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## EVALUATING THE SUSTAINABILITY OF FOUR ORGANIC VEGETABLE PRODUCTION SYSTEMS

Delia W. Scott

*University of Kentucky*, [delia.scott@uky.edu](mailto:delia.scott@uky.edu)

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Delia W. Scott, Student

Dr. Mark Williams, Major Professor

Dr. Dennis B. Egli, Director of Graduate Studies

EVALUATING THE SUSTAINABILITY OF FOUR ORGANIC VEGETABLE  
PRODUCTION SYSTEMS

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THESIS

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A thesis submitted in partial fulfillment of the Requirements for the  
degree of Master of Science in Crop Science in the College of  
Agriculture at the University of Kentucky.

By

Delia W. Scott

Lexington, Kentucky

Director: Dr. Mark Williams, Associate Professor of Horticulture

Lexington, Kentucky

2013

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## ABSTRACT OF THESIS

### EVALUATING THE SUSTAINABILITY OF FOUR ORGANIC VEGETABLE PRODUCTION SYSTEMS

A field study evaluating the sustainability of four organic vegetable production systems was conducted in Lexington, Kentucky in 2006 and 2007. The four systems included no-till, raised beds covered with biodegradable black mulch, bare ground with shallow cultivation, and bare ground with shallow cultivation and wood chip mulch. The two-year study compared yield, weed control, labor, and costs associated with each system, as well as physical, chemical, and microbiological soil characteristics. In 2006, tomatoes (*Lycopersicon esculentum* Mill.) were grown in the four systems, with no significant difference in yield. Summer squash (*Cucurbita pepo* L.) was grown in the four systems in 2007. The no-till system had significantly lower yields than other systems. The bare ground with cultivation and mulch system had the best weed control in both years.

Keywords: organic, sustainability, no-till, vegetable production, biodegradable mulch

Delia W. Scott  
30 April 2013

EVALUATING THE SUSTAINABILITY OF FOUR ORGANIC VEGETABLE  
PRODUCTION SYSTEMS

By

Delia W. Scott

Dr. Mark A. Williams  
Director of thesis

Dr. Dennis B. Egli  
Director of Graduate Studies

30 April 2013

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## CHAPTER 1

### Introduction

Kentucky's agriculture producers are mostly small, limited-resource farmers who have depended on burley tobacco (*Nicotiana tabacum*) production as a major economic crop for decades. These producers are among those most impacted by the federal government's recent settlement against the tobacco price-stabilization program, which ended in 2004. According to Snell (2005), few post-buyout tobacco growers in Kentucky indicated plans to expand burley tobacco production for 2005, and estimates for overall tobacco production in Kentucky were down 31% from the previous year. The USDA Census of Agriculture determined that the number of tobacco farms in Kentucky declined 72% between 2002 and 2007, to 8,113 (USDA-NASS, 2012). Growers in Kentucky as well as other states are seeking to diversify their operations, with some producers looking toward alternative markets to fill the void left by the loss of tobacco. In response to the need for information for growers interested in finding tobacco alternatives, the U.S. Department of Agriculture awarded a special grant to the University of Kentucky to create a project evaluating organic vegetable production systems. The USDA's plan to initiate research into replacing tobacco in Kentucky, the New Crops Opportunities Grants program, challenged farmers and

researchers to explore vegetable, flower, and herb production, as well as alternative production systems such as integrated pest management (IPM) systems, sustainable, and organic production systems.

According to the United States Department of Agriculture Economic Research Service, there were 2.3 million acres of certified organic cropland in the United States in 2007 and 2.7 million acres in 2008, representing an increase of 16% (Greene, 2012). 2005 was the first year all 50 states had some certified organic farmland (Rawson, 2007). Retail sales of organic foods are up \$21.1 billion in 2008 from \$3.6 billion in 1997, with fresh produce continuing to be the most popular organic category; retail sales of organically grown fresh produce averaged a 15% growth per year between 1997 and 2007 (Dimitri and Oberholtzer, 2009). From 1997 to 2011, the organic industry grew from \$3.6 billion to \$31.5 billion (Dimitri et al., 2012).

However, despite the premium prices commanded by organic fruits and vegetables, some growers have been hesitant to adopt organic production practices. Reasons range from the risks associated with changing management systems to higher labor costs, as well as a lack of infrastructure and marketing and limited available information about alternative farming systems (Greene, 2007). The New Crops Opportunities Grant funded this research project to work at the

systems level and simulate a commercial organic production system, thus making available information useful for farmers interested in transitioning from a conventional tobacco operation into organic vegetable production.

Concerns for organic growers are many and include sustainable soil management, conservation, and fertility; lower yields as compared to conventional agriculture, and higher labor costs. Among the most important concerns is the ability to control weeds (Bond and Grundy, 2001; Walz, 2004). Weed management in organic farming is continuously linked to relying on clean cultivation since herbicides are not allowed in organic production; this assumption has been used to portray organic crop production as environmentally destructive and erosive (Kuepper, 2001). However, more growers are becoming interested in conservation tillage and are exploring no-till systems, which leave cover crops as surface residue and can reduce erosion by 95% as compared to clean tillage systems (Harrelson et al., 2004). No-till systems help conserve water, reduce evaporation, control erosion, and moderate soil temperatures. According to Brady and Weil (2002), soil physical properties have a profound influence on how soils can best be managed and how they function in an ecosystem. Well-structured soils are necessary to attain sustainable and productive agricultural systems (Diaz-Zorita et al., 2004). Changes in soil

chemical conditions influence soil microorganisms, which are essential for long-term sustainability of agricultural systems (Spedding et al., 2004; Wardle et al., 1999).

The experiments presented here represent efforts to evaluate the sustainability of organic production systems suitable for small to mid-scale growers in Kentucky and make systems-based recommendations.

## CHAPTER 2

### Review of Literature

In recent decades, organic agriculture and organically produced fruits and vegetables have gained popularity, partially due to increased concern about the potentially negative impacts that conventional agriculture and the use of synthetic fertilizers and pesticides have on both the environment and on human health. In an organic production system, farm management tools incorporate the basic components and natural processes of ecosystems, including nutrient cycling, soil microorganism activities, and species distribution and competition (Greene et al., 2001). Crop rotations, green and animal manures, biological pest and disease management, and composting are used to mimic the natural cycles of farm ecology. According to Rawson (2007), organic agriculture is both a philosophical approach to farming that values ecological harmony and resource efficiency as well as a food production approach based on biological methods that circumvent synthetic crop inputs.

Organic agriculture is defined by the USDA National Organic Standards Board (USDA, 1995) as "an ecological production management system that promotes and enhances biodiversity, biological cycles, and soil biological activity. It is based on minimal use of off-farm inputs and on management practices that restore,

maintain, or enhance ecological harmony. The primary goal of organic agriculture is to optimize the health and productivity of interdependent communities of soil life, plants, animals, and people.”

Land under organic production in the United States has increased from 2.3 million acres in 2002; over 4.1 million acres were in organic production nationally as of 2011(Dimitri and Greene, 2002). By December 2011, over 17,000 farms and processing facilities in the United States were certified according to USDA organic standards, representing a 140% increase in the number of certified organic enterprises since 2002, when the federal organic standards were implemented (Dimitri et al., 2012). According to the Organic Farming Research Foundation (2006), the organic industry in the United States has increased 20% per year for over 10 years.

Growers and researchers worldwide interested in agricultural systems that are sustainable have turned to ecology-based models, also called low-input, natural, biodynamic, holistic, biological, and organic farming systems (Earles, 2005). Sustainable agriculture strives to meet environmental, economic and social objectives simultaneously. According to Debertin and Pagoulatos (1995), one of the key elements of a sustainable farming system is economic viability over the long term. Self-sustainability is another goal of sustainable agriculture, with limited to no off-farm inputs needed to maintain an ecological balance

between what is produced and what is taken away. Characteristics associated with sustainable agriculture include reduced soil erosion, lower fossil fuel expenditure, less nitrate leaching, greater carbon sequestration, and limited or no pesticide use (Kuepper and Gegner, 2004). This shared vision of 'farming with nature' promotes conservation, biodiversity, minimum tillage systems, prevents soil erosion, and protects water sources (Earles, 2005). According to Schonbeck and Morse (2004), a basic tenet of sustainable agriculture states that greater diversity leads to greater agroecosystem stability, in addition to more sustained crop yields, fewer diseases and pests, and more beneficial organisms.

### Weed Management

Weed management in an organic production system is considered to be one of the most formidable obstacles faced by growers, with production losses from weed competition rated as one of the most important crop management concerns (Bond and Grundy, 2001; Walz, 2004). Weed control in organic crop production is approached using both direct and indirect practices. Kristiansen (2003) summarized many of these practices, with direct or physical methods including mulching, tillage, hand weeding, biological control, machine or hand mowing, and grazing. Indirect or cultural weed control methods include cover cropping, soil management, crop rotation,



planting density, intercropping, prevention, and timing. More growers and researchers are beginning to look at weed control from a holistic perspective, encompassing both direct and indirect methods.

According to Barberi (2002), weed management in conventional agriculture is often focused on comparing types of implements for mechanical weed control in a crop versus herbicide efficacy in a crop. Since the 1960s, weed management in the U.S. has been focused primarily on the use of herbicides to the extent that over 226 million acres of U.S. land had herbicides applied to them in 2007 (USDA, 2007). Herbicides have been shown to improve crop productivity in the short term; however, herbicide applications have contaminated surface and ground water throughout North America (Barbash et al., 1999), and questions regarding the long term sustainability of herbicide usage have arisen in recent years. Herbicide resistance among weed species is also a growing concern (Benbrook, 2012). By looking at and evaluating the whole system with a range of cultural, preventive, and direct weed control methods, weed management can be approached from many different angles. While weed management in an organic system is more challenging and often more labor intensive during the initial transition from conventional to organic production, studies have shown that weed seed populations become depleted over time, due in part to changes in soil physical, chemical,

and microbiological properties when growers holistically integrate weed management practices (Ngouajio and McGiffen, 2002).

### Tillage

Clean tillage using a moldboard plow was a fundamental part of American agriculture for the first half of the century, with viewpoints changing as late as the 1960s (Kuepper, 2001). Brady and Weil (2002) state that although tillage loosens the soil, intense and prolonged tillage can increase soil bulk density by depleting soil organic matter and weakening soil structure. Bare soil and the potential for erosion by wind and water, organic matter loss, and nutrient leaching inspired the need for conservation tillage and other alternatives such as no-till. Tillage can influence weed populations by the combined effects of mechanical destruction of weed seedlings and by changing the vertical distribution of weed seeds in the soil. Tillage also acts indirectly on weed populations through changes in soil conditions, which can influence weed dormancy, germination, and growth (Peigné et al., 2007).

Primary tillage is the initial step in crop production. The moldboard plow is typically used for this first step, although there are drawbacks associated with this implement, primarily high erosion rates. However, these plows can be adapted to invert only the top 2 inches of soil, eliminating the negative effects that can occur with deep

inversion plowing (Nordell and Nordell, 1998). Chisel plows or spading machines that do not invert soil layers may also be used in conservation tillage systems. Secondary tillage occurs after primary tillage and involves the preparation of a seedbed for crops. Secondary tillage conducted to eliminate weed seedlings that have germinated after primary tillage and before crop emergence is called stale seed bed and often involves the use of cultivators such as basket or tine weeders. This technique, when combined with early season shallow cultivation with mid-season mulch applications, can minimize crop losses due to weed competition (Law et al., 2006).

No-tillage prevents erosion, conserves soil moisture, and helps maintain soil structure and quality by leaving a layer of organic mulch at the soil surface, which can increase soil organic matter (SOM) and soil biodiversity over time, while conventional tillage using a moldboard plow or chisel disturbs the structure of the soil by inverting the soil layers, which can negatively affect crop production (Diaz-Zorita et al., 2004). Soil aggregation is enhanced with continuous no-till, and over time, reduced evaporation and greater water infiltration and storage can be achieved (Diaz-Zorita *et al.*, 2004). According to the Conservation Technology Information Center (CTIC) (2005), in the United States between 1990 and 2004, crop acreage using no-till management more than tripled, from 17 million acres or 6 %, to 62

million acres or 22%; this number had risen to 88 million acres, or over 35% of U.S. cropland planted to eight major crops by 2009 (Horowitz et al., 2010). Although many conventional farmers use no-till systems in order to benefit from the enhanced fertility and weed suppression, conventional no-till often requires as many or more herbicide applications as traditional tillage systems (Sayre, 2004). Although organic no-till is a challenge, these systems are cost-effective in soil quality and weed management as compared to applying organic mulch, which can be cost-prohibitive. An important component to organic no-till production is the presence of high-residue surface mulch, which helps moderate soil temperature, conserves moisture, and suppresses weeds and pests (Morse, 2006).

### Cover Crops

Cover crops can aid in weed control through competition, enhancing weed seed decay, changes in the soil environment, physical effects, and sustaining surface residues (Conklin et al., 2002). Known benefits include biomass production, providing habitat for natural enemies of vegetable crop pests, and favorable effects on available soil N, P, and K (Schonbeck and Morse, 2004). Cover crop management is important due to its implications for soil, nutrient, pest and weed management (Barberi, 2002). Using cover crops in an organic vegetable production system may help enhance soil fertility, suppress

weeds and pests, and prevent soil erosion. The choice of cover crop varies depending on desired effect and farm location. Integrating legumes increases the potential for soil organic carbon and soil nitrogen mineralization, while a cereal cover crop produces large amounts of biomass, which helps build soil organic matter (Snapp et al., 2005). This enhanced biomass production benefits organic matter inputs, mulch thickness, and weed suppression (Schonbeck and Morse, 2004). Rye (*Secale cereale*) provides good winter cover and is often grown in conjunction with hairy vetch (*Vicia villosa*) in Kentucky (Rasnake et al., 2005). Research has shown that rye possesses allelopathic properties that may help suppress weed seed germination from the release of chemicals by residue decomposition, leaching, or root exudations; however, these compounds may also cause reductions in the growth of subsequent crops (Conklin, et al. 2002). Using a combination cereal/legume cover crop balances the carbon to nitrogen (C:N) ratio, which allows gradual release of plant available N, whereas an all-cereal or grass cover crop can lead to N-immobilization and an all-legume cover crop can lead to a too-rapid N release and potential leaching (Schonbeck and Morse, 2004).

### Mulches

A commonly used vegetable production system is raised beds covered with polyethylene mulch. Introduced in the 1950s and

commercially used in vegetable production since the 1960s, polyethylene mulch is used to retain moisture, control weeds, enhance plant growth and ripening, and increase soil warming in the spring (Lamont, 1991; 1999). Although polyethylene mulches are allowed in certified organic vegetable production in the United States, the identification of alternatives is important to many organic producers (Wittwer, 1993; Lamont, 1993; Schonbeck, 1998). Despite the advantages polyethylene mulches offer, important disadvantages include increased soil erosion, increased agricultural chemical runoff, and difficulty of removal (Lamont, 1993; Rice et al., 2001). Disposal of non-biodegradable polyethylene typically involves taking the used material to a landfill, where it can persist for many years (Warner and Zandstra, 2004). Disposal also includes substantial hauling and landfill fees. In 1999, approximately 30 million acres worldwide were covered with polyethylene mulch, with more than 185,000 acres located in the United States; the majority of this material presumably ended up in a landfill (Takakura and Fang, 2001). While polyethylene mulch is effective and convenient, many growers are looking for more ecologically-friendly products; rapidly rising fuel costs are also increasing the demand for alternative mulch products.

Biodegradable mulches such as recycled kraft paper, oil-coated paper, Planters paper, butcher paper and corn, wheat, or potato-based

plastics are being trialed and evaluated by researchers nationwide (Bachmann, 2005). Rangarajan et al. (2003) evaluated several commercially available biodegradable mulches and concluded that yields were similar for both Mater-Bi, a biodegradable cornstarch-based black mulch, (BioTelo Mulch Film, Dubois Agrinovation, Québec, Canada) and black polyethylene mulch in a field experiment conducted on muskmelon in 2002. A similar experiment conducted in 2005 also concluded that both the biodegradable mulch and polyethylene mulch treatments produced similar yields (Rangarajan and Ingall, 2005). Another study evaluating biodegradable mulches was conducted at Penn State University in 2004. According to Orzolek and Dye (2005), the biodegradable Mater-Bi mulch performed as effectively as the non-biodegradable black polyethylene mulch in trials growing watermelon and bell pepper, and did not begin to degrade in the field until 80 days after application. The Mater-Bi mulch was also evaluated in Ontario, Canada in 2004; this research determined that the performance of the biodegradable Mater-Bi was similar to polyethylene mulch in total and marketable yield of bell pepper. However, the Mater-Bi did not require field removal at the end of the season (Warner and Zandstra, 2004). Starch-based mulches, while initially more expensive, can be tilled in at the end of the season, which reduces labor hours needed for removal as well as disposal costs. Polyethylene mulch requires

removal, which is typically done with an undercutting tractor implement for the initial cuts. The material must then be pulled up by hand.

The use of organic mulches in vegetable production is not a new concept; grass clippings, cover crops and animal manures are all commonly used. Abdul-Baki et al. (2002) affirms that mulches in vegetable production systems are veering more toward organic mulches and away from nonrenewable mulches, such as polyethylene-based plastics. A study conducted by Law et al. (2006) had more than 70% weed control with the use of wood chip mulch in a vegetable production system as compared to other mulches. The costs associated with wood chip mulch are typically higher initially and include the sourcing, hauling, and labor for application. Pimentel et al. (2005) estimated an average of 15% higher labor inputs in organic farming systems, but noted that the distribution was more evenly distributed over the production system than in a conventional production system. Organic mulches have also been shown to increase microbial activity and enhance soil biodiversity (Schonbeck, 2006). Studies conducted by Teasdale (1995) showed that soil temperatures were highest under black polyethylene, intermediate under bare soil, and lowest under hairy vetch. While high soil temperatures can be beneficial in establishing initial spring plantings, these high



temperatures can be correlated to lower water retention as the season progresses. Using mulch helps moderate soil temperature and conserves soil moisture.

### Soil Properties

Soil physical properties have a profound influence on how soils can be managed optimally, and how they function in an ecosystem (Brady and Weil, 2002). Soil management effects on physical properties such as compaction and water holding capacity are often measured. The density of the soil can determine the potential for roots to grow, as well as the capacity of the plants to explore the surrounding soil, and consequently absorb more of the nutrients necessary for plant growth and health (Herrero et al., 2001). Changes in both physical and chemical soil conditions can influence microbial activity (Spedding et al., 2004).

Soil chemical properties such as pH, buffer pH, cation exchange capacity, and organic matter determination can also impact the microbial community. Soil tests are routinely conducted on agricultural soils to evaluate various nutrient levels and optimize growing conditions for productive crops. Deep inversion cultivation and resulting erosion can enhance carbon mineralization and soil organic matter loss, as well as the microbial decomposition of formerly microaggregate-protected SOM (Zhang et al., 2006). According to

Bending et al. (2004), the quality of an agricultural soil is a measure of its ability to sustain crop productivity while simultaneously preserving the environmental quality.

Soil microbiological properties are measured to evaluate microbial biomass, activity, and diversity. Microbial parameters are a consistent and effective indication of soil management-induced changes to soil quality, while varied agricultural crops and different tillage practices can affect the microbial characteristics of the soil (Bending et al., 2004; Egamberdiyeva et al., 2004). According to Wardle et al. (1999), essential to the long-term sustainability of agricultural systems are soil microorganisms and their overall contributions to soil health; intensely cultivated agricultural systems can affect microbial biomass and microbial activity, which can become apparent immediately.

The long-term sustainability of organic production systems is determined by and dependent upon a holistic approach to farm management. This approach includes practices to maintain and enhance soil health, fertility, and conservation; IPM practices and biological methods for pest control; the use of scouting practices to monitor disease progression and organic sprays; crop rotations and the use of green and animal manures. A goal of organic and sustainable production systems is economic feasibility over the long

term, attained by mimicking the natural cycles of the farm ecosystem. The experiment presented in Chapter 2 represents efforts to develop a model system suitable for transitioning organic vegetable farmers, as well as to make recommendations for sustainable systems.

## CHAPTER 3

### Evaluating the Sustainability of Four Organic Production Systems

#### Introduction

Production of alternative crops such as organically grown vegetables and fruits has increased in Kentucky partially due to the ending of the federal government's tobacco-stabilization program in 2004. Since becoming authorized to perform organic certification duties in 2006, the Kentucky Department of Agriculture has certified over 125 Kentucky producers on behalf of the USDA (Clary, 2006), with the number of certified organic Kentucky farms growing from 26 to more than 100 between 2006 and 2010 (Greene, 2012). Although there is a growing interest in organic production in the state, a major constraint exists in the lack of research-based information on organic production practices.

Conventional production relies heavily upon the use of chemical sprays to control disease and insects, while organic production takes a more holistic approach, combining different techniques such as continual scouting and monitoring crops to identify problems, crop rotation, cover cropping and biological or organic insect and disease controls. More recently, organic growers are exploring reduced or no

tillage systems to further reduce the impact agriculture can have on soil.

This approach to systems development is ideal for organic and sustainable agriculture in which the health and productivity of the system is dependent upon each of the parts. Since soil is the critical component of the agricultural system, beginning at the ground level and examining soil fertility can give indications as to long-term management to optimize the health and sustainability of the soil environment upon which plants depend.

This research project was designed to develop and evaluate four organically managed horticultural production systems applied to two commonly grown vegetables that would be suitable for Kentucky farmers transitioning from tobacco or conventional vegetable production to organic or sustainable vegetable production. The experiment was carried out over two years at the University of Kentucky Organic Farming Unit in Lexington, Kentucky. Crop yield and quality was analyzed and documented, as well as the economic feasibility and sustainability of the different production systems. Selected soil physical, chemical, and microbiological properties were evaluated, and weed, disease, and insect dynamics were monitored as additional indicators of sustainability. The goal of this project was to determine the relationships between organic management practices,

microbial population shifts, and soil physical and chemical properties, as well as to make research-based recommendations to Kentucky farmers for optimal organic production systems. Knowledge of sustainable organic production practices in Kentucky is limited at this time; this project was initiated to help fill in some of the existing knowledge gaps.

### **Materials and Methods**

This experiment was carried out over a two-year period in the summers of 2006 and 2007. Four organic production systems applied to two vegetable crops (tomatoes and squash) were compared for their crop yield and quality, weed control efficacy, economic profitability, and influence on physical, chemical, and microbiological changes to the soil. The organic production systems were: no-till (NT), raised beds covered with biodegradable black mulch (BP), bare ground with shallow cultivation (BG), and bare ground with shallow cultivation with the addition of wood chip mulch (BGM). This research was conducted at the University of Kentucky Organic Farming Unit in Lexington, KY. Total plot size was  $\frac{1}{4}$  acre (10,890 sq ft). The entire plot consisted of Maury silt loam soil, which is characterized by deep, well-drained, moderately permeable soils that are formed in silty material and weathered limestone (NRCS, 2007). The site had been in sod (fallow) for at least 3 years prior to the experiment.

## **PRODUCTION SYSTEMS OVERVIEW**

NO-TILL (NT). The no-till organic production system utilizes cover crops as an integral part of the crop rotation. Cover crops such as hairy vetch (*Vicia villosa* Roth.) and annual rye (*Secale cereale* L.) are planted in the fall and killed the following spring using mechanical methods rather than the herbicides commonly used in conventional no-till. This method results in uniformly distributed mulch over the soil surface. The in-situ mulch provides weed suppression, temperature moderation, and moisture conservation. According to Snapp et al. (2005), the dense mulch has also been shown to reduce some insect and disease problems. Integrating legumes, such as hairy vetch, increases the potential for soil organic carbon and soil nitrogen mineralization, while a cereal cover crop, such as rye, produces large amounts of biomass, which helps build soil organic matter (Snapp et al., 2005). The recent development and commercialization of no-till vegetable transplanters and seeders has facilitated the widespread implementation of this production system on a growing number of horticultural crops (Morse, 1999). A no-till transplanter (RJ Equipment, Ontario, Canada) was used to transplant crops into the field in this experiment.

BIODEGRADABLE BLACK MULCH (BP). Raised beds covered with black polyethylene mulch are commonly used for vegetable production

in Kentucky to help reduce weed problems, soil compaction, foliar diseases, fertilizer leaching, and moisture loss from evaporation, as well as earlier spring crops, improved drainage, and cleaner harvested products (Rowell et al., 2006). Polyethylene mulch used in conjunction with drip irrigation is a standard practice for many Kentucky growers. However, concerns about the sustainability of polyethylene mulch have arisen in recent years and alternative mulch products are currently being tested. The 0.6 mil thick biodegradable black mulch BioTelo Mulch Film (Dubois Agrinovation, Québec, Canada) was used for this experiment. BioTelo Mulch Film is made of Mater-Bi, a 100% biodegradable, cornstarch-based raw material that is obtained from renewable sources and is not genetically modified. BioTelo is certified with ECOCERT CAN-USA (USDA, NOP). Mater-Bi disintegrates and biodegrades completely over the course of a growing season. The decision to use biodegradable black mulch was due in part to the rising costs associated with petroleum-based products and the limited recycling options available for non-biodegradable polyethylene products in Kentucky, as well as to evaluate the durability of the product, weed control, moisture retention, and crop yield. Biodegradable black mulch is more environmentally sustainable although the initial cost of the product is nearly triple that of non-biodegradable, polyethylene mulch. However, there are higher labor



costs associated with disposal of non-biodegradable polyethylene mulch, which must be pulled up and thrown away at the end of the season, while pieces of polyethylene mulch may remain in the soil indefinitely. Polyethylene mulch also requires a high level of management and high startup costs. Annual rye grass was sown in between the rows as a living mulch.

BARE GROUND WITH SHALLOW CULTIVATION (BG). The bare ground with shallow cultivation system utilized specialized cultivation equipment, primarily a Glaser 10" center mount oscillation hoe mounted on a wheelhoe (Johnny's Selected Seeds, Winslow, Maine). The timing of shallow cultivation is critical, and is typically done when weeds are in the 'thread stage.' Cultivations are done to a depth of 0.5 to 1 inch early in the growing season, shortly after transplanting the crop and prior to crop canopy closure. According to Nordell and Nordell (1998), inverting only the top 2 inches of the soil eliminates the negative drawbacks that deep inversion cultivation can have, such as bringing up additional weed seeds that can germinate. A number of annual weed species are influenced by tillage type; eliminating deep soil inversion reduces the surface weed seedbank over the long term (Buhler and Oplinger, 1990; Coolman and Hoyt, 1993). Reliance on cultivation may cause reductions in soil quality indices, including aggregate stability and soil organic matter content (Grandy and

Robertson, 2006). Shallow cultivation was conducted to observe the effects on microbiological activity, as well as impacts on soil fertility and weed control.

**BARE GROUND WITH SHALLOW CULTIVATION AND WOOD CHIP MULCH (BGM).** The bare ground with shallow cultivation and wood chip mulch system expanded upon an experiment initiated in the summer of 2003 at the University of Kentucky Horticulture Research Farm, which evaluated weed control practices in an organic bell pepper production system (Law et al., 2006). In 2006 and 2007, this system was cultivated simultaneously with the other shallow cultivation system; wood chip mulch was applied approximately halfway through the growing season to evaluate the efficacy of the mulch on weed control.

**2006 EXPERIMENT.** The four organic production systems were compared for their crop yield and quality, weed control efficacy, economic sustainability, and influence on physical, chemical, and microbiological changes to the soil. The tomato cultivar 'Mountain Fresh F1 Hybrid' (Totally Tomatoes, Randolph, Wisconsin) was selected for its determinate quality, flavor, and large size. The cultivar was developed by Gardner (1999) and is known for its crack-resistance and early blight tolerance. Approximately 1600 non-treated seeds were sown in a media mixture of 5 parts Sunshine Organic Gro-Mix (Sun

Gro Horticulture, Bellevue, Wash.) and 1 part Vermont Compost Company Manure Compost (Vermont Compost Company, Montpelier, Vermont) in the University of Kentucky University of Kentucky Organic Farming Unit organic greenhouse on 13 April and transferred on 29 April to individual cells (black plastic, 60 cell count flats, Landmark Plastic Corporation, Akron, Ohio) containing the same media. Plants were fertigated twice while in the greenhouse with Omega 6-6-6 (6N-2.6P-5K) (Peaceful Valley Farm Supply, Grass Valley, Calif.) at a rate of 25 fl oz/gal of water.

Prior to the 2006 experiment, on 6 October 2005, composted manure (University of Kentucky Woodford County Research Farm, Versailles, Kentucky) was added to the experimental plots at a rate of 25 tons/A. The plots were then planted with annual rye at a rate of 100 lbs/A and hairy vetch at a rate of 40 lbs/A (Southern States, Lexington, Kentucky) on 14 October 2005 and left to grow through the winter. All treatments except the NT were tilled using an Imants (Reusel, Netherlands) spading machine on 23 May 2006. The NT treatment was mechanically killed using a rolling stock chopper (Buffalo Farm Equipment, Columbus, Nebraska) on 5 June 2006 prior to transplanting the tomatoes. NaturSafe Fine 10-2-8 (10N-0.9P-6.6K) granular fertilizer (Griffin Industries, Cold Spring, Kentucky) was broadcast and incorporated at a rate of 50 lbs/A of N to the plots

before transplanting. Additional N was fertigated through drip irrigation during the growing season at a rate of 50lbs/A N using Omega 6-6-6 (6N-2.6P-5K) on 7 July, and Phytamin 7-0-0 (7N-0P-0K) (California Organic Fertilizers, Fresno, Calif.) on 8 August.

INSECT AND DISEASE CONTROL. Pests of Solanaceous crops include potato aphids (*Macrosiphum euphorbiae*), silverleaf whitefly (*Bemisia argentifolii*), brown and green stink bugs (*Euschistus servus* and *Acrosternum hilare*), and Colorado potato beetle (*Leptinotarsa decemlineata*), all of which were present in late summer in the 2006 experiment. Surround WP<sup>®</sup> (Engelhard Corporation, Iselin, New Jersey) at a rate of 12.5 lbs/A, Agroneem (Agro Logistic Systems Inc., Diamond Bar, Calif.) at a rate of 1 gal/A and M-Pede<sup>®</sup> insecticidal soap (Dow Agrosiences/Mycogen, Indianapolis, Indiana) at a rate of 1 gal/A were applied to control insects on an as-needed basis determined by monitoring. PyGanic<sup>®</sup> (McLaughlin Gormley King Co., Golden Valley, Minnesota) at a rate of 2 oz/A was also used sporadically to knock down insect pest populations.

Diseases were also prevalent and included powdery mildew (*Leveillula taurica*), which persisted despite weekly sprays of Kumulus DF Sulfur (Arysta Life Science North America Corp., Cary, North Carolina), applied at a rate of 5 lbs/A. Early blight (*Alternaria solani*) and bacterial speck (*Pseudomonas syringae* pv. *tomato*) were also

present in all four treatments; Champion WP<sup>®</sup> Copper (NuFarm Americas, Inc., Burr Ridge, Illinois) at a rate of 2 lbs/A was applied to combat this problem as needed.

The experimental design was a randomized complete block design with four replications of each treatment. Each individual plot included all four treatments: 1) no-till, 2) raised beds covered with biodegradable black plastic, 3) bare ground with shallow cultivation, and 4) bare ground with shallow cultivation with the addition of mulch (Fig 1). The individual treatments were 18 ft x 25 ft; the replicated plots (each containing all four treatments) were 72 ft x 25 ft. Rows were spaced on 6 ft centers. Drip irrigation (Martin's Produce Supplies, Liberty, Kentucky) was used on all plots. Tensiometers were placed in each replicated plot, and water was applied to the plots when a reading of 30 centibars was reached. Seedlings were transplanted on 6 June. Approximately 16 tomato plants were planted per row, with in-row spacing of 18 inches. For the cultivated treatments, BG and BGM, the first cultivation was done on 16 June using the wheelhoe. This cultivation was timed and recorded in order to calculate labor costs in a partial budget analysis. Tomato stakes were added on 20 June between every other plant; tomatoes were also suckered to maintain a balance between fruit production and vegetative growth. Tomatoes were trellised according to the *University of Kentucky Cooperative*

*Extension Service Vegetable Production Guide for Commercial Growers ID-36* (Bessin et al., 2007) on 21 June, at a height of 10 inches; subsequent trellising followed as the plants grew. A second cultivation using the wheel hoe was done on 23 June. The BG and BGM plots were cultivated a third and final time on 24 July with the wheel hoe before mulch application to the BGM plots on 25 July. Municipal hardwood mulch (University of Kentucky Horticulture Research Farm, Lexington, Kentucky) was applied by hand at a depth of 2 to 4 inches. Annual rye (*Lolium multiflorum*) was sown into the rows for the BP treatment as living mulch on 16 June.

YIELD DATA. The first harvest occurred on 15 August, with tomatoes harvested from the center 10 ft of the middle row of each treatment. Harvested tomatoes were weighed, counted, sorted by size, and graded according to the USDA U.S. Standards for Grades of Fresh Tomatoes (1991). Subsequent tomato harvests occurred on an as-needed basis, typically once per week. Harvest dates were 8/15, 8/21, 8/29, 9/10, and 9/26.

TISSUE ANALYSIS. A plant tissue analysis was conducted during the 2006 growing season on the tomato crop to evaluate plant health and nutrient availability. Tissue samples were collected from each treatment in mid-July 2006 and sent to Waters Agricultural Laboratories (Owensboro, Kentucky) for analysis.

WEED RATINGS. Weed control was rated twice over the season using visual analysis on a 0 to 100% scale, with 0% indicating no evident control and 100% indicating complete weed control. The visual analyses were performed mid-season and at the end of the season for the BG plots and BGM plots. The percent weed control was recorded and results were analyzed using SAS.

PLANT DRY WEIGHT. Above ground plant dry weights were recorded in fall 2006 after the final harvest. Plants were cut at the base and any remaining fruits were removed. The plants were weighed and recorded before drying and after drying in an oven for one week at 65.5°C.

**2007 EXPERIMENT.** The same four organic production systems were evaluated again in 2007 for their crop yield and quality; weed control efficacy, economic sustainability, and influence on physical, chemical, and microbiological changes to the soil. The systems were 1) no-till (NT), 2) raised beds covered with biodegradable black mulch (BP), 3) bare ground with shallow cultivation (BG), and 4) bare ground with shallow cultivation with the addition of wood chip mulch (BGM). The orientation of the plots was the same as in 2006. After the 2006 harvest and prior to the second year of the experiment, composted manure (University of Kentucky Woodford County Research Farm, Versailles, Kentucky) was added to the experimental plots at a rate of

25 tons/A. Research plots were then planted in an annual rye (100 lbs/A) and hairy vetch (40 lbs/A) mixture (Southern States, Lexington, Ky.).

The yellow squash cultivar 'Sunray' was selected for its straightneck quality, powdery mildew resistance, and precocious yellow gene that masked virus symptoms. The cultivar was selected for its powdery mildew resistance over virus resistance, as powdery mildew is a bigger problem in early squash crops in Kentucky than viruses (Bessin et al., 2007). Approximately 2000 non-treated seeds (Seedway, Hall, New York) were sown in a 5:1 media mixture of Sunshine Organic Gro-Mix (Sun Gro Horticulture, Bellevue, Wash.) and Organic Worm Castings (Prather Worm Castings, Salvisa, Kentucky) in the University of Kentucky Organic Farming Unit organic greenhouse on 17 May into flats (black plastic, 98-cell count flats, Landmark Plastic Corporation, Akron, Ohio). Plants were fertigated once with Omega 6-6-6 (6N-2.6P-5K) (Peaceful Valley Farm Supply, Grass Valley, Calif.) at a rate of 25 fl oz/gal of water while in the greenhouse. Nearly 95% germination occurred by 24 May. On 1 June, flats were moved outside to harden off prior to transplanting.

INSECT AND DISEASE CONTROL. Squash bugs (*Anasa tristis*) and cucumber beetles (*Acalymma vittatum*) are common insect pests that plague Cucurbit crops grown in Kentucky. These pests were found



in the 2007 experiment; attempts at control included weekly applications of Surround WP<sup>®</sup>, applied at a rate of 12.5 lbs/A and Entrust (Dow AgroSciences, LLC, Indianapolis, Indiana), applied at a rate of 0.5 oz/100 gal. Bacterial wilt (causal agent *Erwinia tracheiphila*) and cucurbit yellow vine decline (CYVD) (causal agent *Serratia marcescens*) were found in the plots, and were presumably vectored by cucumber beetles and squash bugs, respectively. Powdery mildew also became problematic as the season progressed; Kumulus DF Sulfur was applied sporadically as needed, at a rate of 5 lbs/A.

The experimental design was the same randomized complete block design and size used in 2006 with four replications of each treatment. Individual plots included all four treatments: 1) no-till, 2) raised beds covered with biodegradable black mulch, 3) bare ground with shallow cultivation, and 4) bare ground with shallow cultivation with the addition of mulch. The individual treatments were 18 ft x 25 ft; replicated plots were 72 ft x 25 ft. Rows were spaced on 6 ft centers, with approximately 16 squash plants per row planted on 18 inch centers. Drip irrigation was used on all plots. Tensiometers were placed in each replicated plot as for the 2006 experiment. Irrigation was provided when tensiometers read 30 centibars. After rolling down the NT treatment on 4 June and plowing the BP, BG, and BGM treatments with a spading machine but prior to transplanting, granular

NaturSafe Fine 10-2-8 (10N-0.9P-6.6K) (Griffin Industries, Cold Spring, Ky.) was broadcast and incorporated at a rate of 50 lbs/A of N. Additional N was fertigated through drip irrigation and at a rate of 50lbs/A N using Omega 6-6-6 (6N-2.6P-5K) (Peaceful Valley Farm Supply, Grass Valley, Calif.) on 26 June and Phytamin 7-0-0 (7N-0P-0K) (California Organic Fertilizers, Fresno, Calif.) on 31 July.

Squash plants were transplanted with a no-till transplanter (RJ Equipment, Blenheim, Ontario) in the NT, BG and BGM subplots and with a water wheel setter (Rain-Flow Irrigation, East Earl, PA) in the BP subplots on 8 June. Immediately after transplanting, wire hoops were installed and plants were covered with Agribon-19 reemay fabric (Martin's Irrigation, Liberty, KY) to exclude insects such as squash bugs (*Anasa tristis*) and cucumber beetles (*Acalymma vittatum*). The reemay was removed on 26 June when plants were at anthesis. For the cultivated treatments, the first cultivation was done on 2 July using the wheel hoe. Further cultivations were not possible due to the squash plants growing into the rows. The cultivation was timed and recorded to calculate labor costs in the partial budget analysis.

YIELD DATA. The first squash harvest occurred on 6 July. Squash was harvested every 3 to 4 days on an as-needed basis at the proper size for the target market; fruits for this experiment were harvested at 4 to 9 inches, which is the size favored by local farmer's markets and

produce auctions. Yield harvest numbers were compiled, as were weights of each harvest. All produce harvested was sized, graded, and culled in accordance with USDA standards (1984). Subsequent harvest dates included: 7/6, 7/9, 7/12, 7/15, 7/18, 7/20, 7/23, 7/27, 7/31, 8/3, 8/8, and 8/13.

WEED RATINGS. Weed control was rated twice over the growing season using visual analysis on a 0 to 100% scale, with 0% indicating no evident control and 100% indicating complete weed control. The visual analyses were performed after the first cultivation for the BG plots and BGM plots and after the mulch application to the BGM plots. Weed ratings were conducted on percent weed cover between rows. The percent weed control was recorded and analyzed.

PLANT DRY WEIGHT. Above ground plant dry weights were recorded in fall 2007 after the final harvests. Plants were cut at the base and all remaining fruits were removed. The plants were weighed and recorded before drying and after drying in an oven for one week at 65.5°C.

PLANT HEIGHT. Randomly selected plants and rows in each treatment were measured due to observed height discrepancies among treatments. Squash plants were measured from the plant base to the uppermost leaf. Plant heights were averaged in each treatment for comparison.

## **SOIL ANALYSES**

Soil sampling was carried out a total of four times over the 2-year experiment. Plots were sampled in spring 2006, fall 2006, spring 2007, and fall 2007. Soil cores were taken from the plots at depths of 0 to 5 cm, 5 to 15 cm, and 15 to 25 cm. Cores were collected when field soil was at optimum moisture content, with the soil containing enough water to be compacted into its densest state. Three soil cores were collected for each replicate of each treatment for a total of 12 samples per treatment. Sod soil cores were collected as a control from an area adjacent to the plot. After cores were collected, they were placed in labeled plastic bags that were double-bagged, tightly sealed, and placed in a cooler filled with ice. Cores were then transported to the laboratory and stored in a walk-in cooler at 4° C. Soil cores were sieved through a 4 mm sieve to remove plant debris, insects, and other foreign objects. The soil was used in select physical, chemical, and microbiological analyses.

**PHYSICAL PROPERTIES.** The physical properties evaluated for this experiment included soil compaction determined by bulk density and penetrometer. Although gravimetric water content can change rapidly through time due to available moisture, it was also analyzed as a physical property.

Soil compaction is characterized by changes in soil bulk density, which measures the weight of the soil per unit volume (g/cc). Soil cores were collected using a hammer-type bulk density sampler with a 4.8 cm x 10.1 cm cylinder and a volume of 384.57 cm<sup>3</sup>. The soil cores were placed in a 105 °C oven for 24 hours until uniformly dried, after which the cores were re-weighed. The resulting weight was used in the formula: bulk density = volume divided by grams of oven dry soil.

Penetrometer readings are also used to measure soil compaction. A hand-held cone penetrometer (Pike Agri-Lab Supplies, Jay, Maine) was used to measure soil resistance to vertical penetration of the cone. Each subplot was sampled 4 times in a random pattern.

The force was expressed in kPa, kg/cm<sup>2</sup>, or PSI.

Gravimetric water is the measurement of water held in soil and is determined by measuring the mass of water relative to the mass of dry soil. Approximately 10 g of moist soil was weighed and dried in a 65.5°C oven for 12-24 hours until uniformly dry and weighed again. The gravimetric water content equals the mass of the dry soil subtracted from the mass of the moist soil, divided by the mass of the dry soil. Measurements are expressed in percent.

CHEMICAL PROPERTIES. Approximately 1 pint of sieved soil was sent to the University of Kentucky Regulatory Services Soil Testing Laboratory for analysis. Soil analyses performed included a standard

soil test (pH, buffer pH, P, K, Ca, Mg, Zn), Mehlich III extraction (Cd, Cr, Ni, Pb, Zn, Cu, Mo), cation exchange capacity (CEC), bases and base saturation, percent soil organic matter, soluble salts, total nitrogen, and water holding capacity.

Inorganic N determination in soil extracts was determined by colorimetric methods. According to Mulvaney (1996), the Berthelot reaction using phenol (Keeney and Nelson, 1982; Dorich and Nelson, 1983) determines ammonium-N, while nitrite-N is analyzed using the Griess-Ilosvay method (Bremner, 1965; Keeney and Nelson, 1982); this method can also determine nitrate-N following the reduction to nitrite-N using copperized cadmium (Huffman and Barbarick, 1981; Keeney and Nelson, 1982; Dorich and Nelson, 1984). These inorganic forms of nitrogen are easily and rapidly transformed by microorganisms and are essential for plant growth. In order to avert  $\text{NO}_2^-$ -N loss due to chemical decomposition of  $\text{HNO}_2$  formed under acidic conditions, a neutral or alkaline reagent is used in soil extractions for  $\text{NO}_3^-$  or  $\text{NO}_2^-$  determination, with a 2 M solution of KCl typically used for the reagent to extract  $\text{NO}_3^-$ ,  $\text{NO}_2^-$ , and  $\text{NH}_4^+$ ; however; in this experiment, 0.5 M  $\text{K}_2\text{SO}_4$  can also be used as the reagent, although formation of precipitate may occur during refrigeration (Mulvaney, 1996). The resulting extractant, determined by chloroform fumigation-extraction (FE) technique (Brookes et al.,

1985, Vance et al., 1987, Amato and Ladd, 1988, Sparling and West, 1988) was used for  $\text{NH}_4^+$ ,  $\text{NO}_3^-$ , and  $\text{NO}_2^-$  determinations, however, nitrite does not usually register using colorimetric methods due to the rapid transformation to nitrate within the soil.

Total nitrogen was analyzed using the Kjeldahl (1883) wet combustion method. Organic N in the soil sample is converted to  $\text{NH}_4^+$ -N by digestion using concentrated  $\text{H}_2\text{SO}_4$ ;  $\text{K}_2\text{SO}_4$  raises the temperature of digestion, and the catalyst Se is used to promote organic matter oxidation (Bremner, 1996).

Total organic carbon was analyzed using a Shimadzu TOC-5000A carbon analyzer equipped with the Shimadzu ASI-5000A auto sampler (Shimadzu Corp., Columbia, Maryland). This wet combustion method, similar to the Walkley and Black (1934) method, detects  $\text{CO}_2$  after sample combustion and acidification. The difference between total and inorganic carbon represents the amount of total organic carbon. The amount of C contained in the sample is quantified by comparing the results with the standards. This reading is commonly used as a basis for soil organic matter estimates.

**MICROBIOLOGICAL PROPERTIES.** Microbiological properties were analyzed to evaluate potential microbial activity. Microbial biomass carbon examines the living component of soil organic matter, and was determined by chloroform fumigation-extraction (FE) technique

(Brookes et al., 1985, Vance et al., 1987, Amato and Ladd, 1988, Sparling and West, 1988). In this assay, microbial membranes were lysed using chloroform, which releases the cytoplasmic contents including proteins, vitamins, DNA, and RNA. The cellular contents were extracted with a dilute salt solution (0.5M K<sub>2</sub>SO<sub>4</sub>) and measured as total organic carbon and total nitrogen. The microbial biomass C was measured by comparing fumigated samples versus unfumigated samples.

Potentially mineralizable carbon (PMC) was examined as an indicator of soil microbial activity and measure of the mineralizable organic C in the absence of a water limitation. According to Alexander (1977) and Paul and Clark (1989), mineralization is the release of CO<sub>2</sub> from metabolizing organisms as applied to carbon. In PMC, the release of CO<sub>2</sub> from metabolizing organisms is measured, which characterizes the nature of decomposition processes in the soil. A static method using 125 mL Wheaton glass serum bottles (Fisher Scientific, Pittsburgh, Pennsylvania) sealed with chlorobutyl serum stoppers and aluminum seals (Fisher Scientific, Pittsburgh, Pennsylvania) were used, with 2 g soil weighed into each vessel. An additional 0.2 mL of H<sub>2</sub>O was added to each vessel. Evolved CO<sub>2</sub> was allowed to accumulate in the headspace of the vessels for GC analysis (Christensen, 1987; Linn and Doran, 1984; West and Sparling, 1986). The release of CO<sub>2</sub>



was measured by gas chromatograph Shimadzu GC-8A (Shimadzu Corp., Columbia, Maryland). Samples were incubated over a period of 5 weeks, with CO<sub>2</sub> measurements taken weekly.

Basal respiration (BR) is an indicator of the amount of mineralizable organic C at the native water content of soil and is also associated with soil organic matter decomposition. Although respiration measurements may not wholly reflect the actual degree of substrate degradation, it is the most popular method to gauge microbial activity and substrate decomposition in soils. A static method was also used to measure BR, with a given volume of atmosphere entrapped above the soil in a closed, non-aerated container (Zibilske 1994). Glass 125 mL Wheaton glass serum bottles (Fisher Scientific, Pittsburgh, Pennsylvania) sealed with chlorobutyl serum stoppers and aluminum seals (Fisher Scientific, Pittsburgh, Pennsylvania) had 2 g soil weighed into each vessel. The release of CO<sub>2</sub> from microorganisms accumulated in the headspace of the vessels (Christensen, 1987; Linn and Doran, 1984; West and Sparling, 1986) and was measured by gas chromatograph Shimadzu GC-8A (Shimadzu Corp., Columbia, Maryland); samples were incubated over a period of 5 weeks, with CO<sub>2</sub> measurements taken weekly.

**ECONOMIC ANALYSIS.** A partial budget analysis compared costs and returns among the four organic production systems (no-till (NT),

raised beds covered with biodegradable black plastic (BP), shallow cultivation on bare ground (BG), and shallow cultivation on bare ground with the addition of wood chip mulch (BGM)). The partial budget itemized the costs and returns directly affected by changes in treatments, and included all itemized costs as for a complete crop budget. Production costs that were not affected by the treatments were based on estimates published by the University of Kentucky (Isaacs et al., 2004). The costs associated with the treatments were determined as follows.

The “total harvesting and marketing costs” included marketing costs, boxes, fuel and lube, and labor costs for harvesting, packing, and grading. All costs were dependent on total yield, with the exception of the fuel and lubrication fees.

The “total production costs” included seed, flats, organic potting media, pre-plant fertilizer, soluble fertilizer, drip tape, mulch, mulch application charges, cultivation, fuel and lube, repairs, transplanting labor, and irrigation labor.

The “mulch application charge” was determined for hand application of mulch. Approximately 15 minutes was needed for a single worker to apply mulch to one subplot replication (BGM treatment) within one plot, with a replication size of 450 ft<sup>2</sup>. A total of four replications within four plots were mulched. An hourly labor rate

of \$8.00 was charged, which was the average hourly farm wage in Kentucky. The cost of transporting the mulch was not included in the budget analysis.

The "cultivation costs" were calculated based on the timing for the wheel hoe cultivations. Weed control for both years of this project was conducted using a wheelhoe, which required approximately 1 man hour for the 8 subplots cultivated within the ¼ acre experimental plot. The labor required for weed control was included in the partial budget analysis and compared with conventional grower labor. These cultivations were performed by the same person a total of three times over the season. The BG and BGM treatments were cultivated on the same dates. After the third cultivation, hardwood mulch was applied to the BGM treatment.

The "total variable costs" included the sum of the total production costs and the total harvesting and marketing costs.

The "total fixed costs" were the same for all treatments and included depreciation on machinery, depreciation on irrigation equipment, insurance, and taxes. The "total expenses" include the sums of all variable and fixed costs.

STATISTICAL ANALYSIS. Analysis of variance of all data was conducted using the PROC ANOVA or PROC GLM procedure of the

Statistical Analysis System (SAS Institute, 1999). Year was assumed to be a fixed variable in the analysis conducted by use of PROC GLM.

## **Results**

MARKETABLE YIELD. For the 2006 marketable yield of tomatoes, there was no significant difference in yield among all four treatments. The average marketable yield weight for all four treatments was 10,459 kg/ha (23,060 lbs/A) and included both Grade 1 and Grade 2 tomatoes. Yields of conventionally grown tomatoes in Kentucky typically average 18,143 kg/ha (40,000 lbs/A), or 1600- 11 kg (25 lb.) boxes per acre (Isaacs et al., 2004). The total average yield weight for all four treatments with culls was much higher than the average marketable yield at 21,900 kg/ha (48,283 lbs/A). Fruits were culled for a variety of reasons, including insect and animal damage; however, most were culled due to cracking, which was likely due to excess water during 2006. The total percent of marketable tomatoes was not significantly different among treatments, nor was the total yield weight significantly different among treatments. The only significant difference was in the ripening date, in which the BP treatment was 3 days earlier in producing marketable fruit. The average 2006 harvest midpoint date was 1 September for the BP treatment, and 4 September for the other three treatments (Table 3).

For the 2007 marketable yield of yellow summer squash, there was a significant treatment difference in yield on a kg/ha basis. Conventionally grown summer squash in Kentucky typically yields between 700 and 1,200 5/9 bushel boxes per acre, with an average yield of 950 boxes per acre (Ernst and Woods, 2005). Comparatively, the 2007 experiment yielded a marketable average of 1,462- 5/9 bushel boxes per acre of organically grown summer squash over all four treatments. The NT treatment had significantly lower yields than the BP, BGM, and BG treatments. The NT treatment was also significantly lower in total marketable yield per acre. There was no significant difference in ripening time for 2007 among the four treatments (Table 3).

WEED RATINGS. Weed ratings were conducted by visual analysis on two dates in 2006 and on two dates in 2007. A scale of 0 to 100% was used, with 0% indicating no observable weed control, and 100% indicating complete weed control. According to the Duncan's Multiple Range Test, in 2006 the BGM and BG treatments had a >90% control range, significantly higher than the BP and NT treatments, which had weed control in the 30% range. In 2007, the BGM treatment was significantly different from the other three treatments, with weed control in the >90% range. The BP and BG treatments had weed control in the >80% to low 90% range, while the NT treatment was

significantly lower than the other three treatments with weed control of <10% (Table 3).

PLANT DRY WEIGHT. Plant dry weight was assessed after the final harvest in both 2006 and 2007. In 2006, there was no significant difference in plant dry weight among treatments. In 2007, the BG and BP treatments had the highest dry weights and were significantly different from the NT treatment. The BGM treatment was not significantly different from any of the other three treatments. The NT treatment had the lowest plant dry weight (Table 3).

PLANT FOLIAR ANALYSIS. Foliar samples were taken from tomato plants grown in the experimental plots in 2006 to evaluate plant health and assess nutrient levels and potential. Tests for Nitrogen (N), Magnesium (Mg), and Copper (Cu) showed significant differences among all four treatments. Foliar N analysis revealed that the BG treatment had significantly higher %N than the BGM and BP treatments. For Mg, the BGM treatment had significantly higher levels of Mg than the BG and BP treatments. Cu levels for the BGM treatment were significantly higher than the BG and BP treatments (Table 3).

PLANT HEIGHT. The height of the squash plants were measured in 2007 due to obvious size discrepancies among the four treatments. The plants grown in the NT treatment appeared to be the smallest and height measurements confirmed this observation. There was a

significant difference in height among the NT treatment and the BGM, BG, and BP treatments. The NT plants were an average of 4.5 cm shorter than the other three treatments and were significantly lower in height overall (Table 3).

Table 3. Effects of four organic vegetable production systems on selected parameters for 2006 and 2007.

2006	Bare Ground (BG)	Black Plastic (BP)	Bare Ground + Mulch (BGM)	No-Till (NT)
<b>TOMATO</b>				
Total Yield kg/ha(lbs/A) <sup>z</sup>	21,517 (47,438) a	22,080 (48,680) a	22,354 (49,284) a	21,513 (47,430) a
Total % Marketable <sup>z</sup>	47.0 a	45.61 a	50.10 a	48.85 a
Harvest Mid-Point (date) <sup>z</sup>	1 Sept a	4 Sept b	4 Sept b	4 Sept b
Weed Control (%) <sup>z</sup>	98.13 a	37.5 b	98.0 a	30.0 b
<b>Plant Foliar Analysis</b>				
% N <sup>z</sup>	4.83 a	4.18 b	4.28 b	4.43 ab
%Mg <sup>z</sup>	0.60 ab	0.56 b	0.69 a	0.68 ab
ppm Cu <sup>z</sup>	20.25 b	19.75 b	24.75 a	22.00 ab
<b>2007</b>				
<b>SUMMER SQUASH</b>				
Total Yield Wt (lbs)/A <sup>z</sup>	40,181 a	40,038 a	39,494 a	24,480 b
Total Mkt. Yield Wt(lbs)/A <sup>z</sup>	34,841 a	33,300 a	32,777 a	21,939 b
Total Number/A <sup>z</sup>	130,500 a	127,950 a	122,250 a	82,200 b
Total Mkt. Yield No./A <sup>z</sup>	119,700 a	116,850 a	111,600 a	76,650 b
Harvest Mid-Point (date) <sup>z</sup>	23 July a	24 July a	24 July a	25 July a
Weed Control (%) <sup>z</sup>	92.25	89.75	98.25	8.88
Plant Dry Wt. Avg.(g) <sup>z</sup>	511.20 a	549.11 a	425.40 ab	372.28 b
Plant Ht. Avg. (cm) <sup>z</sup>	75.18 a	73.53 a	75.44 a	68.71 b

<sup>z</sup> Means in a column followed by the same letter(s) are not significantly different (Waller-Duncan K-ratio t-test  $P < 0.05$ ).

## **SOIL PHYSICAL ANALYSES**

**BULK DENSITY.** Analysis of bulk density measurements indicated that all treatments with the exception of the BGM treatment did not have any significant differences in bulk density over time (data not shown). The BGM treatment showed an increase in bulk density in g/cm<sup>3</sup> between 2006 and 2007, contradicting other research that shows the addition of wood chip mulch to soil decreases bulk density, due to an increase in organic matter associated with the decomposing mulch (Himelick and Watson, 1990).

**GRAVIMETRIC WATER.** Gravimetric water analysis showed no significant differences among all four treatments in the first soil baseline samples taken in spring 2006. The second soil sampling in fall 2006 showed significant differences among all four treatments. The BGM treatment had the highest gravimetric water content, followed by the NT treatment, BP treatment, and BG treatment. For the third sample date, taken in spring 2007, the BGM treatment was significantly higher in gravimetric water content. The NT and BP treatments had similar values; the BG treatment had the lowest value and was significantly different only from the BGM treatment. The final sampling in fall 2007 again reflected this trend; the BGM treatment was significantly higher in gravimetric water content, followed by a significantly lower NT treatment. The BP and BG treatments were significantly lower than the BGM and NT treatments (Table 3.1).



PENETROMETER. Penetrometer readings were taken in spring 2006 and spring 2007 to measure soil compaction in PSI. There were no significant differences among treatments for either year. There were also no significant interactions among treatments or among years.

### **SOIL CHEMICAL ANALYSES**

TOTAL NITROGEN. There were no significant differences in percent total nitrogen among all four treatments for 2006. In 2007, there was a significant difference among treatments with time. The total N averaged over all four treatments for spring 2007 was significantly higher than the four treatment averages in spring 2006, fall 2006, and fall 2007. However, in Duncan's Multiple Range Test using the GLM Procedure, results ranged from 28 ppm N to 14 ppm N for spring 2006 analyses (Table 3.1).

NITRITE, NITRATE, AMMONIUM. ( $\text{NO}_2^-$ ,  $\text{NO}_3^-$ ,  $\text{NH}_4^+$ ). There were no significant differences in nitrite, nitrate, and ammonia among all four treatments for both 2006 and 2007; however, there were significant interactions for nitrite, nitrate, and ammonia with time over the course of the two year, four soil sampling periods.

Nitrite was determined with colorimetric methods. There was no significant difference over the four soil sampling dates and the two-year period or among any of the four treatments.

Nitrate determination was conducted using colorimetric methods. There was a significant difference over the four soil sampling dates and the two-year period, with the fall 2006 sampling date significantly different from the spring 2006, spring 2007, and fall 2007 sampling dates. The  $\text{NO}_3^-$  value in mg/kg  $\text{NO}_3^-/\text{gsoil}/\text{day}$  was highest in fall 2006 (Table 3.1).

Ammonium was determined using colorimetric methods. There was a significant difference over the four soil sampling dates and the two-year period, with the spring 2006 and spring 2007 sampling dates significantly different from the fall 2006 and fall 2007 sampling dates. The  $\text{NH}_4^+$  value in mg/kg  $\text{gsoil}/\text{day}$  was highest in spring 2006, followed by spring 2007 (Table 3.1).

## **SOIL MICROBIOLOGICAL ANALYSES**

**MICROBIAL BIOMASS CARBON.** Readings obtained from the Shimadzu TOC-5000A carbon analyzer indicated a significant difference in microbial biomass carbon over time. The fall 2007 sampling date was significantly higher than the spring 2007, fall 2006, and spring 2006 sampling dates. The spring 2007 sampling date was significantly higher than both the fall 2006 and spring 2006 sampling dates, and significantly different from the fall 2007 sampling date (Table 3.1).

In the spring 2007 analyses of microbial biomass carbon, there was a significant difference among treatments, with the BGM treatment significantly higher than the NT and BP treatments. For all of the other soil sampling dates; spring 2006, fall 2006, and fall 2007, there were no significant differences in microbial biomass carbon among treatments.

Soil test results from University of Kentucky's Regulatory Services indicated a significant difference in soil organic matter (SOM) with differing soil depths and over time. For the 0-5 cm sampling depth for fall 2006, spring 2007, and fall 2007, the BGM treatment was significantly higher than the BP and BG treatments. The NT treatment was significantly higher than the BP and BG treatments in spring 2007 and fall 2007. The BGM and NT treatments had the highest percentages of SOM, presumably due to the wood chip mulch and the cover crop mulch, respectively. For the 0-5 cm and 5-15 cm sampling depths, fall 2006 had the significantly highest overall SOM (Table 3.1).

Table 3.1. Selected soil physical and microbiological properties for four vegetable production systems over four soil sampling dates in a two-year period.

	Bare Ground (BG)	Black Plastic (BP)	Bare Ground + Mulch (BGM)	No-Till (NT)
<b>SPRING 2006</b>				
<b>SOIL PROPERTIES</b>				
<b>PHYSICAL</b>				
Gravimetric H <sub>2</sub> O (% wt. (g))	0.31 a	0.31 a	0.31 a	0.31 a
<b>MICROBIOLOGICAL</b>				
SOM (%) 0-5 cm depth	1.88 a	1.96 a	1.90 a	1.93 a
<b>Fall 2006</b>				
<b>SOIL PROPERTIES</b>				
<b>PHYSICAL</b>				
Gravimetric H <sub>2</sub> O (% wt. (g))	0.23 d	0.23 c	0.25 a	0.24 b
<b>MICROBIOLOGICAL</b>				
SOM (%) 0-5 cm depth	1.76 b	1.81 b	1.98 ab	1.90 b
Corg (%) 0-5 cm depth	1.70 b	1.75 b	1.97 ab	1.87 b
<b>SPRING 2007</b>				
<b>SOIL PROPERTIES</b>				
<b>PHYSICAL</b>				
Gravimetric H <sub>2</sub> O (% wt. (g))	0.24 b	0.25 ab	0.25 a	0.25 ab
<b>MICROBIOLOGICAL</b>				
SOM (%) 0-5 cm depth	1.57 c	1.56 c	2.01 a	1.75 b
Corg (%) 0-5 cm depth	1.63 c	1.62 c	1.99 a	1.85 b
MBC (ugC/gsoil)	240.17 ab	140.19 b	313.21 a	174.39 b
Corg (%) 5-15 cm depth	1.55 b	1.58 b	1.86 a	1.48 b
<b>Fall 2007</b>				
<b>SOIL PROPERTIES</b>				
<b>PHYSICAL</b>				
Gravimetric H <sub>2</sub> O (% wt. (g))	0.23 c	0.23 c	0.26 a	0.25 b
<b>MICROBIOLOGICAL</b>				
SOM (%) 0-5 cm depth	1.59 b	1.56 b	1.91 a	1.88 a
Corg (%) 0-5 cm depth	1.62 b	1.57 b	1.96 a	1.91 a
Corg (%) 5-15 cm depth	1.58 ab	1.49 b	1.71 a	1.49 b

<sup>z</sup> Means in a column followed by the same letter(s) are not significantly different (Waller-Duncan K-ratio t-test P<0.05).

The measurement of soil organic matter also determines the % carbon in the soil. Soil organic matter is calculated as % carbon multiplied by 1.72, which equals the % organic matter. To calculate % carbon only, the % SOM value is divided by 1.72. This number is the soil organic carbon ( $C_{org}$ ).  $C_{org}$  was significantly different across treatments in the 0-5 cm soil depth for fall 2006, spring 2007, and fall 2007. For the 5-15 cm soil depth, there was a significant difference among treatments for spring 2007 and fall 2007, with the BGM treatment significantly higher than all other treatments in spring 2007, and significantly higher than the NT and BP treatments in fall 2007 (Table 3.1).

When results from all four sampling dates and all three soil depths were averaged, the BGM treatment was significantly higher in % carbon than the other three treatments. The NT, BG, and BP treatments were not significantly different from each other (data not shown).

The ratio between microbial biomass carbon ( $C_b$ ) and  $C_{org}$  is the microbial quotient ( $C_b/C_{org}$ ) and is indicative of changes in soil properties (Sparling, 1992). Microbial quotient size and activity are directly related to the amount and quality of carbon available (Breland and Eltun, 1999). In this experiment, there was a significant difference in the  $C_b/C_{org}$  over time, but no significant differences among

treatments. The fall 2007 sampling date was significantly higher than the spring 2007, fall 2006, and spring 2006 sampling dates. The spring 2007 sampling date was significantly higher than fall 2006 and spring 2006 dates, and significantly different from the fall 2007 sampling date (Table 3.2).

Table 3.2. Select results of soil chemical and microbiological properties over four soil sampling dates in a two-year period.

	Spring 2006	Fall 2006	Spring 2007	Fall 2007
<b>Soil Properties</b>				
<b>Chemical</b>				
Total N (ppm) <sup>z</sup>	0.193 b	0.142 b	0.288 a	0.187 b
NO <sub>3</sub> -(mg/kg/gsoil/day) <sup>z</sup>	0.52 b	1.11 a	0.06 c	0.38 b
NH <sub>4</sub> <sup>+</sup> (mg/kg NH <sub>4</sub> + gsoil/day) <sup>z</sup>	24.33 a	2.76 b	20.89 a	4.15 b
<b>Microbiological</b>				
Microbial Biomass C (ugC/gsoil) <sup>z</sup>	31.45 c	70.87 c	125.22 b	182.91 a
Soil Organic Matter (%) <sup>z</sup>	1.49 b	1.59 a	1.46 b	1.46 b
Microbial Quotient (Cb/Corg) <sup>z</sup>	20.01 c	46.06 c	80.73 b	125.39 a

<sup>z</sup> Means in a column followed by the same letter(s) are not significantly different (Waller-Duncan K-ratio t-test  $P < 0.05$ ).

**BASAL RESPIRATION.** The measurement of soil basal respiration (BR) indicates the amount of mineralizable organic carbon at the native water content of the soil.

**SPRING 2006.** Soil samples were taken before any of the treatments had been applied; these baseline soil samples were determined not to be statistically different.

**FALL 2006.** The second soil sampling occurred in fall 2006.

0-5 cm SOIL DEPTH. The first BR reading occurred on 21 October, and in the 0-5 cm soil sampling depth, the BG treatment had significantly less BR than the NT, BGM, and BP treatments (data not shown).

5-15 cm SOIL DEPTH. For the second BR reading on 27 October in the 5-15 cm soil sampling depth, the BGM treatment was significantly higher than the BP treatment, while on the third BR reading on 2 November, the BGM and NT treatments were significantly higher than the BP treatment. The fourth reading on 8 November showed no significant differences among treatments; on the fifth reading on 14 November, the BGM treatment was significantly higher than the BP treatment in the 5-15 cm soil sampling depth (data not shown).

15-25 cm SOIL DEPTH. In the 15-25 cm soil sampling depth, the first reading on 21 October showed the BP treatment to be significantly higher, while for the second BR reading on 27 October, the BP treatment was significantly higher than all 3 other treatments; the fourth BR reading on 8 November confirmed a significantly higher BP treatment than the other 3 treatments; the fifth reading on 14 November also showed the BP treatment to be significantly higher than the BG treatment (Figure 3).

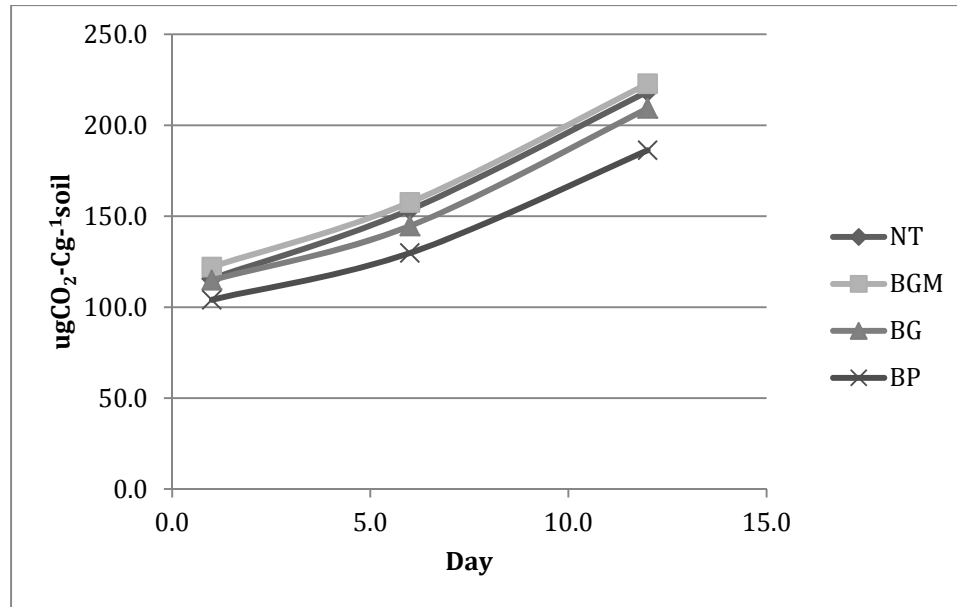


Figure 3: Basal Respiration, 15-25cm soil sampling depth (Fall 2006)

SPRING 2007. The third soil sampling period occurred in spring 2007.

0-5 cm SOIL DEPTH. On the first BR reading on 15 May, the BGM and NT treatments were significantly higher than the BG and BP treatments in the 0-5 cm soil sampling depth, while on the second reading on 21 May, the BGM treatment was significantly higher than the BP treatment. For the third reading on 27 May, the BGM treatment was significantly higher than the BG and BP treatments; the fourth reading on 4 June showed the BGM treatment was significantly higher than the BG and BP treatments. The fifth and final reading on 9 June had the BGM and NT treatments significantly higher than the BG and BP treatments in the 0-5 cm soil sampling depth (Figure 3.1).



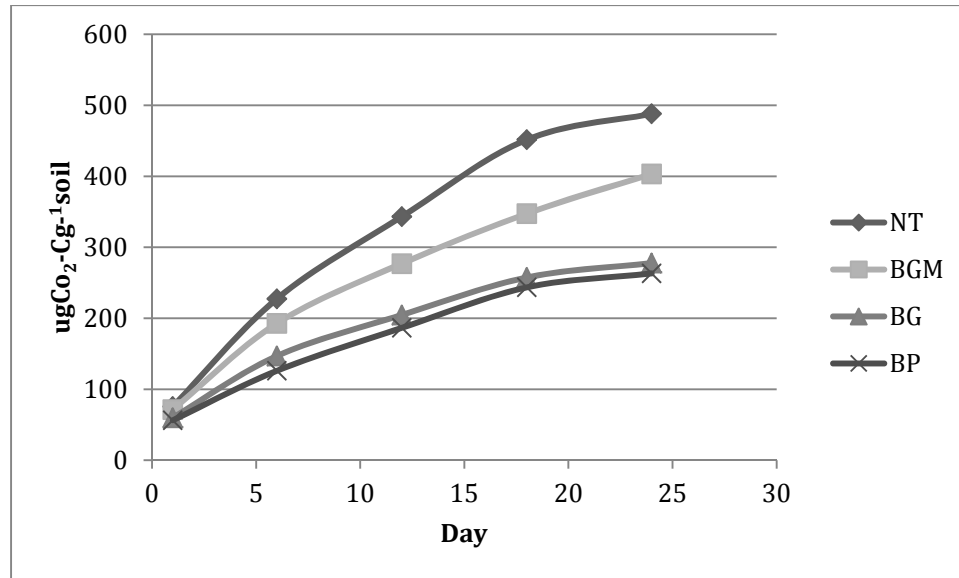


Figure 3.1: Basal Respiration, 0-5cm soil sampling depth (Spring 2007)

5-15 cm SOIL DEPTH. On the first sampling date, 15 May, the BGM treatment was significantly higher than the other 3 treatments. The second BR reading occurred on 21 May; the BGM treatment was significantly higher than the other 3 treatments; while on the third BR reading on 27 May, BGM was significantly higher than all 3 other treatments. The fourth BR reading occurred on 4 June; and 15-25 cm soil sampling depths, the BGM treatment was significantly higher than all 3 other treatments. The fifth and final BR reading for spring 2007 occurred on 9 June; for the 5-15 cm soil sampling depth, the BGM treatment was significantly higher than all 3 other treatments (Figure 3.2).

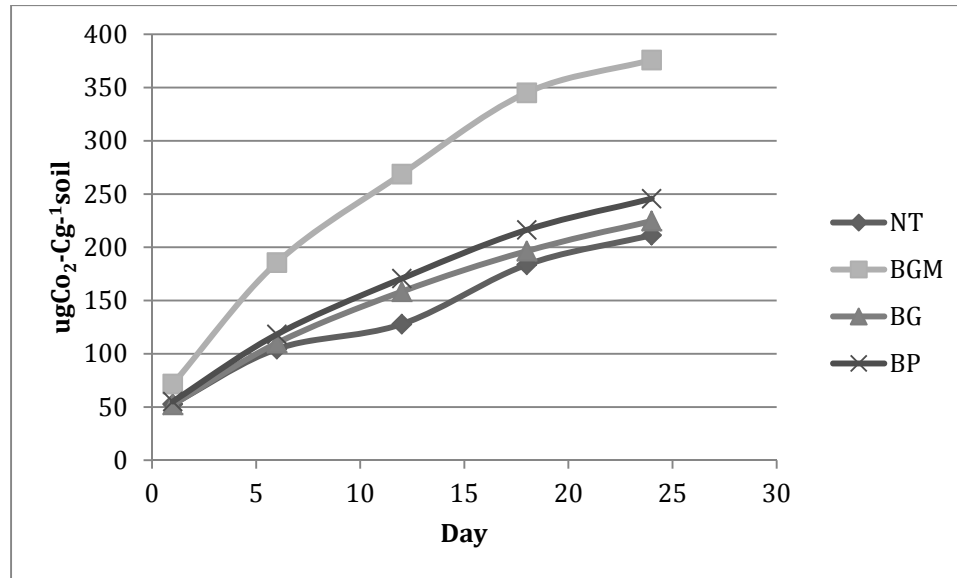


Figure 3.2: Basal Respiration, 5-15cm soil sampling depth (Spring 2007)

15-25 cm SOIL DEPTH. For the second BR reading on 21 May, the BGM treatment was significantly higher all 3 other treatments, while on the third reading on 27 May, the BGM treatment was significantly higher than the BG treatment. The fourth BR reading occurred on 4 June; the BGM treatment was significantly higher than all 3 other treatments. The fifth and final BR reading for spring 2007 occurred on 9 June; the BGM treatment was significantly higher than the BP and NT treatments in the 15-25 cm soil sampling depth (Figure 3.3).

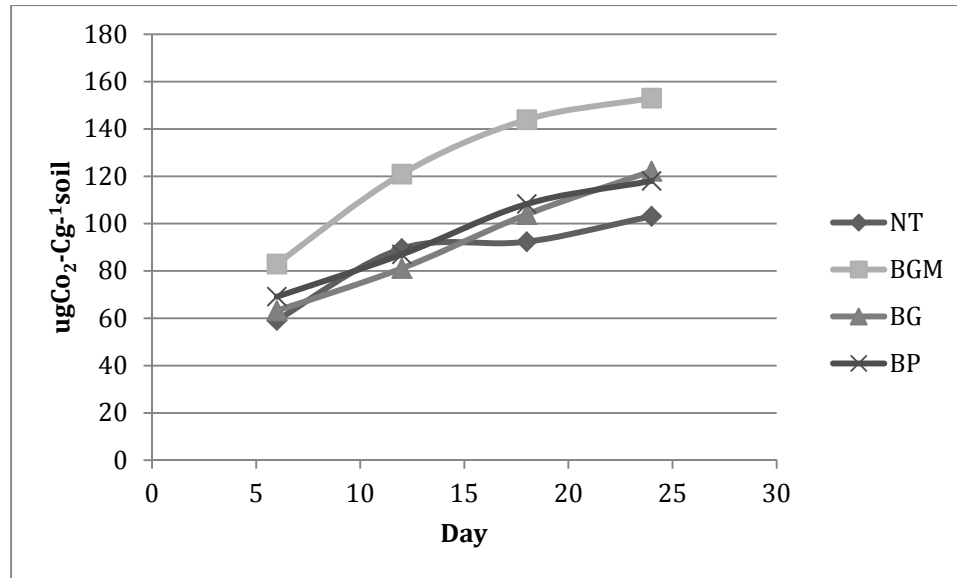


Figure 3.3: Basal Respiration, 15-25cm soil sampling depth (Spring 2007)

FALL 2007. Fall 2007 was the fourth and final soil sampling for this experiment.

0-5 cm SOIL DEPTH. The first BR reading for fall 2007 occurred on 25 October, and the BGM and NT treatments were significantly higher than the BG and BP treatments. On the second BR reading on 31 October, the BGM and NT treatments were significantly higher than the BG and BP treatments. The third reading occurred on 6 November, and the BGM and NT treatments were significantly higher than the BG and BP treatments. For the fourth BR reading on 12 November, the BGM and NT treatments were significantly higher than the BP and BG treatments, while the fifth and final BR reading occurred on 18 November and the NT and BGM treatments were significantly higher than the BP and BG treatments (Figure 3.4).

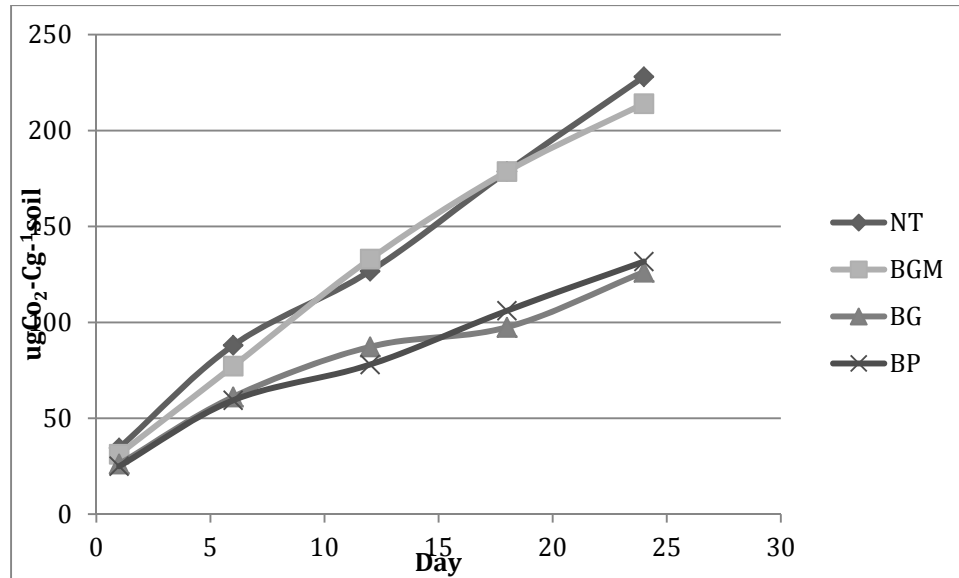


Figure 3.4: Basal Respiration, 0-5cm soil sampling depth (Fall 2007)

5-15 cm SOIL DEPTH. For the second reading on 31 October, the BGM treatment was significantly higher than the BG treatment, while on the third reading on 6 November, the BGM treatment was significantly higher than the BG and NT treatments. For the fourth reading on 12 November, the BGM treatment was significantly higher than the BG treatment. On the fifth and final reading on 18 November, the BGM treatment was significantly higher than the BG treatment (Figure 3.5).

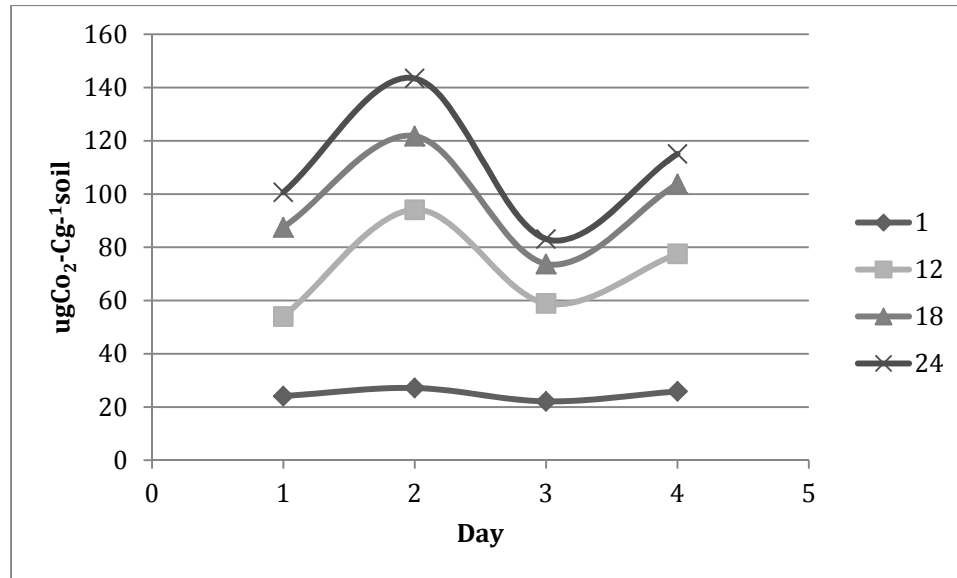


Figure 3.5: Basal Respiration, 5-15cm soil sampling depth (Fall 2007)

Using Duncan's Multiple Range Test for the fall 2007 sampling period and the 0-5 cm soil sampling depth, the NT and BGM treatments were significantly higher than the BP and BG treatments. In spring 2007, the BGM treatment was significantly higher than the BP treatment in the 0-5 cm soil sampling depth. At the 5-15 cm soil sampling depth in fall 2006, the BGM treatment was significantly higher than the BP treatment for the 5-15 cm soil sampling depth. In fall 2007, the BGM treatment was significantly higher than the NT and BG treatments at the 5-15 cm soil sampling depth, while in spring 2007 the BGM treatment was significantly higher than all 3 other treatments. At the 15-25 cm soil sampling depth in fall 2006, the BP treatment was significantly higher than the NT and BG treatments. In

spring 2007, the BGM treatment was significantly higher than all 3 other treatments at the 15-25 cm soil sampling depth.

POTENTIALLY MINERALIZABLE CARBON. The measurement of potentially mineralizable carbon (PMC) represents the mineralizable organic C in the absence of a water limitation. In spring 2006, soil samples were taken before any of the treatments had been applied; these baseline soil samples and resulting data were determined not to be statistically different.

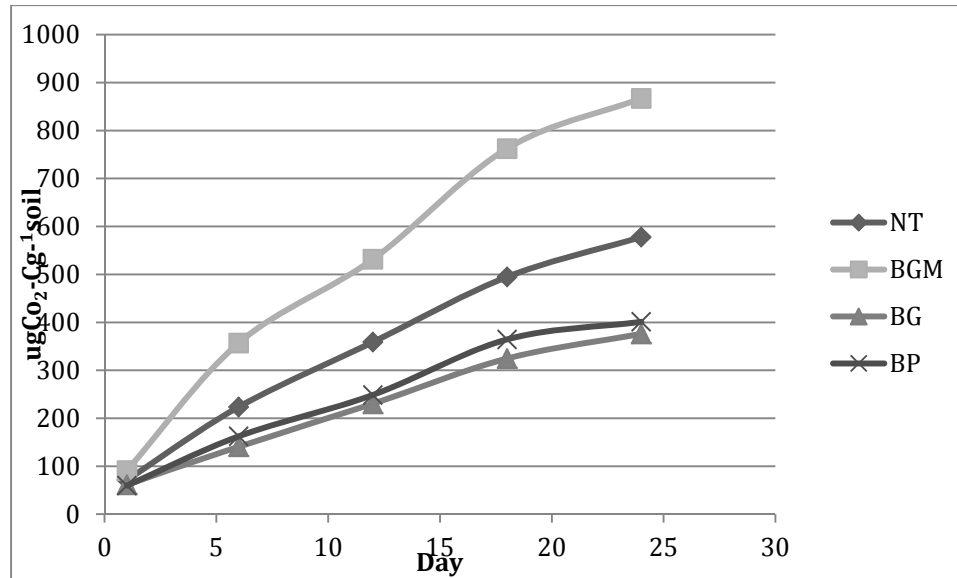
FALL 2006. The second soil sampling occurred in fall 2006; soil samples were analyzed for PMC beginning on 21 October.

0-5cm SOIL DEPTH. For the first reading, the BGM and NT treatments were significantly higher than the BP and BG treatments for the 0-5 cm soil sampling depth. There was no significant difference for the second reading on 27 October. For the third and fourth PMC readings on 2 November and 8 November respectively, there were no significant differences among any treatments or any soil depths. The fifth and final PMC reading for fall 2006 occurred on 14 November. The BGM treatment was significantly higher than the BG treatment for the 0-5 cm soil sampling depth (data not shown).

15-25cm SOIL DEPTH. For the first reading on 21 October, the BP treatment was significantly higher than the BG treatment. The second PMC reading occurred on 27 October, and the BP treatment was significantly higher than the BG treatment (data not shown). For the third, fourth, and fifth PMC readings on 2, 8, and 14 November, there were no significant differences among any treatments or any soil depths.

SPRING 2007. The third soil sampling was in spring 2007; the first PMC reading occurred on 15 May.

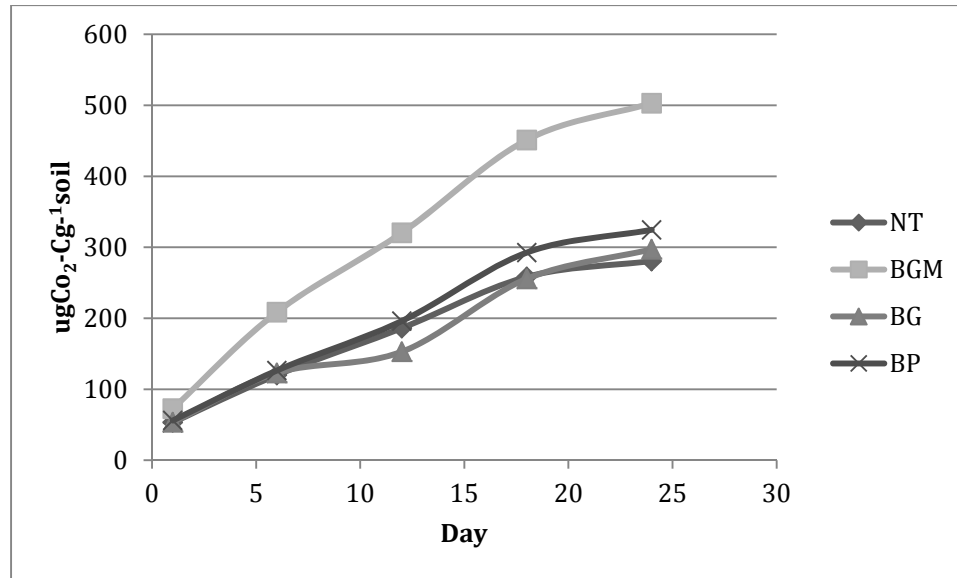
0-5cm SOIL DEPTH. The first PMC reading occurred on 15 May; the BGM treatment was significantly higher than all 3 other treatments for the 0-5 cm soil sampling depth, as it was in the second PMC reading on 21 May. The third PMC reading on 27 May determined that the BGM treatment was again significantly higher than all 3 other treatments for the 0-5 cm soil sampling depth. The fourth PMC reading occurred on 4 June; again, the BGM treatment was significantly higher than all 3 other treatments. The fifth and final PMC reading for spring 2007 occurred on 9 June; the BGM treatment was significantly higher than all 3 other treatments for the 0-5 cm soil sampling depths (Figure 3.6).



**Figure 3.6: Potentially Mineralizable Carbon, 0-5 cm soil sampling depth (Spring 2007)**

5-15cm SOIL DEPTH. The BGM treatment was significantly higher than all 3 other treatments for the 5-15 cm soil sampling depth for the first reading on 15 May; for the second reading on 21 May; the third reading on 27 May; the fourth reading on 4 June; and the fifth and final reading on 9 June (Figure 3.7).



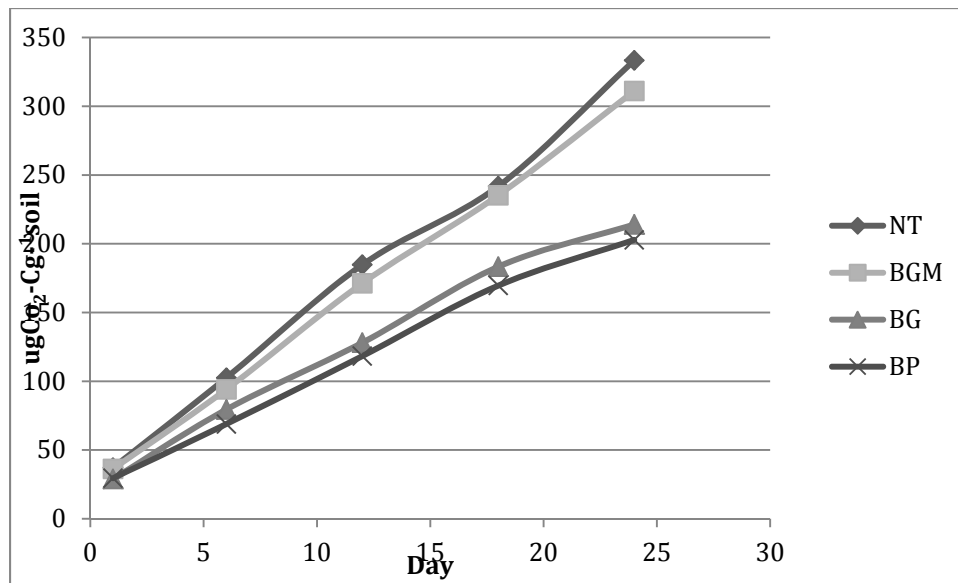


**Figure 3.7: Potentially Mineralizable Carbon 5-15 cm soil sampling depth (Spring 2007)**

FALL 2007. The fourth and final soil sampling for this experiment was in fall 2007 over a three-week period.

0-5cm SOIL DEPTH. In the first PMC reading on 25 October for the 0-5 cm soil sampling depth, the NT and BGM treatments were significantly higher than the BP and BG treatments. The second PMC reading occurred on 31 October; the NT treatment was significantly higher than the BG and BP treatments for the 0-5 cm soil sampling depth. The third PMC reading on 6 November determined that the NT and BGM treatments were significantly higher than the BG and BP treatments in the 0-5 cm soil sampling depth. For the fourth PMC reading on 12 November, the NT and BGM treatments were significantly higher than the BG and BP treatments in the 0-5 cm soil

sampling depth. The fifth and final PMC reading for fall 2007 and this experiment occurred on 18 November. The NT and BGM treatments were significantly higher than the BG and BP treatments in the 0-5 cm soil sampling depth (Figure 3.8).



**Figure 3.8: Potentially Mineralizable Carbon, 0-5 cm soil sampling depth (Fall 2007)**

15-25cm SOIL DEPTH. For the first reading on 25 October, the BP treatment was significantly higher than the NT treatment in the 15-25 cm soil sampling depth. The second PMC reading occurred on 31 October; for the 15-25 cm soil sampling depth, the BGM treatment was significantly higher than the BG treatment. The third PMC reading on 6 November determined that in the 15-25 cm soil sampling depth, the BGM treatment was significantly higher than the NT and BG treatments. The fifth and final PMC reading for fall 2007 and this

experiment occurred on 18 November. For the 15-25 cm soil sampling depth, the BGM treatment was significantly higher than the BG and NT treatments (data not shown).

Using Duncan's Multiple Range Test, the fall 2006 PMC readings determined that there were no significant differences among treatments and soil depths. The spring 2007 PMC readings determined that the BGM treatment was significantly higher than all 3 other treatments; the NT treatment was also significantly higher than the BP and BG treatments for the 0-5 cm soil sampling depth. In the 5-15 cm soil sampling depth, the BGM treatment was significantly higher than the 3 other treatments. The fall 2007 PMC readings determined the NT and BGM treatments to be significantly higher than the BG and BP treatments in the 0-5 cm soil sampling depth. For the 15-25 cm soil sampling depth, the BGM treatment was significantly higher than the NT and BG treatments.

ECONOMIC ANALYSIS. Yield and other data from 2007 showed an improvement in management practices over 2006 and were more consistent with optimized organic production system results. Therefore, only the 2007 data was used for a partial budget analysis (Table 3.3).

For both 2006 and 2007, weed control was the best in the BGM treatment, and yields were high and similar to those attained by

conventional growers using black polyethylene mulch. However, costs for the BGM treatment were dramatically higher than the BG and NT treatments due to hand application (labor) costs, at an increase of \$300 to \$600 per acre even though the mulch was obtained at no cost. The BP treatment was also more expensive, due to the decision to use biodegradable mulch rather than the typical black polyethylene mulch. Once disposal and labor costs associated with using polyethylene mulch were factored in, the BP treatment was not cost-efficient.

Table 3.3. Partial budget analysis for four organic production systems for 2007.

Associated Expenses/Returns	No-till (NT)	Bare ground with wood chip mulch (BGM)	Biodegradable black plastic (BP)	Bare ground with cultivation (BG)
Black biodegradable mulch/drip	--	--	520	--
Organic mulch/cover crop	--	--	30	--
Organic mulch application charge	--	300	--	--
Cultivation costs	--	768	--	768
Weed control, total costs	--	1068	550	768
Total production cost	1321	2421	1903	2121
Total harvesting and marketing cost	3716	4647	4824	4690
Total variable cost	5433	7578	7245	7320
Total expenses	5708	7853	7520	7595
Yield (no. of 5/9 bushel boxes harvested)	1045	1561	1659	1585
Gross returns (with premium)	8412	12566	13355	12759
Net Return with premium	<b>2704</b>	<b>4713</b>	<b>5835</b>	<b>5164</b>

## Discussion

The primary objective of this research was to evaluate the sustainability of four organic vegetable production systems based on their effects on soil physical, chemical, and microbiological characteristics, yield, weed control, labor, and cost. This holistic approach to systems development is ideal for organic and sustainable agriculture in which the health and productivity of the system is dependent upon each of the parts.

MARKETABLE YIELD. In the United States, the tomato industry has an average annual yield of 3.5 billion pounds, valued at \$1.1 billion for fresh market tomatoes (Davis et al., 1998). Tomato production in Kentucky is typically done on raised beds covered with polyethylene mulch, with yields of 40,000 to 44,000 lbs/A typical with conventional management practices (Isaac et al., 2004); however, studies conducted by Rasnake et al. (2005) used hairy vetch in no-till production systems for fresh market tomatoes with excellent results and similar yields.

In 2006, there was no significant difference in yield among all four treatments. This first year of research, as well as the second year, can be considered transition years, due to the experimental plot having been in sod for the previous three years. Implementing new management techniques typically requires several years for natural

processes to take effect (Michalak, 2003) and to see significant differences in indicators such as yield. An experiment conducted in organic no-till tomato production in North Carolina initially had low yields, but after a three-year establishment period, there was a steady increase in yield in the ensuing four years (Hoyt, 2004). Although wide acceptance of alternate tillage practices in tomato production systems has not yet occurred, certain conservation tillage systems have maintained good growth, yields, and post harvest quality (Thomas et al., 2001).

Irrigation was problematic during the first year of the study. Plots may have been over-irrigated at times during the summer due to the misreading of tensiometers. The tensiometers are used to determine the negative pressure (tension) of water in the soil; the decision to irrigate is largely based on these readings. Irrigation is turned on when the tensiometers are between 30–40 kPa and turned off when a reading of 5-10 kPa is reached. There were some irrigations during the growing season of 2006 when the tensiometer readings went below the 5-10 kPa reading, which may have resulted in too much water being added to the system, particularly as fruit were approaching maturity. This error could have led to a higher number than average of tomato culls, mostly due to cracking, and influenced the low tomato yields. According to Peet and Willits (1995), the

percentage of cracked tomatoes was 20% higher in treatments receiving more water; therefore, it is likely the cracking in this experiment was primarily due to the overabundance of water. Yields on a lb/A basis were also below average, again presumably due to over-irrigation. Tomato yields for 2006 would have been similar to those yields typically obtained by conventional growers if the culled fruits had been Grade 1 or Grade 2 instead.

Diseases and insects were prevalent in late summer 2006, again presumably due to over-irrigation. Powdery mildew was problematic and required weekly sprays of Kumulus DF Sulfur. Early blight and bacterial speck were also present in all four treatments; Champion WP<sup>®</sup> Copper was applied as needed. Insect pressure was high and required spraying with Surround WP<sup>®</sup>, M-Pede<sup>®</sup> insecticidal soap, and PyGanic<sup>®</sup>. There was no difference among any of the treatments in terms of insect and disease pressure; all insect and disease issues were managed with spraying.

The 2007 marketable yield were more typical of conventional averages in Kentucky and were in fact higher. Yellow summer squash is a highly prolific crop that can have multiple harvests over many months. The frequency of harvest is largely determined by the grower and the amount of labor available to harvest this fast-growing crop. For this experiment, fruits were harvested every 3 to 4 days at the

proper size for the target market. Plants were harvested on 13 dates over 2 ½ months in 2007, and there were significant differences in yield among the four treatments. The BGM, BG, and BP treatments had significantly higher yields than the NT treatment; the low-yielding NT treatment could be explained by the high percentage of weeds in the NT plots, where weed control for the NT treatments was <10% (Table 3). NT plant dry weight was also significantly lower than the BGM, BG, and BP treatments; height measurements confirmed observations that the NT plants were smaller (Table 3), which could also potentially be explained by increased weed pressures.

Insects and diseases were present to a limited extent in the 2007 experiment and included squash bugs and cucumber beetles, powdery mildew, bacterial wilt, and cucurbit yellow vine decline. Attempts at controlling insects included as-needed applications of Surround WP<sup>®</sup> and Entrust; powdery mildew became more prevalent as the season progressed and was controlled by applications of Kumulus DF Sulfur. Again there were no apparent differences among treatments regarding incidence of disease or insect damage.

**WEED RATINGS.** The weed ratings taken over the two-year experiment had significant differences among treatments in both years. The NT treatment had the worst weed control, with multiple weed infestations occurring among the replications (Table 3). Organic



no-till plots are typically established for and over a long-term period; weed pressures are typically high during the transition, and time is required to eradicate the weed seedbed. According to Morse (2006), when attempting to transition into NT management, a major challenge is to calculate the weed suppression potential of any situation. Morse and Creamer (2005) use six criteria for assessing the probability of weed suppression in organic NT: 1) mulch quantity, including dry wt. (ton/A), percent soil coverage, and depth (inch); 2) mulch quality (C:N ratio); 3) perennial weeds (% total weeds); 4) minimum weed-free period (MWFP), which is defined as the length of time a crop remains free of weeds after planting; 5) monthly in-season rainfall (inches); and 6) fertigation method.

For the 2006 experiment, the cover crop quantity, including the dry weight, percent soil coverage, and mulch depth was low; this was likely due to problems with germination the preceding fall of 2005, caused by inconsistent rain after seeding. Perennial weeds, particularly Johnsongrass (*Sorghum halepense*) and yellow nutsedge (*Cyperus esculentus*) were also problematic and comprised a high percentage of the total weeds present. The MWFP was also low according to the standards set by Morse and Creamer (2005). Weeds were not kept below the yield-limiting levels in 2006 or 2007. Weed control in 2007 was similar to that of 2006 for the NT treatment, which had the lowest

percent control, and for the BGM treatment, which had the highest percent weed control. The BGM treatment, which incorporated hardwood mulch after several cultivations, had excellent weed control of >98% for both years. This method also had good results for Law et al. (2006), which combined transplanting and shallow cultivation followed by mid-season mulch application in an organic pepper production system.

PLANT DRY WEIGHT. Plant dry weight was not significantly different among treatments in 2006; however, in 2007, the NT treatment was significantly lower in weight than the other treatments (Table 3). This is consistent with visual observations that the plants appeared smaller and grew more slowly. The low NT plant dry weight also correlates with the determination that plants grown in the NT treatments were the lowest yielding of the four production systems (Table 3). The low plant dry weight and low yield could possibly be attributed to cooler soil temperatures (Dam et al., 2005) or more weed pressures within the NT treatment.

PLANT FOLIAR ANALYSIS. Plant foliar analysis was conducted on tomato plants grown in the 2006 experiment to evaluate plant health and nutrient levels; this did not occur in 2007. Waters Agricultural Laboratories (Owensboro, Ky.) performed the tissue analysis for

macro- and micronutrients. Foliar %N content, %Mg, and ppm Cu were significantly different among treatments (Table 3).

The BG treatment was significantly higher in %N; this was unexpected due to studies that have shown plant-available nutrients including nitrogen to be higher for crops grown in surface or cover crop residues, such as in no-till or mulched systems (Schonbeck and Morse, 2004; Schonbeck and Morse, 2007). Previous N fertilization, cropping patterns, and tillage can all affect the rates of N mineralization (Rasmussen et al., 1998).

The BGM treatment was significantly higher than the BG and BP treatments in % Mg. This is consistent with results from a study conducted by Miyasaka et al. (2001), which evaluated the impact of organic inputs such as mulch on taro (*Colocasia esculenta*) production and found increased leaf concentrations of magnesium in the mulch treatments.

The BGM treatment was significantly higher in ppm Cu than the BG and BP treatments; this was unexpected, and Cu was not analyzed in soil tests performed by the University of Kentucky Regulatory Services Laboratory. Without further evidence of high Cu levels in any other analyses, any explanation as to the reason would be speculative.

PLANT HEIGHT. Summer squash plants grown in the 2007 experiment were measured due to observed height inconsistencies

among the four treatments; this did not occur in 2006. Plants growing in the NT treatment were significantly shorter in height among the treatments, with an average of 4.5 cm shorter than the BGM, BG, and BP treatments (Table 3). The substantial height difference could be explained by delayed early season growth caused by lower soil temperatures and higher moisture content as has been seen in some conservation systems such as no-till (Dam et al., 2005). According to Morse (1999), crop maturity in a no-till system is often delayed compared to conventionally transplanted crops.

## **SOIL PHYSICAL ANALYSES**

**BULK DENSITY.** Bulk density changes occur over time and are typically a good indication of soil compaction and quality. Although there was a significant difference in bulk density in 2006 in the BGM treatment, this was unexpected and contradicts other research indicating that wood chip mulch lowers bulk density instead of raising it. This result may signify that the changes in the BGM treatment may have been due to something other than treatment effect. According to Himelick and Watson (1990), mulched soils typically have low bulk density due to high levels of organic matter from the incorporation of the decomposing mulch. Compacted soils with less pore space have higher bulk densities than those soils with a high proportion of pore space to solids (Brady and Weil, 2002). Soil structure, which plays a

major role in determining bulk density, can be strongly influenced by the type of tillage system, as soil physical properties are sensitive to tillage regimes (Overstreet et al., 2004). However, according to Diaz-Zorita et al. (2004), a two-year period without tillage is not long enough to permit the recovery of soil structure. Prior to this experiment, the soil at the site had been under sod for at least three years. The tillage history on the section of the University of Kentucky Horticulture Research Farm used for this experiment was limited; the land had been used for nursery crop evaluations for at least a decade, with limited soil disturbance. These results could also be due to land-use transition, with the removal and subsequent decomposition of tree roots increasing bulk density as well.

GRAVIMETRIC WATER. Soil surfaces covered with mulch or other organic matter typically retain and conserve soil moisture, as well as help to control soil erosion. In this experiment, the BGM treatment had the highest gravimetric water content among the 4 treatments for the fall 2006, spring 2007, and fall 2007 soil sampling dates; the NT treatment had the second highest gravimetric water content for fall 2006 and fall 2007 soil sampling dates (Table 3.1). This is consistent with results obtained by Diaz-Zorita et al. (2004) and Peigne et al. (2007), who found that advantages of conservation and no-till systems include increased water infiltration, reduced evaporation and run-off,

and increased SOM. Both of the mulch treatments, NT and BGM, had higher water retention rates at the end of the season than the BP and BG treatments, which are standard industry practices.

PENETROMETER. Readings were taken in spring 2006 and spring 2007 to measure soil compaction. There were no significant differences among treatments for either year. This is consistent with other studies that found compaction typically increases both the bulk density and soil strength of a soil (Brady and Weil, 2002). Research has determined the critical soil strength values that can limit plant growth and prohibit root penetration for a variety of crops (Gorucu et al., 2006). Root growth for oat is linearly restricted by soil penetration resistance values ranging from 290 to 435 PSI (Ehlers et al., 1983). Penetrometer values for both years of this experiment ranged from a mean of 171.82 PSI in 2006 to a mean of 158.54 PSI in 2007, indicating unrestricted root growth for all the plants grown in both years of this experiment.

## **SOIL CHEMICAL ANALYSES**

TOTAL NITROGEN. There were no significant differences in percent total nitrogen among all four treatments for 2006. In 2007, there was a significant difference among treatments with time. The ppm total N averaged over all four treatments for spring 2007 was significantly higher than the four treatment averages in spring 2006,

fall 2006, and fall 2007. The high N values in spring 2007 could be due to the hairy vetch and rye cover crop sown the previous fall, as well as above normal precipitation for September, October, and November 2006, which could have led to more  $\text{NO}_3^-$  leaching from the soil profile. According to Sainju et al. (2005), a biculture of hairy vetch and rye may increase N supply, due to higher biomass yield and C and N contents. Although a cover crop of hairy vetch and rye was also sown in fall 2005 preceding the 2006 experiment, germination of the crop was poor due to above average temperatures and below normal precipitation, and the visual observations determined the cover crop stand was thin as compared to the 2007 cover crop. Biomass yield obtained from the cover crop could have been lower in 2006 than in 2007, thus explaining the higher total N ppm.

NITRITE, NITRATE, AMMONIUM. ( $\text{NO}_2^-$ ,  $\text{NO}_3^-$ ,  $\text{NH}_4^+$ ). Nitrite, which can be determined by colorimetric methods, is often difficult to detect due to its rapid transformation to nitrate within the soil. Nitrification progresses most quickly when there is an abundance of exchangeable metallic cations, including  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  (Brady and Weil, 2002). Soil tests performed by the University of Kentucky Regulatory Services laboratory determined that the soils in the experiment were high in both of the above cations (data not shown); thus, nitrification was presumed to have occurred too rapidly for nitrite

to record readings using colorimetric methods. Plant foliar analysis conducted during the first year of the study indicated that Mg levels were significantly higher in plants grown in the BGM treatment and lowest in plants grown in the BP treatment (Table 3.1). The presumed abundance of excess Mg could also have enhanced the nitrification process within the soil and treatment, thus giving no readings for nitrite in both 2006 and 2007.

Nitrate determinations had no significant differences among treatments in either 2006 or 2007, but there were significant differences over time over all treatments. The fall 2006 sampling period was significantly higher in nitrate than the spring 2006, spring 2007, and fall 2007 sampling dates (Table 3.2). This could be due to the above normal precipitation that occurred in fall 2006, leading to more leaching of  $\text{NO}_3^-$  from the soil profile.

Ammonium measurements were significantly different over time over all treatments, with the spring 2006 and spring 2007 sampling dates significantly higher than the fall 2006 and fall 2007 sampling dates (Table 3.2). This is most likely due to the abundant cover crop biomass present in the spring. According to Schonbeck and Morse (2004), the combination of a grass such as rye and a legume such as hairy vetch enhance biomass production. Cover crops were planted in both fall 2005 and fall 2006 prior to soil sampling and after the final



harvests were completed. The cover crops were allowed to grow throughout the winter months and soil sampling was performed before the cover crop was cut. Hairy vetch is a nitrogen-fixing annual legume, while the cereal rye takes up excess N and slowly releases it as the rye decomposes. The rye decomposition may also stimulate what is known as a priming effect, leading to more SOM breakdown and the release of more N. This organic matter decomposition undergoes mineralization and registers as ammonia.

## **SOIL MICROBIOLOGICAL ANALYSES**

### **TOTAL ORGANIC CARBON/MICROBIAL BIOMASS CARBON.**

According to Kennedy and Papendick (1995), soil microbial biomass is a highly responsive indicator of sustainable cropping systems. As soil management changes, soil microbial biomass responds faster than the amount of total organic C; the differences in C-to-C ratios between management systems are assumed to be due to the differences in crop management (Anderson and Domsch, 1989).

Results from the two-year experiment indicated a significant difference over time in microbial biomass carbon among the treatments. In spring 2007, the BGM treatment at the 0-5 cm soil depth was significantly higher in biomass carbon than the BG and BP treatments, while the NT treatment was significantly higher than the BG and BP treatments (Table 3.1). This is likely due to the wood chip

mulch applied to the BGM treatment midway through the growing season, as well as the in situ cover crop mulch in the NT treatment. According to a study conducted by Overstreet et al. (2004), microbial biomass is enhanced in conservation tillage treatments, while Schonbeck (2006) stated that the use of organic mulches has been shown to increase microbial activity. Overall, the fall 2007 sampling date was significantly higher than the other 3 sampling dates of spring 2007, fall 2006, and spring 2006. The fall 2007 sampling date was the last soil sampling date of the two-year experiment; the significant difference in biomass carbon among sampling dates could be due to the length of time the treatments had been in effect.

Conventional tillage exposes SOM and increases its decay rate, due to increased aeration and temperature (Cambardella and Elliot, 1993). The incorporation of carbon inputs increases microbial activity and releases previously protected SOM with tillage (Balesdent et al., 2000). Soil test results from University of Kentucky's Regulatory Services showed that there was a significant difference in soil organic matter percent with different soil depths and with regard to time. For the 0-5 cm sampling depth, the BGM treatment was significantly higher than the BP and BG treatments; the NT treatment was significantly higher than the BP and BG treatments, and significantly different from the BGM treatment (Table 3.1). The BGM treatment had

the highest percentage of SOM; this is likely due to the application and eventual breakdown and incorporation of the wood chip mulch into the upper soil horizon. The NT treatment had a SOM content of 3.19%, presumably due to the thick layer of cover crop residue on the top of the soil, and perhaps also the structural integrity of the soil layers. For the 0-5 cm and 5-15 cm sampling depths, spring 2006 had the highest overall SOM (Table 3.2). This date is the first sampling date, with soil tested from fallow fields, and before the treatments had been applied; this sampling period is considered baseline data.

According to Balesdent et al. (2000), the tillage system used can affect the mineralization of the SOM, as can cultivation, which increases C mineralization and lowers concentrations of TOC. Raiesi (2006) concluded that TOC contents in the soil were significantly affected by cultivation, with cultivation decreasing TOC by 33% as compared to uncultivated treatments at a soil depth of 0 to 15 cm. Although the NT treatment in this experiment did not have the highest concentrations of carbon for any of the sampling dates, it was significantly different from the BG treatment in the 5-15 cm depth for fall 2007 (Table 3.1). The BGM treatment was consistently higher than the other treatments in soil organic carbon in spring 2007, and significantly higher than the NT and BP treatments in fall 2007. Although this treatment was cultivated at a shallow depth three times

over the course of the growing season, the addition of the wood chip mulch midway through the growing season apparently increased the soil organic carbon at a greater rate than did the cover crop in the NT treatment. This is also evident from the averages of the four sampling dates and the three soil depths; the BGM treatment was significantly higher in % carbon than all other treatments (Table 3.1). According to Overstreet et al. (2004), microbial biomass is greatest in conservation tillage systems with organic inputs, such as the BGM treatment.

For the microbial quotient, the ratio between microbial biomass carbon and total organic carbon, there was a significant overall difference over time. The fall 2007 sampling date was significantly higher than the spring 2007, fall 2006, and spring 2006 soil sampling dates (Table 3.2). This could be due to the treatment effect over the two-year period. The spring 2007 sampling date was significantly higher than the fall 2006 and spring 2006 sampling dates, which could also be due to treatment effect over time and the abundance of cover crop residue present at that date.

**BASAL RESPIRATION.** Basal respiration indicates the amount of mineralizable organic carbon at the native water content of the soil. According to Fang et al. (2005), soil basal respiration is closely linked to carbon pool variations that occur at different soil depths. This agrees with our findings that basal respiration varied with depth and

treatment for both years of the experiment. Franzluebbers et al. (1995) found that the wide range of soil microbial biomass and potential activity represented soil microbial property variations due to soil depth, as well as differences in crop management practices such as tillage.

FALL 2006. The fall 2006 soil sampling occurred after completion of the first year's crop, tomato, and after the treatments had been in place for approximately 6 months. Results varied across treatments; there were few significant differences in the 0-5 cm soil sampling depth, with the exception of the first BR reading on 21 October; the BG treatment was significantly lower in  $\text{mg} \cdot \text{C kg}^{-1}$  soil than the NT, BGM, and BP treatments. This could be explained by the absence of soil cover; the other 3 treatments had either cover crop mulch, wood chip mulch, or biodegradable mulch on the soil surface. According to Prior et al. (2000), tillage and other soil disturbances can result in a rapid release of  $\text{CO}_2$  from the soil. In the 5-15 cm soil sampling depth, the BGM treatment was consistently significantly higher than the BP treatment on 3 of the 5 BR reading dates. For the 15-25 cm soil sampling depth, the BP treatment was significantly higher than all 3 other treatments on 3 of the 5 BR reading dates, and significantly higher than the BG treatment on another BR reading date. The BP treatment did not reflect high microbial activity in the 0-5 cm or 5-15

cm soil sampling depths; however, in the 15-25 cm soil sampling depth, BP was consistently higher than the other treatments. This could be due to variation in carbon pools that occur at different soil depths, as studies conducted by Fang et al. (2005) have shown, and whose research indicated that soil basal respiration is correlated to variation in microbial biomass, which is thought to be a major cause of temporal changes. This effect could also be due to increased soil temperatures and more soil moisture content in the lower soil depth under the black plastic.

SPRING 2007. In spring 2007, the BGM and NT treatments were significantly higher than the BP and BG treatments in the 0-5 cm soil sampling depth for the first BR reading. This is consistent with research conducted by Schonbeck (2006), who stated that organic mulches increase microbial activity, indicated by the higher rates of BR in this treatment. The BGM treatment had significantly higher BR rates than the other 3 treatments in the 5-15 cm soil sampling depth; this could also be due to the presence of the organic mulch. In the second and third BR readings, which occurred on 21 May and 27 May respectively, the BGM treatment was significantly higher than the BP treatment for the 0-5 cm and 5-15 cm soil sampling depths. The BGM treatment was consistently higher than at least the BP and BG treatments in the 5-15 cm soil sampling depths for all five BR sampling

dates. Little variation occurred with results from this soil sampling period; the BGM treatment consistently had higher BR rates than the other three treatments. Conservation tillage treatments with organic inputs such as mulch typically display large increases in CO<sub>2</sub> evolution over a growing season, which indicates a soil environment suitable for large microbial populations (Duiker and Beegle, 2005).

FALL 2007. The final BR readings for the experiment occurred in fall 2007, with results indicating the trend of the BGM treatment having consistently higher BR rates than the other three treatments. This can again be correlated with the assertion that organic mulches can influence microbial activity (Schonbeck, 2006), as can differences in crop and residue management, tillage, and soil depth. Wardle et al. (1999) concluded that a mulched treatment had positive effects on CO<sub>2</sub>-C release from chloroform-fumigated soil, with the CO<sub>2</sub>-C rates highest in soil depths of 0-5 cm and 5-10 cm for the mulched plots.

POTENTIALLY MINERALIZABLE CARBON. The measurement of potentially mineralizable carbon (PMC) represents the mineralizable organic C in the absence of a water limitation, and is used to estimate the metabolic activity of heterotrophic microbes that release labile carbon as CO<sub>2</sub> (Kadono et al., 2008).

FALL 2006. The fall 2006 soil sampling occurred after completion of the first year's crop, tomato, and after the treatments

had been in place for approximately 6 months. Results were varied among treatments. There were few significant differences in the 0-5 cm soil sampling depth with the exception of the first and fifth PMC readings, which occurred on 21 October and 14 November, respectively. On both dates, the BG treatment was significantly lower in  $\text{mg} \cdot \text{C kg}^{-1}$  soil than the BGM treatment. This could be explained by the absence of soil cover, as the BGM treatments had wood chip mulch on the soil surface. According to Prior et al. (2000), tillage and other soil disturbances can result in a rapid release of  $\text{CO}_2$  from the soil. For the 15-25 cm soil sampling depth, significant differences occurred on the first and second PMC readings on 21 October and 27 October. The BP treatment was significantly higher than the BG treatment, which could again be due to the soil cover or elevated temperatures below the black plastic.

SPRING 2007. PMC readings began on 15 May and concluded on 9 June. For all five PMC readings, the BGM treatment was significantly higher than the other three treatments for the 0-5 cm and 5-15 cm soil sampling depths. The BGM treatment was also significantly higher than the NT treatment for the 15-25 cm sampling depth on the first PMC reading date, 15 May. The consistently higher readings of the BGM treatment are likely due to the wood chip mulch that provided soil cover. According to Prior et al. (2000), increased  $\text{CO}_2$  loss is



directly related to increased soil disturbances, while planting methods that minimize soil disturbance can enhance the retention of soil C.

FALL 2007. The first PMC reading occurred on 25 October for the fourth and final round of soil sampling for this experiment. Results were varied; the BGM treatment was again significantly higher than the BP and BG treatments for the 0-5 cm soil sampling depth. The NT treatment was also significantly higher than the BP and BG treatments for the 0-5 cm soil sampling depth for the first reading on 25 October and the second reading on 31 October. For the remaining three readings on 6 November, 12 November, and 18 November, the BGM and NT treatments were significantly higher than the BP and BG treatments in the 0-5 cm sampling depth. Both the BGM and NT treatments had the highest amount of residue on the soil surface; with wood chip mulch for the BGM treatment and rye/hairy vetch cover crop for the NT treatment. According to Franzluebbers et al., (1995), differences in tillage can cause variations in soil microbial properties and affect potential activity.

ECONOMIC ANALYSIS. Law et al. (2006) determined that shallow cultivation followed by mid-season mulch application produced good yields in organic bell pepper production; however, due to hand application (labor) costs, the use of woodchip mulch increased costs substantially. This is consistent with the results of this experiment. For

both 2006 and 2007, weed control was the best in the BGM treatment, and yields were high and similar to those attained by conventional growers using black polyethylene mulch. However, costs for the BGM treatment were higher than the BG and NT treatments, with an increase of \$300 to \$600 per acre. The BP treatment was also more expensive, due to the decision to use biodegradable mulch rather than the typical black polyethylene mulch. Once disposal and labor costs associated with using polyethylene mulch were factored in, the BP treatment was not cost-efficient. The NT treatment had the least amount of inputs and labor; however, yields were consistently low throughout both years of the experiment. The BG treatment also had low labor and input costs; yields were also lower than those attained in both the BGM and BP treatments.

The goal of this experiment was to evaluate the sustainability of four different organic vegetable production systems, as well as to provide high quality research-based information for growers interested in organic production. The specific objectives of the proposed research were to: 1) create an organically managed horticultural production system suitable for Kentucky farmers transitioning from tobacco or conventional vegetable production; 2) analyze and document crop yield and quality, and economic feasibility and sustainability of four organic production systems: no-tillage, raised beds covered with black

plastic, shallow cultivation on bare ground, and shallow cultivation on bare ground with mulch; and 3) evaluate the effects of the four production systems on selected soil biological, chemical, and physical properties during a two year rotation. Weed, disease and insect dynamics were also monitored as additional indicators of sustainability. Although there was no definitive optimal production system among the four treatments in terms of sustainability, this research did discern multiple benefits and limitations of each system.

NO-TILL. Already used by many conventional farmers for controlling erosion and building healthy, microbiologically diverse soils, the NT treatment ranked high in % soil organic matter and microbial biomass carbon, although yields were the poorest of the four treatments for both years. Weeds were also problematic, with control only at 30% or less. Plant dry weight and plant height were also the lowest of the four treatments. According to Hoyt (2004), no-till tomato production in North Carolina had poor yields for the first three years of the experiment; however, yields increased steadily the following four years. Transitioning to no-till typically requires a period of 3 to 4 years, after which yields begin to match and exceed average yields.

BIODEGRADABLE BLACK MULCH. The cornstarch-based Mater-bi mulch was guaranteed to be 100% biodegradable, and therefore eliminated the labor costs associated with the removal and disposal of

polyethylene mulch. Although more sustainable than polyethylene, the biodegradable mulch ripped easily during application, and the cost prohibited its' use on a large scale. Yields were earlier, as with polyethylene mulch, due to the warmer soil temperatures; however, yields were still not as high as those recorded from the BGM treatment. Weed control was good in 2007, at >85% control, although 2006 weed control was poor. The BP treatment also had a low amount of SOM and total Carbon was also consistently ranked in the bottom two.

**BARE GROUND WITH CULTIVATION.** A potential consideration when using this system is the impact on microbiological activity. According to Nordell and Nordell (1998), inverting only the top 2 inches of the soil reduces any negative effects that occur with deeper inversion plowing; however, in this experiment, the BG treatment was ranked in the bottom two in microbial biomass carbon, percentage of soil organic matter, and percentage of total carbon. The level of weed control was high for both 2006 and 2007, at >90% control.

**BARE GROUND WITH CULTIVATION AND WOOD CHIP MULCH.** For both 2006 and 2007, the BGM treatment had >90% weed control as well as the highest percentages of microbial biomass carbon, soil organic matter and percent total carbon. However, the effectiveness of this treatment was tempered by the somewhat prohibitive cost.

Although combining early season cultivation with woodchip mulch application in mid-season has the potential to provide organic growers with an alternative to decrease yield loss due to weed competition (Law et al., 2006), the cost of obtaining and applying woodchip mulch could exclude large-scale growers from using this system.

This research project was designed to work at the systems level and simulate a commercial organic operation, ultimately providing information for farmers transitioning from a conventional tobacco operation into organic vegetables as well as those already raising vegetables but wanting to move from conventional to organic methods. We experienced many of the same problems that a producer faces, from weed pressures to yield problems. Commercial vegetable production continues to increase in Kentucky due to the decline of tobacco acreage. If effective, cost-efficient, sustainable rotational cropping systems can be developed for Kentucky farms, organic acreage is almost certain to increase in the state. Although all four vegetable production systems tested in this experiment may be viable, they will each have trade-offs. This research showed that a limited two-year period is not long enough to determine any significant differences for one system to be considered the standard organic vegetable production system.

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**Delia W. Scott  
Vita**

The author was born in Richmond, Kentucky and grew up in Hodgenville, Kentucky. She received a Bachelor of Science degree in Plant and Soil Science with an emphasis in Horticulture Enterprise Management in 2002.