Economic Viability and Environmental Impact Assessment of Three Different Strawberry Production Systems in the Southeastern United States

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Summary. **In this study, we investigate the economic viability and environmental impact of three different soil management systems used for strawberry (*Fragaria ×ananassa)* production in the southeastern United States: 1) a conventional production system that is based on the current production practices implemented by growers, 2) a nonfumigated compost system with summer cover crop rotations and beneficial soil inoculants, and 3) an organic production system that includes practices approved for use under the National Organic Program (NOP). Under our assumptions, all three systems resulted in positive net returns estimated at $14,979, $11,100, and $19,394 per acre, respectively. The nonfumigated compost system and organic system also both resulted in considerable reductions in negative environmental and human health impacts measured by a set of selected indicators. For example, the total number of lethal doses (LD_{50}) applied per acre from all chemicals used in each system and measuring acute human risk associated with each system declined from 118,000 doses/acre in the conventional system to 6649 doses/acre in the compost system and to 0 doses/acre in the organic system. Chronic human health risk, groundwater pollution risk, and fertilizer use declined as well in the compost and organic systems as compared with the conventional system.**

Maintaining soil quality continues to be a key challenge to the sustainability of strawberry plasticulture production systems. This challenge to soil quality is particularly strong in the southeastern United States where warm temperatures can lead to increased pest pressures, including high levels of soilborne pathogens, weeds, and nematodes. These soil-born pest pressures combined with strawberry growers' limited ability to rotate their crops on small acreage have led to a historic dependency on methyl bromide, which is now being replaced with other synthetic fumigants or nonfumigant based systems (Louws, 2009; Sydorovych et al., 2006). Due to warm climatic conditions, organic matter and soil fertility can be depleted rapidly, particularly in these plasticulture systems where little organic residues are returned to the soil. This combination of factors can rapidly lead to losses in soil quality that threaten the long-term productivity and sustainability of strawberry production systems, which is especially important considering that some of the largest strawberry producing states (Florida and North Carolina) are located in this region [U.S. Department of Agriculture (USDA), 2015].

In this study, we address economic viability and environmental impact of different soil and pest management practices in strawberry production in the southeastern United States. First, three different strawberry production systems that are feasible for the region have been identified. The conventional production system is defined as the current production practices implemented and recommended to growers in the region and is based on annual soil fumigation. The nonfumigated compost system is an intermediate between the conventional and organic systems with the same pesticide use as in the conventional system, but with the addition of compost application, summer cover crop rotations, and beneficial soil inoculants. Finally, the organic production system includes only production practices approved for use under the NOP, as outlined by USDA for growers using the certified organic label (National Organic Program, 2015). It includes organic pesticides, compost application, summer cover crop rotations, and beneficial soil inoculants. Second, we developed strawberry enterprise production budgets to compare production costs and revenues for each system to assess their economic viability. Finally, we used a set of environmental indicators to compare the environmental and human health impacts of each system. The goal of this study was to provide growers with the economic and environmental information that would help them transition to more sustainable soil and pest management production practices.

A number of studies have attempted to compare various aspects of different strawberry productions systems. Reganold et al. (2010) investigated significant differences in fruit and soil quality for conventional and organic strawberry production in California and found that organic fruit had longer shelf life, greater dry matter, higher antioxidant activity and concentrations of ascorbic acid and phenolic compounds, and lower concentrations of phosphorus and potassium. Organically farmed soils had more carbon and nitrogen, greater microbial biomass

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
2.54	inch(es)	cm	0.3937
0.4536	lb	kg	2.2046
1.1209	lb/acre	kg·ha^{-1}	0.8922
1	ppm	mg·kg^{-1}	1
0.9464	qt	L	1.0567

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and activity, and higher concentration of micronutrients. Stevens et al. (2009) compared environmental effects of three cold-climate strawberry production systems: traditional matted row, advanced matted row (nonfumigated raised beds with subsurface drip irrigation and organic mulch), and cold-climate plasticulture. Annual mean runoff volumes were similar for all three production systems but the soil and nitrogen losses and pesticide residues were much greater in the traditional matted row system. The other two systems performed similarly but the plasticulture system also used nonrenewable plastic mulch, which needed to be disposed to a landfill. Khoshnevisan et al. (2013) compiled information on potential environmental impact for open-field and greenhouse strawberry cultivation in Iran using a cradle-to-farm-gate life cycle analysis. They looked at abiotic depletion, acidification, eutrophication, global warming impact, ozone depletion, human, terrestrial and aquatic toxicity, and photochemical oxidation. They found that the greenhouse system produced the largest environmental burden. Murthy (2014) also applied life cycle assessment to compare strawberry production practices in three largest strawberry producing states (California, Florida, and North Carolina) based on each states' strawberry enterprise budgets. Strawberry production practices varied considerably for different geographical regions in the United States. Strawberry production in California had the lowest environmental impact while production in Florida had the highest environmental impact due to high consumption of agricultural chemicals.

With exception of Sydorovych et al. (2006), who applied partial budget analysis to evaluate various soil treatment alternatives to methyl bromide in production of strawberries in the southeastern United States and Goodhue et al. (2006), who look for economically feasible alternatives to methyl bromide in commercial California strawberry production, we are not aware of any study comparing the impact of strawberry production systems on economic performance and returns in addition to environmental impact. The primary objective of growers is to make their farms financially successful and sustainable. Therefore, they require economic information to make decisions related to adoption of more sustainable production practices (Safley et al., 2004).

Materials and methods

The annual plasticulture strawberry production in the southeastern United States follows a fall to spring schedule, with planting occurring in September or October and harvesting occurring from April to early June. All strawberry production systems presented in this study employ raised beds covered with black plastic mulch with a drip tape buried 2 inches below the ground in the center of each bed. About 120 lb/acre nitrogen, 60 lb/acre phosphate (26.2 lb/acre phosphorus), and 120 lb/acre potash (99.6 lb/acre potassium) were applied in accordance with current recommendations (Poling et al., 2005). Sources (chemical vs. organic) for these nutrients varied among systems. Plants were transplanted in two staggered rows and spaced 12–14 inches between plants. The systems were defined and differentiated as described below.

CONVENTIONAL. The conventional production system was defined as the current production practices that are implemented and recommended to growers in the region, also known as the grower standard (Poling et al., 2005). This includes annual fumigation at the time of bed shaping, and standard chemical fertilizers applied before bedding and through the drip in the spring. Insect and pest populations are monitored and controlled with recommended chemical products and cultural management practices. Specifically, regular sprays for common recurring annual pests, including twospotted spider mite (*Tetranychus urticae*), anthracnose disease (*Colletotrichum* sp.), and gray mold (*Botryis cinarea*) were accounted for.

COMPOST. The compost system was an intermediate between the conventional and organic. This system did not include fumigation and instead relied on a system of crop rotations and soil amendments to manage for soilborne pathogens. Specifically, the incorporation of compost and summer cover crops was added. Research has identified cowpea (*Vigna unguiculata* cv. Iron Clay) and pearl millet (*Pennisetum glaucumgenus*) at an enhanced seeding rate of 100 and 10 lb/acre, respectively, as a good combination for strawberry production (Beck, 2011). Based on previous research, a reduction in yield resulted in the absence of fumigation and thus for this system yields were set at 85% of the conventional yields (A. McWhirt, unpublished data). However, this estimate will vary based on local soilborne pest pressure and conditions. Furthermore, the lack of fumigation may result in greater weed pressure and an increase in hand labor requirements to remove the weeds, as chemical controls are generally not available for strawberry production. In addition, the application of nitrogen via the use of compost and cover crops was accounted for by eliminating fall preplant fertilizers. However, the ability of composts and cover crops to supply sufficient preplant nitrogen (preplant nitrogen recommendation is 60 lb/acre nitrogen) can vary based on the type and rates of inputs used. Chemical fertilizers applied via the drip in the spring remained the same as what was applied in the conventional system. In addition, all pest controls remained the same as in the conventional system to estimate cost for a grower who ceases with fumigation in favor of crop rotation and soil building strategies, but who does not fully convert to organic. In this system we also included the use of beneficial plug inoculants [arbuscular mycorrhizal fungi (various species) and vermicompost] added to the plug media. Previous research has demonstrated the benefits of using this technique in nonfumigated systems on increasing yields (Beck, 2011).

ORGANIC. The organic production system includes only production practices approved for use under the NOP as outlined by USDA for growers using the certified organic label (NOP, 2015). Part of the organic rules are that cover crops and practices that increase soil organic matter are included, thus we included compost, cover crops, and the use of the plug inoculation technique just as in the nonfumigated compost budget. Further, all fertilizer inputs are approved by the NOP, including the stipulation that sodium nitrate would not exceed 20% of the nitrogen budget. This production system was similar to the nonfumigated compost budget in terms of labor for controlling weeds, but also accounted for the additional labor required for plant sanitation to control botrytis populations for which organic chemical

Table 1. Estimated costs needed to produce, harvest, and market strawberries in the southeastern United States based on conventional production system.

Operation	Labor ($/acre)[z]	Machinery ($/acre)	Materials ($/acre)	Total ($/acre)
Land preparation (June)				
Treat old crop with herbicide	38.16	61.97	18.40	118.53
Remove and dispose plastic	241.68	65.32	0.00	307.00
Disk	12.72	18.74	0.00	31.46
Apply lime (custom)	0.00	0.00	55.00	55.00
Total land preparation	292.56	146.04	73.40	512.00
Preplant operations (July to second week of September)				
Subsoil	19.08	21.27	0.00	40.35
Break up soil clods	12.72	18.74	0.00	31.46
Assemble irrigation system	127.20	0.85	0.00	128.05
Irrigate for fumigation	1.40	12.93	0.00	14.33
Rotovate for fumigation	38.16	54.41	0.00	92.57
Preplant fertilizer	9.54	6.83	195.31	211.68
Preplant fumigation	50.40	151.69	1,164.12	1,366.21
Seed annual ryegrass in aisles	9.54	6.83	8.00	24.37
Total preplant operations	368.04	273.56	1,367.43	1,909.03
Transplant operations (third week of September to November)				
Transplant plugs and replant (2%)	333.90	83.33	3,519.00	3,936.23
Irrigating plugs	114.48	241.35	0.00	355.83
Drip irrigation (2 h × 2)	5.60	28.83	0.00	34.43
Inject fungicide and drip (2 h)	14.00	15.27	62.50	91.77
Spray mites	8.27	13.43	79.80	101.50
Winterize drip system	21.20	0.00	0.00	21.20
Anthracnose spray and deer control	8.27	13.43	145.45	167.15
Total transplant operations	505.72	395.63	3,806.75	4,708.10
Dormant period (December to second week of February)				
Clean and weed beds	254.40	0.00	0.00	254.40
Dormant spray	8.27	13.43	25.20	46.90
Apply floating rowcovers and hold downs	63.60	0.85	1,308.40	1,372.85
Remove rowcover	63.60	0.00	0.00	63.60
Remove dead foliage, weed beds	424.00	0.00	0.00	424.00
Scout for pests	14.00	0.00	0.00	14.00
Reapply rowcovers	63.60	0.00	0.00	63.60
Total dormant period	891.47	14.28	1,333.60	2,239.35
Preharvest (third week of February to second week of April)				
Pull plants through plastic	159.00	0.00	0.00	159.00
Apply herbicide to aisles	8.27	13.43	29.90	51.60
Scout for pests (×4)	56.00	0.00	0.00	56.00
Remove rowcovers	63.60	0.00	0.00	63.60
Spray pests, diseases (×6), and deer control	49.61	80.56	858.29	988.46
Connect drip system	63.60	0.00	0.00	63.60
Inject fungicide and drip (2 h)	14.00	15.27	62.50	91.77
Control irrigation system	7.00	0.00	0.00	7.00
Tissue sample (×3)	15.90	0.00	21.00	36.90
Pull plants and weeds	106.00	0.00	0.00	106.00
Inject fertilizer and drip (2 h × 7)	98.00	106.89	133.10	357.99
Reapply and remove rowcover (×2)	254.40	0.00	0.00	254.40
Freeze protection (×4)	238.00	439.59	0.00	677.59
Pollinate with bees	0.00	0.00	35.00	35.00
Total preharvest	1,133.33	655.73	1,159.79	2,948.90

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Table 1. (*Continued*) Estimated costs needed to produce, harvest, and market strawberries in the southeastern United States based on conventional production system.

Operation	Labor ($/acre)^z	Machinery ($/acre)	Materials ($/acre)	Total ($/acre)
Harvest (third week of April to May)				
U-pick supervision	551.20	0.00	0.00	551.20
Prepick harvest	2,621.20	0.00	2,250.00	4,871.20
Drip irrigation (14 h)	19.60	100.89	0.00	120.49
Spray pests, diseases (×3)	24.81	40.28	312.30	377.39
Tissue sample	5.30	0.00	7.00	12.30
Inject fertilizer and drip (2 h × 3)	42.00	45.81	79.04	166.85
Disassemble irrigation system	63.60	0.00	0.00	63.60
Total harvest	3,327.70	186.98	2,648.34	6,163.02
Total variable production and harvest costs				18,480.39
Annual administrative costs, taxes, and land rent				141.00
Total costs				18,621.39

^{z}\$1/acre = \$2.4711/ha.

controls are generally less effective. Only organic controls for the main pests were included. The chemicals included in the detailed budgets (Fernandez, 2015) were not meant to be interpreted as recommended controls for these pests, but rather to account for the costs a grower would incur for implementing a control measure, whether it be a cultural or chemical measure. The yields in organic production systems were also generally reduced and could be further reduced by losses to pathogens for which no organic controls exist. As a result and based on previous research, organic yields were estimated to be at 78% of the conventional budget (Beck, 2011; Garland et al., 2011), but actual yields will vary based on local soilborne pest pressures and conditions.

STRAWBERRY ENTERPRISE PRODUCTION BUDGETS. Production budgets were developed based on 5-acre strawberry planting, and per acre production cost estimates for each system are presented in Tables 1–3. The production budgets assumed management practices recommended by North Carolina State University extension services. Information for the budgets was obtained from research horticultural specialists, local strawberry growers, and agricultural suppliers. All production expenses were separated into different phases: land preparation, preplant operations, transplant and postplant operations, dormant, preharvest and harvest operations, and different expense categories: labor, materials, and equipment. Administrative costs were also estimated and included land rent ($100/acre), property taxes ($16/acre), per acre share of overhead expenses ($25) for all systems, and in the case of the organic system, additional expenses associated with organic certification ($2000/acre), mitigation ($1000/acre), and record keeping and training ($1680/acre). The machinery and equipment used in strawberry production were assumed to be purchased new or used (Fernandez, 2015) and used in various farming operations, which is typical for a diversified farm. The overhead irrigation system was used for freeze protection and the drip irrigation system was used for soil moisture. Reported numbers included all expenses associated with owning machinery and equipment, as well as repairs, maintenance, and fuel. The water was assumed to be used at no cost. A land rent was assumed to be $100/acre, which is representative of current land values in the region. Hired employees were paid $10.60/h while the owner/operator was compensated at a rate of $14/h (USDA, 2014).

The harvest season was estimated to begin in mid-April and to continue through May for a total of 6 weeks. The fruit was assumed to be sold at the farm. Two-thirds of harvested strawberries were sold through the pick-your-own (PYO) operation and one-third was prepicked and sold at the fruit stand. The fruit was packed into 4-qt baskets containing ≈6 lb of strawberries. Based on personal conversations with local growers, harvest labor was paid $1.15/4-qt basket for the prepicked strawberries.

Assumed yields were 1.2 lb/plant or 18,000 lb/acre in the conventional system, 1.02 lb/plant or 15,300 lb/acre for the compost system (15% reduction compared with the conventional system), and 0.94 lb/plant or 14,100 lb/acre for the organic system (22% reduction compared with the conventional system) with planting density of 15,000 plants/acre (Table 4).

The prices strawberry growers can receive for their fruit can vary significantly. We assumed that the growers received on average $10/4-qt basket ($1.67/lb) for PYO and $12/4-qt basket ($2/lb) for prepicked conventional strawberries and $17/4-qt basket ($2.83/lb) for PYO and $19/4-qt basket ($3.17/lb) for prepicked organic strawberries (Table 4). The prices were selected based on expected local seasonal averages reported by growers for the Raleigh area of North Carolina, but the sale prices can vary widely based on an enterprise's location to major population areas and local supply and demand.

ENVIRONMENTAL INDICATORS. We adopted the environmental indicator method developed by Sydorovych et al. (2009) to assess the impact of the three strawberry production systems on the environment and human health. LD_{50} measure was used to express the acute effects of solids and liquids. It is the dosage of the material that would result in the death of 50% of a population of test species under standard conditions and is expressed as milligrams of the material per kilogram of body weight. Following Sydorovych et al. (2009) we calculated the total number of LD_{50} doses applied per acre through various chemicals that were used in each system. This approach allowed us to account for

Table 2. Estimated costs needed to produce, harvest, and market strawberries in the southeastern United States based on compost production system.

Operation	Labor ($/acre)[z]	Machinery ($/acre)	Materials ($/acre)	Total ($/acre)
Land preparations (June)				
Treat old crop with herbicide	38.16	61.97	18.40	118.53
Remove and dispose plastic	241.68	65.32	0.00	307.00
Apply compost	12.72	17.45	204.00	234.17
Disk	12.72	18.74	0.00	31.46
Apply lime (custom)	0.00	0.00	55.00	55.00
Plant cover crop	38.16	59.87	47.16	145.19
Total land preparation	343.44	223.35	324.56	891.35
Preplant operations (July to second week of September)				
Mow cover crop	25.44	33.64	0.00	59.08
Rotovate cover crop	76.32	108.81	0.00	185.13
Subsoil	19.08	21.27	0.00	40.35
Break up soil clods	12.72	18.74	0.00	31.46
Set up misting system	147.60	0.00	0.00	147.60
Fill trays with soil	14.00	0.00	961.72	975.72
Moisten soil media	10.60	0.00	0.00	10.60
Stick runner tips for plugs	354.77	0.00	1,365.53	1,720.29
Irrigate and fertilize plugs	254.40	0.21	0.72	255.33
Assemble irrigation system	127.20	0.85	0.00	128.05
Rotovate	38.16	54.41	0.00	92.57
Bed formation	50.40	95.06	645.12	790.58
Seed annual ryegrass in aisles	9.54	6.83	8.00	24.37
Total preplant operations	1,140.23	339.83	2,981.08	4,461.14
Transplant operations (third week of September to November)				
Transplant plugs and replant (2%)	333.90	83.33	0.00	417.23
Irrigating plugs	114.48	241.35	0.00	355.83
Drip irrigation (2 h × 2)	5.60	28.83	0.00	34.43
Inject fungicide and drip (2 h)	14.00	15.27	62.50	91.77
Spray mites	8.27	13.43	79.80	101.50
Winterize drip system	21.20	0.00	0.00	21.20
Anthracnose spray and deer control	8.27	13.43	145.45	167.15
Total transplant operations	505.72	395.63	287.75	1,189.10
Dormant period (December to second week of February)				
Clean and weed beds	286.20	0.00	0.00	286.20
Dormant spray	8.27	13.43	25.20	46.90
Apply floating rowcovers and hold downs	63.60	0.85	1,308.40	1,372.85
Remove rowcover	63.60	0.00	0.00	63.60
Remove dead foliage, weed beds	466.40	0.00	0.00	466.40
Scout for pests	14.00	0.00	0.00	14.00
Reapply rowcovers	63.60	0.00	0.00	63.60
Total dormant period	965.67	14.28	1,333.60	2,313.55
Preharvest (third week of February to second week of April)				
Pull plants through plastic	159.00	0.00	0.00	159.00
Apply herbicide to aisles	8.27	13.43	29.90	51.60
Scout for pests (×4)	56.00	0.00	0.00	56.00
Remove rowcovers	63.60	0.00	0.00	63.60
Spray pests, diseases (×6), and deer control	49.61	80.56	858.29	988.46
Connect drip system	63.60	0.00	0.00	63.60
Inject fungicide and drip (2 h)	14.00	15.27	62.50	91.77
Control irrigation system	7.00	0.00	0.00	7.00
Tissue sample (×3)	15.90	0.00	21.00	36.90
Pull plants and weeds	106.00	0.00	0.00	106.00

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Table 2. (*Continued*) Estimated costs needed to produce, harvest, and market strawberries in the southeastern United States based on compost production system.

Operation	Labor ($/acre)^z	Machinery ($/acre)	Materials ($/acre)	Total ($/acre)
Inject fertilizer and drip (2 h × 7)	98.00	106.89	133.10	357.99
Re-apply and remove rowcover (×2)	254.40	0.00	0.00	254.40
Freeze protection (×4)	238.00	439.59	0.00	677.59
Pollinate with bees	0.00	0.00	35.00	35.00
Total preharvest	1,133.38	655.73	1,159.79	2,948.90
Harvest (third week of April to May)				
U-pick supervision	551.20	0.00	0.00	551.20
Prepick harvest	2,310.71	0.00	1,912.51	4,223.22
Drip irrigation (14 h)	19.60	100.89	0.00	120.49
Spray pests, diseases (×3)	24.81	40.28	312.30	377.39
Tissue sample	5.30	0.00	7.00	12.30
Inject fertilizer and drip (2 h × 3)	42.00	45.81	79.04	166.85
Disassemble irrigation system	63.60	0.00	0.00	63.60
Total harvest	3,017.20	186.98	2,310.84	5,515.02
Total variable production and harvest costs				17,319.07
Annual administrative costs, taxes, and land rent				141.00
Total costs				17,460.07

^{z}\$1/acre = \$2.4711/ha.

both the quantity of applied materials as well as their relative toxicity. In addition, we calculated the number of products applied in each system with reported human chronic health impacts, such as evidence of development of cancer in test animals in laboratory experiments on these products, developmental, and/or reproductive effects. If any of these effects were present, the product was counted as a potential risk to chronic human health.

Product impact on water resources focused on its leaching potential, which depends on product solubility, persistence, and mobility in soil. The products' groundwater ubiquity scores (GUS) were calculated as:

$$\mathrm{GUS} = \log(t_{1/2}) \times [4 - \log_{10}(K_{\mathrm{oc}})]$$

where $t_{1/2}$ is the product's half life and K_{oc} is its soil adsorption potential (Gustafson, 1989). A GUS value of 2.8 or greater indicates high leaching potential, between 1.8 and 2.8 a moderate potential, and less than 1.8 a low potential.

Information on specific environmental and human safety characteristics of pesticides used in the three strawberry production systems was obtained from the products' Material Safety Data Sheets (MSDS). MSDS follow established standards for presenting various environmental and human risk information and are strictly regulated by the U.S. Environmental Protection Agency.

Finally, we calculated the total weight of several different fertilizers applied per acre in each system. Included fertilizers were nitrogen, potassium, phosphorus, sulfur, calcium, and boron.

Results

The detailed interactive budgets for the conventional, compost, and organic systems are available online (Fernandez, 2015). The summaries of these production budgets are presented in Tables 1–3. For each system, production costs were separated in different production stages: land preparation, preplant, transplant, dormant, preharvest, harvest, as well as annual administrative costs. Production costs were also broken down into labor, machinery, and materials categories within each production stage. Total annual production costs were estimated to be \$18,621/acre for the conventional system, \$17,460/acre for the compost systems, and \$23,376/acre for the organic system. For the three systems, labor costs were the highest in the organic system (\$7118/acre), equipment/machinery related expenses were the highest in the compost system (\$1816/acre), materials were the most expensive in the conventional system (\$10,389/acre), and administrative expenses were the highest in the organic system (\$4821/acre).

Gross revenues in each system were calculated as yield per acre times selling price and were estimated to be \$33,600 in the conventional system, \$28,650 in the compost system, and \$42,770 in the organic system (Table 4). Net revenues were calculated as gross revenues less total annual production costs, and were estimated to be \$14,979 in the conventional system, \$11,100 in the compost system, and \$19,394 in the organic system (Table 4).

Finally, selected indicators of the environmental and human safety were presented in Table 5. A total of 118,649 LD_{50} doses have been applied per acre in the conventional system based on all weed, disease, and pest control products used. Just due to elimination of fumigation, this measure was reduced to 6649 LD_{50} doses/acre in the compost system (94% reduction). Fumigant, which was removed in compost and organic system, was the only product that was listed under toxicity category "Warning" indicating moderate level of risk by ingestion, while all remaining product classified under toxicity category "Caution" (were slightly toxic by ingestion), or considered safe based on label information. It is important to note that the LD_{50} values do not account for the risk associated with repeated long-term exposure to the toxins present in the materials.

Table 3. Estimated costs needed to produce, harvest, and market strawberries in the southeastern United States based on organic production system.

Operation	Labor ($/acre)[z]	Machinery ($/acre)	Materials ($/acre)	Total ($/acre)
Land preparations (June)				
Remove and dispose plastic	241.68	65.32	0.00	307.00
Apply compost	12.72	17.45	204.00	234.17
Disk	12.72	18.74	0.00	31.46
Apply lime (custom)	0.00	0.00	55.00	55.00
Plant cover crop	38.16	59.87	60.76	158.79
Total land preparation	305.28	161.38	319.76	786.42
Preplant operations (July to second week of September)				
Mow cover crop	25.44	33.64	0.00	59.08
Rotovate cover crop	76.32	108.81	0.00	185.13
Subsoil	19.08	21.27	0.00	40.35
Break up soil clods	12.72	18.74	0.00	31.46
Set up misting system	147.60	0.00	0.00	147.60
Fill trays with soil	14.00	0.00	1,236.80	1,250.80
Moisten soil media	10.60	0.00	0.00	10.60
Stick runner tips for plugs	354.77	0.00	2,779.25	3,134.01
Irrigate and fertilize plugs	254.40	0.21	0.72	255.33
Assemble irrigation system	127.20	0.85	0.00	128.05
Rotovate	38.16	54.41	0.00	92.57
Bed formation	50.40	95.06	645.12	790.58
Seed annual ryegrass in aisles	9.54	6.83	16.00	32.37
Total preplant operations	1,140.23	339.83	4,677.88	6,157.94
Transplant operations (third week of September to November)				
Transplant plugs and replant (2%)	333.90	83.33	0.00	417.23
Irrigating plugs	114.48	241.35	0.00	355.83
Drip irrigation (2 h × 2)	5.60	28.83	0.00	34.43
Spray mites	8.27	13.43	76.32	98.02
Winterize drip system	21.20	0.00	0.00	21.20
Total transplant operations	483.45	366.93	76.32	926.70
Dormant period (December to second week of February)				
Clean and weed beds	286.20	0.00	0.00	286.20
Apply floating rowcovers and hold downs	63.60	0.85	1,308.40	1,372.85
Remove rowcover	63.60	0.00	0.00	63.60
Remove dead foliage, weed beds	466.40	0.00	0.00	466.40
Scout for pests	14.00	0.00	0.00	14.00
Reapply rowcovers	63.60	0.00	0.00	63.60
Total dormant period	957.40	0.85	1,308.40	2,266.65
Preharvest (third week of February to second week of April)				
Pull plants through plastic	159.00	0.00	0.00	159.00
Mow aisles (×5)	127.20	11.60	0.00	138.80
Scout for pests (×4)	56.00	0.00	0.00	56.00
Remove rowcovers	63.60	0.00	0.00	63.60
Spray mites (×3)	24.81	40.29	228.96	294.06
Spot treat fire ants (×2)	42.40	0.00	80.00	122.40
Botrytis control	8.27	13.43	54.00	75.70
Connect drip system	63.60	0.00	0.00	63.60
Control irrigation system	7.00	0.00	0.00	7.00
Tissue sample (×3)	15.90	0.00	21.00	36.90
Pull plants and weeds	106.00	0.00	0.00	106.00
Inject fertilizer and drip (2 h × 7)	98.00	106.89	300.80	505.69
Reapply and remove rowcover (×2)	254.40	0.00	0.00	254.40
Freeze protection (×4)	238.00	439.59	0.00	677.59

(*Continued on next page*)

Table 3. (*Continued*) Estimated costs needed to produce, harvest, and market strawberries in the southeastern United States based on organic production system.

Operation	Labor ($/acre)[z]	Machinery ($/acre)	Materials ($/acre)	Total ($/acre)
Pollinate with bees	0.00	0.00	35.00	35.00
Total preharvest	1,264.17	611.78	719.76	2,595.71
Harvest (third week of April to May)				
U-pick supervision	551.20	0.00	0.00	551.20
Prepick harvest	2,172.71	0.00	1,762.51	3,935.22
Drip irrigation (14 h)	19.60	100.89	0.00	120.49
Spray mites (×2)	16.54	26.86	152.64	196.04
Spot treat fire ants	21.20	0.00	40.00	61.20
Botrytis control (×3)	24.81	40.28	162.00	227.09
Tissue sample	5.30	0.00	7.00	12.30
Mow aisles (×2)	50.88	4.64	0.00	55.52
Inject fertilizer and drip (2 h × 3)	42.00	45.81	510.72	598.53
Disassemble irrigation system	63.60	0.00	0.00	63.60
Total harvest	2,967.82	218.47	2,634.86	5,821.15
Total variable production and harvest costs				18,554.59
Annual administrative costs, taxes, and land rent				4,821.00
Total costs				23,375.59

[z] $1/acre = $2.4711/ha.

Two products applied in the conventional system contained human chronic health warning and only one in the compost system. Average GUS score was reduced from 1.81 (representing moderate risk) in the conventional system to 1.72 (representing low risk) in the compost system. No products presenting risk to the environment or human health based on selected indicators were used in the organic system.

We also observed significant reduction in chemical fertilizer application rates per acre in the compost and organic system as compared with the conventional system. Nitrogen application was reduced from 111.25 lb/acre in the conventional system to 51.25 lb/acre (54% reduction) in the compost system and to 19.2 lb/acre (83% reduction) in the organic system. Potassium application was reduced from 102.8 lb/acre in the conventional system to 52.8 lb/acre (49% reduction) in the compost system and to 20.7 lb/acre (80% reduction) in the organic system. No phosphorus was applied in the compost and organic system as compared with 22 lb/acre in the conventional system. Sulfur was reduced from 37.4 lb/acre in the conventional system to 15.4 lb/acre (59% reduction) in the compost system. No reduction was observed in calcium and boron applications in the compost system as compared with the conventional system (51.48 lb/acre of calcium and 0.23 lb/acre of boron were applied). No sulfur, calcium, or boron were applied in the organic system.

Conclusions

Because strawberry growers in the southeastern region of the United States need to make profits in order for their businesses to be sustainable, an understanding of how sustainable soil management practices will impact net revenues is very useful to them to make decisions about adoption of these practices. The information presented in this study can serve as a guide to assist individuals who are currently growing strawberries in the region and are considering improved soil management practices, those considering starting new strawberry enterprises, or professionals who are advising strawberry growers to make better business management decisions.

The results presented here show that all three strawberry productions systems resulted in positive net returns to growers. The compost system resulted in lower net returns compared with the conventional system ($11,100/acre as compared with $14,979/acre), which was primarily a result of a presumed reductions in yields following an abandonment of fumigation in this system. At the same time, the compost system resulted in considerable improvement in all environmental and human health impact indicators as compared with the conventional system. We believe that the compost system should be considered as economically viable transitional alternative to proactive growers who are interest to improve their soil quality especially given any possible future restrictions on the use of fumigation and further deterioration in soil quality in the conventionally managed system which might lead to future yield reductions.

The organic system had the highest net returns ($19,394/acre) and demonstrated the highest values in the environmental and human health impact indicators. This system had the highest production costs and relatively low yields. The highest net returns were a result of high selling prices reported by growers who cooperated with our research team and should be interpreted with caution. For example, a $2 sale price reduction for each type of harvest ($15/4-qt basket for PYO and $17/4-qt basket for prepicked organic strawberries) would result in the net revenue estimate of $14,694/acre, which would be very similar to the net revenue in the conventional system.

Online enterprise budgets for the three strawberry production systems (Fernandez, 2015) are interactive and allow users to adjust selected values for expected yields, selling prices, and various production costs and investigate how these different values

Table 4. Economic impact comparison of three strawberry production systems in the southeastern United States.

	Strawberry production system		
	Conventional	Compost	Organic
Annual production costs ($/acre)[z]	18,621	17,460	23,376
Labor	6,419	7,106	7,118
Equipment	1,672	1,816	1,699
Materials	10,389	8,398	9,737
Administrative	141	141	4,821
Yield			
Per plant (lb)[y]	1.2	1.02	0.94
Per unit area (lb/acre)[y]	18,000	15,300	14,100
Selling price ($/lb)[x]			
U-pick	1.67	1.67	2.83
Prepick	2.00	2.00	3.17
Gross revenue ($/acre)	33,600	28,650	42,770
Net revenue ($/acre)[w]	14,979	11,100	19,394

[z] $1/acre = $2.4711/ha.

[y] 15,000 plants/acre (37,065.8 plants/ha) planting density; 1 lb = 0.4536 kg, 1 lb/acre = 1.1209 $kg \cdot ha^{-1}$.

[x] Strawberries are sold in 4-qt (3.8 L) baskets containing ≈6 lb of fruit; 40% of fruit is sold as U-pick and 60% is prepicked; $1/lb = $0.4536/kg.

[w] Net revenue is calculated as gross revenue less annual production costs.

Table 5. Environmental and human safety impact comparison of three strawberry production systems in the southeastern United States.

	Strawberry production system		
	Conventional	Compost	Organic
LD_{50} (doses/acre)[z]	118,649	6,649	0
Products with chronic health warnings (no.)	2	1	0
Average GUS score[y]	1.81	1.72	0
Chemical fertilizers (lb/acre)[x]			
Nitrogen	111.25	51.25	19.20
Potassium	102.80	52.80	20.70
Phosphorus	22.00	0	0
Sulfur	37.40	15.40	0
Calcium	51.48	51.48	0
Boron	0.23	0.23	0

[z] LD_{50} is the dosage of the material that would result in the death of 50% of a population of test species under standard conditions expressed as milligrams of the material per kilogram of body weight; 1 $mg \cdot kg^{-1}$ = 1 ppm, 1 dose/acre = 2.4711 doses/ha.

[y] Groundwater ubiquity score; a value of 2.8 or greater indicates high product groundwater leaching potential, between 1.8 and 2.8 a moderate potential, and less than 1.8 a low potential.

[x] 1 lb/acre = 1.1209 $kg \cdot ha^{-1}$.

would affect revenues in each system. Any economic estimates presented here are not substitutes for individuals calculating their own expected returns. Costs vary from one grower to another because of market conditions, labor supply, age and condition of the machinery and equipment, managerial skill, and land costs among many other factors. Since every situation is different, it is highly recommended that each grower estimates their individual production, marketing, and harvest costs based on their own production techniques, price expectations, and local market situation. Finally, the growers should always continue to research alternative marketing channels to ensure they are getting the best price available.

Our study showed considerable reduction in human and environmental risks in the compost and organic systems as compared with the conventional system based on the set of selected indicators. We also observed significant reduction in the use of chemical fertilizers, particularly nitrogen, in the compost and organic systems. Chemical nitrogen fertilizers, particularly when over applied, are associated with many environmental disruptions including drinking water contamination and freshwater hypoxia (Schlesinger, 2009). Organic sources of nitrogen like the compost and cover crops used in the compost and organic systems present a much lower risk for runoff (Evanylo et al., 2008; Pimentel et al., 2005), and therefore a lower risk to the environment.

Levitan et al. (1995) state that there is no perfect system to account for environmental and human risks from agricultural practices, as it is difficult to strike a balance between the ease of use of simpler frameworks and informational richness of more complex frameworks that may be prohibitively difficult to use. The best framework is often determined by the objectives of the analysis and resource constraints. The advantage of our indicator approach is that we based our analysis on readily available information and transparent and simple procedures. The drawback is a difficulty to assess relative impact and significance of identified reductions in risks. The development of an improved system quantifying various human and environmental risks in agricultural production systems could be a fruitful area for future research.

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