sustainability of the system by recycling unused nutrients from previous vegetable crops, improve soil structure, increase soil organic matter (SOM) and fertility, retain moisture, prevent leaching of nutrients, decrease soil density, suppress weeds, increase population of beneficial insects, control erosion, manage plant-parasitic nematodes, increase soil biological activity, and increase yields (Abdul-Baki et al., 1997a, 1997b; McSorley, 1998; Sainju and Singh, 1997; Stivers-Young, 1998; Sullivan, 2003; Treadwell et al., 2008a). Some benefits may occur during the cover crop life cycle, while other benefits may take effect after the cover crop is incorporated (Treadwell et al., 2008b). Disadvantages of growing cover crops within a vegetable production system include additional production cost, delayed vegetable planting, increased pest pressure, immobilization of fertilizer nitrogen (N), and difficult to control ratoon vegetable crop (Treadwell et al., 2008c).

Compost can be defined as “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” (Florida Department of Environmental Protection, 1989). The technological and scientific advances in compost production (DeBertodi et al., 1987; Epstein, 1997), utilization (Stoffella and Kahn, 2001), microbiology (Insam, et al., 2010), and engineering (Haug, 1993), which has occurred during the past two decades, and implications that compost is environmental “friendly” and sustainable have been the reasons for the tremendous increase in worldwide compost usage. In areas of high population, there are a variety of non-hazardous wastes suitable for composting and land application that can provide an economically sound and environmentally acceptable option for utilization, but the majority of these wastes are currently landfilled or burned (Ozores-Hampton et al., 1998). Organic amendments composed of wastes produced by urban populations include MSW; yard trimming; food wastes from restaurants, grocery stores, and institutions; wood wastes from construction, demolition, or both; wastewater (from water treatment plants); and biosolids (sewage sludge). Agriculture produces other organic wastes that can be composted: poultry, dairy, horse, feedlot, and swine manures; wastes from food-processing plants; spoiled feeds; and harvest wastes (Ozores-Hampton et al., 1998, 2005; Ozores-Hampton, 2006). The use of organic amendments may improve soil quality and enhance the utilization of fertilizer, thus improving the performance of vegetable crops (Ozores-Hampton et al., 1998, 2011; Ozores-Hampton and Peach, 2002). In addition, compost application may control weeds (Ozores-Hampton et al., 2001a, 2001b), suppress plant diseases (Hoitink and Fachy, 1986; Hoitink et al., 2001), increase SOM, decrease erosion by water and wind (Tyler, 2001), and reduce nutrient leaching (Jaber et al., 2005; Yang et al., 2007).

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4536	lb	kg	2.2046
1.1209	lb/acre	kg·ha ⁻¹	0.8922
(°F - 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

Increased SOM improves physical properties by decreasing bulk density and increasing available water-holding capacity; chemical properties by increasing CEC, pH, and macro- and micronutrient supplies (Ozores-Hampton et al., 2011; Sikora and Szmids, 2001); and biological properties by increasing soil microbial activity (Ozores-Hampton et al., 2011).

Raw manures supply macro- and micronutrients, and SOM. Increasing SOM improves soil structure or tilth, increases the water-holding capacity, improves drainage, provides a source of slow-release nutrients, reduces wind and water erosion, and promotes growth of earthworms and other beneficial soil organisms (Rosen and Bierman, 2005). However, in areas of intense animal production, overfertilization with animal manure often occurs (Paik et al., 1996). The result is often manifested by nutrients entering adjacent water bodies. To obtain maximum economic value of plant nutrients in animal manure and to protect water supplies from excessive nutrient runoff or leaching, animal manure should be applied to match the most environmentally limiting nutrient needs of a crop. In some states, application of higher manure rates than the most limiting environmentally sensitive nutrient that are required by the vegetable crop [N or phosphorous (P)] is illegal. The remaining nutrient amount, if any, must be supplied through the use of synthetic fertilizers.

Developing the nutrient budget in conventional vegetable production

Those using cover crops, composts, and raw animal manures must practice sound soil fertility management to prevent nutrient imbalances and associated health risks, as well as surface water and groundwater contamination. Matching amendment-supplied nutrients to vegetable nutrient requirements should be the goal of a conventional vegetable fertility program (Ozores-Hampton et al., 2011). Overfertilization will be inefficient and expensive, which may contribute to nutrient runoff, groundwater pollution, soil toxicity, pest and disease susceptibility, excessive production of foliage, and reduced vegetable quality and yields. Similarly, underfertilization can reduce vegetable yield, quality, or both. Table 1 provides an analysis of cover crop, compost, and raw animal

Table 1. Nitrogen (N), phosphorus (P), and potassium (K) concentrations, and N mineralization rates of cover crops, compost, and raw animal manures for conventional vegetable crop production.

	N	P ^y	K ^y	Annual rate of N release
Organic material ^z	(%)			
Legume cover crops ^x				
Buckwheat	1.25	0.2–0.4	2.0–4.0	30–50
Cowpea	1.4–4.0	0.4	1.4	30–50
Crimson clover	2.7	0.4	3.4	30–50
Crimson clover	3.5	0.4	3.4	30–50
Hairy vetch	4.3	0.6	4.1	30–50
Rye	1.6	0.3	1.9	30–50
Sesbania	4.3	0.6	3.5	30–50
Soybean	2.3–7.5	0.7	2.4	30–50
Sunnhemp	1.7–2.3	0.5	3.2	30–50
Sweetclover	2.0–3.0	0.5	3.2	30–50
Nonlegume cover crops ^x				
Millet	1.0	0.2–0.4	2.0–4.0	30–50
Sorghum-sudangrass	1.5	0.2–0.4	2.0–4.0	30–50
Compost				
Biosolids	3–6	2–3	0.10–0.15	3.0–20
Brewery waste solids	1.3–1.8	0.02	0.13–0.18	5.0–10
Dairy manure	1.2–1.5	0.3	0.9	6.0–15
Feedlot manure	1.9–2.2	0.3–1.2	0.6–3.2	3.0–15
Fruit and vegetable wastes	1.39	0.26	1.19	10
Gin trash	1.2–3.8	0.2	1.2	10
Horse manure	0.5	0.2	0.4	10
Food waste	1.1–1.8	0.03–0.09	0.35–0.45	2.0–12
Municipal solid waste	2.3	1.11	0.64	3.0–10
Mushrooms	2.5	1.3	0.9	10
Olive mill waste	3.5	0.17	2.3	20
Poultry manure	1.3–5	3.0	2.0	20
Yard waste	1.0–1.2	0.2–0.3	0.2–1.4	2.0–10
Animal manure				
Beef (no bedding)	0.6–0.7	0.35–0.45	0.5–0.65	35
Beef (with bedding)				25
Dairy (no bedding)	0.5	0.15–0.3	0.3–0.45	35
Dairy (with bedding)	0.45	0.2	0.6	25
Goat fresh	1.1	0.6	0.9	25
Horse (fresh)	0.6	0.3	0.6	20
Mature compost	0.8–1.5	0.3–0.5	1.5	10
Poultry litter pellets	4.0	2.0	2.0	21
Poultry broiler house litter	3.6	3.9	2.3	45
Poultry layer–deep pit	1.9	2.8	1.5	45
Poultry layer–under cage	1.3	1.6	1	50
Poultry stock piled litter	1.8	4	1.7	45
Rabbit (fresh)	1.2	1.2	0.7	20
Sheep (fresh)	1.1	0.5	1.0	25
Sheep with bedding	0.9	0.4	1.0	20
Swine (fresh)	0.6	0.5	0.3–0.5	50
Swine (with bedding)	0.6	0.3	0.5	25

^xAltieri and Esposito, 2010; Ahmad et al., 2008; Aram and Rangarajan, 2005; Bellows, 2003; Chellemi and Lazarovits, 2002; Creamer, et al., 1997; Diver, et al., 1999; Drinkwater, 2007; Gaskell, 2009; Gaskell and Smith 2006, 2007; Gaskell and Klauer, 2004; Greer and Adam, 2005; Hartz and Johnstone, 2006; Hartz et al., 2000; Kuepper and Everett 2004; Marr et al., 1998; Prasad, 2009a, 2009b; Pressman, 2009; Sooby et al., 2007; Sullivan, 2003; Rosen and Bierman, 2005; VanTine and Verlinden, 2003; University of California, 2009; Zhang and Li, 2003.

^yP × 2.2910 = P₂O₅, K × 1.2047 = K₂O.

^zBuckwheat (*Fagopyrum esculentum*), cowpea (*Vigna unguiculata*), crimson clover (*Trifolium incarnatum*), hairy vetch (*Vicia villosa*), rye (*Secale cereale*), sesbania (*Sesbania exaltata*), soybean (*Glycine max*), sun hemp (*Crotalaria juncea*), sweetclover (*Melilotus officinalis*), millet (*Pennisetum glaucum*), sorghum-sudangrass (*Sorghum bicolor* × *S. sudanense*).

manure suitable for vegetable production. Since actual nutrient content varies considerably between organic amendment sources, a representative product sample should be sent to a laboratory for analysis of moisture and nutrient content such as total N, phosphate (P_2O_5), potash (K_2O), calcium (Ca), magnesium (Mg), and micronutrients analysis. Additionally, for compost and animal manure nitrate (NO_3) and ammonium (NH_4), N is recommended. Accurate manure or compost analysis requires that a representative sample be submitted; so several subsamples should be collected and combined for analysis. It is important to know the mineralization (decomposition or microbial breakdown) rate of the organic amendment before determining its application rate to vegetables. The rate of N release or availability is especially important because this nutrient moves readily through sandy soils. Evaluations of N mineralization in situ can be used to improve N use efficiency. However, the direct, quantitative measurement of N mineralization in situ is difficult because of the complex and dynamic nature of N transformations in the soil environment (Preusch et al., 2002).

COVER CROPS. There are legume and nonlegume cover crops that can be used in a conventional vegetable production system (Table 2). Biomass, N content, or both can be increased by a cover crop mixture. Cover crops provide organic N, which benefits succeeding vegetable crops, for example, 1.0 and 2.0 lb per 100 lb of dry weight for grasses and legumes, respectively (Treadwell et al., 2008b). However, the availability of N from the cover crops may not coincide with the N uptake requirements of the vegetable crop. Thus, vegetable yield and quality may be adversely affected by short-term shortages or a short lag time between the release of the N from the cover crop and subsequent vegetable crop uptake can result in NO_3 -N pollution by leaching (Weinert et al., 2002).

COMPOST AND COMPOSTING. There are no U.S. government restrictions on how and when compost can be used in vegetable production, except compost derived from sewage sludge or biosolids [Ozores-Hampton and Peach, 2002; U.S. Environmental Protection Agency (USEPA), 1994, 1995, 1999]. To eliminate or reduce human and plant pathogen, nematodes, and weeds, the temperature during the compost process

must remain between 131 and 170 °F for 3 d in an in-vessel or static aerated pile or 15 d in windrows, which must be turned at least five times during this period (USEPA, 1994, 1995, 1999). More than 90% of the total N in compost will be in an organic form and only 10% will be in the inorganic forms of NO_3 -N or NH_4 -N (Hartz et al., 2000). Therefore, application time may not be as critical as compared with raw animal manures. The composting process converted raw organic materials such as raw manure high in NH_4 and NO_3 , which is susceptible to runoff or leaching, to a humus-stable form minimizing the environmental impact on air and groundwater contamination. Compost N mineralization rates or N availability will vary depending on compost feedstocks, soil characteristics, and environmental conditions. It is generally considered that N immobilization occurs in composts when the initial carbon to nitrogen (C:N) ratio is greater than 20:1 and mineralization occurs when C:N ratio is lower than 20:1. However, C:N ratio as a predictor of N mineralization is not exact, as it may depend on the type of C (Prasad, 2009a; Rosen and Bierman, 2005; Wallace, 2006). Mineralization N rates guidelines developed by Wallace (2006) indicated that the availability of N will be 0% to 20% or even negative in the first year and 0% to 8% in the following years. However, P and potassium (K) will not react as N when compost will be added to soil. P and K in compost will be readily available to plants as commercial fertilizer. This is because the OM content in the compost will block sites where P will be adsorbed; in addition the compost biological activity can cause the release of soil-bound P resulting in a net P up-take by the crop. There were no differences between compost and commercial P in studies using biosolids compost or manure compost (Preusch et al., 2002; Sikora and Enkiri, 2003). Hence, a compost end user should be cautious when using compost as an N fertilizer because only a portion of the N (5% to 30%) will behave as a commercial fertilizer during the first year, but all the P and K in the compost will react as a commercial fertilizer. Therefore, compost application on sensitive land to P addition should be done based on crop P rather than N crop requirements (Preusch et al., 2002; Sikora and Enkiri, 2003).

RAW ANIMAL MANURES. Manures are an excellent source of nutrients and

can be incorporated into most fertility programs. The nutrient content in manures varies with animal type, bedding, storage, and processing. Nutrient analysis of manure may be required by law in some cases, but analysis is always recommended and should include total N, NH_4 -N, P_2O_5 , and K_2O . Usually 25% to 50% of the organic-N in fresh manure will be available during the first year (Table 1; Rosen and Bierman, 2005). If the manure contains bedding or is composted, the percentage of organic N will be lower. Raw animal manure contains more NH_4 -N content than compost, which increases the risk of volatilization to ammonia (NH_3) gas. Therefore, raw animal manure should be field incorporated within 12 h of application to decrease NH_3 -N losses (Rosen and Bierman, 2005).

Proposed P availability from various compost made from different feedstock relative to superphosphate are available for spent mushroom compost (100%), animal manures (90%), sewage sludge (85%), source-separated food waste (75%), and yard waste (60%) (Prasad, 2009b). However, generally for compost or raw animal manures, 70% to 80% of the P and 80% to 90% of the K will be available from manure during the first year after application (Rosen and Bierman, 2005). To calculate the correct application rate of compost or raw animal manure, multiply by availability factors (70% to 80% for P and 80% to 90% for K) to obtain the amount of P and K that will be available to vegetables from the application of composted or raw animal manure. Then, multiply the total P by 2.2910 and K by 1.2047 to obtain P_2O_5 and K_2O (Table 1). The advantage using compost rather than raw manure will be that, although P can be overapplied with compost, the improvement in soil structure with the compost OM application will increase water infiltration and reduce runoff, thereby decreasing the total P transported over the land surface to potentially pollute surface water (Spargo et al., 2006).

For successful integration of organic amendments into conventional vegetable fertility programs, we recommended the construction of an N-P-K crop mass balance where the fertility inputs and net release of N will be quantified, and vegetable crop N- P_2O_5 - K_2O requirement will be taken into consideration (Table 3). Calculating

Table 2. Cover crop biomass dry weight production, location, total nitrogen (N) contributions, and source.

Cover crop	Scientific name	Location ^z	Biomass dry wt (kg·ha ⁻¹) ^y	N (kg·ha ⁻¹)	Source
Aeschynomene	<i>Aeschynomene virginica</i>	FL	2,240–4,480	56–112	Crow and Dunn, 2010
Alfalfa	<i>Medicago sativa</i>	ME	3,682–5,659	105–174	Griffin et al., 2000
Alyce clover	<i>Alysicarpus vaginalis</i>	FL	1,680–3,920	22–73	Crow and Dunn, 2010
Black oat	<i>Avena strigosa</i>	GA	2,150–5,193	71–78	Schomberg and Endale, 2006
Berseem clover	<i>Trifolium alexandrinum</i>	NC	800–7,700	26–169	Parr et al., 2011
		VA	1,100	70	Prunty, 2009
Buckwheat	<i>Fagopyrum esculentum</i>	NC	3,545	48	Creamer and Baldwin, 1999
Common vetch	<i>Vicia sativa</i>	NC	2,300–5,400	60–188	Parr et al., 2011
		AL	4,900	118	Touchton et al., 1984
		GA	4,300	134	Hargrove, 1986
Cowpea	<i>Vigna unguiculata</i>	SC	6,930	205	Harrison et al., 2004
		CA	4,256–5,376	63–81	University of California, 2009
		FL	2,250–5,050	56–100	Newman et al., 2010
Crimson clover	<i>Trifolium incarnatum</i>	NC	2,000–7,800	32–179	Parr et al., 2011
		VA	1,400	100	Prunty, 2009
		GA	6,130–6,310	147–225	Sainju et al., 2000
		GA	2,029–5,052	50.4–146	Schomberg and Endale, 2006
		FL	1,685–5,050	40–135	Newman et al., 2010
Hairy vetch	<i>Vicia villosa</i>	MD	3,300–4,500	126–169	Abdul-Baki et al., 1997a
		FL	1,685–6,180	40–168	Newman et al., 2010
		GA	4,250	153	Hargrove, 1986
		VA	1,750	110	Prunty, 2009
		GA	4,730–4,870	167–208	Sainju et al., 2000
Lupin	<i>Lupinus angustifolius</i>	NC	300–2,300	10–60	Parr et al., 2011
		FL	2,250–5,050	50–134	Newman et al., 2010
Pearl millet	<i>Pennisetum glaucum</i>	NC	6,664	65	Creamer and Baldwin, 1999
		FL	6,720–8,960	62–78	Crow and Dunn, 2010
Oat	<i>Avena sativa</i>	ON	970–1,170	15–22	Vyn et al., 2000
Oil seed radish	<i>Raphanus sativa</i>	ON	890–1,270	18–21	Vyn et al., 2000
		GA	3,267–6,240	75–95	Schomberg and Endale, 2006
		MI	6,262	311	Wang et al., 2008
Red clover	<i>Trifolium pratense</i>	ON	1,240–4,020	43–134	Vyn et al., 2000
Rye	<i>Secale cereale</i>	ON	610–2,120	12–40	Vyn et al., 2000
		CO	690–7,399	27–296	Dabney et al., 2001
		GA	5,642–9,397	80–103	Schomberg and Endale, 2006
		GA	6,030–6,710	76–137	Sainju et al., 2000
		ME	4,071–6,619	52–66	Griffin et al., 2000
Sesame	<i>Sesamum indicum</i>	NC	3,762	46	Creamer and Baldwin, 1999
Sesbania	<i>Sesbania exaltata</i>	NC	4,794	97	Creamer and Baldwin, 1999
		FL	2,240–8,960	39–90	Crow and Dunn, 2010
Soybeans	<i>Glycine max</i>	SC	7,740	218	Harrison et al., 2004
		NC	3,935	80	Creamer and Baldwin, 1999
Subterranean clover	<i>Trifolium subterraneum</i>	NC	900–7,600	16–102	Parr et al., 2011
Sorghum-sudangrass	<i>Sorghum bicolor</i> × <i>S. sudanense</i>	MI	8,032	264	Wang et al., 2008
		FL	7,300–10,670	62–90	Newman et al., 2010
		NC	8,783	87	Creamer and Baldwin, 1999
Sunnhemp	<i>Crotalaria juncea</i>	FL	5,050–11,235	100–200	Newman et al., 2010
Sweetclover	<i>Melilotus officinalis</i>	NC	3,920	134	Sullivan, 2003
		VA	1,750	120	Prunty, 2009
Velvet bean	<i>Mucuna pruriens</i>	SC	5,890	218	Harrison et al., 2004
		NC	1,419	33	Creamer and Baldwin, 1999
		FL	2,470–4,500	56–95	Newman et al., 2010
Wheat	<i>Triticum aestivum</i>	CO	454–2,203	18–74	Dabney et al., 2001
White clover	<i>Trifolium repens</i>	NC	1,685–2,250	225	University of California, 2009

^zU.S. Postal Service abbreviations for U.S. states and Canadian provinces.^y1 kg·ha⁻¹ = 0.8922 lb/acre.

Table 3. Florida nutrient mass budget for conventional tomato production. Tomato nutrient requirements based on 224 kg·ha⁻¹ (i.e., 200 lb/acre) of nitrogen (N), 112 kg·ha⁻¹ (i.e., 100 lb/acre) phosphoric acid (P₂O₅), and 112 kg·ha⁻¹ potassium oxide (K₂O) with medium soil test levels of phosphorus (P) and potassium (K), respectively (Olson et al., 2010).

Material inputs ^z	Application rate (kg·ha ⁻¹ dry wt) ^z	N rate (kg·ha ⁻¹)	N mineralization rate (%)	Total NO ₃ (kg·ha ⁻¹) ^y	Total P ₂ O ₅ (kg·ha ⁻¹) ^x	Total K ₂ O (kg·ha ⁻¹) ^x
Soil and organic amendments application						
Sorghum-sudangrass with 1.5% N, 0.2% P, and 2% K with 70% P and 80% K availability	8,783	131.7	23	30.3	28.2	168.7
Yard waste compost at 10 Mg·ha ⁻¹ (40% moisture and 1% N, 0.2% P, and 0.8% K with 70% P and 80% K availability	6000	60.0	10	6.0	19.2	38.4
Subtotal	14783	191.7	—	36.3	47.4	207.1
Inorganic fertilizer application ^w						
Ammonium nitrate	552.1			187.7	—	—
Triple phosphate	140.4			—	64.6	—
Total	—	—		224	112	112

^z1 Mg·ha⁻¹ = 0.4461 ton/acre, 1 kg·ha⁻¹ = 0.8922 lb/acre.

^yNO₃ = nitrate.

^xP₂O₅ × 0.4365 = P, K₂O × 0.8301 = K.

^wAmmonium nitrate (34% N), triple phosphate (46% P₂O₅).

Fig. 1. Diagram of process for calculating the contribution of nutrients from selected organic sources to satisfy the crop nutrient requirements for commercial vegetable production using the tables in this document.

N availability from organic amendments can be complex as N must be transformed by soil microorganisms before it can be used by the vegetable crop as NO₃-N. An example of a tomato

fertility program for Florida is provided as a guide (Table 3). A flowchart (Fig. 1) shows the calculations diagrammatically. The first step in building the tomato fertility program is to determine the

nutrient requirements of tomato crop by taking a soil sample for analysis of N-P-K and micronutrients. These results can be compared with the local crop recommendations for N-P₂O₅-K₂O.

This information can be found in a local state or regional "vegetable production handbook," or contact a local extension faculty. Then, the identification of cover crops suitable for the location and locally available compost and raw animal manures can be obtained from the local state or regional "vegetable production handbook," or contact a local extension faculty. Once cover crop, compost, and raw animal manure are located and identified, determine the nutrient content and N, P, and K availability from laboratory analysis or other sources as shown in Table 2. The microbial activity involved in the N cycles, which is accelerated by high temperatures and slowed down by low temperatures needs to be considered and N release rate adjusted as needed. The next step will be the calculation of the cover crop biomass production (dry weight), and compost and raw animal manure application rates to supply recommended amounts of N, P_2O_5 , and K_2O to the tomato crop so that yield estimates are realized (Tables 1 and 2). Finally, determine whether application of inorganic commercial fertilizer is needed. Once a fertility program is established, a unit cost per nutrient can be calculated. The cost per unit of nutrients can be calculated by multiplying the unit cost of the nutrient fertilizer with the available nutrient content of the organic amendment and then select the most cost-effective one to be applied to the tomato crop.

The fertility program for conventional vegetable production can be divided into two major parts: an organic-amendment-based program consisting of cover crops, compost, or raw animal manures and a supplemental fertility program consisting of inorganic fertilizer application such as ammonium nitrate, urea, potassium sulfate, etc. plus micronutrients to supply the plant nutrient requirements.

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