INTEGRATED AND ORGANIC PRODUCTION OF ‘LIBERTY’ APPLE: TWO AGROECOSYSTEMS FROM THE GROUND UP

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INTEGRATED AND ORGANIC PRODUCTION OF 'LIBERTY' APPLE: TWO AGROECOSYSTEMS FROM THE GROUND UP

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An orchard of disease-resistant 'Liberty'/'M.9' apple (*Malus* × *domestica* Borkh.) trees, during and after the transition from conventional to integrated (IFP) and organic fruit production (OFP) was investigated. Over four years, cumulative yields and tree growth were similar in both systems. IFP apples had from 3-17% total cumulative damage (internal and cosmetic), while OFP apples had 3-75% damage. Organic fruit had more cosmetic blemishes. The Environmental Impact Quotient model estimated 79-88% greater negative impact in OFP, largely due to the application of liquid lime sulfur, fish oil, and kaolin clay. Partial budgets estimated 9% greater variable expenses for OFP. Sales values for IFP were estimated at 3% greater with direct market prices and 16% greater with wholesale prices. At harvest, fruit quality indicators, and total phenolic concentrations and antioxidant capacity, were similar between IFP and OFP fruit. In triangle taste tests, consumer panelists were able to discriminate between treatments, but in hedonic and intensity tests, panelists did not consistently rate one treatment more highly than the other. In 2006, panelists rated fruit appearance of OFP apples as less acceptable than IFP. In 2007 after fruit were stored for 9 weeks, organic apples were firmer and had higher SSC, TA and SSC:TA ratios. The mulch-herbicide system used in IFP provided effective weed control while increasing soil organic matter, soil nutrient status, and microbial biomass and respiration rates. The cultivation-chicken manure compost system used in OFP increased soil porosity, mineralizable nitrogen and total inorganic nitrogen, and decreased aggregate stability. Minimal differences were found between treatments in the lower soil depth. In the upper soil depth, bacterial communities were highly influenced by sampling time; the two treatments had different communities by the last observation. Fungal communities in the upper depth were distinct by the third sampling date. Four years of evaluation suggest that IFP could be widely implemented in the Northeastern US, but the current lack of market incentives might impede its adoption. In OFP, producing apples with disease-resistant cultivars showed potential, especially for direct market operations, but a price premium would be necessary to offset greater production costs.

BIOGRAPHICAL SKETCH

Born to Edward and Paula Peck in 1972, Gregory Michael Peck spent the next 18 years roaming the woods in his suburban environment. After graduating from Rye High School, the author attended the University of Vermont. During his collegiate days, he developed a strong affection for horticulture and spent many hours growing fruits and vegetables in the kitchen gardens of his co-operative house. In 1994, he received his B.A. degree in Comparative Religion with a minor in Sociology. The author spent the next few years were skiing the mountains of Vermont and Utah.

By 1996, the author was back on his horticultural journey and apprenticed at the UC Santa Cruz Farm & Garden. It was there that he met his future wife, Kathi. After a stint of farming in Sonoma County, he moved to the Bay Area to start a landscape design business. It was during this time that he decided to return to school for an advanced degree, and so he moonlighted as a post-baccalaureate student filling his transcript with natural science courses.

In the summer of 2001, he and Kathi married. Soon thereafter they moved to Pullman, WA where the author was once again studying the forbidden fruit. During this time, his son Ethan was born. After the author earned his M.S. degree in Horticulture at Washington State University, he and his family moved to Trumansburg, NY, so that he could do his doctorate work at Cornell University.

To teachers who believe in their students,

especially those who believed in me during my long pursuit of this degree.

And to my family, who worked, learned, and endured with me the whole way.

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LIST OF ABBREVIATIONS

a.i.	active ingredient
AMMI	additive main effects multiplicative interaction
ANOVA	analysis of variance
AWC	available water capacity
Bt	*Bacillus thuringiensis*
CpGV	*Cydia pomonella* granulosis virus
EIQ	Environmental Impact Quotient
ICP	inductively coupled argon plasma spectrophotometer
IFP	integrated fruit production
IPM	integrated pest management
IPCA	interaction principal components analysis
IEC	internal ethylene concentration
IOBC	International Organization for Biocontrol
qCO_2	metabolic quotient
MBC	microbial biomass carbon
MBN	microbial biomass nitrogen
qMic	microbial quotient
OFP	organic fruit production
PMD	pheromone mating disruption
PCR	polymerase chain reaction
PMN	potentially mineralizable nitrogen
SOM	soil organic matter
SSC	soluble solids concentration
SB/FS	sooty blotch/flyspeck disease complex

T-RF	Terminal-restriction fragment
T-RFLP	Terminal-restriction fragment length polymorphism
TA	titratable acidity
TP	total phenolic concentration
TCSA	trunk cross-sectional area
NOP	USDA National Organic Program
VCEAC	vitamin C equivalent antioxidant capacity

Chapter One

Introduction

Apple (*Malus* × *domestica* Borkh.) production in the Northeastern United States faces numerous challenges. These include frequent precipitation that results in long disease susceptibility periods, season-long weed pressure, and a formidable local pest complex for this region's tree fruits. Even though apples have been cultivated in New York since the early 1600's, commercial apple production in upstate NY did not begin in earnest until the late-nineteenth century with the advent and application of inexpensive and effective pesticides products, such as Paris Green and arsenical insecticides, and Bordeaux mixture, copper, and sulfur fungicides (Beech, 1905). While pesticides have allowed for the expansion and intensification of agriculture, over the last century, they have also posed numerous noted negative impacts; as a result, a search for safer agrichemicals and agricultural practices has continued.

Integrated pest management (IPM), has perhaps become the most widely used systems approach to reduce agrichemical inputs. From more than 60 definitions, Prokopy (2002) summarized IPM as a decision-based process involving coordinated use of multiple tactics for optimizing the control of all classes of pests (insects, pathogens, weeds, vertebrates) in an ecologically and economically sound manner. Various IPM elements are now widely employed in many Northeastern orchards (MacHardy, 2000), and in small commercial orchards comprehensive IPM systems have been successfully employed with less than 10% of the fruit damaged by pests (Prokopy, 2002). However, for larger scale commercial orchards the time needed to establish such intensive IPM systems, coupled with the additional costs and micromanagement, has made this approach unprofitable without additional price incentives (Prokopy, 2002). Integrated (IFP) and organic fruit production (OFP) systems both use intensive IPM programs, but they also attempt to manage the orchard with ecological processes, biodiversity, and plants that are adapted to local conditions. Both systems minimize the use of inputs that have adverse effects on the environment or human health.

Sometimes called “green” or “ecological” fruit growing, IFP has become the dominant apple production system in Western Europe and New Zealand. Encompassing all aspects of fruit growing, IFP is a science-based system that involves biological and chemical pest controls based on monitoring and damage-action thresholds, selection of disease-resistant and locally adapted fruit cultivars and rootstocks, strict limits on fertilizer applications determined by crop nutrient status and soil fertility tests, a short-list of permissible and restricted pesticides, and on-farm inspections to certify that growers are following appropriate regulations. Integrated fruit production is of particular interest to those who export apples to Europe, where most major supermarket chains now accept only EurepGAP certified IFP or organic fruit, and require complete traceability for all produce on their shelves. Currently, IFP has multiple national or regional guidelines but no unified global standards.

The US domestic market for products from IFP systems has not been well explored, and it is questionable whether IFP has the potential to be competitive with either conventional produce, or produce grown and labeled as organic. However, IFP has had some market penetration in the Northeast with programs such as CORE Values Northeast and the Red Tomato EcoApple. At this time, “integrated” does not invoke the same name recognition as “organic” in the marketplace, and as an agricultural system it is not well understood by consumers. There is, however, both grower and researcher interest in further developing the IFP market; for example, Cornell

Table 1. Estimations of organic and total tree fruit production for New England based upon a Spring 2005 survey (Source: Merwin et al., 2005).

State	Number of organic farms	Number of organic orchards	Organic tree fruit area (ha)	Number of tree fruit orchards	Total tree fruit area (ha)	Percentage of tree fruit area certified organic
Connecticut	28	2	<4	100	1,214	0.3
Maine	280	10	50	138	1,416	3.5
Massachusetts	212	3	<4	128	1,813	0.2
New Hampshire	86	9	<4	68	850	0.5
New Jersey	52	2	<4	240	931	0.4
New York	312	22	51	600	20,558	0.2
Pennsylvania	~ 200	6	5	790	11,736	0.0
Rhode Island	12 (?)	2 (?)	4	24	121	3.7
Vermont	333	13	<10	87	1,093	0.9

University recently developed an IFP protocol for NY State (Carroll and Robinson, 2006). IFP appeals to growers in the Northeast because it allows the use of a greater number of materials compared with organic, but is still considered an “environmentally friendly” farming system.

Organically produced foods make up the most rapidly growing sector in the North American and European food markets, accounting for more than 10% of total food sales in some countries, with worldwide sales estimated at greater than US$40 billion (Willer and Yussefi, 2007). Products sold with an organic label are often more expensive than a non-organic equivalent, in part due to increased production costs associated with this production strategy. Despite higher market value for organic produce, less than 0.5% (approximately 50 ha) of New York’s apple production was organically certified in 2005 (Table 1). By comparison, there are 1400 ha of organic apple orchards in California and over 3080 ha in Washington State (Granatstein and Kirby, 2008). Currently, the majority of organic apples grown in the US are from Washington State, which also produces the greatest total volume of apples. As the second largest apple producer, NY must continue to explore marketing channels that offer growers a competitive niche in the marketplace. The market for organic food has grown at around 20% annually for the past decade, and coupled with the increased consumer interest in purchasing locally grown food, New York has the potential of providing some of the larger markets in the US with locally grown organic apples.

Many NY fruit growers have expressed interest in producing for the IFP or organic sector. However, only a limited number of scientific trials in commercial IFP or organic orchards exist. Nonetheless, much research has been conducted in NY that has direct applicability to IFP and organic systems. For example, substantial research efforts have been made in disease and insect biocontrol, herbicide-free orchard floor management, pheromone mating disruption to control internal lepidopteron pests, and various low-input spray programs. Additionally, since the 1940s, apple breeders from Cornell University, Purdue University, Rutgers University, and the University of Illinois have worked to develop high quality, disease-resistant apple cultivars, which are well adapted to our climate, and have characteristics similar to mainstream cultivars. Disease-resistant cultivars should be the basis for both IFP and organic apple systems.

While both IFP and organic systems have been implemented throughout the world there is little understanding of how these systems affect the orchard agroecosystem in the Northeast. In California, transitional organic and conventional apple orchards have been compared for orchard productivity (Caprile et al., 1994; Vossen et al., 1994; Werner, 1997; Swezey et al., 1998); and in Canada, Switzerland, and Belgium, the harvest or post-harvest fruit quality of IFP and organically or conventionally grown apples have been studied (DeEll and Prange, 1992; DeEll and Prange, 1993; Weibel et al., 2000; Róth et al., 2007). In Washington State, organic, integrated, and conventional apple production systems were assessed for horticultural performance, soil quality, environmental impacts, energy efficiency, economic sustainability, and fruit quality (Glover et al., 2000; Reganold et al., 2001; Peck et al., 2006). Many claims have been made about IFP and OFP systems, both in published reports and in the popular media, most of which have never been validated under NY conditions.

Within this dissertation, I describe a four-year comprehensive experiment comparing IFP and OFP systems in an established commercial orchard in Ithaca, NY. The primary objectives of this research were to study the multiple horticultural, agroecological, fruit quality, economic, and soil quality aspects of producing apples under these systems. In Chapter 2, I discuss comparative apple production by investigating the yield, arthropod and cosmetic fruit damage, tree growth, leaf nutrient levels, environmental impacts, variable costs of production, and potential sale value at the direct market and wholesale level. In Chapter 3, fruit maturity and quality were evaluated using internal ethylene concentration, starch pattern index, flesh firmness, soluble solids concentration (SSC), titratable acidity (TA), percent of surface blush, antioxidant capacity, total phenolic content, and consumer sensory panels. In Chapter 4, soil effects are described at two depths (0-6 and 6-12 cm) for chemical, physical, and biological properties. Weed coverage and biomass were also measured. Terminal-Restriction Fragment Length Polymorphism (T-RFLP) analysis was used to determine differences in bacterial and fungal microbial community composition between the two systems. The null hypothesis was that the above-cited parameters would not be different between IFP and OFP management.

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Chapter Two

Integrated and Organic Fruit Production Systems for 'Liberty' Apple in the Northeast USA: Yields, Tree Growth, Fruit Damage, Economics, and Environmental Impact

Abstract

Yields, tree growth, and fruit damage under integrated (IFP) and organic fruit production (OFP) of disease-resistant 'Liberty' apples (*Malus* × *domestica* Borkh.), during and after the transition from conventional management in an established high-density commercial orchard was studied and assessed in terms of environmental impact and economics. Evaluations included: yields, tree growth, leaf nutrient levels, arthropod and cosmetic fruit damage, environmental impacts, variable costs of production, and potential sale value using both direct market and wholesale market prices. Cumulative yields (2004-07) of both harvested and total (harvested + dropped) fruit were not different between the two systems. Tree size (trunk cross-sectional area) was not consistently different between the production systems. The IFP apples had between 3-6% insect damage (within normal percentages for this region) and between 3-17% total damage (either internal or cosmetic). The OFP apples had between 3-25% insect damage and 3-75% total damage, varying greatly from year to year. In 2006, superficial blemishes caused by diseases and scarf-skin were serious problems on OFP fruit. Using the Environmental Impact Quotient Field Use Rating, the potential for negative environmental impacts were estimated to be 79-88% greater in the OFP system, largely due to the use of lime sulfur and fish oil for thinning, and the large quantity of kaolin clay used for pest control under. Partial budgets of the systems estimated variable expenses to be 9% greater for OFP. Sales value was estimated to be 3% greater for IFP using direct market prices (e.g., farm stand or farmer's market),

and 16% greater using wholesale market prices. A 62% premium was used to calculate the OFP sale value in the fourth year (the first year fruit could have been sold with an organic label). Four years of evaluation suggest that IFP could be widely implemented in the Northeastern US, but the lack of market incentives will likely impede adoption. Producing disease-resistant apples under an OFP system also showed potential for success, but a price premium would be needed to offset the reduced profitability incurred from arthropod pests, poor fruit finish, and small fruit size.

1. Introduction

Formidable disease and arthropod problems, tree nutrition, and crop load adjustment all pose barriers to adoption of integrated (IFP) and organic fruit production (OFP) of apples (*Malus* × *domestica* Borkh.) in the Northeastern United States. (Croft and Hoyt, 1983; Schupp, 2004; Merwin et al., 2005). These barriers have kept commercial fruit growers in this region from accessing the potentially lucrative markets in all but a few niche market situations, such as roadside and farmers' markets. However, advanced integrated pest management (IPM) and some effective biocontrol agents have recently been successfully employed in Northeastern US orchards (MacHardy, 2000; Prokopy et al., 2003; Agnello et al., 2003). Additionally, formulations and utilization of neonicotinoids, strobilurins, naturalytes, kaolin clay, *Cydia pomonella* granulosis virus (CpGV), and pheromone mating disruption for several species of Lepidoptera pests have greatly improved. For OFP, advances have also been made in tractor-mounted cultivators, chemical thinning strategies, and foliar nutrient formulations. The confluence of these factors has increased the potential for IFP and OFP systems in humid growing regions.

The International Organization for Biocontrol (IOBC) defined IFP as "the economical production of high quality fruit, giving priority to ecologically safer methods, minimising the undesirable side effects and use of agrochemicals, to enhance the safeguards to the environment and human health”. More specifically, IFP is a science-based system that utilizes biological and chemical pest controls based on monitoring to assess damage-action thresholds, selection of disease-resistant and locally adapted fruit and rootstock cultivars, strict limits on fertilizer applications determined by crop nutrient status and soil fertility tests, a short-list of permissible and restricted pesticides, and on-farm inspections to certify that growers are following IFP regulations (Anonymous, 2002). Most IFP guidelines comply with the EurepGAP (European Good Agricultural Practices) certification system that is a requirement of many European retailers (Carroll and Robinson, 2004). This has fostered the widespread adoption of IFP in much of Western Europe, as well as New Zealand, Chile, Australia, and other countries exporting to Europe. Despite being the standard method for apple production in many parts of the world, IFP has not been widely practiced in the US. In order to help New York growers access these markets, Cornell University recently developed an IFP protocol based on IOBC standards (Carroll and Robinson, 2006).

Organic agriculture, as defined by the USDA National Organic Program (NOP), also places strong emphasis on ecological farming methods (Federal Register, 2000). However, the NOP restricts inputs to those that are derived from natural substances, such as manure-based fertilizers and pesticides derived from biological or mineral sources. A three-year transition period and the development of a farm plan for nutrition and pest management are additional requirements under the NOP (Federal Register, 2000). Most OFP in the US is located in arid, inland valleys of the West Coast, where disease and arthropod pests are relatively few and can be managed without synthetic pesticides. Granatstein and Kirby (2008) reported that 4.5% of Washington State’s apple orchards (>3,080 ha) are under organic management, and that production may double by 2009. Though New York is the second largest US producer of apples (after Washington), less than 0.5% of NY's apple production (50 ha) was organically certified in 2005 (Merwin et al., 2005).

Disease control contributes greatly to pesticide use in NY's apple orchards, with over 5.6×10^5 kg of fungicides being applied annually (USDA NASS, 2006). In OFP systems, where synthetic fungicides are not permitted, the use of sulfur, copper, and lime sulfur may increase the total amount of applied fungicides, compared with conventional systems (Kovach et al., 1992). In addition, some organically approved fungicides have potential negative effects on soil organisms, farm worker health, and fruit appearance (Holb et al., 2003; http://extoxnet.orst.edu/). One approach for reducing the quantity of pesticides needed in apple production is to grow cultivars developed specifically for disease resistance, particularly apple scab [*Venturia inaequalis* (Cooke) G. Wint.]; one of the most common and severe diseases in the many humid growing regions. Breeding scab-resistant apples began in the 1940s, and dozens of high quality scab-resistant cultivars are now commercially available (Merwin et al., 1994; Jönsson and Nybom, 2006). One of the better-known scab-resistant cultivars, 'Liberty' (a cross of 'Macoun' × Purdue 54-12), has functional immunity to apple scab, and resistance to fire blight [*Erwinia amylovora* (Burrill) Winslow et al.], cedar apple rust (*Gymnosporangium juniperi-viginianae* Schwein), and powdery mildew [*Podosphaera leucotricha* (Ellis & Everh.) E. S. Salmon], thus making it an excellent cultivar for IFP and OFP (Lamb et al., 1978; Ellis et al., 1998).

There is little understanding of how IFP or OFP systems affect orchard agroecosystems in the Northeastern US (Merwin et al., 2005). Research in arid climates has indicated that organic apple orchards could be more profitable, sustainable, and have improved fruit quality and nutritional content compared with integrated and conventional systems (Reganold et al., 2001; Peck et al., 2006). Studies in New Zealand and Iowa have shown that pest pressure in humid environments may be a serious impediment to these production systems, and better management of new materials will be needed (Suckling et al., 1999; Delate et al., 2008). Additionally, OFP has led to smaller fruit with less market value (Reganold et al., 2001; Peck et al., 2006; Delate et al., 2008).

Over four-years, IFP was compared with the more widely recognized OFP system during and after the transition from conventional management. This systems-level project was conducted in a 'Liberty' apple orchard under humid growing conditions. Both systems used published certification protocols and recent advances in IPM, groundcover management, pesticides, machinery, and crop load management techniques. The null hypothesis was that yields, tree growth, fruit damage, economics, and environmental impact would not be different between IFP and OFP management.

2. Materials and Methods

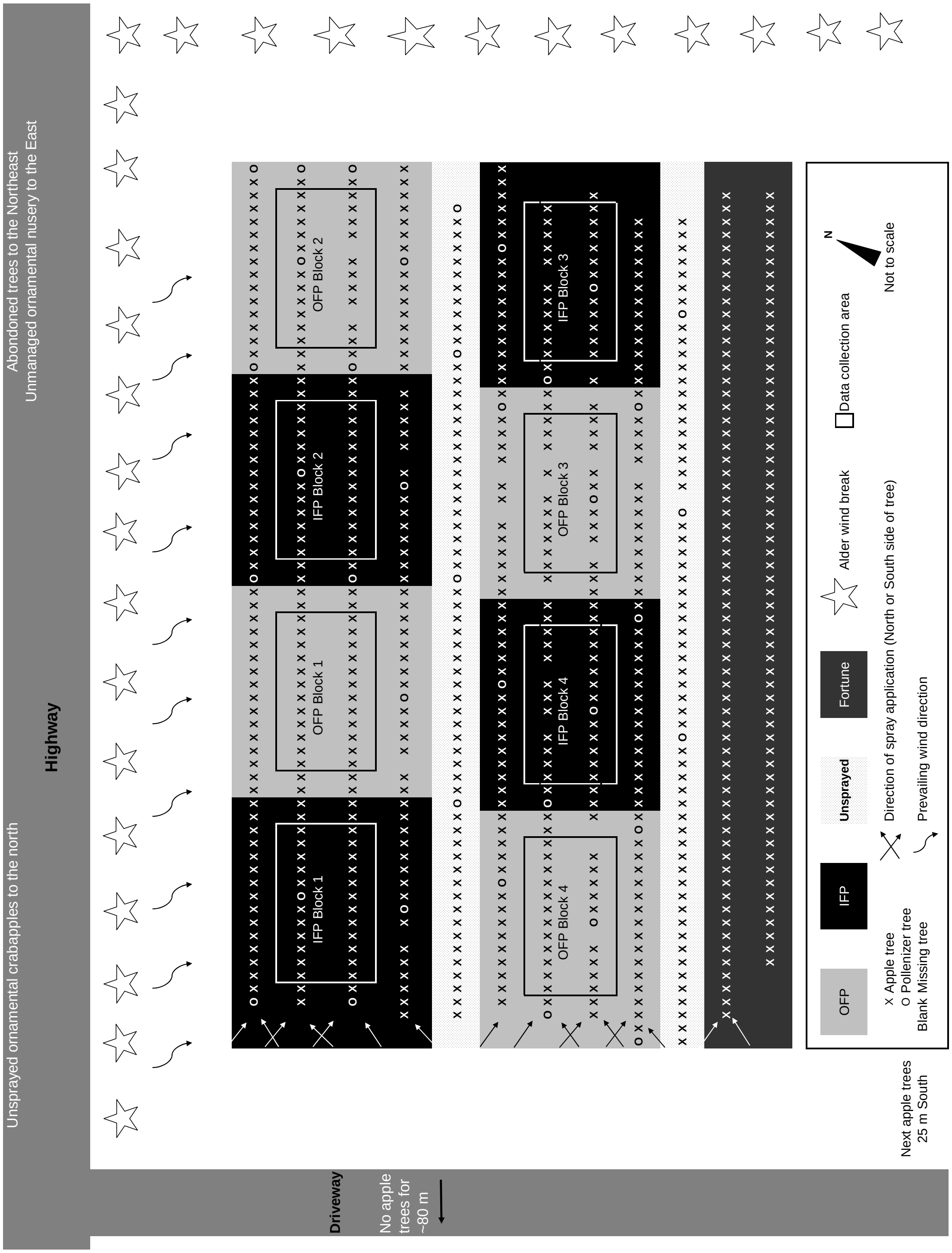
2.1. Study location and experimental design

The experiment was located in a 0.42 ha block of high-density (1537 trees ha^{-1}; 1.5 m between trees; 4.3 m between rows; 2.7 m tall) 'Liberty'/'M.9' apple trees at the Cornell Orchards in Ithaca, NY (42º 26' N, 76º 27' W). The soil was a Collamer silty clay loam series (fine-silty, mixed, active, mesic Glossaquic) formed from glacial lacustrine sediments. The orchard was planted in 1994 and trained to a modified vertical-axe form with pollenizer crabapple trees located throughout. At the outset of the experiment (May 2004) soil nutrient availability, organic matter (3%), and pH (6.4) were found to be similar among the plots in the top 20 cm (Vollmer, 2005). Drip (1994-2005) and low-flow micro-sprinkler (2006-07) irrigation systems were used to supplement precipitation at the site. The irrigation system was altered in 2006 raising the emitters to 0.5 m above ground, improving access for the cultivation equipment. A windbreak of European black alder [*Alnus glutinosa* (L.) Gaertn.] bordered the north and east sides of the experiment, beyond which were unsprayed ornamental crabapples (*Malus spp.*), abandoned apple trees, and nurseries for University landscaping (Figure 1). A conventionally managed block of 'Fortune' apple trees bordered the experiment to the south, with the next block of apple trees 25 m farther south. The next closest planting of conventionally managed orchard was 80 m to the west. Prevailing winds at the site were from the northwest. While the orchard was in close proximity upwind from conventionally managed orchards, the site provided ample influx of pests and diseases from surrounding flora and would be similar to commercial plantings in the region.

A randomized complete block design with four replications of the two production systems (IFP and OFP) was implemented in 2004. Each experimental plot consisted of four adjacent rows, each containing sixteen trees (Figure 1). The experimental design and execution of the treatments were intended to prevent spray drift among plots. All sampling occurred in the center 12 trees of the two middle rows of each experimental plot, with buffer trees on all sides. Chemical thinners, crop protectants, and foliar fertilizers were applied on a tree-row-volume basis of 935 L ha^{-1} with a compact Turbo-mist curtain airfoil sprayer (Slimline Manufacturing LTD). An unsprayed buffer row of trees was situated between the northern and southern treatment blocks, and between the southern block and the 'Fortune' apple trees to the south. Sprays were directed toward the sample area within the exterior non-sample rows. Close inspection of the orchard after applications of the highly visible kaolin clay during each growing season confirmed that spray cross contamination across plots was negligible.

For the ten years prior to the implementation of this project the orchard was under an insect and disease management program similar to many commercial NY

Figure 1. Map of the 0.42 ha high-density (1537 trees ha^{-1}; 1.5 m between trees; 4.3 m between rows; 2.7 m tall) research block of 'Liberty'/'M.9' apple trees at the Cornell Orchards in Ithaca, New York. Each treatment [integrated (IFP) or organic fruit production (OFP)] was replicated four times in a randomized complete block design and consisted of four adjacent rows, each containing sixteen trees. Sampling occurred in the center 12 trees of the two middle rows of each experimental plot.


Abondoned trees to the Northeast
Unmanaged ornamental nusery to the East
Highway
Unsprayed ornamental crabapples to the north
Driveway
No apple trees for ~80 m
OFP Block 2
IFP Block 2
OFP Block 1
IFP Block 1
IFP Block 3
OFP Block 3
IFP Block 4
OFP Block 4
OFP
IFP
Unsprayed
Fortune
Alder wind break
Data collection area
N
Not to scale
X Apple tree
O Pollenizer tree
Blank Missing tree
Direction of spray application (North or South side of tree)
Prevailing wind direction
Next apple trees 25 m South

orchards, as described in Agnello et al. (2007). Predatory mites were well established at the site, and no residual soil-active herbicides had been used in the six years before this experiment began. An intensive IPM program was used to make pest control decisions in both treatments. Before bloom, pheromone lure traps for codling moth [*Cydia pomonella* (L.)], oriental fruit moth [*Grapholita molesta* (Busck)] and lesser appleworm [*Grapholita prunivora* (Walsh)], spotted tentiform leafminer [*Phyllonorycter blancardella* (Fabr.)], and obliquebanded leafroller [*Choristoneura rosaceana* (Harris)], and white sticky traps for tarnished plant bug [*Lygus lineolaris* (Palisot de Beauvois)] and European apple sawfly [*Hoplocampa testudinea* (Klug)] were placed in each of the eight plots to monitor weekly pest flights. Sampling for folivorous and beneficial arthropods was also conducted weekly throughout the growing season, as described in Agnello et al. (2007). Insecticide applications were timed based upon these monitoring data, species- and site-specific degree-day based phenological models, and local knowledge of the pest complex. If more than one pesticide was permitted to control a particular pest within a treatment, then the preferable material was selected based upon toxicity, efficacy, residual activity, cost, and recommendations from Cornell Cooperative Extension personnel and farm management.

In addition to the sprayed chemicals, various cultural practices were employed following recommended ecological pest control approaches under both IFP and organic certification schemes (Federal Register, 2000; Carroll and Robinson, 2006). Pheromone mating disruption (PMD) was used throughout the planting for codling moth and oriental fruit moth in 2006 (Isomate® C Plus at 988 ties ha^{-1} and Isomate-M-100 at 371 ties ha^{-1}) and 2007 (Isomate® CM/OFM TT at 484 ties ha^{-1}). To trap-out apple maggot flies, red spherical sticky traps along with an apple fruit essence (butyl hexanoate ester) attractant volatile were placed in early July around the perimeter of the entire experimental orchard at a distance of 10 m between traps, with fruit removed within a 30 cm radius of each trap (Prokopy et al., 2003; Rull and Prokopy, 2004). Whenever the same active ingredient (a.i.) was applied to both systems, equivalent rates were used. Other orchard operations such as pruning, irrigation, and mowing were the same in both treatments.

Neither IFP nor OFP systems have been widely employed for apples in NY, so available guidelines and personal knowledge of how the systems operate in other apple-growing regions were used in conjunction with consultations with practicing growers and Cornell Cooperative Extension personnel to develop the management strategies for each system. During all four years, the overall treatments (IFP or OFP) were maintained. However, due to weather, changing pest and disease complexes, the availability of new products, and results from the previous seasons, the inputs and cultural practices were adapted to the specific seasonal conditions each year as in comparable commercial operations.

IFP-certifiable treatment

The IFP system followed published NY IFP standards (Carroll and Robinson, 2006). Broad-spectrum pesticides (i.e., organophosphates, carbamates, chlorinated hydrocarbons, synthetic pyrethroids, and residual soil-active herbicides) that are often used in conventional apple orchards in NY were not applied in the IFP treatment. Instead, IFP utilized EPA-defined “reduced risk” pesticides, which have “low impact on human health, low toxicity to non-target organisms (birds, fish, and plants), low potential for groundwater contamination, lower use rates, low pest resistance potential, and compatibility with Integrated Pest Management” (http://www.epa.gov/opprd001/workplan/reducedrisk.html). Products included indoxacarb (Avaunt®), spinosad (SpinTor®), several neonicotinoids [acetamiprid

(Assail® 70WP), thiacloprid (Calypso®), and thiamethoxam (Actara™)], and bifenazate (Acramite®). Two “attract and kill” (pheromones mixed with a synthetic pyrethroid in a sticky carrier) products (LastCall™ CM and LastCall™ OFM) were applied to the IFP orchard at a rate of two drops per tree in 2004. Streptomycin was applied when fire-blight infections were likely based upon the CougarBlight model (Smith, 1999). Applications for Botryosphaeria rot (*Botryosphaeria dothidea*), sooty blotch [a fungal complex; including, *Peltaster fruticola* (Johnson, Sutton & Hodges), *Leptodontium elatius* (G. Mangenot) De Hoog, and *Geastrumia polystigmatis* Batista & M.L. Farr], and flyspeck [*Schizothyrium pomi* (Mont. & Fr.) Arx], consisted of the stobilurin, kresoxim-methyl (Sovran®; 0.06 kg a.i. ha^{-1}) or the strobilurin–anilide mixture of pyraclostrobin + boscalid (Pristine®; 0.13 kg a.i. ha^{-1} + 0.26 kg a.i. ha^{-1}, respectively) when predictive models and scouting records indicated high risk of infection (Brown and Sutton, 1995). To control weeds in the IFP system, two glyphosate herbicide treatments (2.9 kg a.i. ha^{-1}) were applied in 2004 and 2005, none in 2006, and one in 2007. To minimize herbicide applications while improving soil quality (Yao et al., 2005), a 1-m-wide composted hardwood bark chip mulch (obtained from local sawmills) was placed under the IFP trees to an average depth of 7.6 cm using a side discharge Millcreek Row Mulcher (Leola, PA) in November 2005. Chemical fruit thinning occurred at petal fall and at 10-12 mm fruitlet diameter with naphthaleneacetic acid (Fruitone N®; 0.0074 kg a.i. ha^{-1}) or 6-benzyladenine (Exilis® Plus; 0.07-0.093 kg a.i. ha^{-1}) in conjunction with carbaryl (0.52 kg a.i. ha^{-1}), followed by selective hand thinning in mid-June each year. Foliar nutrients consisted of average yearly (2005-2007) spring to early summer applications of Solubor® DF (US Borax Inc.; Valencia, CA; 1.8 kg ha^{-1}), Zinc EDTA (3.8 L ha^{-1}), Epsom salt (28 kg ha^{-1}), and Urea (2.8 kg ha^{-1} in 2006-2007 only). Calcium chloride was applied in late summer at a yearly (2005-2007) average of 10.2 kg ha^{-1}. In Fall 2005-07, sulfate of potash-magnesia (Sul-Po-Mag) was applied at a rate of 112 kg K_2O ha^{-1}.

OFP-certifiable treatment

The organic treatment followed USDA-NOP guidelines and the published list of approved materials (Federal Register, 2000; www.omri.org). *Bacillus thuringiensis* (*Bt*), CpGV (CYD-X®), petroleum oils, pyrethrum (PyGanic® EC 1.4$_{II}$), and spinosad (Entrust®) were used as insecticides. Kaolin clay particle film (Surround® WP) was used as a crop protectant. Streptomycin for fire blight, and lime sulfur and potassium carbonate for botryosphaeria rot and the sooty blotch/flyspeck (SB/FS) complex were applied based on the same decision protocol described for IFP. Organic weed control originally consisted of mechanical tillage with a tractor-mounted Rinieri side-sweep subsurface cultivator (Forli, IT) in 2004 (2 passes) and 2005 (1 pass), and subsequently consisted of a tractor-mounted Wonder Weeder (Harris Manufacturing; Burbank, WA) cultivator in 2005 (1 pass), 2006 (3 passes), and 2007 (3 passes). Chemical fruit thinning involved applications of Crocker's fish oil (Quincy, WA) (18.3 kg a.i. ha^{-1}) and liquid lime sulfur (4.1-8.1 kg a.i. ha^{-1}) at petal fall and then again in 5-12 d, followed by selective hand thinning in mid-June each year. Foliar nutrients consisted of average yearly (2005-2007) spring to early summer applications of Solubor® DF (1.8 kg ha^{-1}), Yeoman® brand 7% zinc (Northwest Agricultural Products; Pasco, WA; 4.8 L ha^{-1}), Epsom salt (28 kg ha^{-1}), and Mermaid™ Soluble Fish Powder (IFM; Wenatchee, WA; 11% N; 12 kg ha^{-1}). Natural-Cal (Genesis AgriProducts; Yakima, WA) was applied in late summer at a yearly (2005-2007) average of 75.2 L ha^{-1}. Chicken manure compost was applied at a rate of 697 kg (fresh wt) ha^{-1} (equivalent to 78 kg N ha^{-1}) in October 2005. In Fall 2005-07, sulfate of potash-magnesia (K-Mag) was applied at a rate of 112 kg K_2O ha^{-1}.

2.2. Orchard productivity

Fruit were harvested on one harvest date in 2004, two harvests in 2005, and three harvests in 2006 and 2007. Trees next to pollenizers or gaps were avoided for harvest assessments. Annual tree growth was measured by calculating trunk cross-sectional area (TCSA) from measurements of trunk circumference at 20 cm above the graft union on all ‘Liberty’ trees within the sample area. Calculations of harvested yield, number and weight of fruit that dropped to the ground prior to harvest, yield including dropped fruit, yield efficiency (yield including dropped fruit per TCSA), crop load (number of fruit including dropped fruit per TCSA), and average fruit weight were calculated by counting and weighing all of the fruit from at least three sample trees per plot per harvest date.

2.3. Leaf nutrient concentrations

In early August of each year, a pooled sample of 100 mid-terminal shoot leaves in each plot was taken from mid-canopy height. Leaves were dried at 82ºC to constant weight, and analyzed for total carbon (C) and total nitrogen (N) by Dumas combustion, and for essential macro- and micronutrients with an inductively coupled argon plasma (ICP) spectrophotometer at the Cornell Nutrient Analysis Lab on a dry-weight basis (Kalra, 1998).

2.4. Cullage assessment

All apples from one harvest date in each year (mean 815 fruit per block) were graded on a computer automated MAF-RODA Pomone fruit sorter (Montauban cedex, FR) for fruit weight and USDA defined color grade (Federal Register, 2002). Box size packouts (19.1 kg equivalent) were determined by fruit count based upon fruit size. For example, an 80-count box consisted of 80 apples, each weighing between 203-

255 g. These fruit were also visually inspected, and arthropod, disease, and cosmetic damage were tallied. Where applicable, USDA grading definitions for injury and damage were used (Federal Register, 2002).

2.5. Environmental Impact Quotient

The EIQ generates composite values for each pesticide based upon calculated ranking for dermal toxicity, chronic toxicity, systemicity, fish toxicity, leaching potential, surface loss potential, bird toxicity, soil half-life, honeybee toxicity, beneficial arthropod toxicity, and pesticide half-life on the plant surface (Kovach et al., 1992). The EIQ values were taken from the most recently updated version (January 2007) of the online database (http://nysipm.cornell.edu/publications/eiq/default.asp). The value for sulfur was used for liquid lime sulfur and the value for petroleum oil was used for fish oil (J. Kovach, personal communication). Values for naphthaleneacetic acid, 6-benzyladenine, and CpGV were not available for the EIQ model, but these materials were applied in very small quantities and would not likely have contributed greatly to the EIQ. Field Use Ratings were calculated by multiplying the EIQ value by the percent a.i. and then by the application rate (Kovach et al., 1992). Field Use Ratings for all materials used each year were summed and reported as EIQ ha^{-1} y^{-1}.

2.6. Variable costs of production

Partial budgets for the costs of production (machinery + labor + materials) for each system were compiled, taking into account the variable costs of machinery use, materials, and labor for operations that were different between systems. For example, this assessment did not include mowing or pruning since these operations were the same in both systems. Equipment costs and wages were based on a 20 ha farm using

NY State data from White (2008) and White et al. (2008). Fixed costs were assumed to be equal between the systems and were not included in the analysis. It was assumed that the farm already owned all necessary machinery except the Millcreek mulcher and the Wonder Weeder. For all other equipment only variable operation costs (fuel, repairs, and lubrication) were calculated. Monetary values are reported in US dollars ($). For the Millcreek mulcher, a rental rate of $150 d^{-1} and an application rate of 2 ha d^{-1} were estimated. The fixed cost for the Wonder Weeder was calculated at $575 y^{-1} and included salvage value, interest, and interest on salvage value (assuming that the implement was purchased for $5000 and would last for 10 years). The operating cost of the Wonder Weeder (not including the tractor) was calculated at $1.50 h^{-1} (based on 60% of total repair costs over 2000 h of life). The Wonder Weeder costs were used for all four years of budget estimates in this experiment, and excluded the costs of owning and operating the Rinieri cultivator. A diesel fuel rate of $0.88 L^{-1} was used for all four years of this study. The following machinery rates were used: spray tractor (62-HP, 2WD, spray cab) at $12.92 h^{-1}; tractor (45-HP, 4WD) for cultivation, herbicide application, and spreading compost and bark mulch at $11.87 h^{-1}; air-blast sprayer (1136 L) at $3.90 h^{-1}; and herbicide sprayer (189 L) at $0.41 h^{-1}.

For skilled labor (tractor spraying) the rate was $18.55 h^{-1}; for semi-skilled labor (tractor driving while applying bark mulch and compost, and when cultivating) the rate was $14.39 h^{-1}; and for unskilled labor (spreading bark mulch and compost, hand hoeing, hand thinning, and hanging the pheromone mating disruption dispensers) the rate was $11.17 h^{-1}. For harvesting, the rate was $0.07 kg^{-1}, which included seasonal labor, tractor drivers, and truck drivers. The same hourly rates were used for all four years of this experiment.

2.7. Potential market value of fruit

Potential prices received for marketable fruit were estimated for two venues: a direct market operation, such as a retail farm stand or farmers' market that made and sold cider onsite as a value added product, and a wholesale market where the selling price represented the money going to the packinghouse or broker. Neither direct market nor wholesale prices represented net returns to the grower in our survey. Costs such as overhead, employee wages, and marketing and storage fees, were not subtracted from reported values. The objective was to show the potential differences in returns between each production system in the two different markets.

The following assumptions went into the price estimations in the analyses. First, the amount of fruit damage graded for either direct market or wholesale levels was subtracted from the total yields, assuming that the damage observed on sampled fruit was similar across all harvests within each year. Second, direct market prices were estimated from the Cornell Orchards commercial retail salesroom (where the fruit was ultimately sold), from two local apple growers, and from an informal survey of local supermarkets and natural foods stores. Third, because 'Liberty' has not been produced in enough volume to determine prevailing wholesale prices, wholesale prices were estimated from published prices for 'Empire' apples grown in the Hudson River Valley, and sold from October through December (the timeframe that 'Liberty' is commonly marketed) at the New York City Terminal Produce Co-operative Market in Hunts Point (USDA AMS, 2008). 'Empire' apples are similar to 'Liberty' in size, color, and harvest timing.

At the direct market level, all fruit weighing less than 122 g was assumed sold for cider at \$0.59 kg^{-1}; fruit greater than 122 g was assumed sold for fresh eating at \$1.84 kg^{-1}. The cider price was the estimated return per kg of fruit (not the higher potential return per L of cider). Fruit that was blemished but not internally damaged was valued at \$1.84 kg^{-1} as “orchard run”, which assumed a higher consumer tolerance threshold for cosmetically imperfect fruit in the direct market.

At the wholesale market, fruit weighing less than 122 g was assumed sold for processing at \$0.11 kg^{-1}; fruit between 122-141 g was valued at \$0.52-0.63 kg^{-1}; fruit between 140-167 g was valued at \$0.63-0.84 kg^{-1}; fruit between 166-204 g was valued at \$0.63-1.10 kg^{-1}; and fruit between 203-255 g was valued at \$0.73-1.36 kg^{-1}. These ranges represented year-to-year variations in average market value and differential prices based upon established color grades (higher prices for greater percentage of red coloration). Fruit that was blemished but not internally damaged was graded for processing at \$0.11 kg^{-1}.

Because the volume of East Coast organic apples sold through major produce terminals was not recorded by the USDA during this study, an average OFP price differential of 62% was estimated, based on average organic and conventional sales data for eight apple cultivars (without regard to origin, color grade, size, or month of sale) sold in the Boston produce terminal during 2007 (USDA ERS, 2008). The lowest organic premium (18%) was for ‘Golden Delicious’ sold in May, and the highest premium (127%) was for ‘Golden Delicious’ sold in February. Conventional apple prices were nearly the same on both dates.

2.8. Statistical analyses

Statistical models included the years (2004-07) and the treatments (IFP and OFP) in a mixed model to assess the long-term effects of each production system, using the PROC MIXED procedure of SAS 9.1 (Cary, NC). The mixed model included Year (2004-07), Treatment (IFP and OFP), and their interactions as fixed effects. Block and Treatment × Block were random effects. Main effects (Year, Treatment), interactions (Year × Treatment), and Treatment effects within an interaction were considered significant at the 0.05 level. For yield data, including crop density, yield efficiency, and fruit size data, the sequential harvest timings within years were not included in the model. An arcsin-square root transformation was performed prior to the analyses for fruit damage, but presented as untransformed means (Tables 3 and 4).

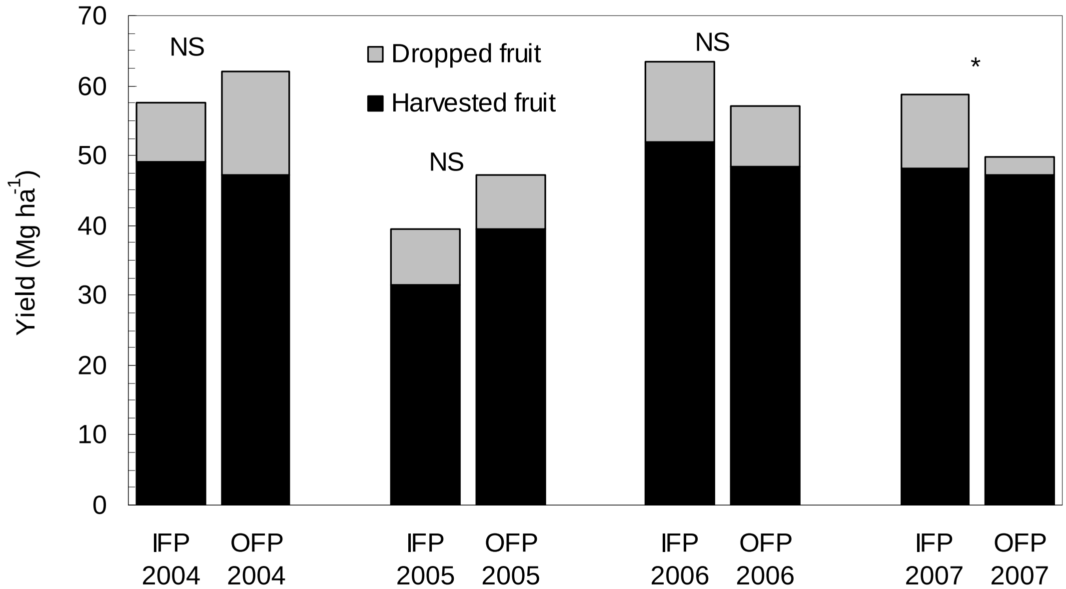
3. Results

3.1. Orchard productivity

Yields of harvested fruit and dropped fruit were similar in both systems (Figure 2). Total (harvested + dropped) IFP yields were greater in 2007. Cumulative yields (2004-07) of harvested and harvested + dropped fruit were similar between treatments. Tree size as measured by TCSA was different between production systems (Figure 3). The IFP trees grew more than OFP trees during 2005, but the OFP trees grew more during 2007, and trees in both systems grew similarly in 2006. In the IFP system there were greater crop densities in 2006 and greater yield efficiencies in 2006 and 2007 (Table 1). Average fruit weight was not closely correlated with yield, indicating that larger fruit were not always produced in the years and treatments with lower yields. IFP fruit weight decreased in 2006 and 2007, compared with the two preceding years. OFP fruit size was smaller in 2006 compared with the other three years and smaller than IFP in 2005, but OFP fruit size was fairly consistent for three of the four years.

3.2. Leaf nutrient concentrations

More C, but not more N nor a greater ratio of C:N, was found in the IFP leaves (Table 2). In the IFP system from 2005 to 2007, leaf N levels were below

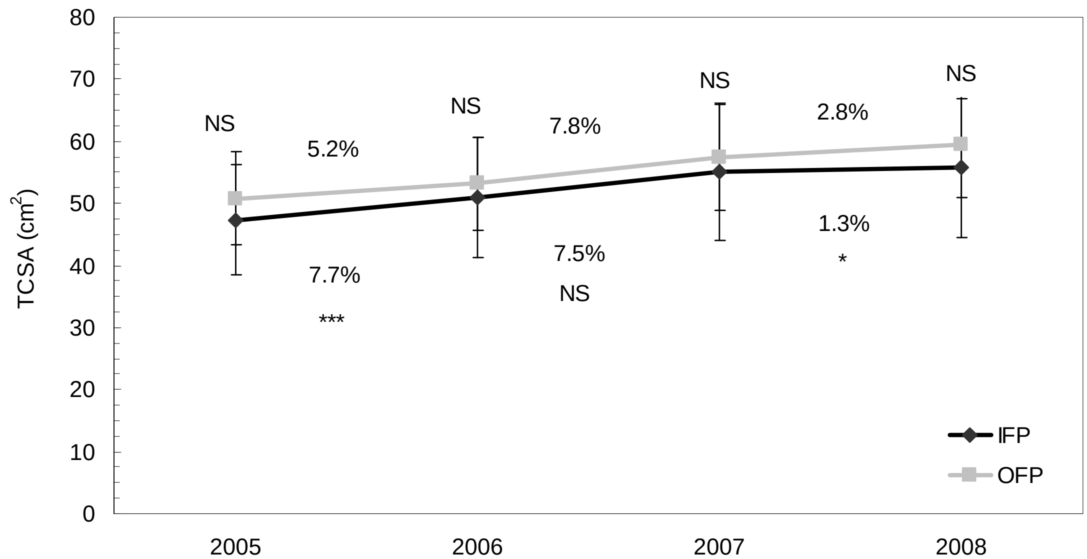


	Harvested fruit	Dropped fruit	Harvested + Dropped fruit
Year	***	*	***
Treatment	NS	NS	NS
Year × Treatment	NS	NS	**

NS, *, **, *** Nonsignificant or significant differences at $p \leq 0.05$, 0.01, or 0.001, respectively.

Figure 2. Apple yields under integrated (IFP) and organic fruit production (OFP) systems during four years. Significance levels of main effects (Year or Treatment) and interactions are at the bottom of the figure. Significance symbols (*) are for Treatment effects within the Year × Treatment interaction for the harvested + dropped fruit yield. Values represent one harvest date in 2004, two in 2005, and three in both 2006 and 2007. At least three entire trees per plot were harvested per harvest date.

recommended values; in the OFP system, leaf N was deficient in 2005 and 2007. Leaf phosphorous (P) concentrations were not different between systems and remained within appropriate ranges during all four years. Leaf potassium (K) concentrations were higher in OFP trees than in IFP trees throughout the experiment. Leaf N concentrations for both systems declined after the first year, but P, K, and calcium (Ca) increased over time, after the bark mulch and compost additions. In both systems, leaf K, Ca, magnesium (Mg), manganese (Mn), iron (Fe), copper (Cu), boron (B), and



	TCSA	Growth (%)
Year	***	***
Treatment	NS	NS
Year × Treatment	NS	***

NS, *, **, *** Nonsignificant or significant differences at $p \leq 0.05$, 0.01, or 0.001, respectively.

Figure 3. Trunk cross-sectional area (TCSA) and the percent change in TCSA from year-to-year for apple trees grown under integrated (IFP) and organic fruit production (OFP) systems for 2005-07. The percent change in TCSA is shown above the trend lines for OFP and below for IFP. Significance levels of the main effects (Year or Treatment) and interactions are at the bottom of the figure. Significance levels of treatment effects for TCSA are above the standard error of the mean bars. Significance levels of Treatment effects within the Year × Treatment interaction for percent tree growth are below the IFP values. Trunk cross-sectional areas (TCSA) were estimated from trunk circumferences measured 20 cm above the graft union.

zinc (Zn) concentrations were below recommended ranges for these nutrients in some years. When differences in leaf nutrient content did occur between treatments, the OFP trees tended to have greater nutrient values. One conspicuous difference in leaf nutrient levels was the eight- to fourteen-fold greater concentration of aluminum (Al) in the leaves of OFP trees.

Table 1. Crop density, yield efficiency, and average fruit weight for apples under integrated (IFP) and organic fruit production (OFP). Significance levels of main effects (Year or Treatment), interactions, and Treatment effects within interactions are at the bottom of the table. Values represent one harvest date in 2004, two in 2005, and three in both 2006 and 2007. At least three entire trees per plot were harvested per harvest date. Trunk cross-sectional areas (TCSA) were estimated from trunk circumferences measured 20 cm above the graft union.

Year	Treatment	Crop density (no. of fruit $TCSA^{-1}$)	Yield efficiency (no. of fruit $TCSA^{-1}$)	Average fruit weight (g)
2004	IFP	4.9	0.80	165
2004	OFP	5.4	0.80	148
2005	IFP	3.4	0.56	167
2005	OFP	4.1	0.60	145
2006	IFP	5.9	0.81	139
2006	OFP	5.1	0.63	126
2007	IFP	5.8	0.74	129
2007	OFP	3.9	0.55	142
Year		***	***	***
Treatment		NS	*	NS
Year × Treatment		***	*	***
Treatment effects within the Year × Treatment interaction				
2004		NS	NS	NS
2005		NS	NS	*
2006		NS	**	NS
2007		***	***	NS

NS, *, **, *** Nonsignificant or significant differences at $p \leq 0.05$, 0.01, or 0.001, respectively.

3.3. Cullage assessment

Apples from one harvest date in each year were assessed for various cullage defects (Tables 3 and 4). There was 16-fold greater internal Lepidoptera (i.e., codling

Table 2. Leaf nutrient concentrations from trees under integrated (IFP) and organic fruit production (OFP) systems during four years. Significance levels of main effects (Year or Treatment), interactions, and Treatment effects within interactions are at the bottom of the table. Values represent pooled samples of 100 mid-terminal shoot leaves per plot taken from mid-canopy height each August.

Year	Treatment	C (%)	N (%)	C:N	P (%)	K (%)	Ca (%)	Mg (%)	Mn (ppm)	Fe (ppm)	Cu (ppm)	B (ppm)	Zn (ppm)	Al (ppm)
2004	IFP	47.6	2.03	23.5	0.152	1.01	1.02	0.268	21.7	49.3	5.95	31.9	10.4	67.1
2004	OFP	46.9	2.02	23.3	0.153	1.03	1.12	0.265	22.1	64.7	5.72	32.7	11.0	537
2005	IFP	48.5	1.83	26.6	0.216	1.10	1.01	0.262	16.3	48.4	5.67	48.2	30.5	85.8
2005	OFP	47.5	1.75	27.1	0.207	1.32	1.17	0.273	20.8	66.3	6.35	42.5	22.5	702
2006	IFP	47.2	1.75	27.1	0.206	1.33	1.19	0.268	26.8	60.2	7.90	35.1	19.3	39.6
2006	OFP	46.4	1.94	24.0	0.182	1.52	1.63	0.296	25.1	69.2	9.22	37.2	35.1	439
2007	IFP	46.1	1.78	26.4	0.243	1.23	1.25	0.281	19.7	48.3	6.41	28.9	27.3	37.8
2007	OFP	45.6	1.80	25.4	0.235	1.39	1.38	0.294	18.9	66.7	7.52	26.7	34.7	509
Suggested nutrient ranges [a]			1.8-2.2		0.13-0.33	1.35-1.85	1.3-2.0	0.35-0.5	50-150	50+	7.0-12	35-50	35-50	N/A[b]
Year		***	**	**	***	***	***	***	***	NS	***	***	***	***
Treatment		***	NS	NS	NS	***	***	**	NS	***	***	NS	NS	***
Year × Treatment		NS	NS	NS	NS	NS	**	*	**	NS	**	*	***	*
Treatment effects within the Year × Treatment interaction														
2004							NS	NS	NS		NS	NS	NS	***
2005							*	NS	***		*	**	**	***
2006							***	***	NS		***	NS	***	***
2007							NS	NS	NS		***	NS	**	***

NS, *, **, *** Nonsignificant or significant differences at $p \leq 0.05$, 0.01, or 0.001, respectively.

[a] Stiles and Reid, 1991.

[b] Not available.

Table 3. Percent of arthropod damage on fruit harvested at maturity under integrated (IFP) and organic fruit production (OFP) systems during four years. Significance levels of main effects (Year or Treatment), interactions, and Treatment effects within interactions are at the bottom of the table. Data were arcsin-square root transformed prior to analyses, but presented as untransformed means representing the percentage of apples from one harvest date in each year that were visually identified for each damage.

Year	Treatment	Internal Lepidoptera (fruit feeding)	Plum curculio	European apple sawfly	Pentatomid	Plant bug	Tarnished plant bug	Green fruit worm	Wooly apple aphid	Leaf rolling tortricid	Aggregate arthropod damage
		(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
2004	IFP	0.2	0.6	1.5	0.0	0.3	0.3	.	.	0.0	2.9
2004	OFP	0.9	0.6	0.6	0.0	0.2	0.4	.	.	0.2	2.9
2005	IFP	0.9	0.5	0.0	0.0	0.0	0.1	0.2	0.0	1.2	2.9
2005	OFP	15	3.8	0.2	0.0	0.2	0.3	0.6	0.0	5.0	25
2006	IFP	0.3	0.8	0.1	1.6	0.2	1.4	0.0	0.0	1.5	5.8
2006	OFP	1.4	1.3	1.4	2.3	0.6	4.4	0.0	0.0	1.9	13
2007	IFP	0.4	0.6	0.0	0.2	0.5	0.3	0.1	0.0	1.0	3.1
2007	OFP	2.8	4.9	1.4	0.2	2.1	0.9	0.0	0.0	1.8	14
Year		***	NS	***	***	***	***	**	NS	***	***
Treatment		**	*	*	NS	*	**	NS	NS	**	***
Year × Treatment		***	NS	***	NS	NS	*	NS	NS	**	***
Treatment effects within the Year × Treatment interaction											
2004		NS		*			NS			NS	NS
2005		***		NS			NS			***	***
2006		NS		***			***			NS	***
2007		**		***			*			*	***

NS, *, **, *** Nonsignificant or significant differences at $p \leq 0.05$, 0.01, or 0.001, respectively.

Table 4. Percent of diseases and physiological disorders causing surface damage on fruit harvested at maturity under integrated (IFP) and organic fruit production (OFP) systems during four years. Significance levels of main effects (Year or Treatment), interactions, and Treatment effects within interactions are at the bottom of the table. Data were arcsin-square root transformed prior to analyses, but presented as untransformed means representing the percentage of apples from one harvest date in each year that were visually identified for each damage.

Year	Treatment	Flyspeck/ Sooty blotch	Russeting	Other markings (scarf skin)	Bird damage	Splitting/Cracking	Sunburn/ Sprayburn	Frost damage	Poorly shaped	Limb rub	Bruise/ Puncture/ Cut	Bitter pit	Boron deficiency	Aggregate surface damage	Fruit unmarketable for fresh sales	Clean fruit
		(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
2004	IFP	.	.	.	0.1	.	.	0.0	.	.	.	.	.	0.1	0.3	97
2004	OFP	.	.	.	0.2	.	.	0.1	.	.	.	.	.	0.3	1.4	97
2005	IFP	0.0	0.0	0.5	0.3	1.0	0.0	1.4	0.1	0.7	0.6	.	0.2	4.3	5.8	96
2005	OFP	0.2	0.8	0.4	0.4	0.1	3.1	0.6	0.7	0.3	0.7	.	0.0	6.6	25	74
2006	IFP	6.3	1.4	3.4	0.1	1.0	0.0	0.0	1.3	0.4	0.3	0.3	0.0	7.7	3.2	83
2006	OFP	68	7.7	37	0.1	0.5	0.3	0.1	13	3.1	0.9	0.0	0.0	62	5.2	25
2007	IFP	0.8	0.8	1.5	0.1	0.2	0.0	0.0	0.1	1.2	0.1	0.0	0.0	3.8	2.0	94
2007	OFP	7.5	0.7	10	0.0	0.1	0.0	0.0	0.2	1.2	0.8	0.4	0.0	13	5.6	67
Year		***	***	***	NS	*	***	***	***	NS	NS	NS	NS	***	***	***
Treatment		***	***	***	NS	*	***	NS	***	NS	NS	NS	NS	***	**	***
Year × Treatment		***	***	***	NS	NS	***	**	***	*	NS	NS	NS	***	***	***
Treatment effects within the Year × Treatment interaction																
2004								NS						NS	*	NS
2005		NS	*	NS			***	**	NS	NS				NS	**	***
2006		***	***	***			NS	NS	***	**				***	NS	***
2007		***	NS	***			NS	NS	NS	NS				***	*	***

NS, *, **, *** Nonsignificant or significant differences at $p \leq 0.05$, 0.01, or 0.001, respectively.

moth, oriental fruit moth, and lesser apple worm) damage in OFP fruit in 2005, and six times greater in 2007 compared with IFP (Table 3). Fruit damage from internal Lepidoptera was well above NY State averages (<5%, codling moth; <1% lesser apple worm; <10% oriental fruit moth) in the OFP system during 2005. However, unmanaged orchards in NY can sustain 30-40% Lepidoptera damage to fruit (Harrington and Good, 2000). Throughout this experiment there was more plum curculio [*Conotrachelus nenuphar* (Herbst)] damage to fruit in the OFP system, although the amount of damage remained within state averages (<5%). Curculio damage control in both systems was effective compared to unsprayed orchards, which often sustain greater than 60% fruit damage from plum curculio (Harrington and Good, 2000). Leafrollers (Tortricidae), European apple sawflies, pentatomids, plant bugs (*Lygus spp.*), green fruitworms [several species causing similar damage including *Orthosia hibisci* (Guenée), *Lithophane antennata* (Walker), and *Amphipyra pyramidoides* (Guenée)], and woolly apple aphids [*Eriosoma lanigerum* (Hausmann)] were present in some but not all years, and caused varying degrees of damage to harvested fruit. The OFP system sustained more insect damage than IFP. During this study, no apple maggot damage was observed in either system. Aggregate damage from all arthropod pests was greater on fruit in the OFP system than the IFP system in all but the first year of this trial. Aggregate arthropod pest damage in IFP fruit ranged from 3-6%, exceeding normal damage percentages for this region. Aggregate arthropod pest damage in the OFP system started at 3% damage in 2004, increased to 25% in 2005, and then decreased at 14% for the final two years.

The summer SB/FS disease complex, as well as russeting and scarf skin were more severe for the OFP system in the final two years of this project (Table 4). Little to no SB/FS occurred in 2004 or 2005, but the following year 6.3% of IFP fruit and 68% of OFP fruit showed SB/FS damage, and in 2007, 1.5% of IFP fruit and 10% of

OFP fruit showed symptoms. Cumulatively, OFP apples had more surface defects than IFP fruit in both 2006 and 2007. When the total number of fruit with at least one defect was calculated, IFP fruit had from 83-97% clean fruit, while organic fruit had 25-97% clean fruit; the two systems differed from each other in 2005-07. The damage recorded in the OFP plots in these final three years was greater than most conventionally managed NY apple orchards, which typically have 90 to 95% clean fruit (Agnello et al., 2005). These numbers represent the percent of unmarketable fruit for fresh market at the wholesale level. It was also apparent that for both of these systems the amount of cullage was lowest in the first year (2004) of this trial (Table 3).

3.4. Environmental Impact Quotient

The EIQ Field Use Rating indicated 79-88% more negative environmental impacts in the OFP system over the years (Figure 4). For the IFP system, herbicides accounted for 7.5%, fungicides accounted for 1.4%, and insecticides accounted for 5.1% of the cumulative EIQ total. For the OFP system, fungicides accounted for 0.6% and insecticides accounted for 1.8% of the cumulative EIQ total. The largest EIQ contributors in OFP were kaolin clay (31-79% of total EIQ per year) and the thinning spray combination of lime sulfur and oil (10-54% of total EIQ per year). Kaolin clay had the lowest possible EIQ value (8), but was applied in large quantities multiple times each season, which enlarged the EIQ Field Use Rating. Lime sulfur and fish oil have high EIQ ratings (46 and 28, respectively), and were used in relatively large quantities for fruit thinning. Stylet Oil had the largest EIQ rating for a single application (250 EIQ units), which was for the used as a miticide in 2006 for OFP. The dormant sprays of copper and oil had high, but similar ratings for both systems.

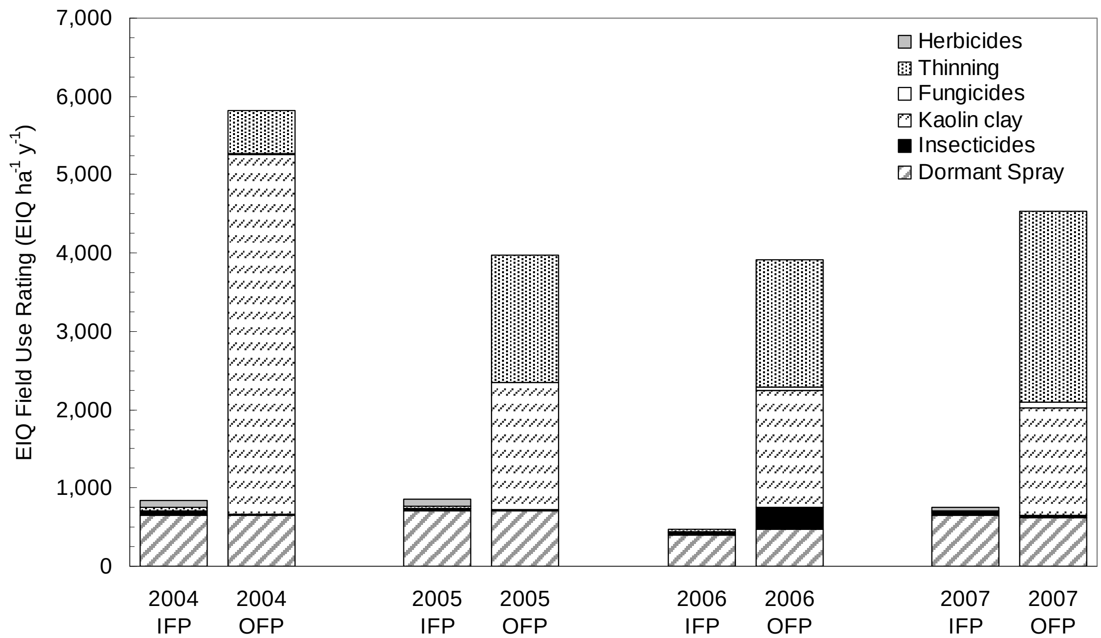


Figure 4. Environmental Impact Quotient (EIQ) Field Use Rating for integrated (IFP) and organic fruit production (OFP) systems during four years. The Field Use Rating equation multiplies the EIQ value × the percent a.i. × the rate per hectare for each material used. No statistical analysis was performed because all plots within a treatment received the same inputs.

3.5. Variable costs of production

Averaged over four years, estimated costs for the OFP system were 9% (\$568 ha^{-1}) more per year than the IFP costs (Table 5). The OFP system cost 19% more in machinery (\$51 ha^{-1}), 19% more in materials (\$313 ha^{-1}), and 5% more in labor (\$204 ha^{-1}) than the IFP system, when averaged over four years. Machinery costs were higher in the OFP because of the need to purchase a specialized cultivator (the Wonder Weeder), but the operating costs were only \$11 ha^{-1}. More airblast sprays were needed in the OFP system, increasing the costs for machinery and labor compared to IFP. Other machinery costs were nominal when averaged over the four years. Comparing the systems, materials such as dormant sprays, foliar fertilizers, and Sul-Po-Mag/K-Mag were similar in dosage rates, but the organic formulations were

Table 5. Machinery, material, and labor costs (US\$ ha^{-1}) for fruit thinning, insect and disease control, fertilizers, groundcover and weed control, and harvesting, for integrated (IFP) and organic fruit production (OFP) systems during four years. No statistical analysis was performed because all plots within a treatment received the same inputs.

	2004		2005		2006		2007		Grand Mean	
	IFP	OFP	IFP	OFP	IFP	OFP	IFP	OFP	IFP	OFP
Machinery Fixed Costs										
Wonder Weeder	0	29	0	29	0	29	0	29	0	29
Machinery Operating Costs										
Tractor + Airblast sprayer	270	312	187	208	208	229	166	229	208	244
Tractor + Herbicide sprayer	30	0	30	0	0	0	15	0	19	0
Tractor + Wonder Weeder	0	22	0	22	0	33	0	33	0	28
Spreading chicken manure compos	0	0	0	59	0	0	0	0	0	15
Mill Creek bark mulch spreading	0	0	148	0	0	0	0	0	37	0
Material Costs										
Dormant spray	37	47	39	39	28	123	37	109	35	79
Insecticides and miticides	593	140	480	246	404	560	326	592	451	384
Kaolin clay	0	1,134	0	399	0	368	0	341	0	561
PMD[a]	230	0	0	0	400	400	494	494	281	224
Fungicides	64	22	0	0	112	69	69	17	61	27
Adjuvants	5	11	0	0	0	32	8	22	3	16
Thinning	35	154	313	297	131	297	127	446	152	299
Foliar fertilizers	0	0	35	106	31	193	42	177	27	119
Herbicides	105	0	105	0	0	0	38	0	62	0
Sul-Po-Mag/K-Mag	129	232	129	232	129	232	129	232	129	232
Bark mulch	0	0	1,747	0	0	0	0	0	437	0
Chicken manure compost	0	0	0	38	0	0	0	0	0	10
Labor Costs										
Tractor airblast spraying	298	344	206	229	229	252	183	252	229	269
Herbicide application	46	0	46	0	0	0	23	0	29	0
Bark mulch application	0	0	340	0	0	0	0	0	85	0
Chicken manure application	0	0	0	55	0	0	0	0	0	14
Cultivation	0	28	0	28	0	42	0	42	0	35
Hand hoeing	0	0	0	0	0	179	0	179	0	89
Hanging PMD[a] dispensors	55	0	0	0	90	90	28	28	43	29
Hand thinning	1,021	1,380	575	677	798	1,028	852	687	812	943
Harvesting	3,256	3,126	2,085	2,611	3,450	3,212	3,199	3,126	2,997	3,019
Total machinery costs	301	362	366	317	208	290	181	290	264	315
Total material costs	1,197	1,741	2,848	1,358	1,235	2,274	1,270	2,430	1,637	1,951
Total labor costs	4,676	4,878	3,252	3,600	4,567	4,802	4,285	4,314	4,195	4,398
Grand Total	**\$6,174**	**\$6,981**	**\$6,465**	**\$5,275**	**\$6,010**	**\$7,366**	**\$5,736**	**\$7,034**	**\$6,096**	**\$6,664**

[a]pheromone mating disruption

were generally more expensive per application. The costs of insecticides and miticides decreased in IFP, and increased in OFP over the four years. The dosage and number of kaolin clay applications and the cost of this spray material were decreased over the course of this experiment. Chemical thinning materials were about twice as expensive in OFP compared with IFP. Bark mulch was the most expensive material purchased in either treatment, and accounted for 9% of the four-year total IFP costs. Harvesting

Table 6. Total machinery, material, and labor costs (US$ ha^{-1}) for fruit thinning, arthropod and disease control, fertilizers, and groundcover/weed control for integrated (IFP) and organic fruit production (OFP) systems during four years. No statistical analysis was performed because all plots within a treatment received the same inputs.

	2004		2005		2006		2007		Grand Mean	
	IFP	OFP	IFP	OFP	IFP	OFP	IFP	OFP	IFP	OFP
Fruit thinning	1,056	1,535	888	974	929	1,325	980	1,132	963	1,242
Arthropod & disease control	1,552	2,009	913	1,122	1,471	2,122	1,312	2,083	1,312	1,834
Fertilizers (foliar & ground)	129	232	163	432	160	425	170	410	156	375
Groundcover/Weed control	181	79	2,416	79	0	283	76	283	668	181

accounted for 49% of the IFP labor costs and for 45% of OFP labor costs. Additional spraying, hand hoeing, and hand thinning were major contributors to the greater OFP labor costs.

Average annual costs for fruit thinning, arthropod and disease control, and fertilizers were 29% (\$278 ha^{-1}), 40% (\$522 ha^{-1}), and 141% (\$219 ha^{-1}) greater under OFP than IFP, respectively (Table 6). However, groundcover/weed control costs were on average 73% (\$488 ha^{-1}) greater in the IFP system. Greater OFP thinning costs were associated with OFP chemical thinning, which was more expensive and less effective than the IFP program, requiring more follow-up hand thinning (Tables 5 and 6). For both systems, arthropod and disease control costs were lowest in 2005 when pheromone-mating disruption (PMD) was not employed. In 2006 and 2007, when PMD was employed in both systems, it accounted for 36% of IFP and 24% of OFP arthropod and disease control costs. When PMD was not included, arthropod and disease costs in the IFP system were fairly constant for the four years. The high cost for OFP in 2004 was due largely to 11 applications of kaolin clay, most of them at the full label rate (56 kg ha^{-1}). While the use of kaolin clay was reduced during this experiment, the use of other insecticides such as spinosad, pyrethrum, and CpGV increased. This raised the overall costs of OFP arthropod and disease control during this study. The additional costs for IFP groundcover/weed management was attributed

Table 7. Estimated direct and wholesale market sales values (US\$ ha^{-1}) for apples produced under integrated (IFP) and organic fruit production (OFP) systems during four years. Direct market prices were derived from interviews with growers in central New York. Wholesale prices were derived from published prices for 'Empire' apples grown in the Hudson River Valley, NY, and sold from October through December (the timeframe that 'Liberty' is commonly marketed) at the Terminal Produce Co-operative Market in Hunts Point, NY. An average organic price premium of 62% was determined for eight different cultivars (without regard to origin, color grade, size, or month of sale) in the Boston produce terminal during 2007.

	2004		2005		2006		2007		Grand Mean	
	IFP	OFP	IFP	OFP	IFP	OFP	IFP	OFP	IFP	OFP
Direct market										
Fresh sales (≥122 g)	65,360	59,520	22,864	7,260	30,316	13,653	19,149	20,853	34,422	25,321
Cider fruit (<122 g)	7,838	8,261	10,097	14,976	19,869	22,539	21,623	19,377	14,857	16,288
Organic premium for 2007 (62%)								25,095		6,274
Total, including organic premium	$73,198	$67,780	$32,961	$22,235	$50,185	$36,192	$40,772	$65,326	$49,279	$47,883
Wholesale market										
80 (203-255 g)	443	258	0	0	0	0	0	0	111	65
100 (166-204 g)	6,473	4,835	682	83	473	43	395	210	2,006	1,293
120 (140-167 g)	8,974	7,997	3,240	502	2,750	248	1,981	1,415	4,236	2,540
140 (122-141 g)	6,651	7,222	3,614	1,226	4,584	767	4,479	3,588	4,832	3,201
Culls (<122 g)	1,368	1,486	1,757	2,320	2,830	914	3,550	2,328	2,376	1,762
Returns for blemished fruit	163	162	127	1,147	1,006	4,033	344	1,704	410	1,761
Organic premium for 2007 (62%)								5,767		1,442
Total, including organic premium	$24,072	$21,961	$9,420	$5,278	$11,644	$6,005	$10,748	$15,013	$13,971	$12,064

to the bark mulch application in 2005. However, using bark mulch cut herbicide applications from two per year, to none the next year, to just one application in 2007, reducing herbicide costs.

3.6. Potential market value of fruit

The first three years of this experiment were transition years for the OFP system; the fourth year, 2007, was the only year that these apples could have been sold as organic and therefore eligible for a 62% price premium (Table 7). Averaged over the four years, the sales value of IFP apples was 3% and 16% greater than OFP grown fruit in the direct and wholesale markets, respectively. In the direct market scenario, fresh sales accounted for 57% of IFP but only 36% of OFP total sales. The amount potentially received for blemished fruit in the wholesale market accounted for 1-9% of IFP, and 1-67% of OFP sales per year. For both systems, under either marketing strategy, the greatest potential returns were seen in 2004 at the beginning of the transition period. In subsequent years, increased arthropod, disease, and cosmetic damage, and decreased fruit size in both systems resulted in less fruit that could be marketed as ‘fresh’ or ‘unblemished’ compared with the first year (Tables 1, 3, and 4). For both treatments, the percent of fruit in the largest wholesale market size categories (80, 100, and 120) diminished over four years (Table 7).

4. Discussion

4.1. Orchard productivity

Using the disease-resistant cultivar ‘Liberty’, high yields and adequate tree growth were maintained in both IFP and OFP systems. In all years of this study, yields were comparable with those recorded for this orchard during the five years prior to the start of the experiment, and substantially greater than the average yields (31 Mg ha^{-1}) of all NY apple orchards (USDA NASS, 2008). One factor in the high yields was inadequate fruit thinning that led to premature fruit drop and small fruit size. ‘Liberty’ is a difficult variety to thin chemically, even with conventional inputs. Follow-up hand thinning was necessary each June in both treatments to eliminate double or triple fruit on many spurs. When not thinned to a single fruit per spur, the short stems of ‘Liberty’ cause adjacent fruit to be pushed off as fruit size increases rapidly approaching harvest. During hand thinning fruit with visible pest damage (usually from internal Lepidopterans and European apple sawflies) were also removed. This selective hand thinning helped to reduce the incidence of arthropod damage at harvest, especially in the OFP, providing an additional benefit.

Definite yearly trends in fruit production existed. The lowest yields for both treatments were recorded in 2005 because of a late-spring frost, and then unpredicted hot temperatures the week after chemical thinning materials were applied. Greater IFP yield efficiencies and crop densities suggested that yield potential would be greater under IFP management if the incidence of preharvest fruit drop could be reduced. The smaller IFP fruit size in 2007 was attributed to the high crop load that year, and to premature leaf defoliation due to an undetermined leaf blotch problem that was less severe in the OFP trees. Symptomatically this leaf spotting was similar to the Necrotic Leaf Blotch that affects ‘Golden Delicious’ and its progeny (Rosenberger, 2004). Consultation with plant pathologists and physiologists led us to two hypotheses about this problem. The first was that the usually non-pathogenic and ubiquitous epiphytic yeast, *Aureobasidium pullulans*, became pathogenic under the specific environmental conditions that occurred in 2007 (Andrews et al., 2002). If the causal agent was *A. pullulans*, then perhaps the broad-spectrum activity of lime sulfur was able to suppress the yeast more effectively than the strobilurin-anilide mix used in the IFP system. The second was that high ozone levels damaged the leaves but the kaolin clay treatments provided some leaf protection for the OFP trees. Jones (1963) showed that tobacco leaves treated with kaolin clay incurred only slight damage when exposed to as much as 0.9 μg ozone m^{-3} atmosphere while untreated leaves incurred damage at 0.4 μg m^{-3}. Kaolin clay (as well as other particulate substances) may also act as a catalyst for the decomposition of ozone some distance away from the leaf surface thereby not harming living tissue (Jones, 1963). The use of kaolin clay as an ozone protectant would be a novel use of this material (Glenn and Puterka, 2005).

4.2. Leaf nutrient concentrations

A proactive fertilization regime that included ground and foliar fertilizer applications for both systems was not sufficient for tree nutrient supply. The trees in both systems remained at the low end of recommended ranges for mature apple trees in NY for leaf N during the last three years of this study (Stiles and Reid, 1991). Nitrogen deficiency symptoms were evident in the leaves from both systems.

Although greater leaf nutrient levels were often found in OFP trees, low levels of K, Ca, Mg, Mn, Fe, Cu, Cu, B, and Zn existed in both systems. Organic apple growers in NY have reported problems with maintaining adequate nutrient levels, possibly due to increased weed competition (Schupp, 2004). While the Wonder Weeder cultivator provided improved weed control compared with the Rinieri cultivator and other cultivators used previously in NY organic orchards, there were stretches of 2-4 weeks when weeds were present under OFP trees (Chapter 4). Decreased tree N status may also have contributed to the small OFP fruit size in our study.

The high Al levels observed in the OFP leaves were likely linked to the kaolin clay applications, as this product is based on aluminosilicate [$Al_4Si_40_{10}(OH)_8$]. Leaves were triple-washed with soap prior to ICP analysis, so even greater Al levels may have existed in the field. However, foliar Al toxicity was not observed, and neither fruit nor soil samples had elevated Al concentrations (Chapters 3 and 4).

4.3. Cullage assessment

The greatest treatment differences observed in this experiment were for arthropod and cosmetic damage to apples. The organic crop protectants were not as effective as those used for IFP, and fruit finish defects were substantially greater in the OFP system. While the number of pesticides available for organics has increased, organically approved insecticides tend to have either low toxicity (e.g., kaolin clay) or relatively short residual activity (e.g., *Bt*, CpGV, pyrethrum). This makes pest control in organic orchards more difficult because frequent applications are needed and sprays must be timed precisely with each pest’s most susceptible life cycle phase. This is dissimilar to IFP management, where pest control materials tend to have longer residual activity and efficacy in the orchard.

Zehnder et al. (2007) suggested that organic pest control should rely upon cultural practices, vegetation management, and the release of biocontrol agents before using insecticides, to establish an agroecosystem equilibrium, after which biological processes and controls can provide adequate control of key pests. Organic principles postulate that this can be attained during the transition from conventional production. For other agroecosystems, primarily for annual crops in arid regions, this may be an achievable equilibrium (Letourneau and Goldstein, 2001; Pimentel et al., 2005). However, in our test apple orchard, pest damage tended to become worse over time, and was caused by a greater number of species in OFP compared with IFP. Four years may not have been long enough, and the test plots may not have been large enough for a biocontrol equilibrium to be attained. However, it is also possible that for organic orchards in NY the dynamic equilibrium among trees, resources, pests, and biological control processes is well above economic damage thresholds for commercial growers. Abandoned apple trees in the Northeastern landscape typically sustain greater than 95% damage to the fruit (Harrington and Good, 2000).

Over the course of this study, it was necessary to adapt and modify OFP pest control strategies. After the first year, the number of kaolin applications was reduced by half because the clay residue was difficult to remove from harvested fruit and the season-long applications were prohibitively expensive. While kaolin clay applications were reduced over time, pyrethrum was added for plum curculio control and an additional spinosad application was necessary in late summer for apple maggot control. Internal Lepidopteran damage was significantly higher in 2005 than in other years, perhaps due to regional population fluxes, or to a buildup of pests within the OFP plots during the early transition period (Table 3). In combination with kaolin clay, *Bt,* and spinosad, a CpGV product with good efficacy against codling moth, and some efficacy against lesser apple worm and oriental fruit moth was added to the OFP pest control strategy in 2006; PMD was also intensified during the 2006 and 2007 seasons. These efforts reduced internal Lepidoptera damage at harvest, but increased the cost of OFP (Tables 3 and 5). In contrast, arthropod control in the IFP system remained relatively similar and effective during the four years of this experiment.

Until kaolin clay became available for pest control, plum curculio was difficult to control organically in NY (Reissig et al., 2002). Kaolin clay applications from petal fall to late June, coupled with an application of pyrethrum at the onset of plum curculio oviposition (night temperatures >15.5ºC after petal fall), appeared to provide adequate curculio control in the OFP system (Lienk, 1980). Overall, the incidence of arthropod damage to fruit in the OFP system was greater than IFP damage. Fruit damage in IFP was comparable with conventionally managed NY orchards (Harrington and Good, 2000).

The indigenous apple maggot fruit fly is considered a severe pest (~30% of fruit infested) without human intervention and has been difficult to control organically in the Northeast (Harrington and Good, 2000; Reissig et al., 2002). Our strategy for apple maggot control involved cultural (red sticky traps) and chemical (spinosad and/or neonicotinoids for IFP; kaolin clay and spinosad for OFP) intervention. Since nearby unsprayed crabapples incur nearly 100% damage, both of these approaches appeared to be successful in our test plot. The use of cultural practices combined with selective hand thinning reduced arthropod damage in both systems, but these were expensive measures, and price premiums would be needed to make these control strategies economically viable. Furthermore, the test orchard was relatively small and the efficacy and economics of these practices might change with smaller perimeter to area ratios in larger orchard blocks.

Cosmetic damage caused by lime sulfur was a significant impediment to OFP, and likely caused russeting, scarf skin, and other unidentified fruit surface blemishes

(Table 2). Lime sulfur has been an effective material for fruit thinning under OFP, but can cause fruit russeting in humid conditions, such as in 2006 in our study (Holb et al., 2003; Noordijk and Schupp, 2003; McArtney et al., 2006). Russeting was almost exclusively found on the OFP fruit. Characterized by a whitish or cloudy hue to the surface of the fruit, scarf skin is most likely caused by abiotic factors (Beach, 1905). Like russeting, scarf skin is cosmetic and does not damage the interior fruit flesh. However, these damages significantly reduced fruit value under USDA grading standards (Federal Register, 2002). The threat of frost precludes widespread use of chemical thinners at bloom time in NY orchards, and post-bloom thinning can be problematic due to unpredictable weather at that time of year (Noordijk and Schupp, 2003). Organic growers may have to cope with poor fruit finish as a consequence of chemical thinning programs during years with unfavorable weather in NY.

Problems with SB/FS and other “summer diseases” have been reported previously in Northeastern orchards where scab-resistant cultivars were grown without fungicide treatments (Merwin et al., 1994; Rosenberger et al., 1996; Ellis et al., 1998). While ‘Liberty’ is resistant to many of the primary fungal pests of apple trees, it is not resistant to SB/FS. In 2006, the SB/FS control program in OFP consisted of two applications of a potassium bicarbonate product (Kaligreen®) after 270 leaf wetting hours at post-petal fall (Brown and Sutton, 1995). Potassium bicarbonate has reportedly provided adequate control of SB/FS in previous studies (Andrews et al., 2001), but this material was ineffective in our study during 2006, a year with abundant rainfall. In 2007, a year with less rainfall, lime sulfur applications also failed to provide adequate control of SB/FS in the OFP system. In contrast, during those same years stobilurin and anilide fungicides provided good control of SB/FS (Table 4). New fungicide development has lagged relative to the newer organic insecticides, and advances in this area would improve the feasibility of OFP in humid growing regions.

The heavy reliance on kaolin clay as a crop protectant in OFP represented both positive and negative effects on the sustainability of OFP in our study. Kaolin clay aided plum curculio control, and perhaps other insect pests (Glenn and Puterka, 2005), but unlike Thomas et al. (2004), kaolin did not appear to be as effective against SB/FS in the present study. We also observed that predacious mite populations were suppressed by kaolin applications (data not shown), as reported by others (Benedict, 2005; Markó et al., 2006). Additionally, the clay residues were difficult to remove from fruit, and this might be detrimental to marketing organic apples (Chapter 3). Kaolin also represented a significant negative impact in the EIQ rating, and it comprised a substantial portion of the OFP costs. Unlike Glenn et al. (2005), consistent improvement in color grade due to the kaolin clay applications was not found in our study. On the positive side, the use of kaolin clay may have increased C assimilation and reduced other heat-related or ozone stresses (Glenn et al., 2003), although excessive leaf temperatures and photo-oxidative damage are not commonly a problem in central NY.

4.4. Environmental Impact Quotient

The large EIQ rating for OFP was largely due to the use of lime sulfur and fish oil for thinning, and the use of kaolin clay for crop protection. These materials are currently considered to be the best management practices for OFP because of their efficacy (Reissig et al., 2002; Noordijk and Schupp, 2003), but the EIQ raises some question as to their potential environmental impact. Lime sulfur and oil (whether fish or petroleum) have potential negative effects on plant health, beneficial insects, and farm workers (http://extoxnet.orst.edu/), so it can be justified that these products would receive high EIQ ratings. Kaolin clay, however, is an inert compound used in ceramics, medicine, coated paper, toothpaste, cosmetics, as a food additive, and is the main component in porcelain. Thus it is difficult to substantiate its large EIQ rating. According to the material safety data sheet (MSDS), the commercial kaolin clay formulation that was used for this project can potentially be a respiratory, dermal, or eye irritant because of its small particle size. But these are largely hazards for applicators before the material is in solution and might not be a health concern at all if applicators wear the personal protection equipment specified on the product label and MSDS. Kaolin clay might also adversely affect beneficial mites (Benedict, 2005), which is certainly cause for concern in an organic orchard that depends upon mites for biocontrol.

The EIQ has been found to be a plausible model for assessing the non-target effects of pesticides (Levitan et al., 1995; Greitens and Day, 2007). However, the basic field-use equation in the EIQ model linearly attributes greater negative impacts to products that are used in larger quantities (i.e., lime sulfur, oils, and kaolin clay), independent of their inherent toxicity following the toxicological dictum, “the dose makes the poison” (Dushoff et al., 1994). Therefore, kaolin clay, which was applied at cumulative rates between 173-575 kg a.i. ha^{-1} y^{-1}, had a major impact on the overall EIQ rating for OFP. The potential negative environmental impacts of different pest control systems should therefore not be inferred solely from EIQ rankings. For example, the EIQ does not include potential environmental impacts of fossil fuel usage, fertilizers, soil management systems, or economic externalities (Levitan et al., 1995). Additionally, many products used in our study have been relatively untested in commercial situations. The heavy reliance on neonicotinoids in IFP, and spinosad in OFP, may lead to pest resistance and control failures for both of these systems (Shono and Scott, 2003; Nauen and Denholm, 2005). However, more IFP-compatible insecticide options have become available, compared with organically approved materials.

4.5. Variable costs of production

Organic fruit production systems have been reported to be more expensive to operate than conventional and integrated systems (Reganold et al., 2001), and this was borne out in our experiment. For comparative purposes, recent reports have shown that a conventional insecticide program in NY costs \$363 ha^{-1} in low pest pressure sites and up to \$647 ha^{-1} in high pest pressure orchards, indicating that the \$451 ha^{-1} for insecticides and miticides in our IFP system is in the mid-range compared with conventional NY orchards (Agnello et al., 2005; White et al., 2008). In contrast, the \$945 ha^{-1} costs for OFP insecticides, miticides, and kaolin clay materials (or \$1169 ha^{-1} with intensive pheromone mating disruption) were well above what commercial apple growers in NY typically spend for arthropod pest control. With a sustained market price premium for organic apples, these pest control costs could still be acceptable, but as organic tree-fruit production increases in other regions (Granatstein and Kirby, 2008), the price premium for organic apples may diminish below the level of profitability for NY growers.

The greatest single input cost for the IFP system was the bark mulch application. Bark mulch is not widely utilized in IFP or conventional NY orchards, but it has been shown to improve soil quality and nutrient availability, while reducing herbicide inputs (Yao et al., 2005; Chapter 4). Bark mulch was not applied to the OFP system because it would have interfered with surface weed cultivation, and because occasional use of herbicides was necessary to control perennial weeds in the bark mulch. Additionally, we did not want to incorporate this mulch (a high C, low N material) into the topsoil because it might immobilize and therefore limit N availability to the trees.

4.6. Potential market value of fruit

While cumulative yields were not significantly different in these two systems, pest damage and small fruit size affected their potential market value. In 2005, both systems had reduced revenue due to a late spring frost, but the OFP system had significant insect damage as well. For the direct market, if we assumed a higher market threshold for surface blemishes caused by insects, physiological factors, or disease, then in all years but 2005 the blemished fruit from the OFP system might have been more acceptable and comparable with the IFP system (Table 3). But this questionable assumption may not be realized in the marketplace. A recent study indicated that consumers were much less willing to pay a premium for blemished organic apples from local orchards, when they were offered other unblemished organic apples that were comparable to conventional fruit (Yue et al., 2006). Nonetheless, a direct market system offers greater potential for OFP fruit because of less stringent grading standards. Cider is often made from culls and sold directly by growers in the eastern US, and this potential use for blemished fruit also makes OFP more feasible. Because ‘Liberty’ tends to produce relatively small fruit, the estimated market values in this report could be different for other disease resistant apples, such as ‘Enterprise’, that typically produce larger sized fruit (Merwin et al., 1994).

Wholesale packinghouses often reject apples with trace amounts of internally damaged fruit, and the amount of damage recorded for OFP apples in 2005 could have eliminated that entire harvest from the wholesale marketplace. Likewise in 2006, when a majority of the organic fruit was cosmetically damaged, a commercial packinghouse would not have accepted that fruit unless there was a critical shortage of organic apples. However, if local direct sales are not an option, then eastern US organic apples will have to compete with those grown in more favorable climates, such as Washington State. Lastly, the greater costs and lower returns during the three-year transition period will be a significant impediment to OFP because this system was profitable only when price premiums were included.

At present there is no price premium for IFP fruit in the mainstream US market, and this has discouraged mainstream growers from adopting this system (Carroll and Robinson, 2004). An IFP system is more expensive than conventional apple production because it is based upon newer reduced-risk materials that are costlier than older generation pesticides (e.g. organophosphates, carbamates, and pyrethroids). Additionally, cultural practices such as bark mulch and pheromone mating disruption, which are encouraged under IFP management, are quite expensive. Major supermarket corporations that insisted upon IFP and EurepGAP certification as preconditions for their wholesale apple suppliers drove the wide-scale adoption of IFP in Western Europe and New Zealand. It may take similar market forces to increase US grower interest in IFP (Loureiro et al., 2001).

In conclusion, under both IFP and OFP systems it was possible to produce marketable yields of apples in NY's humid growing conditions. The feasibility of these systems required a holistic approach that included soil quality improvement, cultural practices for arthropod control, and an intensive IPM program. However, this study evaluated a scab-resistant cultivar, and while there are several effective and economical fungicides approved for IFP, an orchard of disease-susceptible cultivars managed under OFP would likely rely upon repeated application of sulfur, lime sulfur, and copper for disease control. The use of these materials would negatively impact the sustainability of an OFP system in the Northeastern US. In NY State, IFP could be widely implemented for apple production, but OFP may be most feasible for small to mid-sized direct market operations.

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Chapter Three

Ripening and Quality of 'Liberty' Apple Fruit under Integrated and Organic Fruit Production Systems are Similar in a New York Orchard

Abstract

Quality of fruit harvested from an orchard of disease-resistant 'Liberty' apple (*Malus* × *domestica* Borkh.) trees, during and after the transition from conventional to integrated (IFP) and organic fruit production (OFP) systems over four years was investigated. Fruit maturity and quality was evaluated using internal ethylene concentration, starch pattern index, flesh firmness, soluble solids concentration (SSC), titratable acidity (TA), percent of surface blush, total phenolic content, antioxidant capacity, and consumer sensory panels. At harvest, measurements were not consistently different between fruit from IFP and OFP systems over the years, and total phenolic concentrations and antioxidant capacity were similar between treatments. Apple flesh from IFP-grown fruit contained more potassium during the first two years and more calcium in all years. After fruit were stored in air at 0.5°C for 9 weeks in 2007, OFP apples were firmer and had higher SSC, TA and SSC:TA ratios. In double-blind triangle taste tests, consumer panelists were able to discriminate between the fruit from each treatment, but in double-blind hedonic and intensity tests, panelists did not consistently rate one treatment more highly than the other. In 2006, when weather and disease caused a high percentage of OFP fruit to have cosmetic defects, the panelists rated fruit appearance of OFP apples as less acceptable than IFP apples. Internal fruit quality was satisfactory under both IFP and OFP systems.

1. Introduction

Despite the high market value of apples (*Malus* × *domestica* Borkh.) and the increasing interest in ecologically-based farming schemes by growers, consumers, and public officials, little is known about the effects of transitioning apple orchards from conventional management to integrated (IFP) and organic fruit production (OFP) systems in the Northeastern United States. In much of Europe, as well as in countries exporting fruit to Europe, IFP has become the standard system used in commercial apple orchards (Sansavini, 1997), and organic apples have become an internationally traded commodity (Peck et al., 2005). The Northeastern US has a humid climate where frequent summer precipitation creates high disease pressure and intense weed competition, as well as a long history of apple cultivation which has allowed a large arthropod pest complex to develop. For these reasons, growers in this region have been at a disadvantage compared to those in arid regions where less pest pressure allows IFP and OFP management with minimal inputs. However, many barriers to IFP and OFP might be overcome by implementing better biocontrol, integrated pest management (IPM), and ground cover management strategies, as well as new pesticide formulations (Merwin et al., 2005). With the possibility of expanding IFP and OFP in the Northeastern US, there is a need to understand the impact these systems have on ripening and fruit quality.

Consumers often purchase organic foods because they believe them to have better quality and be more nutritious (Wier et al., 2008), and the popular media tends to reinforce the perception of higher quality (Pollan, 2006; Nestle, 2006). However, fruit quality is a complex notion that includes sensory components, size, color, nutritional value, the presence of pesticide residues or pathogens, as well as externalities such as environmental and societal benefits, and the location where the fruit was grown. Because of these numerous attributes, fruit quality means different things depending upon the end-user and the needs within the supply chain (Watkins and Ekman, 2005). For organic foods, purchase decisions appear to be motivated by attributes that benefit consumers, such as freshness, taste, and nutritional value, more than externalities (Chryssohoidis and Krystallis, 2005; Wier et al., 2008).

One recent review of studies comparing organic with IFP and conventional production found limited evidence supporting the hypothesis that organic production increases essential nutrients or phytochemicals for a wide range of fruit crops (Zhao et al., 2006). For apples, the results of quality comparisons of OFP with IFP and conventional have also been inconsistent. DeEll and Prange (1992) reported higher soluble solids concentrations (SSC) for OFP-grown 'Cortland' and 'McIntosh' apples in Nova Scotia, compared with conventional apples of the same cultivars, but no differences for firmness, titratable acidity (TA) or sensory perception. A single year comparative study of IFP and OFP 'Golden Delicious' apples in Switzerland, found that OFP apples were firmer, were rated better by sensory panelists, and had higher concentrations of phenolic compounds in unpeeled apples, but no differences between systems were detected for SSC or TA (Weibel et al., 2000). In Washington State, OFP grown 'Golden Delicious' apples were found to be firmer and sweeter, as measured by the SSC:TA ratio at harvest and after six months of storage, than either conventional or IFP fruit, but only the higher sweetness of the OFP apples was discernible by sensory panels (Reganold et al., 2001). Organically grown 'Gala' apples were firmer, with higher peel and flesh total antioxidant activity than IFP or conventionally grown apples in Washington (Peck et al., 2006). Also, consumer panels found OFP and IFP apples to have equal or better overall acceptability, firmness, and texture than conventional apples (Peck et al., 2006). However, few differences were found between 'Jonagold' apples grown under IFP and OFP systems in Belgium (Róth et al., 2007); or between OFP and conventional 'Golden Delicious' whole apples tested in

Switzerland for antioxidant activity and effects on DNA in humans (Briviba et al., 2007). Additionally, when OFP apples had higher quality than conventional or IFP systems (DeEll and Prange, 1992; Weibel et al., 2000; Reganold et al., 2001; Peck et al., 2006), no single component of fruit quality appeared to be a universal trait of OFP apples.

Since many pre- and postharvest factors can influence fruit quality, Harker (2004) recommended that a comparative systems study should match cultivar and rootstock, plant age, and soil type by using paired orchards or replicated treatments within the same orchard to minimize external variables. Production practices (e.g., fruit thinning materials and timing, pesticide active ingredients and formulations, the use of kaolin clay, fertilizers, and ground cover management systems) are inherently different between IFP and OFP managed apple orchards. These differences will affect crop load, pest and disease incidence, weed competition, nutrient status, and soil conditions, which can ultimately affect fruit maturity and quality. Therefore, a systems comparison should evaluate fruit of similar maturity. Additionally, fruit size affects maturity and quality measurements, and comparisons should be between similarly sized fruit.

Over four-years, IFP was compared with OFP during and after the transition from conventional management in a ‘Liberty’ apple orchard. Both systems used published certification protocols and recent advances in IPM, ground cover management, pesticides, machinery, and crop load management techniques. The null hypothesis was that fruit maturity and quality measurements would not be different between IFP and OFP management.

2. Materials and Methods

2.1. Experimental site and design

All fruit used for this experiment was grown in a 0.42-ha block of high-density (1537 trees ha^{-1}; 1.5 m between trees; 4.3 m between rows; 2.7 m tall), disease-resistant ‘Liberty’/‘M.9’ apple trees at the Cornell Orchards in Ithaca, NY (42º 26’ N, 76º 27’ W). The soil was a Collamer silty clay loam series (fine-silty, mixed, active, mesic Glossaquic) formed from glacial lacustrine sediments. The orchard was planted in 1994 and trained to a modified vertical-axe form with pollenizer crabapple trees located throughout. Conventional practices, using IPM appropriate for NY, were used to control pests, diseases, and weeds from 1994 to 2003 (Agnello, 2007). In 2004, a randomized complete block design was implemented with four replications of the two production systems (IFP and OFP). The IFP system followed guidelines developed for NY (Carroll and Robinson, 2006). From 2004 to 2006, the orchards’ OFP treatment was considered transitional under USDA National Organic Program guidelines; only in 2007 would the OFP apples have been certifiable as organic (Federal Register, 2000). The experimental plots consisted of four adjacent rows, with each row having sixteen trees (Figure 1). The experimental design and execution of the treatments were designed to prevent spray drift across treatments. The 12-centermost trees of the two middle rows of each treatment unit were used for sampling. Further details on the experimental design and practices used for each production system have been described in Chapter 2.

2.2. Sampling procedures

To assess the effects of each production system on fruit maturity and quality at

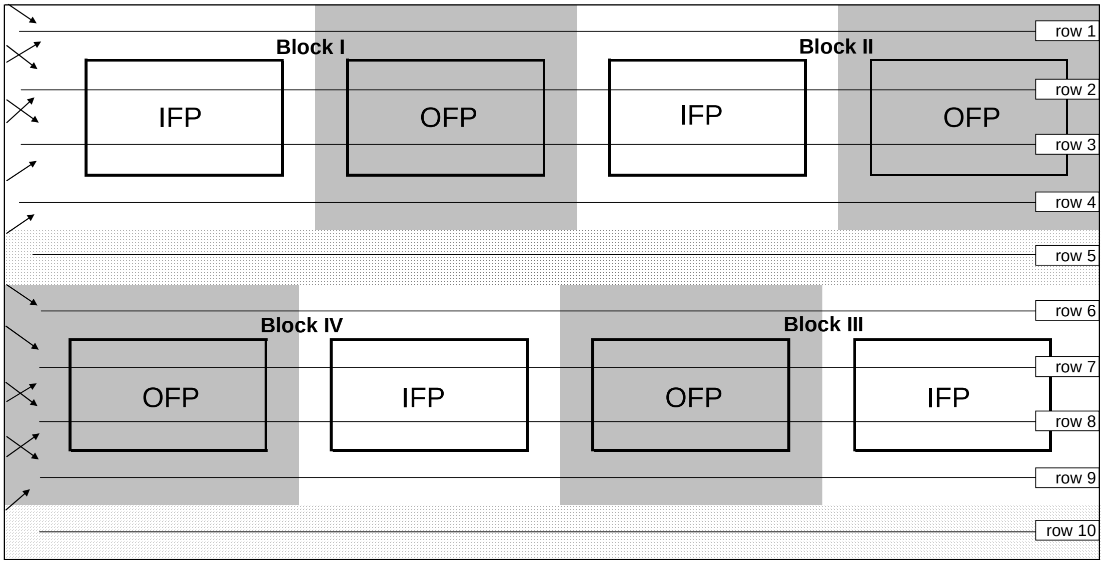

Figure 1. Map of the study area. Each horizontal line represents a tree row. Sampling occurred within the inner rectangles. Arrows on the left show the spray direction, which minimized drift among the treatment plots.

harvest, sequential harvests at weekly intervals were conducted each year. At each harvest a 10-fruit subsample was selected from each plot for measurements of percent surface blush, internal ethylene concentration (IEC), flesh firmness, SSC, starch index rating, and TA. Based upon the harvest indices, one harvest date in each year was selected for sensory, mineral concentration, and biochemical measurements. The fourth harvest in 2004 and the third harvests in 2006 and 2007 were used for these evaluations. In 2005, the first harvest for IFP was compared to the second harvest for OFP. A 10-fruit subsample was collected for measurements of moisture content and fruit mineral concentration. A second 10-fruit subsample was collected for analysis of total phenolic (TP) concentration and vitamin C equivalent antioxidant capacity (VCEAC). On that same harvest day, two separate 100-fruit subsamples were collected for the consumer sensory evaluations (triangle test and hedonic test). All subsampled fruit were mid-sized for the fruit within the respective treatment and similarly sized across treatments. Fruit had no visible subsurface damage, but surface blemishes were not a consideration for the subsampling among harvest data.

2.3. Maturity and quality measurements

At harvest the apples were weighed and visually assessed for percent red blush. The IEC was determined by gas chromatography (Series II; Hewlett Packard 5890, Wilmington, DE) using a 1 mL gas sample from the core cavity of each apple (Alwan and Watkins, 1999). Flesh firmness was measured, after removing part of the peel at two locations along the equator of each apple, with an EPT-1 penetrometer (Lake City Technical Products, Inc., Kelowna, BC) fitted with a cylindrical 11.1 mm diameter Effegi tip. Juice from the punctures was pooled to measure SSC using an Atago, Inc. PAL-1 digital refractometer (Bellevue, WA) and reported as °Brix. Starch index was determined by staining the stem-side of an equatorial cross-section of the apples with iodine solution (I_2-KI) and visual rating, where 1 = 100% staining and 8 = 0% staining (Blanpied and Silsby, 1992). TA was measured on two slices taken from opposite sides of the fruit, from the stem to the calyx, by titrating a 10 mL juice aliquot against a 0.1 N KOH solution to an end-point of pH 8.1 with a Mettler-Toledo DL12 autotitrator (Columbus, OH).

2.4. 2007 post-storage evaluations

Fruit was stored in air at 0.5°C for 9 weeks. Samples were sequentially removed from storage according to harvest date and held at 20ºC for either 1 or 7 d. A 10-apple subsample from each experimental unit was then assessed for firmness, SSC, and TA as described above.

2.5. Sensory panels

Once per year in 2005-07, two separate double-blind consumer (untrained) taste panels were conducted at the Cornell Sensory Tasting Facility. In the triangle test, panelists tasted three slices of apple (two from one treatment and one from the other) and were asked to identify the slice that was different from the other two (Lawless and Heymann, 1999). Each panelist assessed all four blocks separately and in a randomized order. Between 83 and 88 independent observations were made per block each year. In the second panel, the overall acceptability, texture, and overall flavor were rated on a 9-point hedonic scale (1 = dislike extremely; 5 = neither like/dislike; 9 = like extremely); while sweetness, tartness, crispness, firmness, and juiciness were rated on a 9-point intensity scale (1 = not at all sweet, not at all tart, not at all crisp, extremely soft, or not at all juicy, respectively; 9 = extremely sweet, extremely tart, extremely crisp, extremely hard, or extremely juicy, respectively). Each panelist judged both treatments from two blocks separately and in randomized order.

On each test day, apples were moved from cold storage and kept at room temperature (22ºC) for approximately 4 h prior to testing. Unpeeled apples were cored and cut into eight equally sized slices (stem to calyx) with an apple corer/slicer. Individual slices were placed in a 3.8-cm wide plastic cup, identified with a three-digit blinding code, and immediately served to a panelist. Panelists were provided water for rinsing and palate cleansing. Taste tests were conducted under red lights to mask blemishes and flesh browning. Each panelist used an individual booth equipped with a computer that led them through the tests and collected data using Compusense® *five* software (ver. 4.6; Guelph, ON).

In 2006 and 2007, panelists also judged the overall appearance of apples on a 9-point hedonic scale. From each experimental unit, ten whole apples were rinsed in water and placed on white trays with three-digit blinding codes. Each panelist judged both treatments from all four blocks separately and in randomized order. Appearance tests were conducted under fluorescent lighting to simulate a retail market. Each year, 48 to 56 independent observations were made per block for both the hedonic/intensity tests and the appearance tests.

2.6. Fruit mineral concentration

A 2-cm equatorial slice of fruit flesh was taken from each sample and two 1.5-cm diameter plugs (No. 9 cork borer) of cortical tissue were removed from opposite sides of the apple beneath the peel (Turner et al., 1977). Composite fruit tissue was lyophilized and then analyzed on a dry-weight basis at the Cornell Nutrient Analysis Lab. Total carbon (C) and total nitrogen (N) were measured with Dumas combustion. Macro and micronutrients were measured with an inductively coupled argon plasma (ICP) spectrometer (Kalra, 1998). Percent moisture was determined after 24 h at 80°C from two 1.5-cm diameter plugs taken from the same 2-cm thick equatorial slice.

2.7. Total phenolic concentrations and antioxidant capacity

Unpeeled cored apples were diced and 150 g subsets were lyophilized. Finely ground 1-g subsamples were extracted with 80% methanol (Kim and Lee, 2002; Valois et al., 2006). Total phenolic concentrations were measured using the Folin-Ciocalteu colorimetric method (Valois et al., 2006) and reported as mg gallic acid equivalents (GAE) per 100 g fruit. The VCEAC was based on the reduction of absorbance at 734 nm on a BrandTech Scientific UV/Vis diode-array spectrophotometer (Essex, CT) after the extracted sample was added to a solution containing free radical generating 2,2’-azino-bis(3ethylbenzothiazoline-6-sulfonic acid) as diammonium salt (ABTS) (Kim et al., 2002). Values are reported as mg VCEAC per 100 g fruit.

2.8. Statistical analyses

All data were analyzed with a mixed model to assess the long-term effects of each production system using the PROC MIXED procedure of SAS 9.1 (Cary, NC). For the moisture content, sensory evaluations, fruit mineral concentrations, total phenolic concentrations, and antioxidant capacity, the mixed model included Year (2004-07), Treatment (IFP and OFP), and their interactions as fixed effects. For the IEC, blush, starch, firmness, TA, SSC, and SSC:TA, the statistical mixed models also included the Harvest timing (1-4) as a fixed effect. For the 2007 postharvest evaluations, the statistical model included Treatment (IFP and OFP), Harvest timing (1, 2, or 3), and Day (1 or 7) as fixed effects. Block, Treatment × Block, and, when the harvest effect was included, Treatment × Block × Year were random effects. The IEC data were log transformed due to skewed distributions, but presented as back-transformed means. Main effects, interactions, and Treatment effects within interactions were considered significant at the 0.05 level.

3. Results

3.1. Maturity and quality measurements

No consistent treatment differences were detected for fruit maturity and quality measurements, although interactions between treatments, year and harvest timing were found for some harvest measurements (Table 1). Following trends in total harvested fruit (Chapter 2), the measured IFP fruit weighed more in 2005 and 2006, but OFP fruit weighed more in 2007. The IEC of fruit was not different between treatments, and the starch index was only different in 2005 when OFP apples had less starch hydrolysis compared with those from the IFP system. The IFP apples were more highly blushed in 2007, but this did not result in a greater percentage of fruit graded into the most highly valued marketing category (US Extra Fancy) (Chapter 2; Federal

Table 1. Internal ethylene concentration (IEC), starch index, blush, firmness, soluble solids concentration (SSC), titratable acidity (TA), the SSC:TA ratio, and moisture content of apples from integrated (IFP) or organic fruit production (OFP) systems at harvest over four years. Significance levels of the main effects (Year, Harvest, or Treatment), interactions, and Treatment effects within an interaction are at the bottom of the table. Each value represents a 10-apple subsample from each of four replicated blocks within each treatment.

Year	Harvest	Treatment	Average fruit weight (g)	IEC ($\mu L\ L^{-1}$)	Starch (1-8)	Blush (%)	Firmness (N)	Soluble Solids ºBrix	Titratable acidity ($g\ mL^{-1}$)	SSC:TA	Moisture content (%)
2004	1	IFP	N/A	0.1	1.4	70.5	88.3	11.4	0.492	23.3	
2004	1	OFP	N/A	0.1	1.7	67.0	86.4	11.3	0.482	23.6	
2004	2	IFP	N/A	0.2	2.1	76.5	83.4	12.0	0.476	25.3	
2004	2	OFP	N/A	0.5	2.0	78.3	82.0	12.2	0.442	27.5	
2004	3	IFP	N/A	5.2	2.8	80.3	85.0	12.7	0.503	25.2	
2004	3	OFP	N/A	7.7	2.9	80.5	83.7	12.2	0.449	27.1	
2004	4	IFP	N/A	12.4	3.3	94.0	78.8	12.9	0.435	29.7	
2004	4	OFP	N/A	30.6	3.6	95.3	81.6	13.4	0.429	31.2	
2005	1	IFP	155	17.9	3.9	89.1	85.3	12.0	0.577	20.9	
2005	1	OFP	141	4.4	3.2	97.1	84.5	12.4	0.564	22.0	
2005	2	IFP	160	23.8	4.2	99.1	80.9	12.8	0.554	23.1	84.2
2005	2	OFP	137	11.1	3.9	98.8	81.2	12.5	0.512	24.7	84.6
2006	1	IFP	133	0.7	1.3	79.8	87.6	11.2	0.464	24.2	
2006	1	OFP	120	1.1	1.5	72.6	86.2	11.6	0.508	22.7	
2006	2	IFP	134	12.1	2.1	89.9	85.5	12.1	0.424	28.6	
2006	2	OFP	121	14.7	2.5	85.6	83.7	12.1	0.466	26.1	
2006	3	IFP	143	40.5	3.8	96.3	80.8	13.2	0.408	32.5	85.1
2006	3	OFP	131	34.1	4.3	93.9	80.4	13.2	0.472	27.9	85.5
2007	1	IFP	124	0.6	1.1	73.0	87.2	11.4	0.442	25.7	
2007	1	OFP	138	0.3	1.0	62.1	85.9	11.4	0.536	21.5	
2007	2	IFP	137	0.8	1.8	84.8	86.4	11.9	0.453	26.3	
2007	2	OFP	148	0.4	1.5	78.0	83.7	11.7	0.508	23.1	
2007	3	IFP	148	21.5	3.3	94.9	80.9	12.1	0.415	29.2	86.3
2007	3	OFP	153	18.0	2.8	93.3	81.1	12.0	0.452	26.5	85.6
Year			***	***	***	***	***	***	***	***	***
Harvest			***	***	***	***	***	***	***	***	
Treatment			**	NS	NS	NS	NS	NS	NS	NS	NS
Harvest × Treatment			NS	NS	NS	NS	***	NS	NS	NS	
Year × Treatment			***	NS	*	*	NS	NS	***	***	*
Treatment effects within the Year × Treatment interaction											
2004					NS	NS			NS	*	
2005			***		*	NS			NS	NS	NS
2006			**		NS	NS			**	***	NS
2007			**		NS	*			**	***	*
Treatment effects within the Harvest × Treatment interaction											
Harvest 1							*				
Harvest 2							*				
Harvest 3							NS				
Harvest 4							*				

NS, *, **, *** Nonsignificant or significant differences at $p \le 0.05$, 0.01, or 0.001, respectively.
N/A data not available.

Table 2. Post-storage measurements of firmness, soluble solids concentration (SSC), titratable acidity (TA), and the SSC:TA ratio of apples from integrated (IFP) or organic fruit production (OFP) systems in 2007. Significance levels of the main effects (Day, Harvest, or Treatment), interactions, and Treatment effects within an interaction are at the bottom of the table. Each value represents a 10-apple subsample from each of four replicated blocks within each treatment.

Harvest	Day	Treatment	Average fruit weight (g)	Firmness (N)	Soluble solids (ºBrix)	Titratable acidity (g mL^{-1})	SSC:TA
1	1	IFP	143	57.9	12.6	0.401	32.0
1	1	OFP	152	64.6	13.0	0.434	30.0
1	7	IFP	149	54.5	12.6	0.344	37.4
1	7	OFP	152	58.3	13.1	0.363	36.5
2	1	IFP	140	52.8	12.7	0.320	39.6
2	7	OFP	161	64.1	13.5	0.393	34.5
2	7	IFP	140	52.1	12.8	0.277	46.1
2	7	OFP	160	61.0	13.4	0.330	40.6
3	1	IFP	158	52.4	12.6	0.334	37.6
3	1	OFP	155	59.2	13.5	0.404	33.5
3	7	IFP	153	47.8	12.7	0.307	42.1
3	7	OFP	156	53.7	13.7	0.350	39.5
Day			NS	***	NS	***	***
Harvest			**	***	NS	***	***
Treatment			*	**	*	***	***
Harvest × Treatment			***	***	NS	NS	NS
Day × Treatment			NS	*	NS	NS	NS
Treatment effects within the Day × Treatment interaction							
1				***			
7				**			
Treatment effects within the Harvest × Treatment interaction							
1			NS	**			
2			***	***			
3			NS	**			

NS, *, **, *** Nonsignificant or significant differences at p ≤ 0.05, 0.01, or 0.001, respectively.

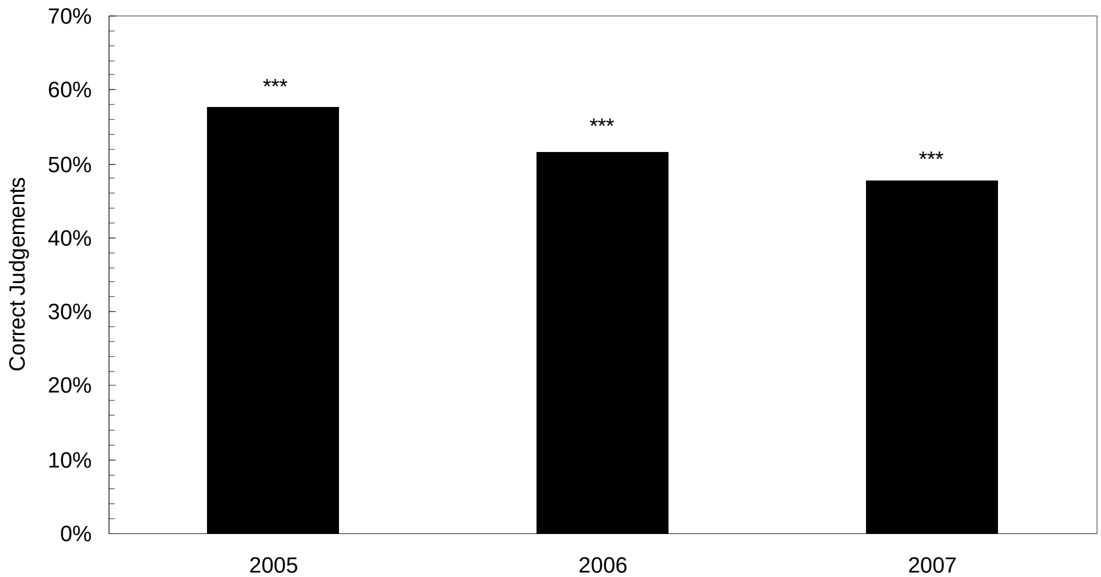

Figure 2. The percent of correct judgments made by consumer panelists identifying the odd sample in a triangle test consisting of apples from integrated (IFP) and organic fruit production (OFP) systems at harvest over three years. Each test represented at least 83 independent observations for each of the four replicated blocks within each treatment. Odds for random correct identification were one in three. The symbols (***) represent significant differences at $p \leq 0.001$.

Register, 2002). Apples from the IFP system were firmer than OFP apples at the first two harvests in each year except 2004, when the OFP fruit was firmer at the fourth harvest. The SSC of fruit was not different between treatments. Titratable acidity was highest in fruit from the OFP system in 2006 and 2007. Fruit from the OFP system had a higher sugar to acid ration (SSC:TA) in 2004, but IFP apples had a higher SSC:TA ratio in 2006 and 2007. In 2007, IFP apples had higher moisture content but this difference was less than 1% and probably had little influence over the other measurements taken in this experiment.

3.2. 2007 post-storage evaluations

Apples from the OFP system were consistently firmer, and had greater SSC, TA, and SSC:TA than IFP apples after nine weeks of storage at 0.5°C (Table 2).

Table 3. Consumer sensory panel ratings of apples from integrated (IFP) or organic fruit production (OFP) systems at harvest over three years. Significance levels of the main effects (Year or Treatment), interactions, and Treatment effects within an interaction are at the bottom of the table. Each value represents at least 48 independent observations for each of four replicated blocks within each treatment.

Year	Treatment	Sweetness	Tartness	Overall Flavor	Firmness	Crispness	Juiciness	Overall Acceptability	Appearance
		(1-9)	(1-9)	(1-9)	(1-9)	(1-9)	(1-9)	(1-9)	(1-9)
2005	IFP	5.7	5.7	5.9	7.0	6.9	6.9	6.4	N/A
2005	OFP	6.3	6.0	6.4	6.9	6.8	6.9	6.8	N/A
2006	IFP	6.4	6.2	6.4	7.0	7.0	6.9	6.7	6.5
2006	OFP	6.1	6.0	6.2	7.0	6.9	6.9	6.5	5.5
2007	IFP	6.2	5.9	6.1	6.8	6.8	6.7	6.4	6.6
2007	OFP	6.1	6.2	6.3	7.2	7.0	6.9	6.6	6.6
Year		NS	NS	NS	NS	NS	NS	NS	**
Treatment		NS	NS	NS	NS	NS	NS	NS	*
Year × Treatment		***	NS	**	NS	*	NS	*	***
Treatment effects within the Year × Treatment interaction									
2005		***		**		NS		**	
2006		*		NS		NS		NS	***
2007		NS		NS		**		NS	NS

NS, *, **, *** Nonsignificant or significant differences at $p \leq 0.05$, 0.01, or 0.001, respectively.
N/A data not available.

Harvest × Treatment and Day × Treatment interactions for firmness resulted from differences in magnitude between IFP and OFP apples at the various test intervals. The measured OFP apples weighed approximately 20 g more than IFP apples at the second harvest.

3.3 Sensory panels

In the triangle test, consumer panelists were able to correctly distinguish the two treatments in all years (Figure 2). This difference started at 58% correct judgments in 2005, but dropped to 52% in 2006, and then to 48% in 2007, compared to a 1 in 3 chance of random correct differentiation (Figure 1). Treatment effects were not significant for the hedonic/intensity tests, and treatment effects with interactions were not consistent (Table 3). For example, OFP apples were judged sweeter in 2005,

Table 4. Mineral concentrations of apple flesh from integrated (IFP) or organic fruit production (OFP) systems at harvest over four years. Significance levels of the main effects (Year or Treatment), interactions, and Treatment effects within an interaction are at the bottom of the table. Each value represents a pooled sample of ten apples from each of four replicated blocks within each treatment.

Year	Treatment	C (%)	N (%)	C:N	P (%)	K (%)	Ca (%)	Mg (%)	Al ($ug\ g^{-1}$)	B ($ug\ g^{-1}$)	Cu ($ug\ g^{-1}$)	Fe ($ug\ g^{-1}$)	Mn ($ug\ g^{-1}$)	Zn ($ug\ g^{-1}$)	N:Ca	N:P	Mg:Ca	Mg+K:Ca
2004	IFP	40.2	0.11	359	0.047	0.50	0.028	0.022	1.3	20.2	5.2	5.5	1.9	3.6	4.2	2.4	0.82	19
2004	OFP	40.1	0.11	377	0.045	0.45	0.023	0.020	1.2	19.5	4.6	5.3	1.6	2.8	4.9	2.4	0.88	21
2005	IFP	39.1	0.13	302	0.072	0.74	0.023	0.024	2.2	27.9	2.3	15.9	2.1	5.0	5.9	1.8	1.08	34
2005	OFP	38.8	0.13	298	0.067	0.68	0.016	0.021	2.4	32.4	2.0	16.8	2.0	5.3	9.8	2.0	1.38	52
2006	IFP	40.8	0.11	373	0.052	0.49	0.024	0.023	4.0	19.5	n/a	11.9	3.8	N/A	5.0	2.1	1.00	23
2006	OFP	40.7	0.10	395	0.054	0.51	0.021	0.024	3.7	19.3	n/a	8.2	2.2	N/A	5.1	1.9	1.16	26
2007	IFP	40.4	0.11	383	0.051	0.48	0.029	0.022	0.0	9.1	1.9	6.5	1.3	12.2	3.8	2.1	0.78	17
2007	OFP	40.1	0.13	343	0.050	0.50	0.028	0.024	1.7	9.7	4.4	6.9	1.3	17.3	4.5	2.5	0.84	19
Year		***	NS	*	***	***	**	NS	***	***	**	**	NS	***	**	*	***	***
Treatment		NS	NS	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	**	NS
Year × Treatment		NS	NS	NS	NS	**	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Treatment effects within the Year × Treatment interaction																		
2004						*												
2005						*												
2006						NS												
2007						NS												

NS, *, **, *** Nonsignificant or significant differences at $p \leq 0.05$, 0.01, or 0.001, respectively.

N/A data not available.

Table 5. Total phenolic concentration and antioxidant activity of unpeeled apples from integrated (IFP) or organic fruit production (OFP) systems at harvest over four years. Significance levels of the main effects (Year or Treatment) and interactions are at the bottom of the table. Each value represents a pooled sample of ten apples from each of four replicated blocks within each treatment.

Year	Treatment	Total phenolics (mg GAE 100 g^{-1} fruit)	Antioxidant capacity (mg VCEAC 100 g^{-1} fruit)
2004	IFP	76.4	241.0
2004	OFP	79.2	227.4
2005	IFP	82.4	137.0
2005	OFP	74.5	153.8
2006	IFP	150.7	225.9
2006	OFP	157.3	239.7
2007	IFP	137.9	232.4
2007	OFP	144.6	223.3
Year		***	***
Treatment		NS	NS
Year × Treatment		NS	NS

NS, *, **, *** Nonsignificant or significant differences at $p \leq 0.05$, 0.01, or 0.001, respectively.

IFP apples were judged sweeter in 2006, and no difference was found in 2007. Apples from the OFP system were judged to have better overall flavor and better overall acceptability in 2005, and to have crisper and firmer flesh in 2007. The largest difference seen between the systems was for overall appearance in 2006. In that year there were significantly more blemishes observed by the panelists on the OFP apples due to sooty blotch/flyspeck, scarfskin, and russeting (Chapter 2).

3.4. Fruit mineral concentration

In 2004 and 2005, the only nutrient content differences found between the systems were in potassium (K) and calcium (Ca) levels that were higher in IFP fruit (Table 4). The ratio of magnesium (Mg):Ca was greater in the OFP fruit, which was likely due to its lower Ca concentrations (Table 4).

3.5. Total phenolic concentrations and antioxidant capacity

The TP concentrations and VCEAC were not different between growing systems (Table 5). However, the total phenol concentrations for both treatments increased from 2004-05 to 2006-07.

4. Discussion

4.1. Maturity and quality measurements

Increases of IEC, starch indices and SSC, and the decreases of firmness and TA during the sequential harvests, indicated a rapid ripening period for ‘Liberty’ apples. Fruit changed from under- to overripe within a one-week interval, indicating that the proper harvest timing of ‘Liberty’ was critical for the comparative fruit quality evaluations that were conducted. Fruit maturity advanced differently between the two systems only in 2005, with delayed maturity for fruit from the OFP system compared to those from IFP. Although higher crop loads can delay maturity (Francesconi et al., 1996), yields were not different between treatments in 2005. In contrast, no maturity effects were detected in 2007, when IFP yields were significantly greater than OFP yields, indicating the effects on maturity were not entirely related to crop load in these experiments.

The absence of consistent differences between system treatments at harvest suggests that both treatments were similar in fruit quality. Fruit size was different between treatments in the three years it was measured, but the differences did not appear to have a strong relationship to the other measurements. This might be because fruit size differences were small, and the fruit from both treatments would have mostly been within the same USDA size grading range (Federal Register, 2002). Neither firmness nor SSC were consistently different between the production systems, although higher TA and lower SSC:TA were measured for OFP apples during the final two years of this experiment. Awad et al. (2001) reported lower TA when crop loads were greater, but with lower OFP yields in 2006 and 2007 this trend was not observed (Chapter 2). In other studies, TA was lower for organic ‘Golden Delicious’ apples than those grown under an IFP system over two years; however, TA was higher one year and then lower in the next for organic ‘Gala’ apples, compared with apples grown under an IFP system, and there was no difference between conventional and OFP for ‘Cortland’, ‘McIntosh’ in Nova Scotia, or between OFP and IFP for ‘Jonagold’ apples grown in Belgium (DeEll and Prange, 1992; Reganold et al., 2001; Peck et al., 2006; Róth et al., 2007).

Kaolin clay, commercially formulated as Surround® WP (Engelhard Corporation, Iselin, NJ), was applied between 173-575 kg active ingredient ha^{-1} y^{-1} for OFP pest control. Kaolin clay has been used for reducing sunburn damage on apple fruit, and several reports have been made about the relationship of kaolin clay to fruit quality (Glenn et al., 2001; Schupp et al. 2002; Glenn et al., 2005; Wand et al., 2006). In Eastern US studies, kaolin clay has been shown to have variable effects based on cultivar and seasonal climatic conditions. Increased fruit weight for ‘Gala’ and ‘Bisbee Red Spur Delicious’ and improved red color for ‘Golden Delicious’, ‘Empire’ and ‘Gala’ (Glenn et al., 2001; Glenn et al., 2005) were reported, but neither fruit weight nor red color were increased for ‘Fuji’ and ‘Honeycrisp’ apples in another study (Schupp et al., 2002). Other measurements, such as SSC, TA, and firmness, were relatively unaffected by kaolin clay application (Schupp et al., 2002; Glenn et al., 2005). In the present study, the percentage red blush was greater for IFP in 2007, and no consistent differences were found for firmness (Table 1).

Many interrelated biotic and abiotic factors can influence fruit maturity and quality. These include fruit nutrient content, pest and disease levels, and ground-cover management system (Ferguson and Watkins, 1992; Francesconi et al., 1996; Merwin, 2003). Carbohydrate and water balance are the most commonly cited factors, but since the objective of our study was to compare production systems, ranking factors that most influenced carbohydrate supply would be difficult. Pest and disease pressure were greater for OFP, and this affected crop quality in terms of cullage and marketability, but there did not seem to be much effect on the internal fruit quality. Additionally, the increase in SSC and firmness that was reported by Merwin et al. (2003) when apple trees were grown in a competitive ground-cover was not found in the present study.

4.2. 2007 post-storage evaluations

In the only year that post-storage quality was evaluated, fruit from the OFP system were consistently firmer and had higher, SSC, TA and SSC:TA ratios. The greater SSC for OFP apples was consistent throughout the postharvest evaluations. TA was greater in OFP apples throughout the postharvest analyses, consistent with what was found at harvest that year. Smaller fruit tend to be firmer than larger fruit, but the OFP fruit were both larger and firmer than IFP fruit for the second harvest measurements. While some studies have also reported that apples grown under OFP had better storage life than IFP apples (Reganold et al., 2001; Peck et al., 2006), others have not found that to be the case (Róth et al., 2007). Fruit mineral concentrations are often related to the storability of fruit. In particular, higher fruit calcium concentrations have been associated with greater flesh firmness (Ferguson and Boyd, 2002). In the current study, however, greater Ca in IFP, not OFP fruit was observed–although in 2007 the difference was small (Table 4). There were also small Mg differences between treatments in that year, so it is unlikely that cation antagonism reduced Ca availability.

4.3. Sensory panels

Panel scores showed that the eating quality of apples from both systems was satisfactory to consumers. While the triangle test panelists consistently discriminated between fruit from the two growing systems, there was no obvious basis for this distinction. Red lighting and equally sized apple slices made it unlikely that panelists were able to visually identify the slice that was different. Additionally, panelists were instructed to identify the fruit that tasted different, regardless of appearance. There were a few correlations between fruit quality measured by lab instruments and rated by the sensory panelists. In 2005, when OFP apples were judged by panelists to be sweeter, the SSC:TA ratio was greater for OFP apples; in 2006, when IFP apples were judged to be sweeter, the SSC:TA ratio was greater for IFP apples. The SSC:TA ratio was also greater for IFP apples in 2007, but the difference between treatments was smaller than in previous years, and was apparently below the level of differentiation for panelists (Harker et al., 2002a). In all years, panelists reported similar firmness ratings between treatments, which were also confirmed by penetrometer firmness measurements. Flesh firmness may need to be greater than 6 N for trained panelists to detect fruit texture differences (Harker et al., 2002b). The greater crispness reported by panelists in 2007 was not consistent with penetrometer measurements taken at harvest, but crispness is a different textural attribute than firmness and is more difficult to relate to penetrometer measurements (Harker et al., 2002b).

The 1-point difference in the 2006 overall appearance test was a strong indication that cosmetic blemishes on the OFP apples were less acceptable to consumers than the mostly clean IFP fruit (Chapter 2). This could be a serious impediment to OFP in the Northeast because of increased likelihood that apples grown under this system will be blemished. Yue et al. (2006) showed that consumers' willingness to pay a premium for organic apples with cosmetic imperfections (such as sooty blotch/flyspeck damage) was reduced 63% when they were also offered organic apples that looked similar to unblemished conventional fruit. Consumers who were primarily interested in local and organic produce were willing to purchase blemished organic apples for a premium, but this was a small segment of the sampled population.

4.4. Fruit mineral concentration

Fruit mineral content differences in this project were most pronounced in the first two years, before regular applications of foliar Ca began in the latter part of the season, and ground applications of a potassium magnesium fertilizer (Sul-Po-Mag for IFP; K-Mag for OFP). Reganold et al. (2001) found only B to be different between OFP and IFP in three out of the four years they measured fruit nutrients, and Peck et al. (2006) reported that only fruit N content was different between OFP and IFP systems in a Washington orchard.

4.5. Total phenolic concentrations and antioxidant capacity

The TP and VCEAC were the same between the two systems, as also found in whole apples by Briviba et al. (2007) and Lamperi et al. (2008). In contrast, these measurements were greater in fruit from OFP than IFP or conventional systems in other studies (Wiebel et al., 2000; Peck et al., 2006). Peck et al. (2006) suggested that glyphosate (a synthetic herbicide) may have inhibited flavonoid production in their

IFP and conventional systems, and that low OFP fruit N content may have increased fruit antioxidant levels in OFP. These hypotheses need further study, because in the current study glyphosate was used minimally (twice in 2004 and 2005, none in 2006, and once in 2007) for IFP, and fruit N content was not different between IFP and OFP systems. The application of kaolin clay has also been suggested to alter TP and antioxidant concentrations, but did not appear to do so in whole fruit from our experiment or in the apple peel of other studies (Wand et al., 2006). Reports from comparative systems studies in other perennial fruit production systems have also shown mixed results for phytochemical content (reviewed by Zhoa et al., 2006), suggesting that there are too many factors involved to consistently attribute nutriceutical differences to a particular production system. Additionally, growing region, cultivar, and cropload have all been shown to affect TP and antioxidant content in whole apples (Awad et al., 2001; McGhie et al., 2005; Lamperi et al., 2008). Differences between OFP and either IFP or conventional systems for TP and antioxidant concentrations found in other growing regions may relate to the location or the cultivar under study more than the production systems.

5. Conclusion

This four-year transition to IFP and OFP apple systems showed that internal fruit quality was rarely different between the growing systems. Furthermore, differences found between treatments in our study did not always coincide with other published reports comparing OFP systems to either IFP or conventional systems. This supports the hypothesis that there is no single attribute that consistently differentiates IFP and OFP fruit. In order for OFP to be broadly employed in the Northeast, better fruit finish must be achieved, because in a supermarket type environment, cosmetic blemishes might be paramount and detract from sales. However, consumers may be prepared to purchase fruit with lesser visual quality if organic is a strong purchasing motivation. The combination of both visual and compositional factors represents a complex interaction and motivations for purchasing or avoiding organic produce such as relative price, pesticide residues, potential enteropathogens, or the externalities of the systems.

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Chapter Four

Changes in Soil Properties During and After the Transition to Integrated and Organic Fruit Production Systems in a New York Orchard

Abstract

Soil quality in an orchard of disease-resistant ‘Liberty’/‘M.9’ apple (*Malus* × *domestica* Borkh.) trees, during and after the transition from conventional to integrated (IFP) and organic fruit production (OFP) systems was investigated. Chemical composition (C, N, P, K, Ca, Mg, Al, Cu, Fe, Mn, Zn, soil organic matter, and pH), physical properties (porosity, available water content, bulk density, penetration resistance, and wet aggregate stability), and biological properties [potentially mineralizable N (PMN), total inorganic nitrogen, microbial biomass carbon (MBC) and nitrogen (MBN), and microbial respiration] were measured in soil at 0-6 and 6-12 cm depth over three years. Weed coverage and biomass were also measured. Terminal-Restriction Fragment Length Polymorphism (T-RFLP) analysis was used to determine community composition differences for bacteria and fungi. Mulch with infrequent herbicide application was used for IFP, and provided effective weed control, while increasing soil organic matter, pH, soil nutrient availability, MBC, and microbial respiration. Mechanical cultivation along with chicken manure compost was used for OFP, and increased soil porosity, decreased aggregate stability, and increased PMN and total inorganic N. In OFP, a relatively new type of cultivator effectively managed weeds for 2-4 week intervals, but overall weed coverage was greater than in IFP. For most measurements, the 6-12 cm depth only showed minimal treatment differences. Sampling time influenced the bacterial communities more so than the treatments, but treatment separation developed by the last observation. By the third

sampling date fungal communities in the 0-6 cm depth segregated by treatment. In the OFP system, soil quality did not improve as much as in the IFP soil.

1. Introduction

The edaphic features of apple (*Malus* × *domestica* Borkh.) orchards are influenced by interrelated management operations, such as weed control and fertilization. In orchards, the primary groundcover management goals are to maximize yields and tree health by increasing nutrient and water uptake. In conventional systems, these goals can be accomplished by reducing weed competition under the trees with herbicides and by applying synthetic fertilizers (Stiles and Reid, 1991; Merwin, 2003). However, many Northeastern United States apple growers have shown interest in producing apples under integrated (IFP) and organic fruit production (OFP) to access profitable niche and global markets, and these systems restrict or prohibit synthetic inputs. Additionally, both IFP and OFP systems are based in ecological farming practices, which require growers to improve or at least maintain soil quality (Federal Register, 2000; Carroll and Robinson, 2006). Directly measuring soil quality can be difficult for growers, so management practices need to be developed in order for these systems to successfully be employed in the Northeastern US. One of the most cited definitions for soil quality, by Doran and Parkin (1994), is “the capacity of a soil to function within ecosystem boundaries to sustain biological productivity, maintain environmental quality, and promote plant and animal health.” In orchards, soil quality can be improved with organic matter additions, such as manure-based composts and natural mulches that contribute nutrients to the soil while fostering biological activity. But little is known about how these practices integrate with an entire IFP or OFP system in this region.

In IFP systems, synthetic soil-active residual herbicides are avoided and synthetic fertilizers are only allowed when plant or soil analyses reveal nutrient deficiencies. The New York IFP protocol emphasizes the use of biomass mulches to suppress weeds, reduce irrigation needs, improve soil quality, and provide a long-term source of nutrients (Carroll and Robinson, 2006). When compared with bare-soil herbicide strips, bark mulch combined with a minimum herbicide program has reduced agrichemical and nitrate-N leaching (Merwin et al., 1996); lowered soil bulk density, increased porosity, and increased water infiltration rates (Hogue and Neilsen, 1987); and increased soil organic matter (SOM) and soil microbial respiration, while shifting microbial community composition in response to increasing SOM and nutrients (Yao et al., 2005). These positive soil quality indicators were achieved without causing detrimental effects to tree nutrient status or yields (Walsh et al., 1996; Yao et al., 2005). In contrast, bark mulches may create habitat that harbors trunk-eating rodents, e.g., *Microtus spp.* (Hogue and Neilsen, 1987), and are expensive to install. However, since bark mulch decomposes slowly, it can remain effective for up to four years thus prolonging its investment by reducing herbicide applications (Merwin et al., 1995; Rifai et al., 2002). Because of the positive impact that biomass mulches can have on the agroecosystem, they have been suggested as a best management practice for IFP orchards, especially when accompanied with infrequent post-emergent herbicide applications, but this has not been satisfactorily tested.

Herbicides that are allowable in organic production are derived from natural compounds (e.g., acetic acid and various essential oils) and are generally ineffective for controlling grasses and sods that typically populate the target area for weed control in orchards (Evans, 2007). Organic orchardists therefore rely on mulches, thermal (flame or steam) control, and/or mechanical cultivation for weed control in OFP (Granatstein and Mullinix, 2008). In regions with frequent summer rains, biomass mulches will eventually become overgrown with monocot and perennial weeds. Without the ability to integrate herbicide applications, as in the IFP system, additional hand-labor for weeding is often needed (Granatstein and Mullinix, 2008). Thermal control often uses liquid propane, where gas is ignited in a flame-burning unit to scorch juvenile weeds. Flame-weeding units have been effective, but many organic tree-fruit growers are reluctant to use these devices because of the additional dependence on petroleum, the danger of explosion, the threat of off-target fires, and excess heat damaging the tree canopy (Rifai et al., 2002; Peck et al., 2006).

Studies have shown that aggressive mechanical weed cultivation, such as with rototillers and other implements that pulverize or invert soil, can be more effective at controlling weeds than other organically approved practices (Walsh et al., 1996; Granatstein and Mullinix, 2008). These implements, however, released nitrate-nitrogen (NO_3-N) from the microbial biomass, and therefore increased the potential for N leaching from the orchard (Walsh et al., 1996), and decreased SOM (Haynes, 1980; Hogue and Neilsen, 1987). In addition, use of the post-emergent herbicide glyphosate increased tree growth and yields compared with mechanical cultivation (Merwin and Stiles, 1994; Merwin et al., 1994). However, rolling cultivators are becoming more widely used in organic farming (Bowman, 1997). These tools shallowly penetrate the soil and have tines that rotate at low speeds, which minimize the negative effects of mechanical weed control on soil quality. One such example is the Wonder Weeder (Harris Manufacturing; Burbank, WA), a specialized Lilliston® Spider-based orchard cultivator.

When compared with conventional herbicide strips in apple orchards, organically managed soils reportedly have lower bulk density (Werner, 1997; Glover et al., 2000; Goh et al., 2001); higher water holding capacity (Werner, 1997); greater water infiltration rates (Glover et al., 2000; Goh et al., 2001); more microbial biomass

C (MBC) (Werner, 1997; Goh et al., 2001; Kramer et al., 2006); greater potentially mineralizable N (Werner, 1997); reduced N leaching and enhanced denitrifier activity (Kramer et al., 2006); greater colonization and diversity of mycorrhizal fungi (Werner, 1997; Purin et al., 2006); increased worm densities (Werner, 1997; Goh et al., 2001); and increased abundance of arboreal detritivores and predators (Doles et al., 2001; Matthews et al., 2002). Comparing all these studies, there were few consistent trends for chemical properties (Werner, 1997; Glover et al., 2000; Goh et al., 2001; Purin et al., 2006). Differences between organic and conventional management were often attributed to the addition of composts and mulch, the greater weed biomass that existed under organically managed trees, or the effects of mechanical cultivation.

A multitude of soil properties have been used to evaluate soil quality. Therefore, minimum datasets have been used based upon experimental objectives (Doran and Parkin, 1996; Karlen et al., 2003). Weighted indices can be used to help synthesize data, but these require either baseline information from undisturbed soils or large databases to provide comparative information (Glover et al., 2000; Gugino et al., 2007), neither of which were available for our experimental site and cropping system. For the present study a dataset was developed that 1) included indicators for chemical, physical, and biological soil properties; 2) was sensitive to management practices used in the treatments; 3) could be used to interpret other edaphic factors; 4) could potentially be used in databases; and 5) added novel information about edaphic conditions under these orchard production systems.

Although soil processes are largely microbe-driven, the understanding of relationships between microbial community composition and soil quality is still evolving (Kennedy and Papendick, 1995; Ibekwe et al., 2002; Bending et al., 2004). Polymerase Chain Reaction (PCR) based techniques have been effective tools for differentiating groundcover treatments in apple orchards (Yao et al., 2005) and have provided considerable insight into apple replant disease (Rumberger et al., 2004; Yao et al., 2005; Rumberger et al., 2007; St. Laurent et al., 2008). The PCR based Terminal-restriction fragment length polymorphism (T-RFLP) technique was chosen for our study because of its sensitivity, reproducibility, rapid throughput, relatively low cost, and ease of use (Thies, 2007).

This study began at the beginning of the transition from a conventional herbicide-strip orchard to IFP and OFP soil management systems, and continued through the fourth year. Most soil properties were measured before and after soil management treatments beginning at the end of the second transition year. Furthermore, soil was assessed at 0-6 cm and 6-12 cm to observe the depth to which management practices affected soil quality. The objective was to determine which system performed better in this humid environment. The null hypothesis was that chemical, physical, and biological soil properties would not be different between IFP and OFP management.

2. Materials and Methods

2.1. Study location and experimental design

The experiment was located in a 0.42 ha block of high-density (1537 trees ha^{-1}; 1.5 m between trees; 4.3 m between rows; 2.7 m tall) 'Liberty'/'M.9' apple trees at the Cornell Orchards in Ithaca, NY (42º 26' N, 76º 27' W). The soil was a Collamer silty clay loam series (fine-silty, mixed, active, mesic Glossaquic) formed from glacial lacustrine sediments. The orchard was planted in 1994 and trained to a modified vertical-axe form. For the ten years preceding this study, conventional practices using IPM appropriate for NY were used to control pests, diseases, and weeds (Agnello, 2007). Soil-active herbicides were last used in 1998, after which glyphosate was applied twice each year through 2003. Baseline soil chemical measurements were taken before the treatments began (Spring 2004).

A randomized complete block design with four replications of the two production systems (IFP and OFP) was implemented in 2004. From 2004 to 2006, the OFP treatment was considered transitional; only in 2007 would the OFP apples have been certifiable under USDA-NOP standards. The experimental plots each consisted of 64 trees evenly distributed in four adjacent rows (Figure 1). All soil sampling occurred under the trees in the two middle rows of each treatment replicate, excluding the two trees at either end of each experimental unit, creating a four-tree buffer between sampled plots. Unsprayed buffer rows were located between the northern and southern treatment areas and between the peripheral rows and adjacent conventionally managed rows to the south. The experimental design was laid out to prevent spray drift across treatments. Drip irrigation was used through 2005, after which a low-flow micro-sprinkler system with emitters positioned 0.5 m above the ground was installed improving access for the cultivation equipment.

2.2. Treatment descriptions

During all four years reported here, the overall treatments (IFP or OFP) were maintained, but inputs and cultural practices were specific to seasonal conditions each year as in comparable commercial operations. Year-to-year alterations were due to weather, pest and disease complexes, the availability of new products, and results from the previous years. The IFP system followed guidelines developed for NY (Carroll and Robinson, 2006). Weed control in the IFP system consisted of glyphosate herbicide treatments [2.9 kg active ingredient (a.i.) ha^{-1}] applied 6 May and 6 July 2004; 31 May and 12 July 2005; and 7 June 2007. A 1-m-wide composted hardwood bark chip mulch (obtained from local sawmills) was placed under the IFP trees to an average

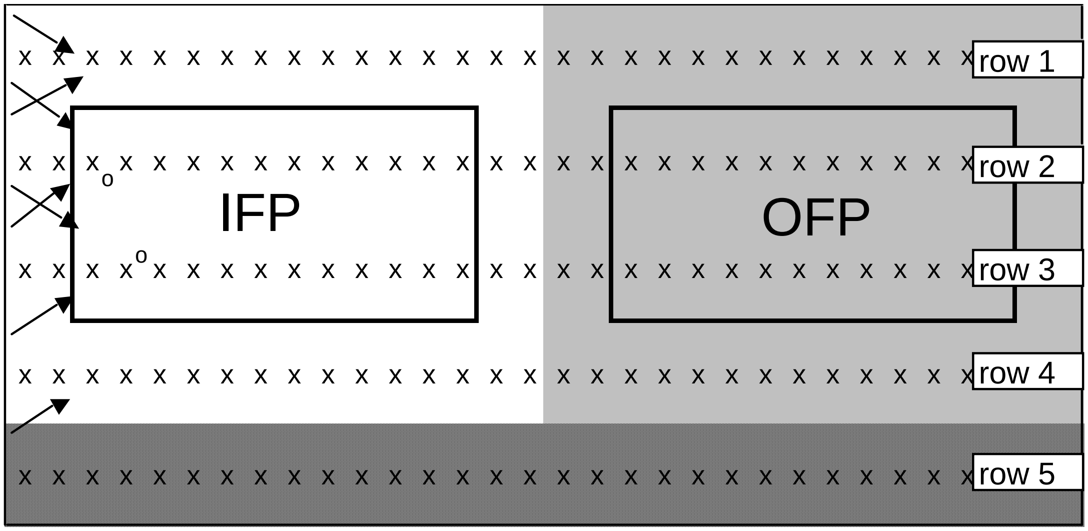


Figure 1. One of four replicated blocks within the study area. Trees are represented with an '×'. Soil sampling occurred within the inner rectangles in each plot at locations comparable to the two 'o's. Arrows on the left show the spray direction, which minimized drift among the treatment plots. Rows 5 and 10 (not shown) did not receive any fungicide or insecticide sprays.

depth of 7.6 cm using a side discharge Millcreek Row Mulcher (Leola, PA) in Fall 2005.

The OFP system followed USDA National Organic Program guidelines (Federal Register, 2000). Organic weed control consisted of mechanical tillage with a tractor-mounted Rinieri side-sweep subsurface cultivator (Forli, IT) on 13 May and 14 June 2004; and 14 June 2005 (Table 1). Use of the Rinieri cultivator was discontinued midway through the second growing year because it did not sufficiently control weeds. Thereafter, a tractor-mounted Wonder Weeder cultivator (Harris Manufacturing; Burbank, WA) was used on 27 June 2005; 11 May, 14 June, and 17 July 2006; and 19 May, 31 May, and 2 July 2007. The Wonder Weeder has four gangs of Lilliston® Spiders mounted in a configuration that allows them to run under the tree canopy at an approximate width of 0.5 m. An attached spring steel sweep cleared weeds in the area between tree trunks. Additional hand-hoeing was done in 2006 and 2007 to clear perennial weeds from the centerline of the tree row. Cultivation occurred

Table 1. Soil management timeline. Cumulative precipitation from 1 May-30 Sept. (approximately full bloom to last harvest) for each year; in parentheses, the difference from the long-term average.

	IFP	OFP
2004		
730 mm (+61%)	Glyphosate (2 × 2.9 kg a.i. ha^{-1})	Rinieri cultivator (2×)
2005		
330 mm (-27%)	Glyphosate (2 × 2.9 kg a.i. ha^{-1})	Rinieri cultivator (1×)
	Sul-Po-Mag + B (112 kg K_2O ha^{-1} equivalent) applied postharvest	Wonder Weeder (1×)
		K-Mag (112 kg K_2O ha^{-1} equivalent).
	1 m wide, 7.6 cm thick composted hardwood bark mulch applied in November	Chicken manure compost applied at 700 kg ha^{-1} (78 kg N ha^{-1} equivalent) in October
2006		
620 mm (+36%)	No herbicide used	Wonder Weeder (3×)
	Sul-Po-Mag + B (112 kg K_2O ha^{-1} equivalent) applied postharvest	Hand hoeing between trees
		K-Mag (112 kg K_2O ha^{-1} equivalent) applied postharvest
2007		
400 mm (-12%)	Glyphosate (1 × 2.9 kg a.i. ha^{-1})	Wonder Weeder (3×)
	Sul-Po-Mag + B (112 kg K_2O ha^{-1} equivalent) applied postharvest	Hand hoeing between trees
		K-Mag (112 kg K_2O ha^{-1} equivalent) applied postharvest

when a weed coverage threshold of approximately 50% was reached. Weeds were controlled through July of each year. Composted chicken manure was applied at a rate of 697 kg (fresh wt.) ha^{-1} (equivalent to 78 kg dry wt. N ha^{-1}) in Oct. 2005.

In Fall 2005-07, sulfate of potash-magnesia (Sul-Po-Mag for IFP and K-Mag for OFP) was applied at a rate of 112 kg K_2O ha^{-1} (Table 1) These products were primarily used for potassium addition, but they also add sulfur (S) and magnesium (Mg) to the soil. The products differed between systems because processing agents used in Sul-Po-Mag were not allowed under organic certification. To reduce rodent habitat, after harvest each year apples were cleared from under the trees, and the entire orchard floor was closely mowed to the ground. Further details on the experimental design and the practices used for each production system have been described elsewhere (Chapter 2).

2.3. Weed coverage and biomass

Prior to herbicide application or cultivation, the percent groundcover and the biomass of all living plants within a 0.6 m^2 PVC quadrant were assessed. Quadrants were placed under the trees in two random locations per experimental unit.

2.4. Soil sampling procedures

Over five dates (29 Aug. 2005, 9 May 2006, 15 Aug. 2006, 11 May 2007, and 6 Aug. 2007) soil was sampled at two depths (0-6 and 6-12 cm) by two methods (bulk and intact cores). May sampling was done before any soil management practices (that is, cultivation or herbicide application) took place in its respective year; August sampling was done after the completion of all soil management practices in each respective year. Bulk soil was used for determining chemical analyses, aggregate stability, and biological measurements. Intact cores were used for all other physical measurements. Sampling occurred between two trees at a distance halfway between the tree trunk line and the edge of the groundcover treatment area. Prior to each sampling, the soil was irrigated to excess and then allowed to drain to field capacity. Loose bark mulch and other organic surface materials were pushed aside before sampling. Bulk samples were pooled from six locations taken equally from the north and south rows using an AMS Slide Hammer (American Falls, ID) with a protective sleeve that contained two stacked cores (61 mm tall × 48 mm internal diam.). Intact cores were taken from three locations by taping together two stacked stainless steel rings (61 mm tall × 73 mm internal diam.). The stacked rings were pushed vertically

Table 2. Sampling times and soil properties measured each year from 2004-2007.

	10 May 2004	29 Aug. 2005	9 May 2006	15 Aug. 2006	11 May 2007	6 Aug. 2007
Soil nutrients, OM, pH	×	×		×		×
Porosity & Penetration resistance		×	×	×	×	×
Water stabile aggregation		×	×	×	×	×
Potentially mineralized nitrogen			×	×	×	×
Microbial biomass C & N			×	×	×	×
Soil respiration			×	×	×	×
Microbial community fingerprinting		×	×	×	×	×

into the soil with a wooden block and hammer. When the top ring was nearly full, an empty ring was placed on top to push the stacked rings slightly below the soil surface. These were then carefully dug out, excess soil removed, and plastic caps affixed to the top and bottom to protect the soil during transit and storage. Within 24 h of sampling, 20 g of bulk soil was placed at -20ºC until DNA extraction. All other soil was stored at 4ºC. Biological assays began within 48 h of sampling. Soil moisture was determined by weight loss after 48 h at 105ºC. Table 2 lists the tests that were conducted for each sampling date.

2.5. Soil organic matter, nutrients, and pH

For each experimental unit, approximately 500 g of bulk soil was submitted to the Cornell Nutrient Analysis Lab to analyze for SOM by loss on ignition after 2 h at 550ºC; total C and total N by Dumas combustion; macronutrients and micronutrients by inductively coupled argon plasma (ICP) spectrophotometry after extraction in Morgan's solution (1:5 soil to solution ratio); P by colorimetric methods; and pH after 1:1 dilution (v/v) soil: 0.01 M $CaCl_2$ solution (Anonymous, 1995; Burt, 2004).

2.6. Physical soil properties

2.6.1. Porosity, available water capacity, penetration resistance, and bulk density

Taped intact cores were carefully separated, soil was leveled to the core rims, and nylon gauze attached to the bottom with rubber bands. Cores were placed in water to just below the top rim to fill pore spaces from the bottom, which minimized air trapped in the pores. Cores equilibrated at three water tensions (Ψ = -0.3, -10, and -1500 kPa) estimated pore sizes (Moebius-Clune et al., 2008). Macroporosity (pore diam. > 1000 µm) was calculated from water loss after saturated cores were allowed to freely gravity-drain for 3 h (Ψ = -0.3 kPa). Mesoporosity (pore diam. 1000 - 30 µm) was calculated from water loss after soil equilibrated to Ψ = -10 kPa on a sand tension table under vacuum pressure. Total porosity and bulk density were determined after samples were dried at 105ºC to constant weight. Microporosity (pore diam. 30 – 0.2 µm) was calculated using oven-dry subsamples brought to Ψ = -1500 kPa on a ceramic high-pressure plate apparatus. Available water capacity was calculated from the water loss between Ψ = -10 and -1500 kPa. Calculations of mesopore sizes between 1000-10 µm and micropore sizes between 10-0.2 µm were also calculated using curve-fitting equations reported by van Genuchten (1980). These did not alter the statistical analyses, and only the measured values are reported.

Penetration resistance was measured at Ψ = -10 kPa by averaging the force needed to insert a 30º angle, 4 mm diam. cone micro-penetrometer to a depth of 50 mm at a rate of 8 mm s^{-1} in three locations per core (Moebius-Clune et al. 2008).

2.6.2. Water stable aggregation

Bulk soil subsamples were oven-dried at 40ºC and then sieved to separate aggregate sizes. For each sample, a single layer of 0.25-2 mm aggregates was spread on a 0.25 mm sieve and placed 50 cm below a rainfall simulator (Gugino et al., 2007).

The simulator was run for 5 min, which delivered 12.5 mm of water in droplets to each sample. Both the soil retained in the sieve and the slaked soil material that fell through the sieve during the run were collected, dried, and weighed. The fraction of stable soil aggregates was then proportionally calculated.

2.7. Biological soil properties

2.7.1. Potentially mineralizable N and total inorganic N

For each sample, two 50 mL plastic centrifuge tubes were filled with 10 g of bulk soil. One tube was used for extraction on Day 0 by adding 40 mL of 0.05 M K_2SO_4 (Mallinckrodt Baker, Phillipsburg, NJ), shaking for 30 min on a platform shaker, and filtering (FisherBrand G6) the supernatant after centrifugation. The soil in the second tube was incubated at 30ºC for 7 days under 10 mL of nanopure water. After the incubation, 30 mL of 0.0667 M K_2SO_4 was added to make a 0.05 M K_2SO_4 solution. These Day 7 samples were then shaken, centrifuged, and filtered. Samples were stored at -20ºC until NH_4^+ and NO_3^- analysis with a Lachat QuickChem® 800 Flow Injection Analyzer (Loveland, CO) using the manufacturer's standard operating procedure 10-107-06-2-A for NH_4^+ and 10-107-04-1-Q for NO_3^- (Lachat Instruments, 2008). The difference in NH_4^+ concentration between samples on Day 7 and Day 0 estimated the N mineralization rate. The combined NH_4^+ and NO_3^- concentrations on Day 0 were used to estimate total soil inorganic N.

2.7.2. Microbial biomass-C and biomass-N

The direct chloroform ($CHCl_3$) fumigation extraction method was used to measure microbial biomass (Gregorich et al., 1990), as modified by Fierer and Schimel (2003). For each soil sample, two 60 mL glass vials were filled with 10 g of bulk soil and 40 mL of 0.05 M K_2SO_4 (Mallinckrodt Baker). One jar from each sample set was fumigated with 0.5 mL of ethanol-free $CHCl_3$. All jars were sealed with Teflon-lined lids and soil was dispersed into solution on a rotary shaker at 150 rpm. After 4 hrs, samples stood still for 30 min to allow soil to settle. The supernatant was then decanted into 50 mL centrifuge tubes and centrifuged. Samples were filtered (FisherBrand G6) and stored at -20ºC until analysis. Chloroform was purged from samples with a 30 min lab air sparge. For total C, triplicate liquid samples were run on a Shimadzu TOC 5050A with ASI-5000A autosampler (Kyoto, JP), using standard platinum-coated alumina beads. Non-purgeable organic C compounds were converted to CO_2 by combustion (680ºC) and quantified with a non-dispersive infrared detector (NDIR). Total N samples were predigested with an alkaline $K_2S_2O_8$ solution in a standard autoclave for 50 min before analysis with a Lachat QuickChem® 800 Flow Injection Analyzer (Loveland, CO), using method 10-107-04-1-Q (Lachat Instruments, 2008). Blanks without soil accounted for background C or N. Microbial biomass was calculated by the difference between fumigated and unfumigated samples. To compensate for extraction inefficiencies, a k_{EC} value of 0.45 (Joergensen, 1996) and a k_{EN} value of 0.54 were applied (Brookes et al., 1985).

2.7.3. Soil respiration

For each soil sample, 50 g of bulk soil were sealed in 240 mL airtight jars along with glass vials containing 20 mL of 0.5 M NaOH (Fischer Scientific, Pittsburgh, PA). Weekly measurements of the respiration rates were calculated from the electrical conductivity of the samples compared with a blank (50 g of autoclaved sand) and 0.25 M Na_2CO_3 (Fischer Scientific), a fully CO_2 saturated standard (Rodella and Saboya, 1999).

2.7.4. Ratios between microbial properties

The metabolic quotient (qCO_2) is an indicator of microbial activity and was calculated by the ratio of the first week of soil respiration to MBC (Rice et al., 1996). The ratio of MBC:MBN and the microbial quotient (qMic; ratio of MBC to soil Dumas combustion C) have been reported to be sensitive indicators of SOM changes (Sparling, 1992; Rice et al., 1996).

2.7.5. Molecular analyses of bacterial and fungal soil communities

The bacterial and fungal soil communities were analyzed by the Polymerase Chain Reaction (PCR) based Terminal-Restriction Fragment Length Polymorphism (T-RFLP) method (Thies, 2007). Total genomic DNA was extracted from 0.25 g of soil following the manufacturer's protocols for the MoBio Lab PowerSoil™ DNA Isolation Kit (Carlsbad, CA). Soil extracts were quantified against a calf thymus DNA standard curve in an ethidium bromide solution with an EC3 Imaging System and its accompanying VisionWorksLS software, ver. 6.4.3. (UVC, Upland, CA). Mean DNA yield was 14 ng μL^{-1}, which was diluted to 1-3 ng μL^{-1} for amplification. Bacterial DNA amplification was done in triplicate 50 µL reactions containing: 2.5 U Taq polymerase (Applied Biosystems, Foster City, CA), 1× Taq buffer (Applied Biosystems), 2.0 mM $MgCl_2$, 0.2 mM dNTPs (Promega, Madison, WI), 0.1 µM FAM labeled 27f primer (5'-[6FAM] AGA GTT TGA TCC TGG CTC AG-3') (Integrated DNA Technologies, Coralville, IA), 0.1 µM 1492r primer (5'-GGT TAC CTT GTT ACG ACT T-3') (Integrated DNA Technologies), 0.1 µg μL^{-1} bovine serum albumin (BSA) (Promega), 5 μL^{-1} template DNA, and nuclease-free water (G Biosciences, St. Louis, MO). Reactions were amplified using a MJ Research thermal cycler PTC-200 (Waltham, MA) by the following program: 5 min at 95ºC, followed by 27 cycles of 95ºC for 45 s, 56ºC for 45 s, and 72ºC for 1 min, with a final extension step of 72ºC for 10 min. Fungal DNA amplification was done in triplicate 50 μL reactions containing: 5 U Taq polymerase (Applied Biosystems), 1× Taq buffer (Applied Biosystems), 3.0 mM $MgCl_2$ (Applied Biosystems), 0.6 mM dNTPs, 0.1 μM fluorescently labeled ITS1f primer (5'-[6FAM] CTT GGT CAT TTA GAG GAA GTA A-3') (Integrated DNA Technologies), 0.1 μM ITS4r primer (5'-TCC TCC GCT TAT TGA TAT GC-3') (Integrated DNA Technologies), 0.1 μg μL^{-1} BSA (Promega), 10 μL^{-1} template DNA, and nuclease-free water (G Biosciences). Reactions were amplified using the same thermal cycler by the following program: 5 min at 94ºC, followed by 30 cycles of 94ºC for 30 s, 51ºC for 45 s and 72ºC for 45 s, with a final extension step of 72ºC for 10 min. The PCR products were verified on a 1.5% agarose gel and stained with SYBR® Green I (Invitrogen, Carlsbad, CA) using the imager and software mentioned above.

For each sample, the triplicate PCR products were pooled, quantified as mentioned above, dried in a vacu-centrifuge, and then re-suspended in nuclease-free water to a concentration of 20 ng DNA uL^{-1}. The PCR products were then digested in 30 uL reactions, containing 5 U Sau96I restriction enzyme (New England BioLabs, Ipswich, MA), 1× of the accompanying buffer, 0.1 μg μL^{-1} BSA, 15 μL of the PCR product, and nuclease-free water (G Biosciences). The digestion conditions were: 37ºC for 4.5 hrs followed by 80ºC for 20 min to deactivate the enzyme. Digestion products were verified on a 1.5% agarose gel, as mentioned above. Digests were filtered through the Performa® DTR Edge Plate (Edge BioSystems, Gaithersburg, MD). Samples were vacu-centrifuged until dry and re-suspended in 85 μL of formamide and 15 μL of LIZ500 size standard (Applied Biosystems). Fragments were sized with an Applied Biosystems Automated 3730xl DNA Analyzer at the LifeSciences Core Facility, Cornell University.

2.8. Statistical analyses

Non-molecular data were analyzed with a mixed model to assess the long-term effects of each production system using the PROC MIXED procedure of SAS 9.1 (Cary, NC). The mixed model included Year (2004-07), Month (May and August), Treatment (IFP and OFP), and their interactions as fixed effects. Random effects were Block, Treatment × Block, Treatment × Block × Year, and when the Month effect was included, Treatment × Block × Year × Month. Cumulative respiration data were analyzed as a repeated measure and included Block, Treatment × Block, Treatment × Block × Year × Month × Day as random effects. Main effects, interactions, and treatment effects within interactions were considered significant at the 0.05 level.

Online T-RFLP Analysis Expedited (T-REX) software was used to analyze T-RFLP data using Additive Main Effects Multiplicative Interaction (AMMI) modeling (Culman et al., 2008a). The AMMI model uses the presence or absence of terminal restriction fragments (T-RF's) at each base pair length, the treatments, and their interaction in an ANOVA. Interaction principal components analyses (IPCA) are then constructed using the ANOVA interaction term. This statistical procedure has been found to be a robust method for analyzing T-RFLP data generated from a wide-range of agricultural soils (Culman et al., 2008b).

3. Results

3.1. Weed coverage and biomass

As measured by the percent of ground covered and weed biomass, OFP trees had consistently greater weed competition in the tree row (Figure 2). There was sparse weed coverage under IFP trees in 2006, the first growing season after the bark mulch application to IFP plots, but by June 2007, weeds had emerged through the mulch. Weed coverage and biomass showed similar treatment differences until June and July

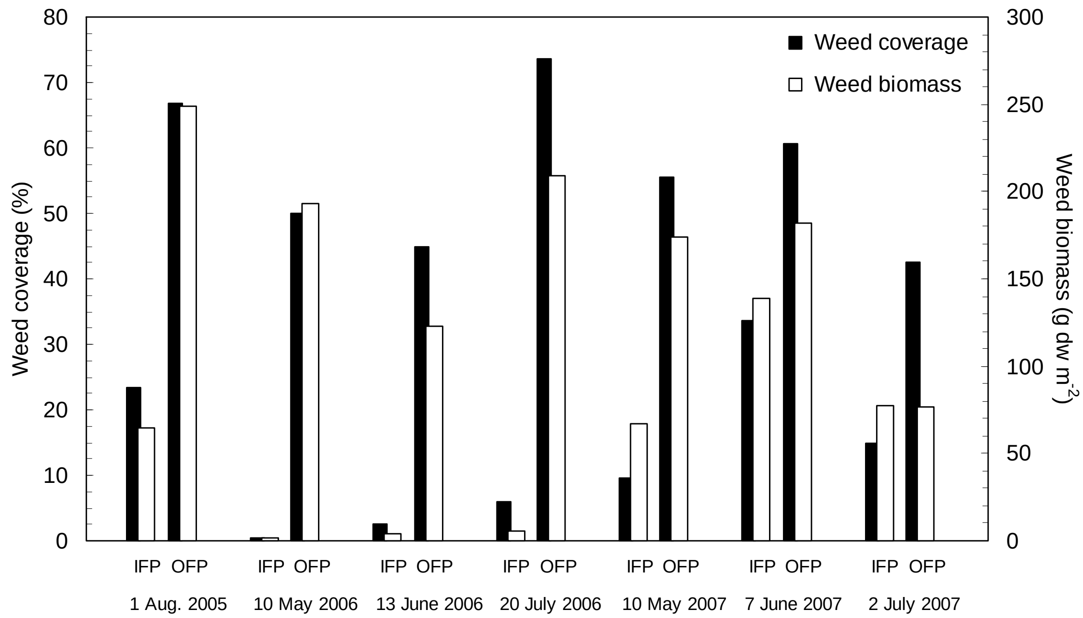


Figure 2. Percent of weed-covered ground and the dry weight of weeds under integrated (IFP) and organic fruit production (OFP) systems, measured over three years. Treatment effects were significant for all dates; interactions were not significant ($p \leq 0.05$). Each value represents a mean of four replicated blocks.

2007, when weeds covered 2-3 times as much area under OFP trees, but the systems had similar weed biomass. Grasses appeared to predominate the OFP weed biomass at those samplings.

3.2. Soil organic matter, nutrients, and pH

At the outset of the experiment (May 2004), an analysis of the top 20 cm of soil showed minimal differences between treatments in nutrient availability, soil organic matter, and pH (Table 3). In the upper IFP sampling depth, SOM increased 41% between 2005 and 2006, and 20% between 2006 and 2007. In the OFP upper sampling depth, SOM increased 26% between 2005 and 2006, but there was no change the following year. In both 2006 and 2007, upper depth IFP soil had greater SOM than OFP soil. Soil C was also significantly different between treatments

Table 3. Mineral, pH, and soil organic matter (SOM) content for the 0-20 cm depth of soil measured prior to implementation of treatments (May 2004); bark mulch; and chicken manure compost.

	C (%)	N (%)	C:N	P (mg kg^{-1})	K (mg kg^{-1})	Ca (mg kg^{-1})	Mg (mg kg^{-1})	Al (mg kg^{-1})	Cu (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})	pH	SOM (%)
Soil baseline (0-20 cm)	1.9	0.16	11.7	4.0	206	1062	318	27	0	3.8	12.9	2.2	6.4	3.0
Bark mulch	41	0.48	85.3	39	1064	2513	375	6.9	0	0	274	3.6	4.8	83
Chicken manure compost	23	7.4	3.16	597	16600	12850	3811	10	14	53	106	60	8.2	61

Table 4. Mineral, pH, and soil organic matter (SOM) content at the 0-6 cm depth of soil in integrated (IFP) and organic fruit production (OFP) systems, measured in August over three years. Significance levels of main effects, interactions, and Treatment effects within an interaction are at the bottom of the table. Each value represents a mean of four replicated blocks.

Year	Treatment	C (%)	N (%)	C:N	P (mg kg^{-1})	K (mg kg^{-1})	Ca (mg kg^{-1})	Mg (mg kg^{-1})	Al (mg kg^{-1})	Cu (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})	pH	SOM (%)
2005	IFP	2.2	0.20	10.7	7.4	244	1345	355	14	2.1	2.0	15.33	4.4	6.8	3.2
2005	OFP	2.0	0.19	10.5	5.4	213	1430	360	15	2.3	2.2	16.06	2.6	6.9	3.0
2006	IFP	2.7	0.21	12.7	8.4	305	1693	367	18	1.4	7.4	23.93	3.0	6.8	4.6
2006	OFP	2.1	0.20	10.0	14	287	1666	395	13	2.0	3.0	15.18	2.6	6.8	3.8
2007	IFP	3.1	0.18	17.6	12	316	2113	369	15	3.8	3.8	21.43	2.7	7.3	5.5
2007	OFP	2.0	0.15	13.6	11	367	1460	407	10	3.1	1.3	11.35	2.7	7.1	3.8
Year		NS	**	***	**	***	**	NS	NS	**	NS	NS	NS	***	***
Treatment		**	NS	***	NS	NS	*	NS	NS	NS	NS	*	NS	NS	***
Year × Treatment		NS	NS	*	*	NS	**	NS	NS	NS	NS	*	NS	**	*
Treatment effects within the Year × Treatment interaction															
2005				NS	NS		NS					NS		*	NS
2006				***	NS		NS					**		NS	*
2007				***	NS		***					**		**	***

NS, *, **, *** Nonsignificant or significant differences at $p \leq 0.05$, 0.01, or 0.001, respectively.

Table 5. Mineral, pH, and soil organic matter (SOM) content at the 6-12 cm depth of soil in integrated (IFP) and organic fruit production (OFP) systems, measured in August over three years. Significance levels of main effects, interactions, and Treatment effects within an interaction are at the bottom of the table. Each value represents a mean of four replicated blocks.

Year	Treatment	C (%)	N (%)	C:N	P (mg kg^{-1})	K (mg kg^{-1})	Ca (mg kg^{-1})	Mg (mg kg^{-1})	Al (mg kg^{-1})	Cu (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})	pH	SOM (%)
2005	IFP	1.6	0.16	10.0	2.9	172	1113	292	20	1.7	2.9	12.7	2.8	6.6	2.6
2005	ORG	1.6	0.15	10.0	2.1	152	1137	289	18	1.9	2.4	12.8	1.1	6.8	2.5
2006	IFP	2.0	0.16	12.2	6.7	257	1464	330	18	1.2	4.0	18.3	4.7	6.8	3.5
2006	ORG	1.8	0.18	9.8	6.4	220	1448	347	12	1.3	1.8	11.5	1.2	6.9	3.2
2007	IFP	1.6	0.11	13.8	4.6	240	1179	312	17	2.5	3.4	9.00	2.1	7.0	3.0
2007	ORG	1.5	0.12	12.9	4.0	244	1176	340	12	2.2	1.9	7.20	1.3	7.0	3.1
Year		NS	***	*	**	***	*	***	**	***	NS	*	NS	**	*
Treatment		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Year × Treatment		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Treatment effects within the Year × Treatment interaction															
2005															
2006															
2007															

NS, *, **, *** Nonsignificant or significant differences at $p \leq 0.05$, 0.01, or 0.001, respectively.

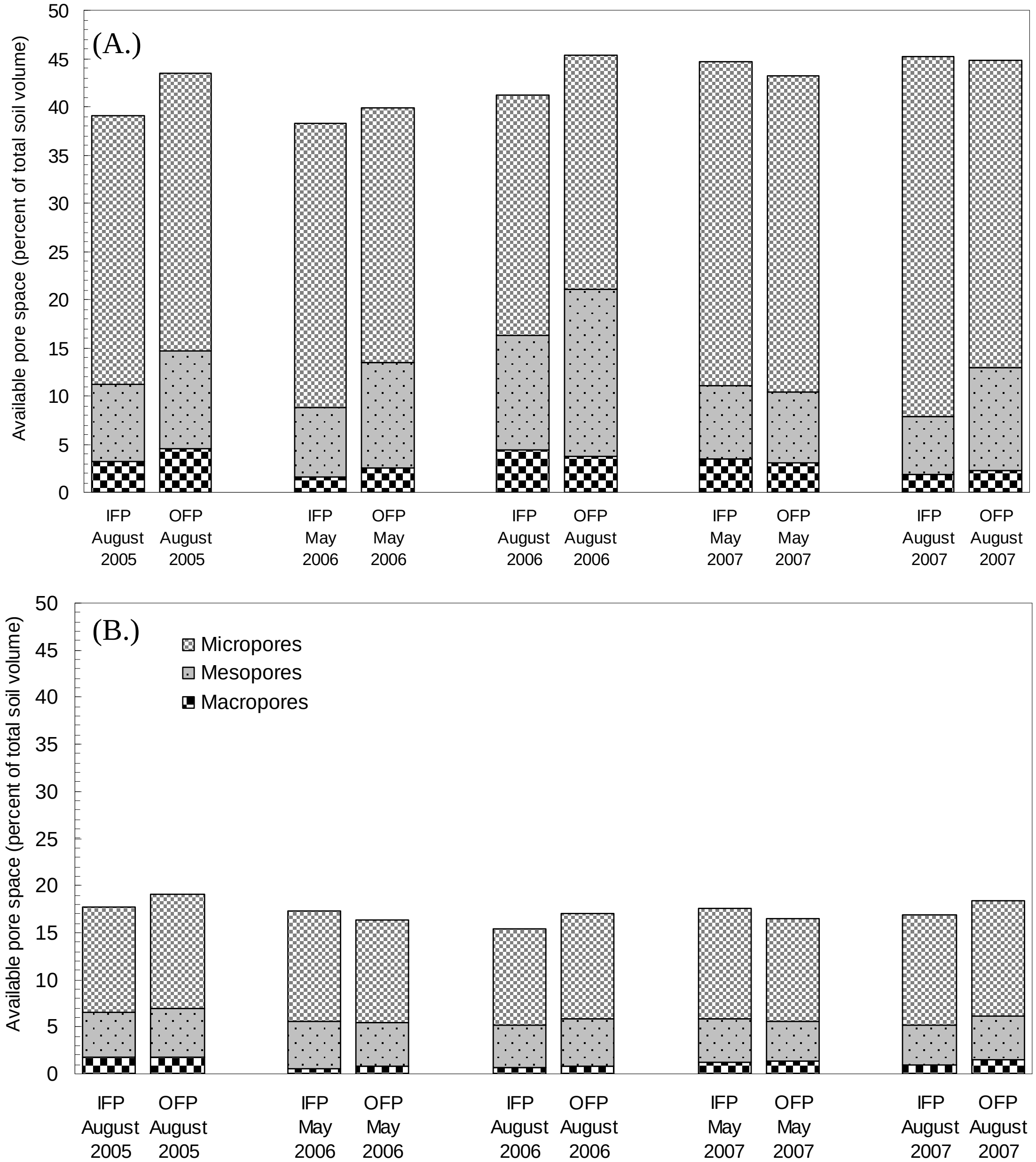
in the upper sampling depth and increased 43% over two years in the IFP soil, but remained constant in OFP soil. Soil N was not different between systems in the upper depth, but the C:N ratio was greater in IFP soil in 2006 and 2007. From 2005 to 2007, the C:N ratio increased 64% in IFP upper depth soil and 29% in OFP soil. Phosphorus increased 58% in IFP upper depth soil and 111% in OFP soil, but the large P concentration in 2006 created a crossing interaction, and so treatments were not statistically different. While not significantly different between treatments, potassium (K) increased 30% in IFP upper depth soil and 73% in OFP soil. Calcium (Ca) was greater in IFP upper depth soil in 2007, and increased 57% from 2005 measurements. Manganese (Mn) was greater in IFP soil in 2006 and 2007, and increased 40% between 2005 and 2007. In OFP upper depth soil, Mn decreased 30% between 2005 and 2007. Soil pH was greater in upper depth OFP soil in 2005, but was greater in IFP in 2007.

Although there was year-to-year variability in the lower sampling depth, there were no consistent treatment differences for SOM, nutrients, or pH (Table 5). Over the three years, P increased 59% in IFP soil and 89% in OFP soil; K increased 40% in IFP soil and 60% in OFP soil; and Mn decreased 29% in IFP soil and 4% in OFP soil.

3.3. Physical soil properties

3.3.1. Porosity, available water capacity, penetration resistance, and bulk density

Across all sampling dates, only mesoporosity in the upper sampling depth and macroporosity in the lower sampling depth were significantly different between treatments (Figures 3A and 3B). There were no significant interaction effects. On average, there were 3.2% more mesopores in the upper depth of OFP soil, and 0.2% more macropores in the lower depth of OFP soil. Overall, the data were highly variable showing significant year effects for meso- and microporosity in the upper



Figures 3 A-B. Total, macro, meso, and microporosity measured at the 0-6 cm (A) and 6-12 cm (B) depth of soil in integrated (IFP) and organic fruit production (OFP) systems, measured in May and August over three years. Each value represents a mean of four replicated blocks. Mesoporosity ($p \leq 0.001$) at the upper depth, and macroporosity ($p \leq 0.05$) at the lower depth were significant between treatments. All porosity measurements were significant between years at the upper depth. Total porosity and macroporosity were significant between years at the lower depth.

Table 6. Available water capacity (AWC), bulk density, and penetration resistance at the 0-6 cm depth of soil in integrated (IFP) and organic fruit production (OFP) systems, measured in May and August over three years. Significance levels of the main effects, interactions, and Treatment effects within interactions are at the bottom of the table. Each value represents a mean of four replicated blocks.

Year	Month	Treatment	AWC[a] ($m^3\ m^{-3}$)	Bulk density ($Mg\ m^{-3}$)	Penetration resistance (MPa)
2005	August	IFP	0.278	1.32	1.05
2005	August	OFP	0.288	1.24	0.66
2006	May	IFP	0.294	1.29	0.80
2006	May	OFP	0.263	1.28	0.82
2006	August	IFP	0.250	1.05	0.86
2006	August	OFP	0.242	1.09	0.44
2007	May	IFP	0.336	1.17	0.74
2007	May	OFP	0.328	1.24	0.92
2007	August	IFP	0.373	1.21	1.06
2007	August	OFP	0.318	1.26	1.00
Year			***	*	***
Month			NS	NS	NS
Treatment			NS	NS	NS
Year × Month			NS	NS	*
Year × Treatment			NS	NS	**
Treatment effects within the Year × Treatment interaction					
2005					NS
2006					*
2007					NS
Treatment effects within the Month × Treatment interaction					
May					NS
August					**

NS, *, **, *** Nonsignificant or significant differences at $p \leq 0.05$, 0.01, or 0.001, respectively.

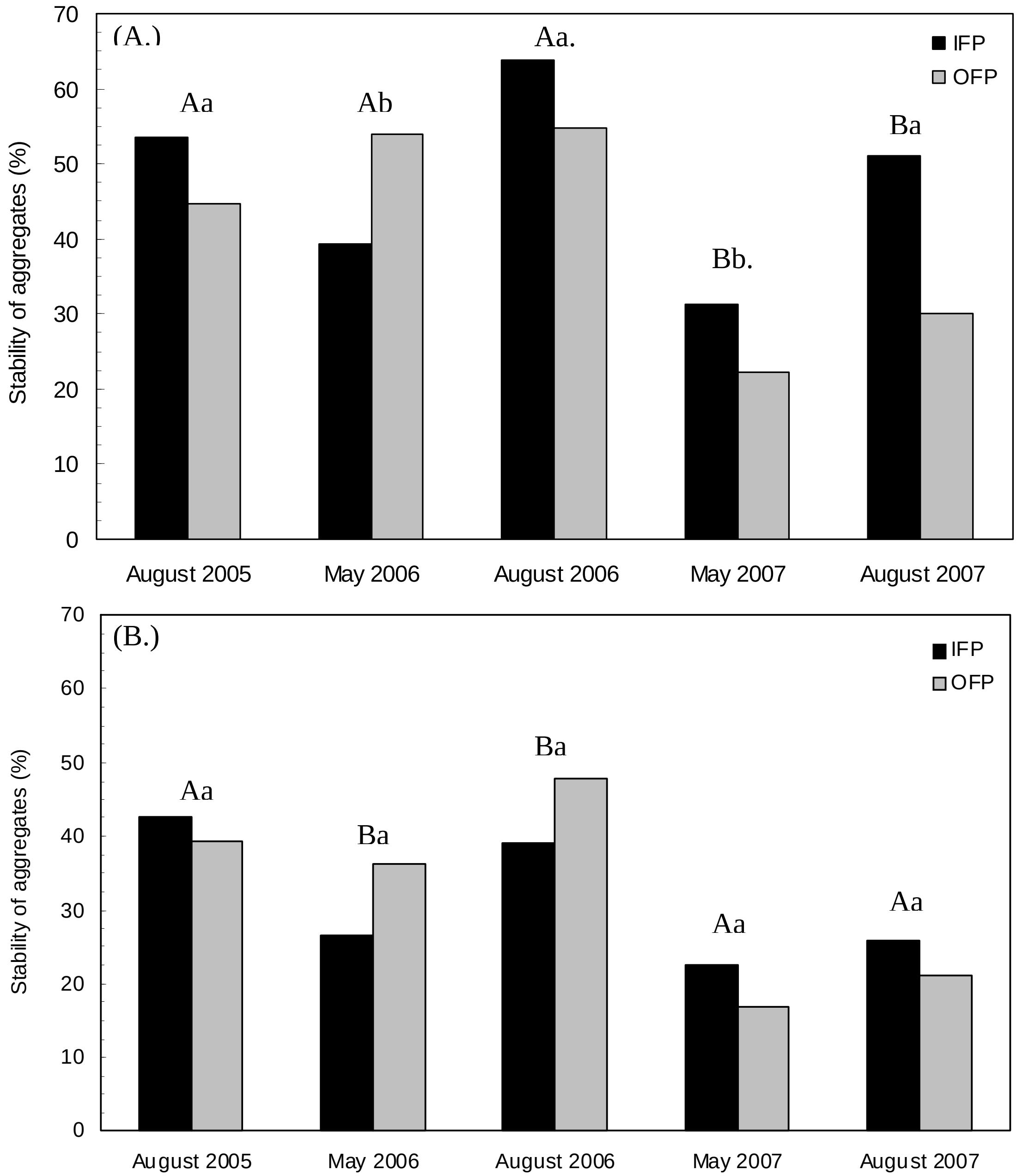
[a] Ψ = -10 kPa (field capacity) and -1500 kPa (permanent wilting point).

Table 7. Available water capacity (AWC), bulk density, and penetration resistance at the 6-12 cm depth of soil in integrated (IFP) and organic fruit production (OFP) systems, measured in May and August over three years. Significance levels of main effects, interactions, and Treatment effects within interactions are at the bottom of the table. Each value represents a mean of four replicated blocks.

Year	Month	Treatment	AWC[a]	Bulk density	Penetration resistance
			(m^3 m^{-3})	(Mg m^{-3})	(MPa)
2005	August	IFP	0.272	1.46	1.62
2005	August	OFP	0.299	1.40	1.47
2006	May	IFP	0.258	1.40	1.24
2006	May	OFP	0.264	1.47	1.63
2006	August	IFP	0.259	1.47	1.54
2006	August	OFP	0.265	1.44	1.35
2007	May	IFP	0.311	1.40	1.07
2007	May	OFP	0.309	1.38	1.35
2007	August	IFP	0.341	1.42	1.37
2007	August	OFP	0.330	1.43	1.53
Year			***	*	NS
Month			NS	NS	NS
Treatment			NS	NS	NS
Year × Month			NS	NS	NS
Year × Treatment			NS	NS	NS
Treatment effects within the Year × Treatment interaction					
2005					
2006					
2007					
Treatment effects within the Month × Treatment interaction					
May					
August					

NS, *, **, *** Nonsignificant or significant differences at $p \leq 0.05$, 0.01, or 0.001, respectively.

[a] Ψ = -10 kPa (field capacity) and -1500 kPa (permanent wilting point).



Figures 4 A-B. Wet aggregate stability at the 0-6 cm (A) and 6-12 cm (B) depths of soil in integrated (IFP) and organic fruit production (OFP) systems, measured in May and August over three years. Each value represents a mean of four replicated blocks. Significance of treatment effects ($p \leq 0.05$) within the Year × Treatment and Month × Treatment interactions are represented by different upper and lower case letters, respectively.

depth, and for macro- and total porosity in the lower depth.

Significant year effects were found for available water capacity (AWC) in both the upper and lower sampling depths, but there were no treatment effects (Tables 6 and 7). Comparing the first (August 2005) and last (August 2007) measurements, AWC increased 34% in the upper depth and 26% in the lower depth of IFP soil; and 11% in the upper depth and 10% in the lower depth of OFP soil. Bulk density was not significantly different between treatments at either depth and remained relatively unchanged through the course of this experiment. Penetration resistance was greater for the upper depth of OFP soil in 2006, and in August of each year (Table 6). The low resistance of OFP soil in August 2005 and 2006 largely caused these differences. Penetration resistance was similar at the lower soil depth (Table 7).

3.3.2. Water stable aggregation

There was greater aggregate stability in the upper depth of IFP soil in four of five sampling times, and these were significantly greater than OFP soil in August of each year, and for both sampling times in 2007 (Figure 4A). At the lower depth, OFP soil was more stable in 2006 (Figure 4B). Upper depth soil always had greater stability than lower depth, and at every measurement except August 2006 the two depths showed a similar pattern between treatments.

3.4. Biological soil properties

3.4.1. Potentially mineralizable N and total inorganic N

At every sampling, PMN was greater in the upper OFP soil depth, but there were no PMN treatment differences in the lower depth (Tables 8 and 9). The Year × Treatment interaction in the upper depth was a result of the large spikes in PMN in August of each year (Table 8). Total inorganic soil N fluctuated greatly in the upper depth of OFP soil over the four times it was measured, and was significantly different from IFP soil in 2007, and in May of each year. In August 2006, total inorganic N was 20-fold greater in the upper OFP soil than IFP soil, and three-fold greater in the lower OFP compared to IFP soil. Similar but smaller differences were also seen in August 2007. Total inorganic N in the upper OFP soil depth increased nearly seven-fold between May and August in 2006, and about 4.5-fold between May and August in 2007. In the lower depth, total inorganic N was also significantly greater for OFP soil, with a large spike in August 2006 (Table 9).

3.4.2. Microbial biomass-C and biomass-N

The upper IFP soil depth had greater MBC than OFP soil, but not greater MBN (Table 8). Both IFP and OFP upper depth soil increased in MBC from May to August in 2006. While MBC in the OFP soil returned to levels similar to what was measured in May 2006, the IFP soil MBC remained high through August 2007. In the lower depth, neither MBC nor MBN were significantly different between treatments, and neither measurement varied much over time (Table 9).

3.4.3. Soil respiration

Soil respiration for the first week of incubation was greater for upper depth IFP soil, but differences in magnitude between months each year caused an interaction effect (Table 8). At the lower depth, there were no statistical differences and respiration rates were not greatly affected over sampling time (Table 9). Over several weeks, cumulative respiration rates were significantly greater for IFP upper depth soil at every measurement, except the first week (Figures 5A-D). In the lower soil depth, the cumulative respiration rates were much lower than the upper soil depth, and the

Table 8. Potentially mineralizable nitrogen (PMN), total inorganic soil nitrogen, microbial biomass carbon (MBC), microbial biomass nitrogen (MBN), soil respiration after seven days, the metabolic quotient (qCO_2), the MBC:MBN ratio, and the microbial quotient (qMic) at the 0-6 cm depth of soil in integrated (IFP) and organic fruit production (OFP) systems, measured in May and August over two years. Significance levels of main effects, interactions, and Treatment effects within an interaction are at the bottom of the table. Each value represents a mean of four replicated blocks on an oven dry weight basis.

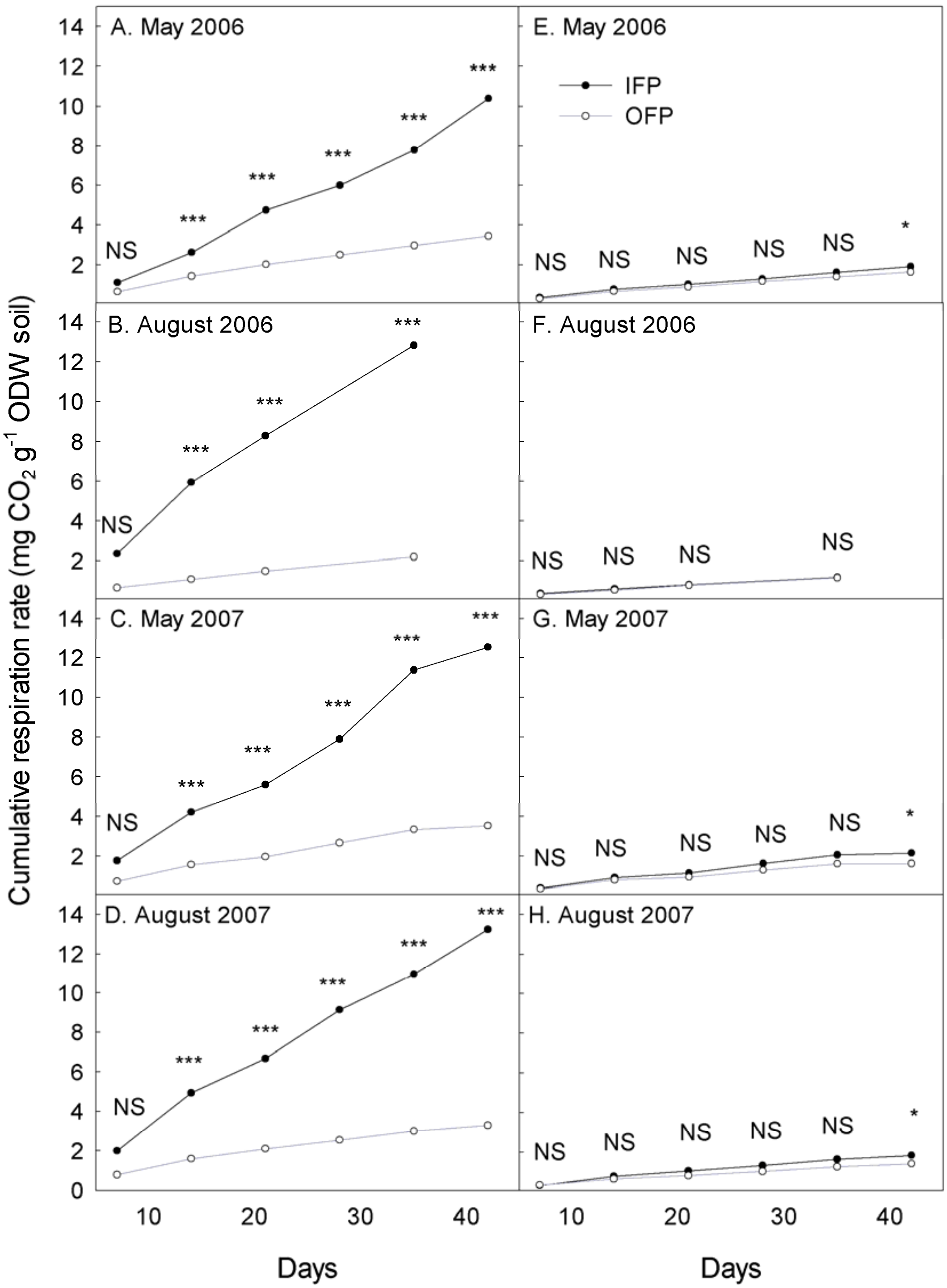
Year	Month	Treatment	PMN ($\mu g\ N\ g^{-1}\ wk^{-1}$)	Inorganic nitrogen ($\mu g\ g^{-1}$)	MBC ($\mu g\ C\ g^{-1}$)	MBN ($\mu g\ N\ g^{-1}$)	Soil respiration ($mg\ CO_2\ g^{-1}\ wk^{-1}$)	qCO_2 ($\mu g\ CO_2\ wk^{-1}$ / $\mu g\ MBC\ g^{-1}$)	MBC:MBN	qMic (%)
2006	May	IFP	5.78	1.20	364	45.8	1.12	3.13	8.4	
2006	May	OFP	13.88	3.42	314	42.0	0.66	2.14	14.8	
2006	August	IFP	6.54	1.35	535	47.4	2.36	4.02	12.7	1.88
2006	August	OFP	20.14	27.08	450	32.8	0.65	1.53	18.3	2.50
2007	May	IFP	8.83	0.75	535	57.7	1.79	3.47	9.9	
2007	May	OFP	12.93	1.15	344	42.1	0.75	2.25	8.4	
2007	August	IFP	12.54	1.85	428	34.7	1.98	4.78	13.0	1.40
2007	August	OFP	18.69	6.40	288	30.5	0.79	2.74	9.4	1.45
Year			NS	**	NS	NS	NS	*	NS	NS
Month			**	***	NS	NS	**	NS	NS	
Treatment			***	***	**	NS	***	***	NS	NS
Year × Treatment			*	**	NS	NS	NS	NS	NS	NS
Month × Treatment			NS	**	NS	NS	**	*	NS	
Treatment effects within the Year × Treatment interaction										
2006			***	***						
2007			**	NS						
Treatment effects within the Month × Treatment interaction										
May				NS			***	***		
August				***			***	***		

NS, *, **, *** Nonsignificant or significant differences at $p \leq 0.05$, 0.01, or 0.001, respectively.

Table 9. Potentially mineralizable nitrogen (PMN), total inorganic soil nitrogen, microbial biomass carbon (MBC), microbial biomass nitrogen (MBN), soil respiration after seven days, the metabolic quotient (qCO_2), the MBC:MBN ratio, and the microbial quotient (qMic) at the 6-12 cm depth of soil in integrated (IFP) and organic fruit production (OFP) systems, measured in May and August over two years. Significance levels of main effects, interactions, and Treatment effects within an interaction are at the bottom of the table. Each value represents a mean of four replicated blocks on an oven dry weight basis.

Year	Month	Treatment	PMN ($\mu g\ N\ g^{-1}\ wk^{-1}$)	Inorganic nitrogen ($\mu g\ g^{-1}$)	MBC ($\mu g\ C\ g^{-1}$)	MBN ($\mu g\ N\ g^{-1}$)	Soil respiration ($mg\ CO_2\ g^{-1}\ wk^{-1}$)	qCO_2 ($\mu g\ CO_2\ wk^{-1}$ / $\mu g\ MBC\ g^{-1}$)	MBC:MBN	qMic (%)
2006	May	IFP	3.23	0.60	165.2	20.0	0.354	2.15	8.6	
2006	May	OFP	4.52	1.89	138.4	16.0	0.300	2.26	15.5	
2006	August	IFP	3.67	3.16	171.4	16.9	0.367	2.33	13.5	0.98
2006	August	OFP	4.11	10.05	183.2	15.3	0.326	1.87	19.8	1.04
2007	May	IFP	3.89	0.87	191.0	15.6	0.408	2.18	13.8	
2007	May	OFP	5.22	0.97	182.5	20.1	0.378	2.11	9.7	
2007	August	IFP	8.11	1.84	158.9	9.7	0.353	2.21	19.1	1.03
2007	August	OFP	4.05	2.67	162.4	14.1	0.372	2.26	14.7	1.08
Year			NS	*	NS	NS	NS	NS	NS	NS
Month			NS	**	NS	NS	NS	NS	NS	
Treatment			NS	*	NS	NS	NS	NS	NS	NS
Year × Treatment			NS	NS	NS	NS	NS	NS	NS	NS
Month × Treatment			NS	NS	NS	NS	NS	NS	NS	NS
Treatment effects within the Year × Treatment interaction										
2006										
2007										
Treatment effects within the Month × Treatment interaction										
May										
August										

NS, *, **, *** Nonsignificant or significant differences at $p \leq 0.05$, 0.01, or 0.001, respectively.



Figures 5 A-H. Soil respiration at the 0-6 cm (A-D) and 6-12 cm (E-H) depths of soil in integrated (IFP) and organic fruit production (OFP) systems, measured in samples taken in May and August over two years, and incubated for up to six weeks. Each value represents a mean of four replicated blocks. Symbols (NS, *, **, ***) represent nonsignificant, or significant differences at $p \leq 0.05$, 0.01, or 0.001, respectively.

treatments were only significantly different for the last week of incubation (Figures 5E-H).

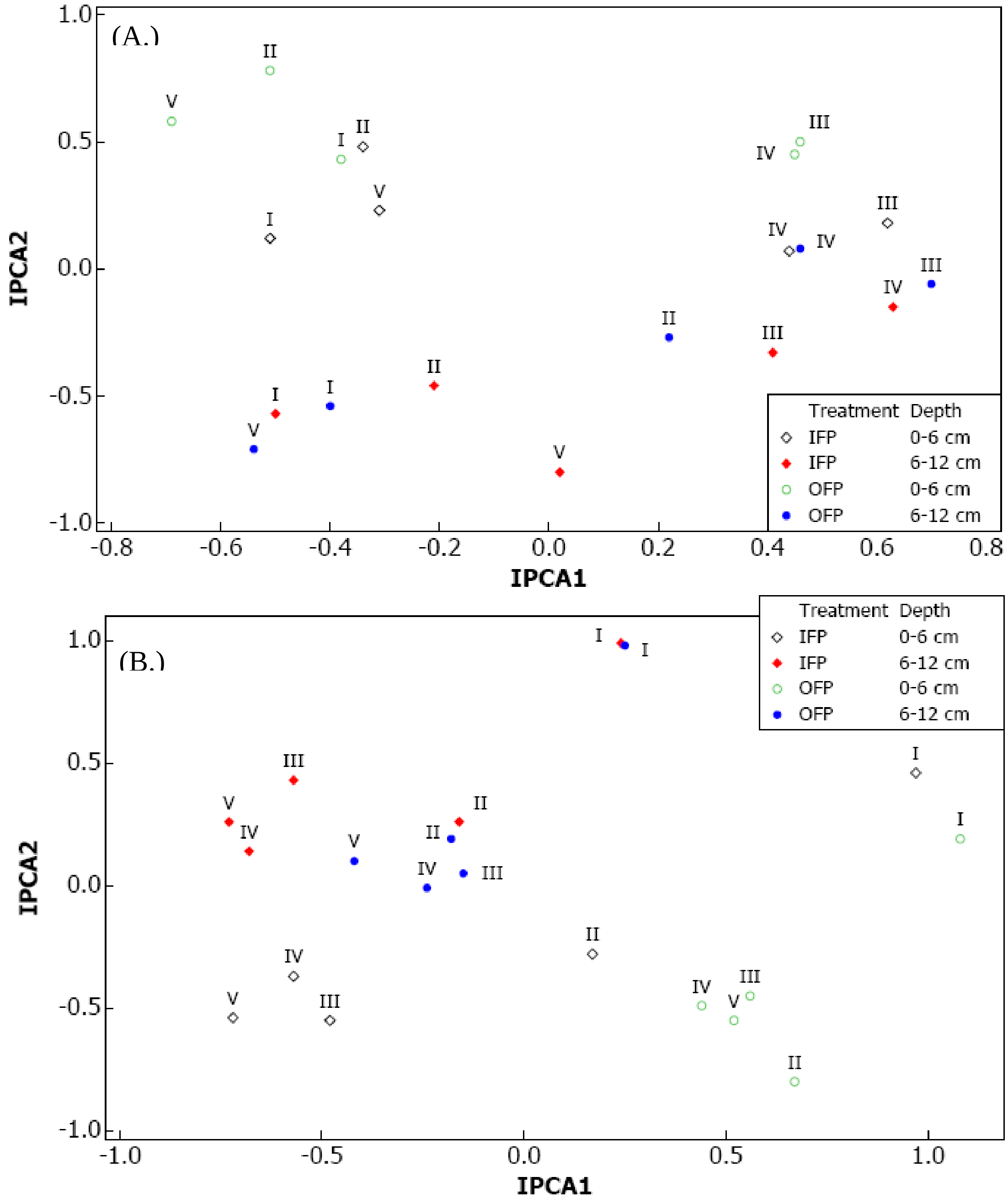
3.4.4. Ratios between microbial properties

The microbial quotient (qCO_2) was found to be greater for IFP upper depth soil throughout these measurements (Table 9). The Month × Treatment interaction was likely a result of the difference in magnitude between treatments over time (Table 8). At the lower soil depth, none of these microbial activity ratios were significantly different between treatments (Table 9).

3.4.5. Molecular analyses of bacterial and fungal soil communities

Trends between the treatments were similar whether the AMMI analysis was run with both soil depths together or individually, so only IPCAs with both depths combined are shown (Figures 6A and 6B). There were 139 unique bacterial T-RFs in the analysis, with a sample heterogeneity of 2.7; and 280 unique fungal T-RFs, with a sample heterogeneity of 4.48. No statistical differences were found between treatments for the total number of T-RFs in either community at either depth (data not shown). For bacteria, IPCA1 captured 54% of the interaction signal variation, and IPCA2 captured the remaining 46%. For fungi, IPCA1 captured 50% of the interaction signal, IPCA2 captured 29%, and IPCA3 captured the remaining percentage.

At the first (August 2005) sampling date, both treatments' bacterial communities were closely placed on the IPCA within the respective depths (Figure 6A). The bacterial community within each depth remained separate for the second (May 2006) sampling date. At this time, IFP and OFP bacterial communities were more different from each other than they were at the first sampling (Figure 6B). For the third (August 2006) and fourth (May 20007) sampling dates, the treatments and



Figures 6 A-B. Bacterial (A) and fungal (B) community composition IPCA plots generated from AMMI analysis of T-RFs. Roman numerals represent the time course: I) August 2005, II) May 2006, III) August 2006, IV) May 2007, and V) August 2007. Each symbol represents a mean of four replicated blocks.

depths increased in value along the IPCA1 axis (Figure 6A). This indicated that bacterial communities were more similar between depths than they had been previously, but treatment differences appeared to be mostly unchanged. By the fifth (August 2007) sampling date, the bacterial communities all shifted negatively along IPCA1 and were similar to the original (August 2005) sampling. However, the treatments and depths all appear to separate from each other at this point.

Similar to the bacterial T-RFLP data, the first sampling data for the fungal communities were similar between treatments within each depth (Figure 6B). In the upper depth, the treatments began to separate at the second sampling time. The upper OFP soil depth fungal community clustered around the second date for the remainder of the samplings. The IFP communities continued to move negatively along IPCA1 and then clustered around the third sampling date. For the final three sampling dates, the treatments occupied different quadrants of the IPCA within the upper depth. A similar trend occurred in the lower depth, but the fungal communities did not separate as clearly between treatments.

4. Discussion

4.1. Weed coverage and biomass

The bark mulch used in the IFP system sufficiently suppressed weeds when combined with a single herbicide application over the two years after a single application. Even though bark mulch is not widely used in non-organic orchards, satisfactory weed suppression with biomass mulches has been reported repeatedly in apple orchards (Merwin, 2003; Granatstein and Mullinix, 2008). As reported by Rifai et al. (2002), applying the bark mulch onto a weed-free strip resulted in low weed cover the following year. The present report also confirmed that reduced frequency herbicide applications are an effective practice for managing weeds in a mulch groundcover system (Rifai et al., 2002; Yao et al., 2005). The combined bark mulch-herbicide groundcover management strategy worked well within IFP management guidelines, and did not interfere with other orchard operations.

In the OFP system, the Wonder Weeder effectively removed weeds in the area from the tree trunk to the drive row, and maintained its effectiveness (<50% coverage) for two to four weeks after each cultivation. Three cultivations per year were needed in 2006 and 2007 to control weeds from late-May until mid-July. Smaller weeds tended to be incorporated into the upper soil depth, while larger weeds were left on the soil surface to desiccate. However, the tines on the Spider wheels also injured some shallow M.9 apple roots. Additionally, in this high-density orchard, the spring steel side-sweep blade sometimes damaged trunks, and was ineffective at clearing weeds in the center of tree-rows. To compensate for this, additional hand hoeing was necessary in 2006 and 2007. Both systems incurred substantial costs—bark mulch for IFP and a new cultivator for OFP (Chapter 2). Overall, the IFP weed management strategy controlled weeds more effectively than the OFP strategy.

4.2. Soil organic matter, nutrients, and pH

Increases in SOM and nutrients were more pronounced in IFP soil than in the OFP soil. In the upper IFP sampling depth, the high C:N ratio (85:1) of bark mulch increased SOM, C, C:N, and nutrient availability over time. By the end of the first year, bark mulch decomposition was apparent at the interface with the mineral soil. Even though soil was sampled below the visible mulch residue, some of the decomposition humus layer was included in the upper depth soil analyses. Deeper incorporation of SOM and nutrients from decomposed bark mulch may take longer. A long-term orchard groundcover management study found that SOM doubled, and P, Ca, Fe, Mn, and soil pH increased in the 0- 20 cm soil depth after 12-14 years of continuously maintained bark mulch (Yao et al., 2005; St. Laurent et al., 2008). Soil OM is a major source of many nutrients, stimulates biological activity, and contributes to good soil structure.

In the OFP upper soil depth, incorporation of chicken manure compost and weed biomass were the likely cause of increased SOM, but this did not occur to the levels seen under bark mulch in the IFP system. Chicken manure compost was also the likely source of elevated P levels in the upper OFP soil depth the year after application, but by 2007 in OFP, the P levels were about equal to IFP. From 2004-2007, leaf P concentrations increased 50-60% in both systems, but were not significantly different between treatments (Chapter 2). The OFP pest control program included cumulative kaolin clay applications between 173-575 kg a.i. ha^{-1} y^{-1}. This product is largely aluminosilicate [$Al_4Si_40_{10}(OH)_8$], and elevated Al levels were found in the OFP leaves but not in fruit tissue (Chapters 2 and 3). For both the upper and lower soil depths Al decreased over time, showing that short-term use of kaolin clay in OFP did not increase Al in the soil (Tables 4 and 5). Sulfate of potash-magnesia fertilizers are typically applied to apple orchards as a routine practice to replace K losses from harvested fruit (Stiles and Reid, 1991), but were not added during the first transition year in this project. With the reintroduction of sulfate of potash-magnesia after the 2005 harvest, soil K levels increased and were maintained at satisfactory levels in both systems.

4.3. Physical soil properties

4.3.1. Porosity, available water capacity, penetration resistance, and bulk density

Although not statistically compared, there were differences between the upper and lower sampling depths, showing that our methodology was sensitive enough to discriminate between depths, but not between treatments within a given depth. Greater mesoporosity in the upper soil depth and greater macroporosity in the lower soil depth were likely attributed to the four years of cultivation in OFP (Haynes, 1980; Merwin et al., 1994). Decreased microporosity due to cultivation, as had been reported after six years of rototiller cultivation (Merwin et al., 1994) was not detected in the present study. The orchard soil contained high clay and SOM contents, which may have mitigated the destructive action of cultivation in this study. Additionally, less aggressive and more effective cultivation equipment (i.e., fewer passes needed per year) were used in this report compared with those used in previous reports. Similar to results found by Merwin et al. (1994), total soil pore space was variable and not readily impacted by groundcover management practice. However, increased total pore space under a mulch treatment and decreased pore space under tillage are possible over the long-term (Haynes, 1980; Oliveira and Merwin 2001).

Effects on AWC and bulk density were minimal, especially at the lower sampling depth. Walsh et al. (1996) also reported minimal differences in bulk density between mulch and cultivation. However, mulch treatments were found to have lower bulk density when compared to sod or herbicide strips after eight years (Oliveira and Merwin, 2001); and cultivated OFP soils were found to have lower bulk density (down to 15 cm) than IFP or conventional herbicide strips (Glover et al. 2000). This might reflect the timing of sampling relative to cultivation. Penetration resistance in both IFP and OFP treatments was variable, representing the heterogeneous structure of the soil surface both within and between sampling dates. Cultivation loosened soil and by the end of each year OFP soil was consistently less resistant to the penetrometer probe in the upper depth. While this test suggests that roots would more easily penetrate OFP soil, repeated cultivation at that depth would inhibit long-term root establishment and could form a compacted soil layer over time. The lack of differences for physical properties at the lower depth indicated that neither management system altered the physical properties for the majority of the rooting zone during the four years of this study.

4.3.2. Water stable aggregation

For samples that were taken after all cultivation had been completed for each year (August), upper depth OFP soil aggregates were less resilient to the rainfall simulator than IFP soil. Additionally, by the third year of cultivation, OFP soil aggregates in the upper depth were less stable than IFP soil aggregates. These results are likely attributed to aggregate destabilization by cultivation in the OFP system and to soil aggregate stabilization with greater SOM and biological activity under the bark mulch in the IFP system (Haynes, 1980; Glover et al., 2000). May 2006 upper depth OFP samples ranged from 44-66% stable aggregation, reflecting that the Wonder Weeder created a very heterogeneous soil surface after its initial use in the previous year. As OFP soil was repeatedly cultivated over 2006 and 2007, the soil surface became more homogenous and the range decreased to 27-33% aggregate stability by August 2007. Soils with low aggregate stability tend to form surface crusts, which can reduce SOM, water infiltration, and air exchange (Haynes, 1980). Therefore, the decreased aggregate stability in OFP soil indicates diminished soil quality. Contrary to this study, Walsh et al. (1996) found no difference in aggregate stability between cultivated and mulch treatments in orchards with similar clay content soils to ours. Glover et al. (2000) also found similar aggregate stability between cultivated OFP and herbicide strip IFP soils, even though OFP soils in that study received twice the compost added as IFP. Differences in SOM, soil water content at cultivation, the number of times and depth to which cultivation occurred, and the amount of time between cultivation and sampling may all factor into the variable results found for physical soil attributes in this report and others.

4.4. Biological soil properties

4.4.1. Potentially mineralizable N and total inorganic N

In upper OFP soil, a large increase in PMN was observed in the May sampling following the chicken manure compost application (Table 8). Chicken manure compost was also found to increase PMN in OFP soils in California and in OFP and IFP soils in Washington (Werner, 1997; Kramer et al., 2006). In the present study, a large spike in inorganic N for both upper and lower OFP soil depths accompanied the PMN increase, which would indicate NO_3^- leaching through the root zone. Nitrate leaching may have been further exacerbated by cultivation (Walsh et al., 1996; Merwin et al., 1996). In the upper IFP soil depth, PMN slowly increased over time but higher levels of inorganic N were not apparent. Kramer et al. (2006) found that OFP soil fertilized with chicken manure compost had less N leaching potential than IFP soil fertilized with chicken manure compost and calcium nitrate, a synthetic fertilizer they showed to be the primary source of leaching. Aside from the different fertilizer applications, the OFP soil in that study had similar C:N ratio and microbial activity to the IFP soil in the present study (Kramer et al., 2006). This indicates that soil properties in each management system are a product of the inputs that are used, more so than the protocols being followed.

For both treatments, leaf N content was at the low end of the acceptable range for mature apple trees, and was likely a limiting factor in both systems (Chapter 2). The OFP leaf N content increased slightly from 2005 to 2006, possibly reflecting N uptake after the compost application. However, this effect was transient and leaf N values returned to low levels by 2007. Compost is a common source of nutrients for organic systems, but it is a complex substrate that must be mineralized into plant available forms. Further work is needed to align compost applications with N demand in the orchard, while reducing the potential for N leaching.

4.4.2. Microbial biomass-C and biomass-N

By increasing SOM and C, the bark mulch fostered larger MBC in the upper sampling depth compared with OFP practices such as cultivation and compost (Wardle, 1992). Werner (1997) and Glover et al. (2000) both found OFP soil to have greater MBC than IFP or conventionally managed orchard soils, but in those reports the OFP system received considerably greater C inputs through composts compared with the herbicide managed conventional treatment. In other comparative studies, as in ours, MBC was a more sensitive indicator of the treatment effects than MBN or the qMic ratio (Werner, 1997; Glover et al., 2000). In fact, despite large PMN rates and large inorganic N concentrations in the OFP system, there were no discernable treatment or year effects for MBN. The fact that tree N status was relatively unchanged, and MBN did not increase, further supports the hypothesis that N was leaching from the OFP soil. Weeds may have taken up some available soil N as well.

4.4.3. Soil respiration

High respiration rates under bark mulch have been reported in other orchard studies (Yao et al., 2005; St. Laurent et al., 2008). Over the four sampling dates, cumulative respiration rates for the IFP upper soil depth continued to increase over time, while OFP samples increased more slowly over time (Figures 5A-D). It is well known that respiration rates are linearly related to soil moisture content (Orchard and Cook, 1983). Despite efforts to equilibrate moisture by irrigation before sampling, the gravimetric water fractions in upper depth were between 34-39% in IFP soils, and between 22-30% in OFP soils at sampling time (data not shown). The treatment soil water contents were significantly different from each other in all but May 2007. In the lower depth, there were no significant differences between treatments, and the water fraction ranged between 27-31% (data not shown). These results are not surprising, as it is well known that bark mulch provides excellent water retention. Even though assayed soils were not fully equilibrated for soil moisture, these respiration assays have implications for the microbial activity that was maintained for much of the growing season.

Leveling off of cumulative respiration rates may represent the point of substrate limitation for the microbial communities (Yao et al., 2005). The steady state of OFP upper depth respiration rates showed that the compost additions and the regular incorporation of weed biomass provided much less substrate to stimulate microbial activity than did the bark mulch. This coincides with SOM and MBC, which were both greater under IFP soil, and confirms that bark mulch can quickly stimulate biological activity. High microbial respiration rates (CO_2 loss) represent greater C utilization by the soil microbes. Despite large increases of PMN and inorganic N in upper depth OFP soil, respiration rates did not increase. This suggests that under the OFP system, C was more limiting than N for the soil microbial community. However, in the IFP system both MBC and respiration increased substantially, suggesting that microbial C limitations were alleviated. With high C:N mulches, immobilization of N by soil microbiota is likely to exceed mineralization, therefore potentially decreasing mineral N levels in the soil (Haynes, 1980). This may have been reflected in the low leaf N content under the bark mulch. However, this potential management issue for IFP systems using bark mulch can be readily corrected through the application of either organic or inorganic fertilizers (Carroll and Robinson, 2006).

4.4.4. Ratios between microbial properties

Among the ratios, only the metabolic quotient (qCO_2) was different between the production systems. As a ratio between respiration and MBC, qCO_2 can indicate greater stress, but in the IFP system it more likely reflected a system undergoing rapid microbial change after large C inputs (Rice et al., 1996). In other orchard systems trials, this ratio was not indicative of management practices (Werner, 1997).

4.4.5. Molecular analyses of bacterial and fungal soil communities

Microbial communities can be influenced by numerous interrelated soil properties that were affected by the treatments, including SOM, nutrient availability, soil aeration, and water status (Ibekwe et al., 2002; Horner-Devine et al., 2004; Yao et al., 2005). Further complicating the observed patterns, factors such as soil sample depth and timing also influence microbial community diversity and composition (LaMontagne et al., 2003; Yao et al., 2005; Culman et al., 2006). Following trends in the other measured soil properties, the upper depth of the T-RFLP microbial community fingerprints for both bacteria and fungi were more responsive to the treatments than the lower depth. Microbial communities in the upper depth would have greater access to nutrients than lower depth communities, and would likely be more responsive to changes in soil physical properties, water status, and aeration (LaMontagne et al., 2003). The exception to the separation between depths was at the third (August 2006) and fourth (May 2007) sampling times for bacteria, especially in IFP soil (Figure 6A). This might have been a result of the amendments (mulch and compost) that were added after the first sampling date (August 2005), providing a quick but not sustained pulse on bacterial community composition through the entire 12 cm that was measured. By the fifth sampling date (August 2007) both upper and lower bacterial communities had returned to a similar composition as seen in August 2005 before soil amendment additions, but the treatments were more dissimilar from each other. This would correspond to increased MBC found in August 2006 and May 2007, and decreased MBC in August 2007. Yao et al. (2006) also observed that immediate responses to bacterial communities after substrate addition (compost) diminished within two years, and in that study, fungal communities were less affected by the soil compost addition.

Bacterial communities varied more among sampling time than between treatments. Due to differences in soil temperature, moisture, and population dynamics, other studies have also shown that sampling time was a primary factor in segregating microbial communities (Yao et al., 2005; Culman et al., 2006). Conversely, fungal communities in our study, particularly in the upper soil depth, clustered together within treatment, but not with sampling times. Others have found that fungal communities in orchard soils were influenced by mulch, differing from herbicide or grass groundcover treatments, while bacterial communities were less affected by treatment (Yao et al., 2005; St. Laurent et al., 2008). This has been interpreted as a function of increased activity of specialized fungal detritivores capable of utilizing complex lignin and polyphenolics (Melillo et al., 1982; Yao et al., 2005). Additionally, bacteria under bark mulch would more likely be N limited compared with fungi (Yao et al., 2005). In the present study, cultivation and the weed cover that grew between cultivations may also have influenced the OFP microbial community, further segregating the two systems over time (Marschner et al., 2001). Clearly, the quality and quantity of substrates used for managing groundcover in each system were dissimilar and had different effects on mineralization, microbial biomass and activity; as a result, community composition segregated between the fruit production systems.

5. Conclusion

Many of the positive soil quality properties attributed to OFP soils in other studies were also found in IFP soils in this study, confirming previous studies showing soil quality improvement when composted bark mulch is applied beneath apple trees. Many treatment differences in soil quality properties were limited to the upper soil depth, and microbial biomass, activity, and community composition were relatively unaffected in the lower rooting zone. Herbicide applications were reduced by mulching without increasing weeds beyond a reasonable threshold for mature apple trees in IFP. Under the OFP system, soil quality did not improve as greatly as the IFP soil during four years. However, over the few years of this study, effects from using mechanical cultivation were not as pronounced as in previous reports. Overall, the management practices that were used in the IFP system outperformed those used for OFP management in promoting soil quality for this orchard.

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Chapter Five

Conclusion

Four years of testing integrated (IFP) and organic (OFP) fruit production systems provided much insight into the workings of these systems at multiple levels. Each fruit production system was evaluated from the ground up, thus the strength of this project was that it supplied realistic assessments of each of the production systems under conditions that would resemble commercial orchard operations in the Northeastern United States. This was crucial aspect of this project because few commercial operations currently grow apples under either IFP or OFP in the Northeast.

While fruit yields were similar between systems, the OFP system incurred more fruit damage, and therefore less OFP apples were marketable for fresh sales. In this region, greater fruit cullage due to insects, diseases, and other cosmetic blemishes will likely remain obstacles for OFP. The IFP system was less expensive to operate and had received better overall returns than OFP in both the wholesale and direct marketplaces modeled in Chapter 2. Both labor and materials were more expensive in OFP. However, the 62% price premium applied to organic sales after the third transition year greatly improved the overall OFP returns. If such sizable premiums are maintained in the future, the long-term economics of OFP could be quite favorable and help to compensate for low revenues during the transition period.

The use of blemished fruit for fresh sales and cider in the direct market operation model improved the overall OFP returns. If consumers are unwilling to purchase blemished apples, then organic apple growers will need to rely upon processing fruit into value-added products, such as fresh cider. The economics of value-added products were not included in my analyses. In the Northeast, many direct market orchard operations are already diversified with value-added products, but it is unclear how much blemished fruit could be profitably used this way. Growers considering organic production might consider being a mixed operation where only a part of their orchard is farmed organically, thereby accessing the organic market without committing the entire operation.

Sales of IFP apples have been limited, and therefore IFP price premiums have seldom existed in the United States. Additionally, IFP apples will have to compete against both the well-established organic label and less expensive conventional apples. While this research gives compelling justification for adoption of IFP by growers, consumers will need to be convinced that an additional cost for IFP apples is justified. Perhaps, like in Europe, the push for IFP apples will come from retailers. Increased government pesticide regulation will continue to limit the available materials, and that might lead to a conventional growing system that closely resembles the IFP system modeled in this project. If this becomes the case, then there will be little to no justification for a price premium, and it is unpredictable whether the overall retail cost of apples will be greater to compensate for production costs.

Further study into the safety and environmental impact of the pesticides used for both systems is warranted. The Environmental Impact Quotient (EIQ) did not appear to fairly assess the use of kaolin clay in the OFP system, as it was difficult to justify the large EIQ Field Use Rating value attributed to this product. Kaolin clay is a material that many people consume on a daily basis as an ingredient in toothpaste, medicines, and food additives, and contact through glossy magazines, porcelain, and cosmetics. In fact, before multiplying the quantity of kaolin clay used each season this material had one of the lowest the EIQ values out of the several hundred rated active ingredients. The EIQ model could be adjusted to account for materials used in large quantity by using non-linear equations in the Field Use Rating, but it is unclear whether enough information is available to formulate accurate dose-response curves. Despite the limitations of the EIQ, few other pesticide impact models account for as many potential environmental effects. A more robust environmental impact assessment could use the EIQ in conjunction with cradle-to-grave environmental models, such as the Life Cycle Assessment (LCA). This would allow modeling of manufacturing and transporting environmental impacts with the LCA, and post-application pesticide impacts with the EIQ. The LCA also accounts for energy consumption, which was not accounted for in this project. The environmental effects of other components of the production system, such as fertilizers, fuel, irrigation components, tractors and tractor implements, and the trellis support materials could also be assessed with the LCA.

Many consumers purchase organic produce because they believe it to be better tasting and more nutritious. These expectations were not confirmed when IFP and OFP apples were compared in Chapter 3. There were few consistent internal fruit quality differences (i.e., soluble solid concentration, titratable acidity, firmness, total phenolics, or antioxidant capacity) over the four years of this project. Furthermore, while consumer panels were consistently able to detect a difference between IFP and OFP apples, they did not show a consistent preference for the flavor or texture of apples from either system. However, diseases and lime sulfur applications negatively affected external fruit quality in OFP, and caused a decrease in OFP market value and in consumer acceptability. The lack of consistent differences in fruit quality measurements suggests that the two systems produced fruit of similar internal quality, both of which were satisfactory to consumers. Further work is needed to explore the inconsistencies between the results found in this study and other studies that have reported differences between OFP and IFP or conventional fruit.

In Chapter 4, within just a few months after bark mulch application to the IFP system and chicken manure compost application to the OFP system, I documented numerous soil property changes. Under bark mulch, the soil organic matter, soil nutrient content, microbial biomass, pH, and microbial respiration all increased in comparison to OFP, while compost stimulated a rapid increase in nitrogen mineralization in OFP soil. However, tree nutrient status was not increased by soil management practice. Nutrients were perhaps immobilized in the microbial biomass, and therefore not readily available for plant uptake. Other factors may have also limited tree nutrient uptake, such as trunk boring insect or root diseases. Bark mulch was the most expensive input for IFP, and although it appeared to improve soil quality justifying the cost may be difficult for growers. Although biomass mulches are a preferred soil management practice, bare soil herbicide strips would also be acceptable under IFP protocol, as is the practice in many European orchards managed under IFP.

In the OFP system, the apparent nitrate-nitrogen leaching from the compost is a concern, and future work is needed to determine more efficient materials, timing, and rates for OFP fertility management. Even with less aggressive cultivation tools than have been used previously, compared with the undisturbed IFP soil, an increase in mesoporosity and a decrease in aggregate stability was found in the OFP surface soil. This might have further exacerbated mineralization and leaching in the OFP system. Nonetheless, mechanical cultivation will probably remain common in OFP systems because weeds can be effectively and inexpensively managed this way.

After data collection for this report concluded, a high incidence of dogwood borer [*Synanthedon scitula* (Harris)] damage has been observed in the graft union of both IFP and OFP trees, as well as several nearby orchard blocks. Dogwood borers can girdle and kill a tree, but more commonly contribute to a slow decline and yield reduction over a long period of time by digging tunnels in the trunk or in burr knots. It was unclear what impact this clearwing moth had on the production systems during the course of this study. However, the greater weed coverage in the OFP system could make the infestation worse by blocking sunlight to the graft union, and thus stimulating burr knot development. In conventional systems, dogwood borers can be controlled using a broad-spectrum trunk spray before bloom. It was unclear if the appearance of dogwood borer more than coincidentally coincided with the termination of organophosphate insecticides in this orchard, since nearby apple trees were treated with multiple organophosphate applications each year. Keeping the area around the trunk free of weeds, covering trunks with latex paint, and mounding soil around the trunk are possible strategies that can be used for IFP and OFP. Further investigation of the dogwood borer infestation is planned, particularly to assess differences between production systems and in comparison with the two unsprayed buffer rows.

The systems level study that I undertook, limits mechanistic explanations for some of the observed results. For example, many factors likely contributed to the low incidence of apple maggot, including the sprays that were used, the sticky traps, the scale of the test orchard, and the proximity of the test orchard to nearby conventionally managed orchards. Additionally, fruit quality measurements, such as firmness, soluble solids, and titratable acidity can be affected by numerous preharvest factors, such as crop load, nutrient status, and pest and disease incidence. However, no one factor could consistently be attributed to the observed results. As these fruit production systems become more widely implemented in the Northeast, the individual components of each system will need to be studied in more detail.

Overall, the IFP system appeared to be more adaptable to the growing conditions in the test orchard than the OFP system. The use of standard fruit thinning materials and reduced-risk pesticides will likely make IFP management more appealing to growers because it is more similar to current standard practices than those used in OFP. However, it is still a system that utilizes synthetic materials, and this might resonate negatively with consumers. Organic production appeared to be most suitable for small to medium sized operations targeting niche markets with price premiums. While further research is needed to optimize both IFP and OFP, these systems appeared to have enough success in the test orchard to recommend their implementation in the Northeastern US. But, as mentioned in Chapter 2, these results are based upon 'Liberty', a scab-resistant cultivar. Implementing these systems in an orchard with disease susceptible cultivars would provide different results.

APPENDICES

Appendix A. Application date, material, active ingredient, (a.i.), rate, cost, and Environmental Impact Quotient (EIQ) Field Use Rating per ha for integrated fruit production (IFP).

Date	Product name	a.i.	Action[z]	Rate	per acre	cost ($)/acre	EIQ
4/15/04	C.O.C.S.	Copper oxychloride sulfate	F	4	lb	8.00	111.7
4/15/04	C.O.C.S.	Basic copper sulfate	F	4	lb	0.00	30.4
4/20/04	Damoil	Parafinnic oil	I	2	gal	6.98	504.8
5/6/04	Roundup Original MAX	Glyphosate	H	2.5	qt	21.28	43.9
5/8/04	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	0.5	lb	4.87	2.4
5/11/04	Agrimycin 17	Streptomycin sulfate	B	4	oz	4.35	1.2
5/11/04	Regulaid	Dihydroxypropane	A	4	fl oz	0.93	0.0
5/14/04	Bac Master	Streptomycin antibiotic	B	4	oz	4.50	1.1
5/14/04	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	0.5	lb	4.87	2.4
5/14/04	Regulaid	Dihydroxypropane	A	4	fl oz	0.93	0.0
5/19/04	Actara	Thiamethoxam	I	5.5	oz	29.98	3.2
5/21/04	Fruitone N	1-naphthaleneacetic acid, sodium salt	T	3	oz	7.29	0.0
5/21/04	Sevin XLR Plus	Carbaryl (1-naphthyl N-methylcarbamate)	T	1	pt	3.45	10.8
5/26/04	Last Call: CM	Permethrin	I	0.0622	L	46.46	0.8
5/26/04	Last Call: OFM	Permethrin	I	0.0622	L	46.46	0.8
5/27/04	Avaunt 30 WDG	Indoxacarb	I	6	oz	28.50	5.4
5/27/04	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	8	oz	4.87	2.4
5/27/04	Sevin XLR Plus	Carbaryl (1-naphthyl N-methylcarbamate)	T	1	pt	3.45	10.8
6/7/04	Avaunt 30 WDG	Indoxacarb	I	6	oz	28.50	5.4

Date	Product name	a.i.	Action[z]	Rate	per acre	cost ($)/acre	EIQ
6/7/04	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	8	oz	4.87	2.4
6/23/04	Avaunt 30 WDG	Indoxacarb	I	6	oz	28.50	5.4
6/23/04	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	8	oz	4.87	2.4
7/6/04	Avaunt 30 WDG	Indoxacarb	I	6	oz	28.50	5.4
7/6/04	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	8	oz	4.87	2.4
7/6/04	Roundup Original MAX	Glyphosate	H	2.5	qt	21.28	43.9
7/6/04	Sovran	Kresoxim-methyl	F	1.6	oz	8.60	0.7
7/19/04	Avaunt 30 WDG	Indoxacarb	I	6	oz	28.50	5.4
7/19/04	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	8	oz	4.87	2.4
7/19/04	Sovran	Kresoxim-methyl	F	1.6	oz	8.60	0.7
8/2/04	Avaunt 30 WDG	Indoxacarb	I	6	oz	28.50	5.4
8/2/04	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	8	oz	4.87	2.4
4/12/05	C.O.C.S	Copper oxychloride sulfate	F	4	lb	8.00	111.7
4/12/05	C.O.C.S	Basic copper sulfate	F	4	lb		30.4
4/12/05	Damoil	Parafinnic oil	I	1	qt	0.87	63.1
4/19/05	Damoil	Parafinnic oil	I	2	gal	6.98	504.8
5/9/05	Actara	Thiamethoxam	I	5	oz	27.25	2.9
5/26/05	Carbaryl 4L	Carbaryl (1-naphthyl N-methylcarbamate)	T	1	pt	3.12	10.5
5/26/05	Exilis Plus	6-benzylaminopurine [N-(phenylmethyl)-1H-purine-6-amine]	T	64	fl oz	62.44	0.0
5/31/05	Avaunt	Indoxacarb	I	3	oz	14.25	2.7

Date	Product name	a.i.	Action[z]	Rate	per acre	cost ($)/acre	EIQ
5/31/05	Carbaryl 4L	Carbaryl (1-naphthyl N-methylcarbamate)	T	1	pt	3.12	10.5
5/31/05	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	8	oz	4.87	2.4
5/31/05	Exilis Plus	6-benzylaminopurine [N-(phenylmethyl)-1H-purine-6-amine]	T	64	fl oz	60.26	0.0
5/31/05	RoundUp Original MAX	Glyphosate	H	2.5	qt	21.28	43.9
6/13/05	Avaunt	Indoxacarb	I	5.6	oz	26.60	5.1
6/13/05	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	8	oz	4.87	2.4
6/13/05	Epsom salts	Magnesium sulfate,heptahydrate	N	15	lb	2.85	0.0
6/13/05	Solubor	Mixture of Orthoboric Acid, H3BO3 Disodium Tetraborate Pentahydrate, Na2B4O7 .5H2O and Disodium Decaborate Decahydrate, Na2B10O16 .10H2O	N	1	lb	0.80	0.0
6/13/05	Zinc EDTA	Chelated zinc	N	1	qt	2.75	0.0
7/1/05	Avaunt	Indoxacarb	I	5.6	oz	26.60	5.1
7/1/05	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	8	oz	4.87	2.4
7/1/05	Epsom salts	Magnesium sulfate,heptahydrate	N	15	lb	2.85	0.0

Date	Product name	a.i.	Action[z]	Rate	per acre	cost ($)/acre	EIQ
7/1/05	Solubor	Mixture of Orthoboric Acid, H3BO3 Disodium Tetraborate Pentahydrate, Na2B4O7 .5H2O and Disodium Decaborate Decahydrate, Na2B10O16 .10H2O	N	1	lb	0.80	0.0
7/1/05	Zinc EDTA	Chelated zinc	N	1	qt	2.75	0.0
7/12/05	RoundUp Original MAX	Glyphosate	H	2.5	qt	28.86	43.9
7/29/05	Acramite 50WS	Bifenazate: Hydrazine carboxylic acid	AC	9	oz	31.50	4.7
7/29/05	Calcium chloride	Calcium chloride	N	3	lb	0.66	0.0
7/29/05	Spintor 2SC	Spinosad	I	2.5	fl oz	14.19	0.7
8/9/05	Assail 70 WP	Acetamiprid	I	3	oz	39.30	4.0
8/9/05	Calcium chloride	Calcium chloride	N	3	lb	0.66	0.0
4/18/06	C.O.C.S.	Copper oxychloride sulfate	F	4	lb	8.00	111.7
		Basic copper sulfate	F	4	lb		30.4
4/18/06	Damoil	Parafinnic oil	I	1	gal	3.49	252.4
5/1/06	Assail 70WP	Acetamiprid	I	3	oz	39.30	4.0
5/1/06	Epsom Salts	Magnesium sulfate,heptahydrate	N	15	lb	2.40	0.0
5/1/06	Solubor	Mixture of Orthoboric Acid, H3BO3 Disodium Tetraborate Pentahydrate, Na2B4O7 .5H2O and Disodium Decaborate Decahydrate, Na2B10O16 .10H2O	N	1	lb	0.80	0.0
5/1/06	Zinc EDTA	Chelated zinc	N	1	qt	2.75	0.0
5/17/06	Carbaryl 4L	Carbaryl (1-naphthyl N-methylcarbamate)	T	1.5	pt	4.68	15.8
5/17/06	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	8	oz	4.87	2.4

Date	Product name	a.i.	Action[z]	Rate	per acre	cost ($)/acre	EIQ
5/17/06	Solubor	Mixture of Orthoboric Acid, H3BO3 Disodium Tetraborate Pentahydrate, Na2B4O7 .5H2O and Disodium Decaborate Decahydrate, Na2B10O16 .10H2O	N	1	lb	0.80	0.0
5/17/06	Zinc EDTA	Chelated zinc	N	1	qt	2.75	0.0
5/29/06	Carbaryl 4L	Carbaryl (1-naphthyl N-methylcarbamate)	T	1	pt	3.12	10.5
5/29/06	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	8	oz	4.87	2.4
5/29/06	Exilis Plus	6-benzylaminopurine [N-(phenylmethyl)-1H-purine-6-amine]	T	48	fl oz	45.20	0.0
6/5/06	Actara	Thiamethoxam	I	5	oz	27.25	2.9
6/5/06	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	8	oz	4.87	2.4
6/5/06	Urea		N	2.5	lb	0.55	0.0
6/12/06	Avaunt	Indoxacarb	I	6	oz	28.50	5.4
6/12/06	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	8	oz	4.87	2.4
6/13/06	Isomate C Plus		Ph	400 ties	A	105.00	
6/13/06	Isomate-M-100		Ph	150 ties	A	56.96	
7/1/06	Calcium Chloride	Calcium chloride	N	3	lb	0.66	0.0
7/1/06	Sovran	Kresoxim-methyl	F	1.6	oz	8.60	5.9
7/1/06	Spintor 2SC	spinosad	I	2	fl oz	11.35	0.6
7/13/06	Calcium Chloride	Calcium chloride	N	3	lb	0.66	0.0
7/13/06	Calypso	Thiacloprid	I	1.5	fl oz	9.26	1.3

Date	Product name	a.i.	Action[z]	Rate	per acre	cost ($)/acre	EIQ
7/13/06	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	8	oz	4.87	2.4
7/13/06	Sovran	Kresoxim-methyl	F	1.6	oz	8.60	0.7
7/27/06	Calcium Chloride	Calcium chloride	N	3	lb	0.66	0.0
7/27/06	Calypso	Thiacloprid	I	1.5	fl oz	9.26	1.3
7/27/06	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	8	oz	4.87	2.4
8/12/06	Calcium Chloride	Calcium chloride	N	3	lb	0.66	0.0
8/12/06	Calypso	Thiacloprid	I	1.5	fl oz	9.26	1.3
8/12/06	Pristine	Pyraclostrobin	F	14.5	oz	28.04	4.1
8/12/06	Pristine	Boscalid	F	14.5	oz		11.2
4/24/07	C.O.C.S.	Copper oxychloride sulfate	F	4	lb	8.00	111.7
		Basic copper sulfate	F	4	lb		30.4
4/24/07	Damoil	Parafinnic oil	I	2	gal	6.98	504.8
5/17/07	Isomate CM/OFM TT		Ph	200 ties	A	200.00	0.0
5/22/07	Carbaryl 4L	Carbaryl (1-naphthyl N-methylcarbamate)	T	1	pt	3.12	10.5
5/22/07	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	2	lb	19.48	9.6
5/26/07	Actara	thiamethoxam	I	5	oz	27.25	2.9
5/26/07	Epsom Salts	Magnesium sulfate,heptahydrate	N	15	lb	2.40	0.0
5/26/07	Solubor	Mixture of Orthoboric Acid, H_3BO_3 Disodium Tetraborate Pentahydrate, $Na_2B_4O_7 \cdot 5H_2O$ and Disodium Decaborate Decahydrate, $Na_2B_{10}O_{16} \cdot 10H_2O$	N	1	lb	0.80	0.0
5/26/07	Urea		N	2.5	lb	0.55	0.0
5/26/07	Zinc EDTA	Chelated zinc	N	1	qt	2.75	0.0

Date	Product name	a.i.	Action[z]	Rate	per acre	cost ($)/acre	EIQ
6/1/07	Carbaryl 4L	Carbaryl (1-naphthyl N-methylcarbamate)	T	16	fl oz	3.12	10.5
6/1/07	Exilis Plus	6-benzylaminopurine [N-(phenylmethyl)-1H-purine-6-amine]	T	45	fl oz	45.20	0.0
6/6/07	Avaunt	Indoxacarb	I	6	oz	28.50	5.4
6/6/07	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	8	oz	4.87	2.4
6/6/07	Epsom Salts	Magnesium sulfate,heptahydrate	N	15	lb	2.40	0.0
6/6/07	Solubor	Mixture of Orthoboric Acid, H3BO3 Disodium Tetraborate Pentahydrate, Na2B4O7 .5H2O and Disodium Decaborate Decahydrate, Na2B10O16 .10H2O	N	1	lb	0.80	0.0
6/6/07	Zinc EDTA	chelated zinc	N	1	qt	2.75	0.0
6/7/07	Credit Extra	Glyphosate	H	3	qt	15.45	44.1
6/21/07	Calypso	Thiacloprid	I	1.5	fl oz	9.26	1.3
6/21/07	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	8	oz	4.87	2.4
6/21/07	Epsom Salts	Magnesium sulfate,heptahydrate	N	15	lb	2.40	0.0
7/2/07	Calcium Chloride	Calcium chloride	N	3	lb	0.66	0.0
7/2/07	LI-700		A	1	pt	3.36	0.0
7/2/07	Spintor 2SC	Spinosad	I	2.5	fl oz	14.19	0.7
7/23/07	Calcium Chloride	Calcium chloride	N	3	lb	0.66	0.0
7/23/07	Calypso	Thiacloprid	I	1.5	fl oz	9.26	1.3
7/23/07	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	8	oz	4.87	2.4
8/6/07	Calcium Chloride	Calcium chloride	N	3	lb	0.66	0.0
8/6/07	Calypso	Thiacloprid	I	1.5	fl oz	9.26	0.4

Date	Product name	a.i.	Action[z]	Rate	per acre	cost ($)/acre	EIQ
8/6/07	Pristine	Pyraclostrobin	F	14.5	oz	28.04	4.1
8/6/07	Pristine	Boscalid	F	14.5	oz		11.2

[z] Action: A = adjuvant; AC = acaracide; B = bactericide; CP = crop protectant; H = herbicide; I = insecticide; F = fungicide; Ph = pheromone mating disruption; PGR = plant growth regulator; T = thinning agent.

Appendix B. Application date, material, active ingredient, (a.i.), rate, cost, and Environmental Impact Quotient (EIQ) Field Use Rating for organic fruit production (OFP).

Date	Product name	a.i.	Action[z]	Rate per acre	cost ($)/acre	EIQ
4/15/04	C.O.C.S.	Copper oxychloride sulfate	F	4lb	8.00	111.7
4/15/04	C.O.C.S.	Basic copper sulfate	F	4lb	0.00	30.4
4/20/04	Damoil	Parafinnic oil	I	2gal	9.40	504.8
5/8/04	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	0.5lb	4.87	2.4
5/10/04	Surround WP	Kaolin clay	CP	40lb	34.00	340.7
5/11/04	Agrimycin 17	Streptomycin sulfate	B	4oz	4.35	187.9
5/11/04	Regulaid	Dihydroxypropane	A	4fl oz	0.93	0.0
5/14/04	Bac Master	Streptomycin antibiotic	B	4oz	4.50	1.1
5/14/04	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	0.5lb	4.87	2.4
5/14/04	Regulaid	Dihydroxypropane	A	4fl oz	0.93	0.0
5/17/04	Surround WP	Kaolin clay	CP	50lb	42.50	425.9
5/19/04	Surround WP	Kaolin clay	CP	50lb	42.50	425.9
5/25/04	Surround WP	Kaolin clay	CP	50lb	42.50	425.9
5/27/04	Lime Sulfur	Calcium polysulfide	T	3gal	41.67	370.5
6/3/04	Lime Sulfur	Calcium polysulfide	T	1.5gal	20.84	185.3
6/3/04	Surround WP	Kaolin clay	CP	50lb	42.50	425.9
6/11/04	Surround WP	Kaolin clay	CP	50lb	42.50	425.9
6/21/04	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	8oz	4.87	2.4
6/21/04	Surround WP	Kaolin clay	CP	50lb	42.50	425.9
7/7/04	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	8oz	4.87	2.4
7/7/04	Surround WP	Kaolin clay	CP	50lb	42.50	425.9
7/19/04	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	8oz	4.87	2.4
7/19/04	Surround WP	Kaolin clay	CP	50lb	42.50	425.9
7/29/04	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	8oz	4.87	2.4
7/29/04	Surround WP	Kaolin clay	CP	50lb	42.50	425.9

Date	Product name	a.i.	Action[z]	per Rateacre	cost ($)/acre	EIQ
8/9/04	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	8oz	4.87	2.4
8/9/04	Entrust	Spinosad	I	0.75oz	22.50	0.7
8/9/04	Surround WP	Kaolin clay	CP	50lb	42.50	425.9
4/12/05	C.O.C.S	Copper oxychloride sulfate	F	4lb	8.00	111.7
4/12/05	C.O.C.S	Basic copper sulfate	F	4lb	0.00	30.4
4/12/05	Damoil	Parafinnic oil	I	1qt	0.87	63.1
4/19/05	Damoil	Parafinnic oil	I	2gal	6.98	504.8
5/26/05	Crocker's Fish Oil	Fish oil	T	2gal	25.40	504.8
5/26/05	Lime sulfur	Calcium polysulfide	T	2.5gal	34.73	308.8
5/31/05	Crocker's Fish Oil	Fish oil	T	2gal	25.40	504.8
5/31/05	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	8oz	4.87	2.4
5/31/05	Lime sulfur	Calcium polysulfide	T	2.5gal	34.73	308.8
5/31/05	Pyganic 1.4EC	Pyrethrins	I	24fl oz	30.33	0.4
6/13/05	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	8oz	4.87	2.4
6/13/05	Epsom salts	Magnesium sulfate,heptahydrate	N	15lb	2.85	0.0
6/13/05	Solubor	Mixture of Orthoboric Acid, H3BO3 Disodium Tetraborate Pentahydrate, Na2B4O7 .5H2O and Disodium Decaborate Decahydrate, Na2B10O16 .10H2O	N	1lb	0.80	0.0
6/13/05	Surround WP	Kaolin clay	CP	50lb	42.50	425.9
6/13/05	Zinc EDTA	Chelated zinc	N	1qt	2.75	0.0
6/20/05	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	8oz	4.87	2.4
6/20/05	Epsom salts	Magnesium sulfate,heptahydrate	N	15lb	2.85	0.0

Date	Product name	a.i.	Action[z]	per Rateacre	cost ($)/acre	EIQ
6/20/05	Solubor	Mixture of Orthoboric Acid, H3BO3 Disodium Tetraborate Pentahydrate, Na2B4O7 .5H2O and Disodium Decaborate Decahydrate, Na2B10O16 .10H2O	N	1lb	0.80	0.0
6/20/05	Surround WP	Kaolin clay	CP	50lb	42.50	425.9
6/20/05	Zinc EDTA	Chelated zinc	N	1qt	2.75	0.0
7/1/05	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	8oz	4.87	2.4
7/1/05	Mermaid Fish Powder	Npk	N	4lb	10.20	0.0
7/1/05	Surround WP	Kaolin clay	CP	50lb	42.50	425.9
7/14/05	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	8oz	4.87	2.4
7/14/05	Mermaid Fish Powder	Npk	N	4lb	10.20	0.0
7/14/05	Surround WP	Kaolin clay	CP	40lb	34.00	340.7
7/29/05	Entrust	Spinosad	I	0.75oz	22.50	0.7
8/9/05	Entrust	Spinosad	I	0.75oz	22.50	0.7
8/9/05	Natural-Cal	Calcium chloride	N	4qt	9.58	0.0
4/17/06	Champion WP	Copper hydroxide	F	8lb	36.72	229.9
4/17/06	JMS Organic Stylet Oil	Parafinnic oil	I	1gal	12.90	250.1
5/17/06	Crocker Fish Oil	Fish oil	T	2gal	25.40	504.8
5/17/06	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	1lb	9.74	4.8
5/17/06	Lime sulfer	Calcium polysulfide	T	2.5gal	34.73	308.8
5/17/06	Solubor	Mixture of Orthoboric Acid, H3BO3 Disodium Tetraborate Pentahydrate, Na2B4O7 .5H2O and Disodium Decaborate Decahydrate, Na2B10O16 .10H2O	N	1lb	0.80	0.0
5/17/06	Yeoman Zinc 7%	Zinc	N	1.22qt	3.66	0.0
5/24/06	DiPel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	8oz	4.87	2.4
5/24/06	Surround WP	Kaolin clay	CP	50lb	42.50	425.9
5/29/06	Crocker Fish Oil	Fish oil	T	2gal	25.40	504.8

Date	Product name	a.i.	Action[z]	per Rateacre	cost ($)/acre	EIQ
5/29/06	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	8oz	4.87	2.4
5/29/06	Lime sulfer	Calcium polysulfide	T	2.5gal	34.73	308.8
5/29/06	Solubor	Mixture of Orthoboric Acid, H3BO3 Disodium Tetraborate Pentahydrate, Na2B4O7 .5H2O and Disodium Decaborate Decahydrate, Na2B10O16 .10H2O	N	1lb	0.80	0.0
5/29/06	Surround WP	Kaolin clay	CP	25lb	42.50	425.9
5/29/06	Yeoman Zinc 7%	Zinc	N	1.3qt	3.90	0.0
6/5/06	CYD-X	Cydia pomonella granulovirus	I	3fl oz	24.01	0.0
6/5/06	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	8oz	4.87	2.4
6/5/06	Mermaid Fish Powder	Npk	N	4lb	10.20	
6/5/06	PyGanic 1.4EC	Pyrethrins	I	32fl oz	40.45	0.6
6/5/06	Surround WP	Kaolin clay	CP	50lb	42.50	425.9
6/12/06	CYD-X	Cydia pomonella granulovirus	I	3fl oz	24.01	0.0
6/12/06	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	8oz	4.87	2.4
6/12/06	Mermaid Fish Powder	Npk	N	4lb	10.20	
6/12/06	Surround WP	Kaolin clay	CP	25lb	21.25	213.0
6/13/06	Isomate C Plus		Ph	400 ties A	105.00	
6/13/06	Isomate-M-100		Ph	150 ties A	56.96	
6/21/06	CYD-X	Cydia pomonella granulovirus	I	3fl oz	24.01	0.0
6/21/06	Entrust	Spinosad	I	0.75oz	22.50	0.7
6/21/06	Mermaid Fish Powder	Npk	N	4lb	10.20	
6/21/06	Surfact 50	Saponin glycosides	A	16fl oz	4.38	0.0
7/1/06	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	8oz	4.87	2.4
7/1/06	Natural Cal	Calcium	N	4qt	9.58	0.0
7/1/06	Surfact 50	Saponin glycosides	A	16fl oz	4.38	0.0

Date	Product name	a.i.	Action[z]	per Rateacre	cost ($)/acre	EIQ
7/13/06	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	8oz	4.87	2.4
7/13/06	Natural Cal	Calcium	N	4qt	9.58	0.0
7/13/06	Surfact 50	Saponin glycosides	A	16fl oz	4.38	0.0
7/23/06	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	8oz	4.87	2.4
7/23/06	Entrust	Spinosad	I	0.5oz	15.00	0.5
7/23/06	Kaligreen	Potassium bicarbonate	F	2.5lb	13.88	18.4
7/23/06	Natural Cal	Calcium	N	4qt	9.58	0.0
7/23/06	JMS Organic Stylet Oil	Severely hydrotreated parrafinic oil	AC	1gal	12.90	250.1
8/4/06	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	8oz	4.87	2.4
8/4/06	Entrust	Spinosad	I	0.5oz	15.00	0.5
8/4/06	Kaligreen	Potassium bicarbonate	F	2.5lb	13.88	18.4
8/4/06	Natural Cal	Calcium	N	4qt	9.58	0.0
4/24/07	Champion WP	Copper hydroxide	F	4lb	18.36	114.9
4/24/07	JMS Organic Stylet Oil	Severely hydrotreated parrafinic oil	I	2gal	25.80	500.1
5/17/07	Isomate CM/OFM TT		Ph	200 ties A	200.00	0.0
5/22/07	Crocker Fish Oil	Fish oil	T	2gal	25.40	504.8
5/22/07	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	2lb	19.48	9.6
5/22/07	Lime- sulfer	Calcium polysulfide	T	2.5gal	34.73	308.8
5/22/07	PyGanic 1.4EC	Pyrethrins	I	32fl oz	40.45	0.6
5/26/07	Crocker Fish Oil	Fish oil	T	2gal	25.40	504.8
5/26/07	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	8oz	4.87	2.4
5/26/07	Lime- sulfer	Calcium polysulfide	T	2.5gal	34.73	308.8
5/29/07	Epsom Salts	Magnesium sulfate,heptahydrate	N	15lb	2.40	0.0

Date	Product name	a.i.	Action[z]	Rateacre per	cost ($)/acre	EIQ
5/29/07	Solubor	Mixture of Orthoboric Acid, H3BO3 Disodium Tetraborate Pentahydrate, Na2B4O7 .5H2O and Disodium Decaborate Decahydrate, Na2B10O16 .10H2O	N	1lb	0.80	0.0
5/29/07	Surround WP	Kaolin clay	CP	50lb	42.50	425.9
5/29/07	Yeoman Zinc 7%	Zinc	N	32fl oz	3.00	0.0
6/1/07	Crocker Fish Oil	Fish oil	T	2gal	25.40	504.8
6/1/07	Lime- sulfer	Calcium polysulfide	T	2.5gal	34.73	308.8
6/1/07	PyGanic 1.4EC	Pyrethrins	I	32fl oz	40.45	0.6
6/1/07	Surround WP	Kaolin clay	CP	25lb	21.25	213.0
6/6/07	CYD-X	Cydia pomonella granulovirus	I	3fl oz	24.01	0.0
6/6/07	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	8oz	4.87	2.4
6/6/07	Mermaid Fish Powder	Npk	N	4lb	10.20	
6/6/07	Solubor	Mixture of Orthoboric Acid, H3BO3 Disodium Tetraborate Pentahydrate, Na2B4O7 .5H2O and Disodium Decaborate Decahydrate, Na2B10O16 .10H2O	N	1lb	0.80	0.0
6/6/07	Surround WP	Kaolin clay	CP	37.5lb	31.88	319.4
6/6/07	Yeoman Zinc 7%	Zinc	N	32fl oz	3.00	0.0
6/13/07	CYD-X	Cydia pomonella granulovirus	I	3fl oz	24.01	0.0
6/13/07	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	8oz	4.87	2.4
6/13/07	Epsom Salts	Magnesium sulfate,heptahydrate	N	15lb	2.40	0.0
6/13/07	Mermaid Fish Powder	Npk	N	4lb	10.20	
6/13/07	Surround WP	Kaolin clay	CP	25lb	21.25	213.0
6/21/07	CYD-X	Cydia pomonella granulovirus	I	1.5fl oz	12.00	0.0
6/21/07	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	8oz	4.87	2.4
6/21/07	Mermaid Fish Powder	Npk	N	4lb	10.20	
6/21/07	Surround WP	Kaolin clay	CP	25lb	21.25	213.0

Date	Product name	a.i.	Action[z]	Rate per acre	cost ($)/acre	EIQ
7/2/07	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	8oz	4.87	2.4
7/2/07	Entrust	Spinosad	I	0.5oz	15.00	0.5
7/2/07	Natural Cal	Calcium	N	1gal	9.58	0.0
7/2/07	Surfact 50	Saponin glycosides	A	16fl oz	4.38	0.0
7/23/07	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	8oz	4.87	2.4
7/23/07	Entrust	Spinosad	I	0.5oz	15.00	0.5
7/23/07	Natural Cal	Calcium	N	1gal	9.58	0.0
7/23/07	Surfact 50	Saponin glycosides	A	16fl oz	4.38	0.0
8/6/07	Dipel DF	Bacillus thuringiensis, subsp. Kurstaki, strain ABTS-351, fermentation solids and solubles	I	8oz	4.87	2.4
8/6/07	Entrust	Spinosad	I	0.5oz	15.00	0.5
8/6/07	Lime- sulfer	Calcium polysulfide	F	2qt	6.95	61.8
8/6/07	Natural Cal	Calcium	N	1gal	9.58	0.0

[z] Action: A = adjuvant; AC = acaracide; B = bactericide; CP = crop protectant; H = herbicide; I = insecticide; F = fungicide; PGR = plant growth regulator; Ph = pheromone mating disruption; T = thinning agent.