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Economic analysis of experimental organic agricultural systems on a highly eroded soil of the Georgia Piedmont, USA

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Abstract

Information about the costs and labor requirements of experimental organic farming systems designed to restore highly degraded soils in the southeastern US are needed. Enterprise budgets were prepared for the production of okra, hot pepper and a corn/winter squash intercrop under 10 different production systems, nine of which were based on organic conservation tillage. A stochastic dominance analysis was conducted to determine the relative risk efficiency of the 10 systems over the course of the experiment in terms of productivity, profitability and carbon sequestration potential. Organic conservation tillage treatments had lower tractor labor and fuel costs than conventional treatments, due to the extensive tillage required in conventional vegetable farming. The subset of organic treatments receiving compost addition without additional mulches also demonstrated increases in soil carbon, an important driver of system productivity. Organic treatments had little pest and pathogen pressure, with the exception of *Fusarium* wilt in some treatments receiving straw mulch. Weed suppression by straw mulches reduced labor requirements by an average of 23%. Yields in all treatments were lower than conventional yields from other studies in the region, due to the degraded nature of the soil on the study site. However, net returns on high-labor, organic crops were over US\$30,000 ha^{-1} in some treatments. The results of this work indicate that organic, conservation tillage systems can restore soil productivity and command high returns per hectare if labor requirements can be met.

Key words: organic agriculture, alley cropping, conservation tillage, enterprise budget, stochastic dominance, soilcarbon, okra, peppers, winter squash

Introduction

Organic retail food sales have consistently grown approximately 20% annually since 1990[1], although certified organic cropland still only accounted for only 0.5% of agricultural lands in the US in 2005[2]. Fresh produce is the top-selling category in organic food production, and accounted for 42% of all organic food sales in 2001, with sales increasing 51.4% from 1999 to 2000[1]. In 2005, Georgia had 439,660 ha in vegetable production[3], and ranks in the top four states nationally for fresh market vegetables in area harvested, production and value[4]. Additionally, the southern and western regions of the US have been identified as the two fastest-growing organic markets in the country[5]. Despite the market potential for organic production in the state, in 2005, Georgia ranked 31st in the country in the number of certified operations and 43rd in the total number of certified organic acres, with only 53 certified organic operations in the state, totaling 2413 ha[2].

Economic decision-making tools may help alleviate the risk associated with converting to new production practices; enterprise budgets are one such tool. Enterprise budgets estimate the costs and returns associated with the production of a commodity, or enterprise[6]. While common for conventionally produced commodities, few enterprise budgets exist for organic agriculture, and even fewer for the Southeast. There are enterprise budgets for organic commodity crops in the Midwest, and for vegetables in California, Wisconsin and New Jersey[7]. Some production cost information for large-scale organic vegetable production has been assembled for the southeastern US[8], and is applicable to the large-scale farms in the southern coastal plains. Only one production cost study was found for the region that would be applicable to the small, diversified organic farms of northern Georgia Piedmont[9].

Although enterprise budgets allow the comparison of input costs and returns between systems, they do not account for changes in the environmental quality associated with production systems. Centuries of tillage-intensive agriculture have left the soils of Georgia Piedmont severely eroded, lacking topsoil, soil organic matter and any appreciable nutrients[10]. In order to restore sustained production to degraded soils, farmers must also restore soil quality, specifically the soil organic matter[11]. These challenges are intensified by the region's subtropical climate, which contributes to rapid pest and disease outbreaks, high weed pressure and rapid decomposition of soil amendments.

The purpose of this work was to provide an economic analysis of a field experiment that examined the ability of two experimental ecological agricultural systems to restore degraded soils in the southeastern US[12]. A 3-year field study was conducted to assess the effects of organic farming systems on soil characteristics, crop production and weed biomass. The two experimental systems were based on best management practices and recommendations from previous agroecological research in the region, including conservation tillage, incorporation of perennial legumes, crop rotation and use of winter cover crops and composts. This analysis was intended to assess the economic costs and benefits of the experimental systems on degraded soils using an enterprise budget approach and to discuss the results from a variety of crops in the rotation using a stochastic dominance analysis. Production economics for these experimental techniques is not intended to be representative of organic conservation tillage systems on fertile soils, but rather to contribute to the discussion of the potential profitability of experimental technologies on degraded lands. Enterprise budgets are presented here to contribute to basic production economics information that is lacking for the region as an aid in the grower's decision-making. Stochastic dominance analysis is employed to compare the risk-return trade-offs of the 10 production systems from crop productivity, economic profitability, to identify risk-efficient systems and discuss these results in the light of desired changes in parameters related to soil quality (soil carbon).

Production practices and methods

The study site was located on the Spring Valley Ecofarm, near Athens, Georgia, USA (33°57′N latitude, 83°19′W longitude). This historic farm had been in cultivation since 1864, with cotton, cattle, sorghum and soybean previously grown on the site until 1993. At this time, the site was removed from extensive cultivation and management shifted to a mowed fallow of pasture grasses and weeds. An alley cropping (AC) system utilizing perennial legumes was established on the site in 2001. AC is a technique where hedgerows of trees or shrubs are planted between rows, or alleys, of crop plants[13]. This technique is often practiced in the tropics where leguminous hedgerow species are used as a perennial source of crop fertility, animal fodder and erosion control[14–16]. In these systems, shoots of hedgerow plants are coppiced, and the pruned branches applied as a mulch and green manure for adjacent crop plants.

In 2004, an experiment was initiated that compared three cropping systems over a 3-year vegetable crop rotation for their effects on soil characteristics, plant production and yields[12]. These systems included two organic systems in conservation tillage, and one tillage-intensive conventional system, outlined further below. The subheadings below the cropping systems describe experimental treatments which employed three levels of compost for nutrient supply (0, 22.4 and 44.8 $Mg\,ha^{-1}\,yr^{-1}$), as well as two levels of mulch (with or without), for weed suppression. For a complete description of the experimental design and rationale, see Jacobsen and Jordan[12].

The three cropping systems and their treatments are as follows:

1. AC with organic vegetables using strip tillage (AC treatments) are as follows:
   (a) AC1: AC (including hedgerow prunings) with winter cover crops.
   (b) AC2: AC1 + straw mulch.
   (c) AC3: AC1 + spring compost.
   (d) AC4: AC1 + spring compost + mulch.
   (e) AC5: AC1 + fall compost + spring compost.
   (f) AC6: AC1 + fall compost + spring compost + mulch.
2. Organic vegetables using strip tillage [no AC, organic strip tillage (OST) treatments] are as follows:
   (a) OST1: winter cover crops + mulch.
   (b) OST2: OST1 + spring compost.
   (c) OST3: OST1 + fall compost + spring compost.
3. Conventionally fertilized, conventionally tilled vegetables [conventional tillage (CT) treatment].

A general outline of the annual management practices for each treatment is detailed in Table 1. In AC treatments, leguminous perennial hedgerows consisted of *Albizia julibrissin* planted in hedgerows 5 m apart with plants 0.5 m apart within the hedgerow. Hedgerows were coppiced using a hedge trimmer 1 to 3 times per summer when the leaves began to shade the adjacent crop plants. These prunings were applied by hand to adjacent cropped areas as a green manure in all AC treatments. Winter cover crops and crop plants were terminated using a commercial grass roller, or roller crimper, in the AC and OST treatments. This implement was used to flatten and kill cover crops before seed maturation and crop residue after crop harvest. All amendments and cover crop seeds were broadcast and spread by hand to ensure uniformity of application. Compost feedstock was primarily poultry litter and wood chips (2% N, C:N ratio = 12.5), and was spread at a rate of 22.4 $Mg\,ha^{-1}$ per application. Planting beds in both the AC and OST systems were prepared using strip tillage to create

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Table 1. General management timeline for the ten treatments in the field study. For a complete management description, see Jacobsen and Jordan[12].

Cropping system	Treatment	October	November to March	April	May	June	July	August	September
Alley cropping	AC1	RC, CC		RC, ST	PT	W, P	H,W	H, P	H
	AC2	RC, CC		RC, ST	PT	W, M, P	H,W	H, P	H
	AC3	RC, CC		RC, ST, CP	PT	W, P	H,W	H, P	H
	AC4	RC, CC		RC, ST, CP	PT	W, M, P	H,W	H, P	H
	AC5	RC, CC, CP		RC, ST, CP	PT	W, P	H,W	H, P	H
	AC6	RC, CC, CP		RC, ST, CP	PT	W, M, P	H,W	H, P	H
Organic strip till	OST1	RC, CC		RC, ST	PT	W, M	H,W	H	H
	OST2	RC, CC		RC, ST, CP	PT	W, M	H,W	H	H
	OST3	RC, CC, CP		RC, ST, CP	PT	W, M	H,W	H	H
Conventional	CT	RC		CT, ST	PT	W	H,W	H	H

Abbreviations for management activity: CC, cover crop planting; CP, compost application; CT, conventional tillage; H, harvest; M, straw mulch application; P, hedgerow pruning; RC, roller crimping; ST, strip tillage; W, weeding.

Table 2. Fixed costs for a 40 ha (100 acre) farm. Total fixed farm costs per hectare are calculated for 4 ha (10 acres) in production.

Item	Details	New cost (US$)	Salvage value (US$)	Life span (years)	Cost per year (US$)
Tractor	40 hp, 4 wd	16,000	1600	10	1440
Roller crimper	120 cm wide	800	80	15	48
Rototiller	120 cm wide	2000	200	15	120
Bale spear		250	25	15	15
No-till rig	30 cm discs, 5 cm shanks	1500	150	15	90
Irrigation pump	5 hp	800	80	5	144
Piping	7.5 cm, buried	1200	0	10	120
Land rent cash value	1 ha irrigated vegetable rent yr^{-1}				305
Total whole farm cost (US$ ha^{-1})					799

two planting furrows per bed 45 cm apart, with 90 cm between each bed. All vegetables were drip irrigated, and were either direct seeded (Years 1 and 3) or transplanted by hand (Year 2) approximately 2 weeks after cover crop termination. Once weeds began to emerge from the cover crop residue layer, generally 4–8 weeks from planting, plots were hand weeded and a 2.5 cm thick layer of wheat straw (Year 1) or pasture hay (Years 2–3) was applied as mulch to designated treatments. Weeding continued as needed throughout the summer.

The timing of CT treatments was similar, with tillage conducted at the same time as spring roller crimping in the other treatments. Fertilizer was applied by hand as a side dressing in bands adjacent to crop plants according to the University of Georgia Cooperative Extension fertilizer guidelines for specific crops[17–19] at the time of planting. Inorganic fertilizer was used on the CT plots only. Herbicides and pesticides were not used on any of the plots. Thus, the input costs for the CT plots are an underestimate, since conventional farmers presumably would use these inputs. However, labor costs may be overestimated, as time spent weeding CT plots would have been lower than if an herbicide were used.

Costs and returns

Fixed farm costs are presented in Table 2, and were calculated for 4 ha of production. Fixed farm costs included only equipment used in this work, and assumed straight-line depreciation and 10% salvage value. The small-scale no-till rig used in this work was fabricated by the University of Georgia machine shop, and consisted of a series of two discs followed by a 10 cm sweep. This cost was not reflective of a no-till seed drill or other commercially available no-till equipment, but could be representative of a rig appropriate for small-scale diversified operations in the region. Fixed farm irrigation costs included a pump and infrastructure for the drip irrigation system. Land rent cash value was an average paid for irrigated vegetable production in the state of Georgia in 2007[20].

While the site was not certified organic, it was organically managed and production costs reported here were for USDA Certified Organically approved materials. They did not include the cost of organic certification or record keeping. Budgeting periods for each crop began with the sowing of the winter cover crop seed in October of the fall preceding the summer crop and ended with the final harvest

Table 3. Production input costs for a 3-year vegetable crop rotation in alley cropping (AC), organic strip-tillage (OST) and conventionally tilled cropping systems. Input quantities and prices are calculated on a per hectare basis.

Inputs	Input rate, AC systems	Input rate, CT and OST systems	Unit price, organic (US$)	Unit price, conventional	AC cost (US$)	OST cost (US$)	Conventional cost (US$)
Cover crop seed							
Austrian winter pea	35 kg	40 kg	2.40 kg^{-1}		84	96	
Crimson clover	17 kg	20 kg	6.60 kg^{-1}		112	132	
Rye	46 kg	54 kg	2.50 kg^{-1}		115	135	
Total cover crop cost					311	363	
Crop seed							
Cayenne pepper	200 g	300 g	0.50 g^{-1}	0.50 g^{-1}	100	150	150
Okra	3.5 kg	5 kg	110 kg^{-1}	4.40 kg^{-1}	385	–	22
Corn 'Ried's yellow dent'	6.2 kg	9 kg	27.70 kg^{-1}	5.5 kg^{-1}	172	250	50
Butternut squash	0.84 kg	1.26 kg	73.70 kg^{-1}	49.28 kg^{-1}	62	93	62
Total cost, corn and squash intercrop					234	343	112
Drip irrigation							
Connectors	144 connectors	174 connectors	0.35 $connector^{-1}$		50	61	61
Drip tape	14,4000 m	17,400 m	0.10 m^{-1}		1440	1740	1740
Total irrigation cost (US$ ha^{-1})					1490	1801	1801

of the summer crop. All costs and returns were calculated on a 1 ha scale, and accounted for a 25% loss of production land to hedgerows in AC treatments.

Production input costs

Production input costs that are consistent across all enterprises are presented in Table 3. Organic crop and cover crop seed prices reflect 2007 costs from the average price of three common organic farming supply sources, but did not include shipping and delivery charges. Estimates from the Georgia Vegetable Budgets[21] were used for conventional corn and okra seed costs. Conventional winter squash and pepper seed costs were the average price from three common farm supply sources for the region, as no data were found for the region with these figures. Irrigation costs for each crop included an annual purchase of drip tape, and a lifespan of mainline and connectors of 3 years. Connector and mainline costs were distributed evenly over 3 years.

Fuel costs for irrigation and tractor operations of each cropping system are presented in Table 4. Costs were based on an average diesel price of US$0.79 per liter and a fuel consumption rate of 3.8 liters h^{-1} for the 40 hp tractor and 1.9 liters h^{-1} for the irrigation pump. Lubrication costs were calculated as a standard 15% of fuel costs[22].

Fertility costs were treatment-specific and are presented in the enterprise budgets (Tables 6–8). Compost costs were calculated from the only organically approved compost provider in the state, and do not include delivery costs, as these would vary by distance from the supplier. Straw mulch costs were the local prices for an approximately 1 short ton round bale, delivery included. Costs for conventional fertilizers were based on estimates from the Georgia Vegetable Budgets[21].

Labor

Labor time for each task was recorded in every experimental plot (25–45 m^2) for the duration of the 3-year study, and the mean value for each treatment was converted to hours per hectare estimates. Due to the experimental nature of this work, practices such as the application of compost, fertilizer and hedgerow pruning, as well as seeding, weeding and harvest were all conducted by hand to ensure consistency in all plots. Labor for general, non-harvest operations were averaged over the 3-year experiment to reduce year-to-year variation (Table 5). A 15-min set-up time was assigned to each tractor operation (the average from this study) to allot for time spent changing equipment, refueling, etc., and spread evenly across all treatments that task was performed upon. Harvest and weeding labor were treatment-specific, and are presented in the enterprises budgets (Tables 6–8).

Labor arrangements on organic farms in the region are highly variable, consisting of family, paid farm workers, interns and volunteer labor under a heterogeneous blend of compensation schemes[9]. Rather than applying a standard hourly wage to the total labor (man) hours calculated for all operations, a US$10.00 per hour hired labor wage was included only when labor exceeded 80 h for any 7-day period throughout the season. This rationale was based on the 2004 survey results from the Organic Farming Research Foundation's (OFRF) National Organic Farmers Survey. The OFRF reported 67% of organic farmers worked on the farm full-time, with an average of two full-time, year-round

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Table 4. Fuel costs for tractor and irrigation operations for each cropping system.

Cropping system	Alley cropping (AC)	Organic strip tillage (OST)	Conventional tillage (CT)
Tractor operations			
Operation time[1] ($h\,ha^{-1}\,yr^{-1}$)			
CT	–	–	37
Roller crimping total (2 × spring, 1 × fall)	30	42	
Strip tillage	12	15	15
Total hours	42	57	52
Fuel use (liters $ha^{-1}\,yr^{-1}$)	159	216	197
Annual tractor fuel cost[2] (US$)	145	197	179
Irrigation operations			
Irrigation time ($h\,ha^{-1}\,yr^{-1}$)			
2005	30	–	10
2006	79	63	68
2007	118	100	98
Irrigation fuel use (liters $ha^{-1}\,yr^{-1}$)			
2005	57	–	19
2006	148	121	129
2007	224	190	186
Irrigation fuel cost[2] (US$)			
2005	52	–	17
2006	135	109	117
2007	203	173	169
Total fuel cost (irrigation and tractor operations, US$ ha^{-1})			
2005	197		196
2006	280	306	296
2007	348	370	348

[1] Operation times were calculated as annual means from 3 years of operations.
[2] Fuel costs assume a gasoline price of US$3.00 $gallon^{-1}$ plus 15% lubrication cost.

Table 5. General operations labor, hours per hectare, expressed as mean values from 2005 to 2007.

Operation	AC	OST	CT
Compost application (per event)	22	35	–
CT	–	–	37
Cover crop sowing	7	10	–
Fertilizer application	–	–	37
Hedgerow pruning (per event)	22	–	–
Hedgerow pruning application (per event)	22	–	–
Irrigation installation	15	20	20
Roller crimping total (2 × spring, 1 × fall)	30	42	–
Straw mulch application (AC2, AC4, AC6 and OST1-3)	72	49	–
Strip tillage	12	15	15

household employees. Our hired labor costs were thus an estimated net of the 80 h weekly family labor limit, derived under the assumption that each full-time household on-farm employee would work 40 h per week. In reality, most farmers would elect to work more than 40 h $week^{-1}$ $person^{-1}$ to the greatest extent possible. Thus our labor values were likely to be overestimates of labor costs on such a farm. Labor and production costs did not include marketing costs.

Yields and returns

Organic crop prices for okra (Table 6), hot pepper (Table 7) and winter squash (Table 8) are the average of market prices from three organic farms in the Athens, Georgia area and a certified organic market in Atlanta, Georgia, the nearest major metropolitan market. The organic corn price was an average value for No. 2 yellow corn from nine nationwide markets reported on the New Farm Organic Price Index[23] for the 2007 crop. Conventional prices for okra and corn were prices reported in the University of Georgia Vegetable Budgets[21]. No prices for conventional winter squash or hot pepper were found for the state. Instead, winter squash and cayenne pepper prices from the Louisiana State University Research and Extension Ag Center[24] were used.

Table 6. Enterprise budget for okra, grown in degraded soil in Georgia Piedmont.

	AC						
Inputs	**With winter cover crop (AC1)**	**AC1 + straw mulch (AC2)**	**AC1 + spring compost (AC3)**	**AC1 + spring compost + mulch (AC4)**	**AC1 + fall and spring compost (AC5)**	**AC1 + fall and spring compost + mulch (AC6)**	**CT**
Harvest materials costs (US$ per hectare)							
Seed (crop and cover crop)	696	696	696	696	696	696	22
Straw mulch	–	38	–	38	–	38	–
Nutrients (compost or fertilizer)	–	–	764	764	1527	1527	339
Irrigation supplies	1490	1490	1490	1490	1490	1490	1801
Fuel (irrigation and tractor operations)	197	197	197	197	197	197	196
Fixed costs	799	799	799	799	799	799	196
Total harvest materials cost	3182	3220	3946	3984	4709	4747	2554
Labor ($h\,ha^{-1}$)							
Non-harvest labor (Table 4)	217	217	217	217	217	217	106
Crop planting (spring)	84	82	79	86	86	86	89
Weeding (summer, throughout)	235	333	234	356	316	331	879
Total non-harvest labor	536	632	530	659	619	634	1074
Payroll detail (annual, per hectare)							
Farm household employee non-harvest labor (h)	536	632	531	657	620	632	1074
Hired employee non-harvest labor cost[1]	0	0	0	0	0	0	480
Total non-harvest labor cost (annual)	0	0	0	0	0	0	480
Total harvest labor hours	731	682	741	699	580	692	608
Total harvest labor cost[1]	0	0	0	0	0	0	0
Total costs (materials and labor)	3182	3220	3946	3984	4709	4747	2554
Returns							
Okra ($kg\,ha^{-1}$)	3946	4013	3382	3858	4369	4511	2602
No. of units (6.8 kg = $\frac{1}{2}$ bushel unit)[2]	580	590	497	567	643	663	383
Price (US$ $\frac{1}{2}$ $bushel^{-1}$)	30	30	30	30	30	30	7
Gross returns (US$ ha^{-1})	17,400	17,700	14,910	17,010	19,290	19,890	2681
Net returns (US$ ha^{-1})	14,218	14,480	10,964	13,026	14,581	15,143	127

[1] Labor costs based on $10.00 hourly wage.
[2] Typical marketing unit = $\frac{1}{2}$ bushel.

Identifying dominant, preferred production methods

Our study employed a stochastic dominance analysis model to evaluate the risk and return structures of the ten treatments in this work over the course of the 3-year study. Stochastic dominance analysis is a risk-efficiency criterion for determining the risk-efficient set of alternatives available to producers when faced with uncertain outcomes. More than just examining the return structures of (or level of payoffs from) different production alternatives, the stochastic dominance framework evaluates trade-offs between such levels and variability (riskiness) of the payoff variable.

Stochastic dominance is a useful, appropriate tool for analyzing decisions in agriculture, as outcomes of production decisions and methods can be influenced by a wide range of risk factors (such as weather, climate and pests). In making production decisions, a farmer thus must not rely solely on absolute figures, such as average yields or total net farm incomes, as these could be misleading and thus produce less optimal decisions. Specifically, without accounting for risk or variability, a farmer may quickly consider a specific production alternative as already adequately profitable merely based on a high average yield result. The stochastic dominance approach looks beyond total and average values, and also considers the variability of the year-to-year (or seasonal) production conditions that produce such figures. This approach helps farmers determine more favorable production alternatives that could ensure more stable or less risky outcomes.

The risk component of this analysis recognized that uncertainty, which is especially a significant factor in farming situations, can affect realization of payoff. Thus, a decision-maker evaluates trade-offs between higher payoffs and lower risk, with the choice determined by his/her level of risk aversion. In this study, the application of the model and the stochastic dominance framework allows for a ranking of alternatives based on producers' risk preferences for the most risk-efficient set of yields and returns to management.

Table 7. Enterprise budget for hot pepper, grown in degraded soil in Georgia Piedmont.

	AC						OST			
Inputs	**With winter cover crop (AC1)**	**AC1 + straw mulch (AC2)**	**AC1 + spring compost (AC3)**	**AC1 + spring compost + mulch (AC4)**	**AC1 + fall and spring compost (AC5)**	**AC1 + fall and spring compost + mulch (AC6)**	**Winter cover crop + mulch (OST1)**	**OST1 + spring compost (OST2)**	**OST1 + spring and fall compost (OST3)**	**CT**
Harvest materials costs (US$ per hectare)										
Seed (crop and cover crop)	411	411	411	411	411	411	513	513	513	150
Straw mulch	–	38	–	38	–	38	38	38	38	–
Nutrients (compost or fertilizer)	–	–	764	764	1527	1527	–	764	764	614
Irrigation supplies	1490	1490	1490	1490	1490	1490	1801	1801	1801	1801
Fuel (irrigation and tractor operations)	425	425	425	425	425	425	306	306	306	306
Fixed costs	799	799	799	799	799	799	799	799	799	799
Total harvest materials cost	3125	3163	3889	3927	4652	4690	3457	4220	4984	3670
Labor (h ha^{-1})										
Non-harvest labor (Table 4)	217	217	217	217	217	217	205	205	205	106
Crop planting (spring)	217	210	230	217	222	217	309	309	309	309
Weeding (summer, throughout)	494	277	425	245	445	237	57	40	49	371
Total non-harvest labor	928	704	872	679	884	671	571	759	563	786
Payroll detail (annual, per hectare)										
Farm household employee non-harvest labor (h)	955	704	872	679	884	672	571	553	561	785
Hired employee non-harvest labor cost[1]	0	0	0	0	0	0	0	0	0	0
Farm household employee harvest labor (h)	496	398	422	435	348	412	210	348	483	257
Hired employee harvest labor (h)	64	0	0	77	62	109	371	227	183	30
Hired employee harvest labor cost[1]	640	0	0	770	620	1090	3710	2270	1830	300
Total costs (materials and labor)	3765	3163	3889	4697	5272	5780	7167	6490	6814	3970
Returns detail										
Peppers (kg ha^{-1})	5832	5532	6373	3764	5697	3204	3798	4542	4846	3424
Price (US$ kg^{-1})	6.60	6.60	6.60	6.60	6.60	6.60	6.60	6.60	6.60	6.60
Gross returns (US$ ha^{-1})	38,491	36,511	42,061	24,842	37,600	21,146	25,067	29,977	31,983	22,598
Net returns (US$ ha^{-1})	34,726	33,347	38,172	20,145	32,328	19,287	17,900	23,487	25,169	18,628

[1] Labor costs based on $10.00 hourly wage.

Table 8. Enterprise budget for corn and winter squash intercrop grown in degraded soil in Georgia Piedmont.

	AC						OST			
Inputs	**With winter cover crop (AC1)**	**AC1 + straw mulch (AC2)**	**AC1 + spring compost (AC3)**	**AC1 + spring compost + mulch (AC4)**	**AC1 + fall and spring compost (AC5)**	**AC1 + fall and spring compost + mulch (AC6)**	**Winter cover crop + mulch (OST1)**	**OST1 + spring compost (OST2)**	**OST1 + spring and fall compost (OST3)**	**CT**
Harvest materials costs (US$ per hectare)										
Seed (crop and cover crop)	334	334	334	334	334	334	706	706	706	112
Straw mulch		38		38		38	38	38	38	
Nutrients (compost or fertilizer)			764	764	1575	1575		764	1575	811
Irrigation supplies	1490	1490	1490	1490	1490	1490	1801	1801	1801	1801
Fuel (irrigation and tractor operations)	493	493	493	493	493	493	370	370	370	348
Fixed costs	799	799	799	799	799	799	799	799	799	799
Total harvest materials cost	3116	3154	3880	3918	4729	4729	3714	4138	1829	2251
Labor ($h\,ha^{-1}$)										
Non-harvest labor (Table 4)	217	217	217	217	217	217	249	249	249	129
Crop planting (spring)	141	128	133	131	106	131	146	146	146	69
Weeding (summer, throughout)	190	111	183	128	141	133	25	32	20	198
Total non-harvest labor	548	266	533	476	464	481	420	247	415	496
Payroll detail (annual, per hectare)										
Farm household employee non-harvest labor ($h\,ha^{-1}$)	548	457	531	474	464	482	373	383	368	373
Hired employee non-harvest labor cost[1] (US$ ha^{-1})	0	0	0	0	0	0	0	0	0	0
Farm household employee harvest labor ($h\,ha^{-1}$)	47	52	37	49	37	119	32	22	44	49
Hired employee harvest labor cost[1]	0	0	0	0	0	0	0	0	0	0
Total hired labor cost	0	0	0	0	0	0	0	0	0	0
Total costs (materials and labor)	3116	3154	3880	3918	4729	4729	3714	4138	1829	2251
Returns detail										
Winter squash ($kg\,ha^{-1}$)	1191	1806	1097	2509	1599	2928	3112	2536	3640	2480
Price (US$ kg^{-1})	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	0.73
Corn (bushels ha^{-1})	27	52	64	32	27	27	27	42	27	7
Price (US$ $bushel^{-1}$)	11	11	11	11	11	11	11	11	11	3.50
Gross returns (US$ ha^{-1})	2262	3552	2514	4492	2935	5128	5432	4646	6303	1835
Net returns (US$ ha^{-1})	−854	398	−1366	574	−1794	399	1718	508	4480	−416

[1] Labor costs based on $10.00 hourly wage.

Researchers have developed multiple variations of stochastic dominance, but its two basic criteria are first- and second-degree stochastic dominance. We employed second-degree stochastic dominance analysis, which eliminates dominated or inefficient distributions from the first-degree stochastic dominance set[25]. This was accomplished by adding the assumption of risk aversion to the decision-making process with respect to the farmer or land managers' preferences.

Risk-averse agents seeking to maximize utility would never prefer a dominated distribution[26]. Therefore, a second-degree stochastically efficient set of alternatives would be comprised of only non-dominated distributions, and any further reduction of this set would require additional assumptions concerning risk preferences[26].

This analysis ranked the risk and return efficiencies of the ten treatments based on the following parameters:

1. Production yields: this measure isolated the production efficiency from other factors that can affect the risk and return profiles of the production methods. In order to standardize yields across all years and reduce variation, this analysis used the proportion (percent) of the experimental yields to conventional yield estimates for Georgia[27], instead of the absolute yield. Yields for the first year were based on a conventional okra yield of 10,946 kg ha^{-1} (325 bushels $acre^{-1}$); Year 2 yields were based on average conventional cayenne pepper yield of 10,105 kg ha^{-1} (9000 lbs $acre^{-1}$); and Year 3 yields were based on a 50% corn/50% winter squash planting area distribution assumption, with an average corn yield of 3.9 Mg ha^{-1} (62.5 bushels $acre^{-1}$) and average squash yield of 3521 kg ha^{-1} (112 bushels $acre^{-1}$).
2. Net returns per man hour of family labor: the combined effects of production and cost efficiencies are captured by this measure of net return. Profitability is also related to the variable rates of labor intensiveness of the different production methods by calculating the net return per man hour of residual family labor invested in farm work that supplemented the assumed hired labor requirements. This measure thus represented the farm owner's family's compensation for their collective labor hour-investment in the farm operations.

Results and discussion

As discussed previously, budgetary information for organic, conservation tillage systems with which to compare our results was sparse. Some yield and production cost information existed for either organic production or conservation tillage, but rarely both. The few exceptions found used living mulches interplanted with organically managed vegetables[28–30]. Although yields were not statistically different between treatments due to high variation within treatments[12], the resulting differences in returns may be of economic significance to the farmer.

Experimental yields were consistently extremely low compared to conventional production estimates for the state. All yield data in this study must be interpreted in the light of the degraded soils in which the experiment took place. The soils in this study were a highly eroded Pacolet sandy clay loam that was devoid of an A horizon and largely consisted of the B (subsoil) horizon. The site was chosen, because it was the worst soil on the experimental farm, and is characteristic, if not worse, than the sandy clay loams commonly found in the region. Additionally, each crop was only grown for one year in the rotation, and thus yields may not be representative of long-term yield potential. Okra yields were in the 'worst production category'[31], and corn was 14% of the average yield for strip tilled corn in South Georgia[32], after accounting for the production area occupied by winter squash. In addition to the degraded soil on the site, a severe drought in 2007 limited the germination of the heirloom corn variety used in this work that was not treated with fungicide or drought tolerant. Although the yields were lower than conventional averages for the state, okra and hot pepper yields were comparable to experimental yields in an organically managed, conservation tillage experimental study in the Midwest[29].

Organic okra and hot pepper production had the highest net returns to management, although the harvest labor requirements for these crops were 10–15-fold higher than the corn/winter squash intercrop. Both okra and hot pepper are high-yielding, labor-intensive crops, the former with a significant organic price premium. Okra production did not require additional hired labor for any of the treatments, but the hot pepper did require additional harvest labor. However, the greater returns to management justified the expense of hired harvest labor.

Previous research in the region suggested that AC may be best suited to high-value horticultural crops due to higher labor and land requirements needed to manage the hedgerows[11]. However, the labor associated with hedgerow management averaged only 30 h pruning $event^{-1}$ ha^{-1}. This time included the precise application of residues for experimental purposes, and was probably an overestimate of actual labor requirements.

Mulches are frequently used in organic farming systems to suppress weeds, control erosion and retain soil moisture. In 2005 and 2006, mulched AC treatments required 23% less labor than non-mulched treatments, due to effective weed suppression. In 2007, mulch only reduced labor requirements by 4%, due to a lack of weed pressure in the extreme drought. All the OST treatments received mulch; thus, mulched versus non-mulched labor requirements could not be compared in this system. Although mulch applications generally reduced weeding requirements, they also resulted in significantly lower soil carbon levels than non-mulched treatments receiving the same level of compost (Table 9). In the hot, subtropical climate of the southeastern US, evapotranspiration rates in the summer are high and soils dry down rapidly. Increased soil moisture under mulch could have led to increased decomposition rates of organic amendments and soil organic matter in

Table 9. Changes in total soil carbon levels over the course of the accompanying field study. For complete discussion and presentation of results, see Jacobsen and Jordan[12].

Method	Year 1		Year 3		Change in total soil carbon ($Mg\,ha^{-1}$)
	Mean total soil carbon ($Mg\,ha^{-1}$)	Standard deviation	Mean total soil carbon ($Mg\,ha^{-1}$)	Standard deviation	
AC with winter cover crop (AC1)	14.2	4.0	11.4	2.0	−3.8[2]
AC1 + straw mulch (AC2)	19.3	4.0	9.6	1.2	−9.8[2]
AC1 + spring compost (AC3)	14.0	4.3	15.3	4.6	1.3
AC1 + spring compost + mulch (AC4)	14.6	3.6	12.0	5.8	−2.6[1]
AC1 + fall and spring compost (AC5)	13.6	3.3	17.1	4.7	3.5[2]
AC1 + fall and spring compost + mulch (AC6)	14.1	0.9	11.4	1.9	−2.7
Organic strip tillage with winter cover crop + mulch (OST1)	9.6	1.6	7.6	1.1	−2.0
OST1 + spring compost (OST2)	10.3	0.8	9.0	1.0	−1.3
OST1 + spring and fall compost (OST3)	9.0	0.5	8.3	1.0	−0.7
CT	12.8	2.2	10.1	1.2	−2.7[2]

[1] Indicates significant change between Year 1 and end of Year 3 at the $P \leqslant 0.10$ level.
[2] Indicates significant change between Year 1 and end of Year 3 and the $P \leqslant 0.05$ level.

mulched treatments; thus, decreased labor requirements also decreased potential environmental benefits to the system (for a complete discussion of the soil carbon dynamics in this work, see Jacobsen and Jordan[12]).

Additionally, mulched treatments had inconsistent effects on yields in the 3 years. Okra, corn and winter squash yields in the mulched treatments were higher than non-mulched treatments receiving the same level of compost. These crops benefited from the increased moisture under the mulch, as the okra is fungal-disease resistant and the corn and winter squash were grown in a drought year. However, the increased moisture under the mulch led to an outbreak of *Fusarium* wilt in the pepper plants in mulched treatments, decreasing yields. This indicates that mulch in addition to the roller crimper killed cover crop residue may be best suited for dry years and for plants that are not susceptible to soil-borne pathogens.

The effects of compost additions were less straightforward and were highly variable in this relatively short study period. The greater compost application rate ($44.8\,Mg\,ha^{-1}$) did not have consistently greater yields than treatments with $22.4\,Mg\,ha^{-1}$ or no compost. This indicates that the ecological interactions in restorative agroecosystems on degraded soils are more complicated than what would be predicted by simply adding more amendments. Generally, the organic treatments had higher yields than the conventional treatment. When accounting for organic price premiums, the organic treatments had consistently higher net returns to management than the conventional treatment.

Treatments AC2, OST2, OST1 and AC3 had the highest net returns per family labor man hour. In this analysis, the first three of these four treatments had the lowest labor requirements due to the presence of mulch, which suppressed weeds and reduced weeding labor. Additionally, these treatments ranked in the top four in net returns, exclusive of labor costs (Table 10). Altogether, the reduction in labor and high net returns produced better risk-efficiency rankings for these alternatives in terms of net returns to family labor (Table 11). The existing literature presents contrasting results regarding the profitability of organic farming systems when considering both the increased labor requirements and organic price premiums. Some have claimed that reduced input costs, high price premiums and endurance under drier conditions have enhanced organic farms' relative profitability[33,34]. Other studies, however, have contested the advantage due to higher labor costs. As reviewed by Friedman[35], the production costs of organic apples in California were 10–25% higher than conventional farms as a result of higher material and labor costs. In contrast, in a potato study in Idaho involving 18 conventional and organic farming systems, the average material costs were lower among organic farms while labor costs were higher. In this study, the stochastic dominance analysis of the net returns to family labor parameter ranked most of the organic systems consistently higher than the conventional system on this highly degraded soil.

Although the year-to-year variation was important for understanding the utility of each system and certain production practices to specific enterprises, the stochastic dominance analysis allowed us to assess variations in system performance over time. These results can be compared with ecological parameters across all enterprises. Treatments AC3 (AC + $22.4\,Mg\,ha^{-1}\,yr^{-1}$ compost), AC2 (AC + mulch), OST2 (OST + $22.4\,Mg\,ha^{-1}\,yr^{-1}$ compost + mulch) and OST3 (OST + $44.8\,Mg\,ha^{-1}\,yr^{-1}$ + mulch) ranked highest in proportional yields across all

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Table 10. Derivation of net return per hour of family labor. Derivations were based on raw data from individual plots across the three crops (okra, hot pepper and corn/winter squash intercrop) grown in the study. Variation reflects differences in labor requirements and net returns between the three enterprises.

Treatment	Net returns, excluding labor costs (US$ ha^{-1})		Labor requirements (h ha^{-1})		Net returns per hour of family labor (US$ ha^{-1})	
	Mean	Standard deviation	Mean	Standard deviation	Mean	Standard deviation
AC with winter cover crop (AC1)	17,387.57	19,675.08	810.48	467.03	35.10	43.52
AC1 + straw mulch (AC2)	17,453.29	19,929.94	659.81	333.82	49.10	57.77
AC1 + spring compost (AC3)	19,736.93	24,429.93	756.76	414.22	39.52	59.23
AC1 + spring compost + mulch (AC4)	10,876.00	13,229.49	749.65	379.76	28.16	3351.80
AC1 + fall and spring compost (AC5)	11,612.88	18,535.45	739.77	413.53	24.13	48.44
AC1 + fall and spring compost + mulch (AC6)	8629.69	12,371.19	799.66	355.51	24.53	39.62
Organic strip tillage with winter cover crop + mulch (OST1)	11,621.89	17,660.52	623.38	496.15	40.56	44.02
OST1 + spring compost (OST2)	14,791.00	20,889.21	648.38	461.45	44.81	71.51
OST1 + spring and fall compost (OST3)	13,438.58	16,396.43	725.56	487.58	36.95	54.66
CT	2390.39	6800.55	699.33	340.71	3.26	22.21

Table 11. Stochastic dominance results based on production yields, revenues and changes in soil carbon levels. Rankings are expressed from low to high, where 1 is the most dominant (preferable) and 10 is the least.

Method	Percent of average crop yields[1]		Net return/family labor man hour (FLMH)		Stochastic dominance rankings	
	Mean	Standard deviation	Mean (US$ ha^{-1})	Standard deviation	Yield	Net return/ FLMH
AC with winter cover crop (AC1)	40	20	35	44	5	6
AC1 + straw mulch (AC2)	45	20	49	58	2	1
AC1 + spring compost (AC3)	46	30	40	59	1	4
AC1 + spring compost + mulch (AC4)	36	13	28	34	7	7
AC1 + fall and spring compost (AC5)	33	22	24	48	9	9
AC1 + fall and spring compost + mulch (AC6)	35	16	25	40	8	8
Organic strip tillage with winter cover crop + mulch (OST1)	38	25	41	44	6	3
OST1 + spring compost (OST2)	44	29	45	72	3	2
OST1 + spring and fall compost (OST3)	42	23	37	55	4	5
CT	21	13	3	22	10	10

[1] To standardize across yields for different crops, yields are expressed as a percentage of average conventional yields. Proportional yields are based on the following average conventional yields per hectare: 10,946 kg ha^{-1} (325 bushels acre^{-1}) of okra (Year 1), 10,105 kg ha^{-1} (9000 lbs acre^{-1}) of cayenne pepper (Year 2) and a 50/50 acreage allocation with 62.7 kg ha^{-1} (62.5 bushels acre^{-1}) of corn and 3521 kg ha^{-1} (112 bushels acre^{-1}) of squash (Year 3).

years, but averaged only 42–45% of the statewide average[27] (Table 11). These four treatments also produced the most risk-efficient yield structures, given their stochastic dominance rankings.

AC3 and AC5 (AC + 44.8 Mg ha^{-1} mulch yr^{-1}) were the only treatments with net increases in soil carbon over the course of the 3-year study, although the latter was the only treatment with a significant increase. It is important to note that appreciable changes in soil carbon levels requires long-term study, and that soil carbon results presented in this work can be considered indicators of trends, but not definitive, long-term data. However, these results suggested that in highly degraded soils in the subtropics compost additions may be necessary to build soil carbon levels even in systems incorporating winter cover crops and perennial legumes. In addition, while the absence of mulch increased weeding labor, only treatments without mulch increased in soil carbon in the AC system. These results demonstrate that while a few treatments may be preferable for a single parameter, no treatment emerged as dominant for all parameters. However, the AC treatment receiving 22.4 Mg ha^{-1} yr^{-1} (AC3) ranked in the top four for all

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parameters in the stochastic dominance analysis, had significant increases in soil carbon levels and required very little additional labor for hedgerow management, as previously discussed.

Conclusions

Organic farming and other ecological approaches to agriculture employ long-term systems approaches to nutrient and pest management. These systems frequently incorporate the use of winter cover crops, fallow periods and organic amendments to increase soil organic matter and thus increase the long-term productive capacity of the soil[36]. The goal of this work was to gain a general understanding of the economic costs and benefits of experimental agroecosystems designed to restore highly degraded soils in the Georgia Piedmont using a suite of these techniques in combination.

The organic conservation tillage treatments had less tractor and labor costs than the tillage-intensive conventional treatment. The application of mulches effectively suppressed weeds and reduced weeding labor requirements by an average of 23% during non-drought years. However, the presence of mulch increased the decomposition of compost and soil organic matter in this 3-year study, highlighting the need for longer term research on potential soil carbon sequestration benefits of organic conservation tillage-based systems. Yields in all experimental treatments were lower than in conventional studies found for the region. This was expected due to the nature of the soil at the study site, which had been abandoned for conventional row crop production due to lack of productivity for a number of years. However, returns on high-labor, organic crops were over US$30,000 ha^{-1} in some treatments. Our stochastic dominance results demonstrate that no one treatment maximized yields, net returns per family hour of labor or soil carbon increases. However, when these parameters were viewed together, AC systems receiving $22.4\,Mg\,ha^{-1}\,yr^{-1}$ of compost were an optimal risk-efficient choice for all parameters and demonstrated significant gains in soil carbon, a key management challenge in the region. These results indicate that some organic, conservation tillage systems could restore soil productivity and command high returns per land area across multiple enterprises, allowing land to remain in cultivation while improving soil quality.

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