ORCHARD PRODUCTIVITY AND APPLE FRUIT QUALITY OF ORGANIC, CONVENTIONAL, AND INTEGRATED FARM MANAGEMENT SYSTEMS

By

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To the Faculty of Washington State University:

The members of the Committee appointed to examine the thesis of GREGORY MICHAEL PECK find it satisfactory and recommend that it be accepted.

Chair

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Abstract

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The first of two studies undertaken in this thesis analyzed Washington State's organic apple (*Malus domestica* Borkh.) exports to the European Union (EU) as a case study of the internationalization of the organic marketplace. Washington's organic apple plantings have grown exponentially and as a result price premiums, which traditionally offset the greater costs of production and motivated many Washington growers to certify their apple orchards, have shrunk. At the same time, demand for organic apples in the EU has been outpacing production, thus making EU member states the most important export market for Washington's organic apples. However, an entanglement of regulatory bodies from around the world are involved in the certification of organic products, therefore making international sales very difficult. In this paper, I explored the expansion in the organic marketplace and the adjustments undertaken by growers, marketers, and regulatory agencies.

As part of a long-term comparison of organic, conventional, and integrated apple farm management systems in the Yakima Valley of Washington State, the second study investigated the productivity and fruit quality of 'Gala' apples during the ninth and tenth growing seasons. We found that the technology available for the organic system limited suitable crop load management and, therefore, consistent yields. Pest and weed control and fertility management

were more difficult to manage in the organic system, as they all appeared to contribute to its limited productivity. However, organic apples had 6-10 N higher flesh firmness than conventional apples, and 4-7 N higher firmness than integrated apples. Additionally, consumers consistently rated organic apples to be firmer and to have better textural properties. Few consistent results were found for fruit flavor as measured by soluble solids concentration or titratable acidity, and this was also reflected in consumer panels. Total antioxidant activity was 10-15% higher in organic apples than conventional apples and 5-12% higher than integrated apples. The conventional and integrated apple farm management systems were more similar to each other than either was to the organic system throughout this study. Although organic apple production provided more management challenges than conventional systems, the superior quality of organic apples was a notable finding.

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DEDICATION

For Ethan, because it’s all about him.

CHAPTER ONE

INTRODUCTION

Around the world, there has been a great expansion in the number of growers and the total land area utilizing organic and integrated farm management systems in apple (*Malus domestica* Borkh.) orchards, contributing to the increasing consumer demand for healthier and more environmentally sustainable agricultural products. Media coverage, expanded shelf-space in retail venues, direct-marketing approaches, such as farmers' markets and community-supported agriculture, and food safety scares have all fostered international household recognition of organic (Dimitri and Richman, 2000; Wier and Calverley, 2002; Canavari et al., 2002) and integrated products, including apples (Sansavini, 1997; Manhoudt et al., 2002). Additionally, a growing body of resources and technologies are now available for organic apple production (Edwards, 1998; Swezey et al., 2000), many of which are transferable to integrated apple production. Both organic and integrated production systems strive towards sustainability by minimizing environmental degradation and improving soil quality, while maximizing productivity as well as economic returns (Reganold et al., 2001).

The term "organic" and the practices used and the products labeled as such are regulated according to standards drawn up by various public, private, and non-profit organizations around the world. In 2002, the United States Department of Agriculture (USDA) centralized the US organic code, giving specific meaning to the term "organic" for products grown and sold within the US. It should be noted, however, that there are a wide spectrum of management practices used in organic systems, all of which may pass organic certification. Labeling informs consumers more about what materials are allowed or prohibited in the production system, rather than what specific products are actually used by the farm management. In other words, not all organic apple orchards are managed alike, just as not all conventional or integrated apple orchards are managed alike. Differences in geography, cultivars, rootstocks, soils, microclimate, and growers' personal preferences are included in the decision-making process of a farming system.

Organic agriculture has gained international attention as more than 100 countries produced organically certified products in 2002 and worldwide consumption of organic products was worth US$19-26 billion in 2001 (International Trade Centre UNCTAD/WTO, 1999; Kortbech-Olesen, 2003). The USDA reported more than over 528,000 hectares of certified organic cropland in the US in 2001, an increase of 53% from 1997 (Greene and Kremen, 2003). Granatstein and Kirby (2002) estimated the US organic pome (apples and pears) and stone (cherries, peaches, apricots, and plums) fruit holdings to be more than 10,000 hectares, which was between 2-3% of the US total for these crops in 2002 (USDA-NASS, 2003). Washington State is the premier growing region for organic apples with its more than 2,600 certified hectares representing approximately 40% of the total land area of US certified organic apples (Granatstein and Kirby, 2002). Washington State's predominance in organic apple production gives the research studies discussed in this thesis additional significance.

In the US, integrated apples have yet to attain the same widespread consumer visibility as organic apples and no production statistics exist to evaluate the US land area under integrated farm management for apple orchards. However, some labeling schemes for apples grown with integrated management practices within the US are emerging, such as Responsible Choice developed by Stemilt Growers, Inc. (http://www.stemilt.com/story/rc.php?t=1), the Food Alliance (http://www.thefoodalliance.org/) in the Northwest, and CORE Values (http://www.corevalues.org/home.html) in the Northeast. In other countries, particularly New Zealand and many European Union (EU) member-states, integrated farm management has become the standard agricultural practice, while conventional management is largely being phased out. The belief is that an integrated agricultural system represents the middle ground between the constraints of certified organic production and the negative impacts of conventional agriculture (Sansavini, 1997; Morris and Winter, 1999). Certification standards, whether organic or integrated, allow growers to market their produce under a recognized system assuring consumers that the products they buy follow specific and known guidelines.

Studies show that current conventional apple systems negatively affect agroecosystems and the environment at large, agricultural workers and their families, and potentially the health of consumers. The US Environmental Protection Agency (EPA) estimates that 60% of impaired rivers, 30% of impaired lakes, 15% of impaired estuarine areas, and 15% of impaired coastal shoreline are due to farm pollution, of which pesticides and nutrients top the list for watershed impairment in Washington State (Aigner et al., 2003). Studies conducted on those working in the conventional apple orchards of Washington State's Wenatchee and Yakima Valleys--the latter of which is the same region where the research for Chapter 3 was conducted--showed that not only are agricultural workers potentially at risk from agricultural chemicals, but their homes and children are also significantly contaminated with organophosphate (OP) insecticides, most prevalently azinphosmethyl and phosmet (Fenske et al., 2000; Curl et al., 2002b). Both of these insecticides are commonly used in conventional apple production, as exemplified by the conventional treatment discussed in Chapter 3, and both are acutely toxic (WHO, 1986). Additionally, after analyzing a population of 2-5 year-old children in a non-agricultural area for OPs, Curl et al. (2002a) found that a diet made up largely of organic foods reduced children's exposure to pesticide residues from agricultural chemicals. Furthermore, Baker et al. (2002) reports that 44% of the apples tested by the EPA for pesticide residues from 1994-1996 contained residues from at least one OP, which was significantly more than for the organic apples that were analyzed.

Results from long-term studies comparing the effects of organic, integrated, and conventional farm management show that organic systems have equal to slightly lower yields in a range of crops than conventional systems, but that organic and integrated systems generally have greater economic and environmental sustainability and energy efficiency (Smolik et al., 1995; Drinkwater et al., 1998; Reganold et al., 2001; Mäder et al., 2002; Porter et al., 2003). The majority of these studies focus on agronomic crops or crop rotations and only Reganold et al. (2001) studied farm management effects on a perennial horticultural cropping system (e.g., apple orchards).

The results from Chapter 3 are a continuation of the Reganold et al. (2001) study and at ten years of age represent the end of what was perhaps the longest running trial comparing farm management systems for a perennial horticultural crop. Since 1994, WSU researchers have examined and compared organic, integrated, and conventional apple orchard systems in Zillah, Washington. In the first six years, research from this study found that the organic and integrated systems had higher soil quality and lower environmental impacts than the conventional system. Organic apples were also found to be the most profitable due to equal overall yields and significant price premiums. The organic system was more energy efficient and ranked first in overall sustainability, followed by the integrated, then the conventional system (Glover et al., 2000; Reganold et al., 2001; Glover et al., 2002).

Results from shorter-term studies comparing transitional organic and conventional apple orchards in California reveal a number of interesting findings. First, pests and pathogens can significantly reduce organic yields (Caprile et al., 1994; Vossen et al., 1994), and as a result, price premiums and successful pest management are necessary for organic apple production to have comparable or better returns than conventional production (Caprile et al., 1994; Vossen et al., 1994; Swezey et al., 1998). Second, codling moth (*Cydia pomonella*) damage was significantly higher in organic production (Caprile et al., 1994; Vossen et al., 1994), but when monitoring and degree-day models allowed for targeted organic insecticide use and with the addition of new organically certified insecticide products, no difference between systems occurred for codling moth damage (Swezey et al., 1998). Third, the lack of organically certified chemical flower or fruit thinners is a technological barrier that reduces fruit size and can lead to biennial bearing (Vossen et al., 1994; Swezey et al., 1998). Fourth, soil organic matter and cation exchange capacity were higher for the organic system (Caprile et al., 1994), as were soil microbial biomass and mycorrhizal fungi, whereas bulk density was lower in the organic system (Werner, 1997; Swezey et al., 1998) and soil nutrient status was comparable and adequate for both systems (Caprile et al., 1994; Vossen et al., 1994; Swezey et al., 1998). Fifth, plant nutrient status, measured by leaf tissue mineral analyses, was adequate for both systems (Caprile et al., 1994; Vossen et al., 1994; Swezey et al., 1998), although Swezey et al. (1998) measured higher nitrogen and lower phosphorus concentrations in the conventional system. Finally, cover crops may add value to organic farming systems by providing refuge for beneficial insects (Caprile et al., 1994; Vossen et al., 1997).

Another study comparing organic and conventional apple orchards found that organic orchards had a lower abundance of *Pythium spp*., a genus of soil dwelling fungi implicated in apple replant disease, but greater root infection by the pathogenic *Rhizoctonia spp*. (Mazzola et al., 2002). Miliczky et al. (2000) found higher populations and greater diversity of spider faunas, many of which are known predators of pest species, in organic orchards. In addition, soil microarthropods, important for regulating microbial populations, decomposing organic matter, and aiding nutrient cycling, did not differ in diversity or density between organic and conventional systems over the course of a season, but higher diversity and density of soil microarthropods did exist early in the growing season, which may increase nitrogen availability for the trees (Doles et al., 2001).

Few studies have compared the harvest or post-harvest fruit quality of organic and conventional grown apples. DeEll and Prange (1992) reported higher soluble solids concentrations (SSC) for organically grown 'Cortland' and 'McIntosh' apples, but there were no differences between systems for firmness or titratable acidity (TA), and trained sensory panelists were unable to detect much difference between organic and conventional apples. These same researchers also reported that more conventional 'Cortland' and 'McIntosh' apples were marketable after storage than organic apples, largely due to a higher incidence of scab and various storage rots in organic apples (DeEll and Prange, 1993). In a one-season comparative study of organic and integrated 'Golden Delicious' apples, Weibel et al. (2000) found that organic apples were firmer, had higher concentrations of phenolic compounds, and were rated better by sensory panelists, but found no difference between systems for SSC or TA. Data from the same site as was used for Chapter 3 showed organic 'Golden Delicious' apples to be firmer and sweeter, as measured by the ratio of SSC to TA, at harvest and after six months of storage, than either conventional or integrated fruit, but only the higher sweetness of the organic apples was detectable by sensory panels (Reganold et al., 2001).

To date, no study has fully explored the differences in nutritional quality between apples grown using organic, conventional, and integrated farm management. Although consumers tend to purchase organic produce for several reasons--(1) a concern for more environmentally sustainable growing practices, (2) a perceived health benefit from eating produce grown without synthetic fertilizers and pesticides, and (3) a belief that organically grown produce is better tasting (Goldman and Clancy, 1991; Basker, 1992; Tregear et al., 1994)--only the first reason is substantiated in the literature, while the second reason may be substantiated for pesticide residues, but not for the intrinsic nutritional value of organic fruit.

Several reviews of studies comparing the nutritional quality of organic and conventional produce were inconclusive (Woese et al., 1997; Brandt and Mølgaard, 2001; Heaton, 2001; Worthington, 2001; Bourn and Prescott, 2002), although some authors have suggested a slight nutritional gain in organically produced fruits and vegetables (Brandt and Mølgaard, 2001; Heaton, 2001; Worthington, 2001). Some recent studies looking more in depth at perennial horticultural crops found higher concentrations of polyphenolic compounds and other antioxidants in pears (*Pyrus communis* L.) and peaches (*Prunus persica* L.) (Carbonaro and Mattera, 2001; Carbonaro et al., 2002); for yellow plums (*Prunus domestica* L.), conventional fruit had higher concentrations of polyphenols and quercetin, while other flavonoids and several vitamins were higher in organic plums (Lombardi-Boccia et al., 2004).

Despite studies that suggested health benefits from increased consumption of antioxidants, such as flavonoids and polyphenols (Knekt et al., 1996), the National Academy of Sciences' Institute of Medicine did not find enough available literature to recommend a dietary reference intake for these antioxidants (IOM, 1998). However, since only 20% of the US population (2 years old and older) is meeting the recommended daily servings for fruits and only

36% for vegetables (USDA-ERS, 2000), any additional nutritional value gained through the consumption of organic produce could potentially be beneficial.

The primary objectives of this thesis were to study the production, quality, and marketing of apples produced from alternative farm management systems. In Chapter 2, I discuss aspects particular to the international marketing of organic products, by using Washington's organic apple industry's high dependence upon export sales to the EU as a case study. Although seeing an apple with an organic label may connote a sense of locally produced or of subverting the conventional farm management paradigm, the reality is that organic apple marketing is an international business involving millions of dollars. By exploring the production, markets, and regulations involved in exporting Washington's organic apples to the EU, I find that organic sales are often more convoluted and difficult than conventional sales.

In Chapter 3, I present data collected over two years of research into the orchard productivity and fruit quality of apples from a continuing study of three apple farm management systems in the Yakima Valley of Washington State. I evaluate the effects of organic, conventional, and integrated growing systems on orchard productivity and fruit quality at harvest, after storage, and after a seven-day shelf-life. By studying the farm management systems and evaluating fruit by standard maturity/quality parameters, volatile production, sensory panels, and antioxidant activity, I believe this to be the most thorough comparative evaluation of apple fruit quality for these production systems.

As the demand for organically grown produce continues to grow, the land area under organic certification also continues to expand. Whether this expansion proves to be an avenue towards sustainable agricultural practices--one that lessens agriculture's environmental impact, is socially just, and maintains economically viability for the grower--remains to be seen. With less than 1% of US farmland certified as organic, it is difficult to assess the impacts of organic farm management on the environment as a whole. However, no longer is the question 'if' farming systems affect the environment and society, but rather 'how much' and, perhaps more importantly, 'how' does society support and develop nutritious food supply systems that are environmentally, socially, and economically sustainable. Thus, studying organic and integrated farm management systems as alternatives to conventional agriculture has become an increasingly important area of research at Land Grant Universities (Sooby, 2003). Researching the quality of produce from organic and integrated compared to conventional farming systems is especially important, since differences, if any, are not yet clearly proven.

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CHAPTER TWO

INTERNATIONALIZATION OF THE ORGANIC FRUIT MARKET: THE CASE OF WASHINGTON STATE'S ORGANIC APPLE EXPORTS TO THE EUROPEAN UNION

Abstract

As acceptance of organic produce into the marketplace continues to grow, so has the total land area planted with organic crops. Although small-scale organic growers may still find sales outlets through direct marketing venues, large-scale organic enterprises encounter international supply and demand pressures forcing these growers to seek new markets. Some organic commodities, such as apples, are heavily concentrated in the United States (US), with Washington State being the leading producer of apples in the US. Washington State's certified organic apple plantings reached an all-time high in 2003. As a result, price premiums, which have traditionally offset the greater costs of organic production and motivated many Washington growers to certify their apple orchards, appear to be shrinking. At the same time, increased demand for organic fruits in the European Union (EU) has been outpacing supply, making EU member states the most important export market for organic apples. However, an entanglement of regulatory bodies from around the world are involved in the certification of organic products which prevent quick sales. For example, growers and marketers may have to interact with as many as a half-dozen different regulatory bodies in order to export organic produce from the US to the EU. Nevertheless, if organic growers and marketers plan ahead and understand the multitude of regulations involved, the EU market may still represent a promising destination for US organic fruit. In this paper, we explore the expansion in the organic marketplace and the adjustments undertaken by growers, marketers, and regulatory agencies, using organic apple

production in Washington State and market opportunities for this organic fruit in the EU as a case study.

Introduction

As products from organic production systems continue to gain consumer acceptance in the marketplace, the number of farmers converting to organic production and the total land area planted with organic crops have also shown tremendous growth. From an environmental perspective, this growth is a favorable prospect since organic systems have been shown to be more environmentally sustainable and energy efficient (Reganold et al., 2001; Mäder et al., 2002). Consumers interested in purchasing organic food have also benefited, because the diversity and quality of organic products have dramatically improved (Dimitri and Richman, 2000). Once only available from small or direct-market venues, such as natural food stores and farmers' markets, organic products are now widely sold at large natural foods retailers, commercial supermarkets, and discount mega-markets (Dimitri and Richman, 2000; Dimitri and Greene, 2002). For apples, however, these increases in organic production and availability have also flooded existing market opportunities, reduced the price premiums that growers receive, and put a burden on existing regulatory agencies that guarantee the authenticity of organically grown apples. Additionally, growers with smaller farms are being squeezed out of the marketplace by large commercial operations (Pollen, 2001). Ironically, some of these small farmers are often credited with starting the organic movement in the 1960s. In this paper, we explore the expansion in organic production and the adjustments undertaken by growers and regulatory agencies, using organic apple production in Washington State and market opportunities for this organic fruit in the EU as a case study.

Organic agriculture has gained international attention as more than 100 countries produced organically certified products in 2002 and worldwide consumption of organic products was US$19-26 billion in 2001 (International Trade Centre UNCTAD/WTO, 1999; Kortbech-Olesen, 2003). Demand for organically produced food grew 20% annually in the US and even faster, exceeding 25%, in much of Europe through the 1990s (Lohr, 1998; Dimitri and Greene, 2003; Willer and Richter, 2003). The US and EU consumers each represent more than 40% of the world's organic food and beverage retail sales and together they account for greater than 90% of total retail sales (Kortbech-Olesen, 2003). However, differences in production and sales statistics vary greatly from various sources due to the lack of a coherent definition for organic and the lack of segregated data collection from nations for the organic sector.

Some organic commodities, such as apples, are heavily concentrated in the US, with Washington State being the leading producer of apples in the US. Washington State's dry climate limits losses due to fungal pathogens, particularly apple scab (*Venturia inaequalis*), making organic apple orchards a feasible alternative to conventional orchards. In 2003, Washington State's certified organic apple plantings reached an all-time high. However, this growth has saturated the US organic apple market and reduced premiums that offset the greater costs of organic production and originally motivated many Washington growers to certify their apple orchards. At the same time, increased demand for organic fruits in the EU has been outpacing supply, making EU member states the most important export market for organic apples. The European marketplace represents a burgeoning opportunity for organically grown apples. Nevertheless, like their conventional counterparts, organic fruit growers face lower returns and slimmer profit margins as both domestic and international competition has become increasingly fierce.

The many governmental agencies and private organizations that are involved in certifying organic produce domestically and internationally make it challenging for growers, marketers, consumers, and research scientists to understand the acceptable standards not only within their own country, but abroad as well. When US growers and fruit brokers target European organic buyers, differences between domestic and international regulations may disallow domestically acceptable organic fruit from entering the European marketplace. As of now, there is no “equivalency”--a technical term referring to the absolute acceptance of products certified by another organization--set between the US Department of Agriculture (USDA) and the EU; however, some accreditation is occurring between EU and US certifiers. For example, Washington State’s Department of Agriculture (WSDA) has EU organic certification equivalency through the Department for Environment, Food, and Rural Affairs (DEFRA) in the United Kingdom (UK) (Beecher, 2003). These agreements allow US certifiers to provide growers multiple certifications and access to international markets, greatly improving the ease of export for those certifying through the WSDA. The purpose of this paper was to explore the intricacies of marketing organic fruit to Europe in regards to the history of organics, US organic apple production, future European organic market trends, and the multitude of certification bodies and their regulations.

One of us, Cindy Richter, is a fruit broker in San Francisco with Pacific Organic Produce, which packs (under a partnership with Pac Organic Fruit, LLC in George, Washington) and markets 20% of Washington’s organic apples to both foreign and domestic destinations. Published information regarding organic apple trade between the US and EU is scant and so Richter’s professional experience, as well as sales data from Pacific Organic Produce, are used to exemplify trends in the international organic apple market.

Certification and Labeling

Definitions

Today, organic agriculture is highly regulated according to standards drawn up by various agencies, both nonprofit and governmental. These regulations or certification standards allow growers to market their produce under a recognized system, assuring the consumer that the products they buy follow specific and verifiable guidelines. Certification, therefore, gives a specific and legal definition for organic. The certification of organic produce can be thought of as a means of consumer protection, and in a more general sense, environmental stewardship. It should be noted, however, that there are a wide spectrum of management practices used in organic systems, all of which may pass organic certification depending upon the certifier's requirements. In other words, not all organic apple orchards are managed alike, just as not all conventional apple orchards are managed alike. Additionally, differences in geography, cultivars, rootstocks, soils, microclimate, and growers' personal preferences determine the production practices and materials used.

Organic producers and marketers need to guarantee that their products' quality and authenticity are representative of consumer expectations. Both domestic and international certification standards are developed for organic products to verify their authenticity and to develop confidence in the entire supply chain to the consumer (Fetter and Caswell, 2002). The certifier's credibility is based upon its ability to enforce organic standards through farm inspections, careful review of farm records and management plans, and random post-harvest pesticide residue sampling. However, even though pesticide residue analyses verify whether prohibited materials exist on the fruit, it is not truly possible to scientifically determine whether a product was grown organically. Indeed, cases have occurred where organically prohibited substances were detected on certified organic apples. For example, the non-organically certified antioxidant DPA (diphenylamine), used by the conventional apple industry to prevent superficial scald, a type of oxidative injury, has been detected on untreated organic apples, most likely because of its volatility and perhaps because it is endogenously produced by apples in very small quantities (Anonymous, 1998, Bramlage et al., 1996). The USDA does have the regulatory power to impose a civil penalty of up to $10,000 that "can be levied on any person who knowingly sells or labels as organic a product that is not produced and handled in accordance with the National Organic Program's (NOP's) regulations" (USDA-AMS, 2002a). However, the USDA relies primarily upon its accredited certifiers for surveillance and enforcement of the NOP. So, organic certification also depends upon the integrity of the producer and all affiliated handlers to be honest with their certifier.

History

In 1928, the Austrian philosopher Rudolf Steiner developed the first agricultural certification system, Demeter Certified Biodynamic. Nearly 40 years later, The Soil Association developed organic certification standards for the UK. In 1973, California Certified Organic Farmers (CCOF), a third-party, non-governmental organization, became the first to certify organic farms in the US. However, not until the 1980s did individual state agencies begin certifying organic produce. In 1983, Austria became the first nation in the world to develop official guidelines for organic farming (USDA-FAS, 2003a). As the demand for organic produce has grown both domestically and internationally, the need to centralize the definitions of organic through uniform procedures and products has become apparent (Fetter and Caswell, 2002). Yet, the sheer number of certifying bodies has made it challenging for those involved in the industry to stay current with the required production standards.

USDA certification

In the US, national regulation of organic commodities began when the US Congress passed the Organic Foods Production Act of 1990, which defined organic agriculture as “an ecological production management system that promotes and enhances biodiversity, biological cycles and soil biological activity. It is based on minimal use of off-farm inputs and on management practices that restore, maintain and enhance ecological harmony” (USDA-AMS, 2002b). This broad definition allows for a wide range of interpretation and management practices, but so often it is the materials that are used in production that can prevent sales of organic produce.

In 2000, the USDA National Organic Standards Board (NOSB) passed a set of rules, collectively known as the NOP, that override all other US certifiers’ regulations and are the minimum requirements that must be followed for organic certification (Fetter and Caswell, 2002). The USDA NOP itself does not certify individual products or growers, but sets guidelines with which other certifying agencies, such as WSDA Organic Food Program (OFP), Quality Assurance International, CCOF, or the Organic Crop Improvement Association must comply. One of the main purposes for developing the NOP was to allow for easier bi-lateral trade through international certifiers by providing uniform standards for foreign buyers to reference when they purchase US organic goods (Fetter and Caswell, 2002). A single national organic standard was thought to increase both domestic and foreign buyers’ confidence and therefore increase organic export sales. The NOP officially went into effect on October 21, 2002, at which time all domestically labeled organic produce and any products imported into the US must meet NOP guidelines and be certified by a USDA-accredited certification organization. To date, the USDA has accredited 90 organizations, 54 domestic and 36 foreign (USDA-AMS, 2004a).

The final version of the NOP was approved after modifying the originally proposed standards following an unprecedented 280,000 public comments to the NOSB (Crucefix and Blake, 2000). The most notable changes to the original rules, which brought the NOP into compliance with most European standards, were the prohibition of food irradiation, genetically modified organisms, the use of sewage sludge in production, and the use of antibiotics for livestock.

The sheer number of public comments sent to the USDA demonstrates that consumer support for strong organic standards is very high. It is, after all, the consumers who are supporting the growth in this market. Consumer support for the high integrity of organic standards was evidenced again in the US when standards for organic animal feed were briefly lessened to allow for the use of conventional feed for price considerations in a Congressional rider. Within several weeks this rider was revoked, largely due to the campaign of organic advocacy groups (Burros, 2003).

European certification and import regulations

As expected, each EU member state wishes to assure their consumers and farmers that imported organic produce meets the same certification requirements as their own domestically grown organic produce. Each member state must also comply with the European Economic Community's (EEC) certification standards' Council Regulation 2092/91, passed in 1991. This EU guideline has had a significant impact on the importation of organic produce into Europe, since importers must demonstrate that the product meets EEC 2092/91 standards (Crucefix and Blake, 2000).

Article 11 of EEC 2092/91 specifies two ways for an importer to comply with the EU regulations. First, the EU can approve a country's certification system for "third-country status", which provides complete equivalency between all EU member states and the importing country (International Trade Centre UNCTAD/WTO, 1999; Crucefix and Blake, 2000). However, this process is arduous, and to date only seven countries (Argentina, Australia, Czech Republic, Hungary, Israel, New Zealand, and Switzerland) have third-country status (USDA-FAS, 2003b). The second, and more frequently used method, allows each member state to grant "importer derogation" whereby the member state evaluates and approves an importing country's inspection/certification body or an individual product (International Trade Centre UNCTAD/WTO, 1999; Crucefix and Blake, 2000). This is done on a case-by-case basis for each product or certifier in contrast to the blanket acceptance that third-country certification grants.

Two critical pieces of information need to accompany every shipment that enters the EU. First, the organic certifier must complete the European Community Certificate of Inspection form, which ensures that the fruit passed organic certification and inspection (Commission Regulation (EC) No. 1788/2001). Second, a phytosanitary certificate must be issued by the USDA on all exported products, whether they are organic or conventional. Without both of these certificates, the entire shipment may be delayed in port, which in the worst case could result in spoilage before reaching the buyer.

Differences in allowable materials between US and foreign guidelines must be determined for each crop in each country where organic produce is to be exported. Allowable material use is perhaps the most difficult information with which to keep abreast, since both the certifiers in the EU and the USDA are constantly reviewing, certifying, and decertifying allowable materials. For example, antibiotics, such as streptomycin, and sodium nitrate (i.e., Chilean nitrate), allowable for up to 20% of the total nitrogen input for a farm under the NOP, are completely prohibited for growers who wish to market to the EU. On the other hand, the EU allows degelatinized bone meal and nicotine extracts, which are prohibited under the NOP (Table 1).

The Organic Materials Review Institute (OMRI) is an important resource for US organic growers, because it maintains the materials list that is compliant with the NOP. "OMRI is a … nonprofit organization created to benefit the organic community and the general public. Its primary mission is to publish and disseminate generic and specific (brand name) lists of materials allowed and prohibited for use in the production, processing, and handling of organic food and fiber" (OMRI, 2003). The EU maintains its own materials list under Council Regulation (EEC) 2092/91 (http://europa.eu.int/eur-lex/en/consleg/main/1991/en_1991R2092_index.html). Recently, the Organic Trade Association (OTA) published an exhaustive comparison between the USDA NOP and EEC 2092/91 (Table1; Sustainable Strategies, 2002). Despite all of these resources, there is still considerable confusion over allowable inputs, thus leaving growers and certifiers with the time consuming task of keeping abreast of the allowable materials for each market.

Within the NOP there are allowances whereby a grower can forgo domestic certification, yet still market produce to an international buyer as organic. For this to occur, however, all product labels must be clearly printed with the words "Export Only" (USDA-AMS, 2002c). This decision might limit the fruit to non-US markets if materials or practices that are not compliant with the NOP are used, but could save a grower US organic certification fees if they have a secure overseas buyer. Whether or not produce destined for export meets USDA certification standards, the produce must pass the organic certification regulations of the destination country and all applicable international bodies discussed below.

Although there is no equivalency between the US and the EU, three EU member states (UK, Spain, and Denmark) do have USDA recognition, meaning that the USDA has determined that these countries' "conformity assessment programs [are] sufficient to ensure conformity to the technical standards" of the NOP (USDA-AMS, 2004b). Canada, Israel, and New Zealand are also approved under this category, which eases imports of goods from these countries into the US, but does not specify a bi-lateral equivalency (USDA-AMS, 2004b). The USDA has recently approved full equivalency with the Japanese Agricultural Standard of Organic Agricultural Products allowing for bi-lateral acceptance of organic labels between these two nations (USDA-AMS, 2004b). As mentioned above, Washington State has importer derogation with DEFRA, and is in the process of becoming certified by the International Federation of Organic Agriculture Movements (IFOAM) (Beecher, 2004), allowing those apple growers certified under the WSDA OFP easier access to EU markets.

International certification

Many of the EU regulations also mirror the IFOAM certification rules, known as Basic Standards of Organic Agriculture (BSOA). IFOAM is the self-proclaimed international umbrella organization for organic agriculture in the world, with a diverse membership of certifying agencies, marketers, retailers, processors, and individual farmers. One of IFOAM's mission statements is to assist in standardizing the various certification regulations that exist around the world with their BSOA, by accrediting organizations involved in organic certification (IFOAM, 2003). For example, CCOF and the Soil Association are accredited by IFOAM, meaning that the certifying guidelines of these organizations are in compliance with the BSOA. Through a contracted accreditation agency, International Organic Accreditation Service, IFOAM also conducts certification of individual farms.

Another international standard, Codex Alimentarius: International Guidelines of Organic Food, was jointly written in 1999 by the United Nations Food and Agriculture Organization (FAO) and the World Health Organization (WHO). The Codex Alimentarius, Latin for "food law", was written for the purpose of protecting the health of consumers and to ensure fair trade. Although the joint FAO/WHO committee has little in the way of enforcing power, it does facilitate international trade by setting guidelines. The Codex Alimentarius was agreed upon by a majority vote of the 163 member nations who together represent 97% of the world's population. These guidelines are largely based on standards previously set by the EU and IFOAM (International Trade Centre UNCTAD/WTO, 1999). The Codex Alimentarius allows for more consistent standards between the various certifiers that exist throughout the world. Additionally, the World Trade Organization (WTO) uses the Codex Alimentarius as a benchmark for its own organic foods policy and as a guide for resolving trade disputes between parties.

A third international body, International Organization for Standardization (ISO), is a worldwide organization made up of national standardization bodies from 140 nations. The ISO has standardization rules on many topics, such as food pesticide residues, weights and measures, and, relative to organic agriculture, certification bodies. Developed in 1996, ISO 65, General Requirements for Bodies Operating Product Certification Systems, acts as a guideline for certifiers of any product, including organic produce, but does not set any particular production standards. There is no legal requirement for certifiers to comply with ISO 65, but all exporters to the EU must use an ISO 65 accredited certifying body. IFOAM, Demeter, EU Regulation 2092/91, the USDA NOP, and the WSDA OFP are all in compliance with ISO 65. However, the USDA's ISO 65 certification does not directly extend to its accredited certifiers. With only 14 USDA accredited certifiers currently ISO 65 certified, meeting NOP requirements is not enough to market produce into the EU.

Within the last year, Pacific Organic Produce has been asked to meet another set of production standards, the Euro-Retailer Produce Working Group's Good Agriculture Practices (EUREPGAP, 2004). EUREPGAP is an international farming standard that involves compliance with the following: food safety of the product (e.g., pesticide and fertilizer use), environmental management on the farm, and worker health, safety, and welfare. Many EU retailers, for example, Sainsbury (London, UK), which operates 450 stores in the UK, are demanding that all suppliers, whether organic or conventional, obtain EUREPGAP certification. Additionally, most UK retailers, as well as some US supermarkets, are now demanding accountability in ethical labor practices in addition to organic traceability.

Although organic agriculture is often thought of as a grassroots and perhaps ideological movement, the regulation and certification procedures for organic foods have become highly institutionalized. To sell fruit to the UK, for example, a US grower may have to deal with the standards of as many as a half-dozen certifying bodies and their particular codes for acceptable materials, record keeping, and general farm management. In the US, these might include the NOP, third-party USDA accredited certifiers like CCOF or Quality Assurance International, or state certifiers, such as the WSDA OFP. Growers and marketers selling to the UK, for example, must meet both EU Regulation 2092/91 and UK's Register of Organic Food Standards

(UKROFS), but depending upon the buyer, they may also need to meet the Soil Association or IFOAM BSOA certification.

IFOAM has standards that are most often reproduced by other certifying bodies, largely due to this organization's mission of unifying standards throughout the world. The FAO/WHO's Codex Alimentarius organic regulations are relatively new, but in the future they may help to further multilateral trade in organic produce by setting international standards that are used in the event of trade disputes. The future of certification will likely be based on international guidelines from IFOAM, the Codex Alimentarius, and compliance with ISO 65. At present, the most important advance that will increase acceptability of importing US organic fruit into Europe will be equivalency between the NOP and EU Regulation 2092/91. While it is the responsibility of the grower to stay abreast of all relevant certification standards, and therefore allowable materials, growers rely heavily on their certifiers and marketers for current and pertinent information.

US Market Trends

History

In 1989, the plant bio-regulator, daminozide, sold under the trade name Alar™ and widely used in Washington's apple orchards, received national media attention as an alleged carcinogen. This publicity sharply decreased sales of conventionally grown apples and increased the demand for organically grown apples, which corresponded to a sharp increase in the land area in organic apple production in 1990 (Figure 1). More recent food safety concerns, such as mad cow disease, hoof-and-mouth disease, the implications of genetically engineered crops, and the continuing concern over the long-term health and environmental effects of synthetic fertilizer and pesticide use, have all bolstered organic food sales in both Europe and the US (Jones et al., 2001; Wier and Calverley, 2002), with a concomitant exponential increase in organically certified and transitional apple plantings in Washington State (Figure 1). Organic apple sales have benefited from this overall increase in organic market share, as fruit and vegetables hold the largest market share of total organic sales in Europe (Foster, 2000).

Organic apple production statistics and expansion

The USDA reported over 528,000 hectares of certified organic cropland in the US in 2001, an increase of 53% since 1997 (Greene and Kremen, 2003). This is a tremendous increase in organically certified land, but it still represents only 0.3% of all US farmland in 2001 (Greene and Kremen, 2003). Granatstein and Kirby (2002a) estimate the US organic pome (apples and pears) and stone (cherries, peaches, apricots, and plums) fruit holdings to be over 10,000 hectares, which is between 2-3% of the US total for these crops (USDA-NASS, 2003).

In Washington State, certified organic apple plantings reached an all time high in 2001 with 2,647 hectares under certification (Granatstein and Kirby, 2002a). This represents about 40% of total US organic apple production, with Washington containing the majority of organic apple orchards. California has the second most organically certified apple orchard hectares, with just under 25% of the total US organic land area. For Washington State, organic production (including transitional) accounts for nearly 17% of the total land planted in apples (Granatstein and Kirby, 2002b).

Under both the USDA NOP and the WSDA OFP certification codes, unless beginning on virgin ground, a farm must transition by being registered and follow all organic standards for three years before being able to sell fruit with an organic label. The US grower receives little, if any, price premium for transitional produce. However, the land area for transitional orchards provides an indication of future organic production trends. The cumulative total of 4,047 hectares of both organically certified and transitional apples in Washington State represents a massive volume of fruit that will be headed for the marketplace in the near future, if all of the transitional orchards become certified organic (Figure 1). Similar trends are occurring in the pear and sweet cherry markets. In 2001, the total US organic pear land area was estimated at 1,133 hectares, with nearly half the orchard area in Washington, followed by Oregon and California (Granatstein and Kirby, 2002a; 2002b). Washington also holds about half of the 283 hectares of organically certified sweet cherry production in the US (Granatstein and Kirby, 2002a; 2002b).

Organic premiums

Price premiums, which historically have offset the greater costs of organic production and motivated many growers to certify their apple orchards, although highly variable depending upon the size of the crop for a particular year, appear to be shrinking. Thus, organic certification may not equate with profitability. In 2000, 'Golden Delicious' apples only received a 16% premium and the 2001 harvest received 23%, both years down from the record high in 1996 of 120% (Figure 2). To get an idea of how important premiums are to organic growers, Reganold et al. (2001) estimated that an organic 'Golden Delicious' orchard would need a 12-14% premium to match the breakeven point (when revenues equal the investment cost over the life of an orchard) of a conventional orchard planted with that same cultivar. Data used for those estimates were from the late 1990s when price premiums were higher. Given the fact that the organic apple market is not growing as exponentially in size as the volume of organic apples being produced, organic 'Golden Delicious' orchards may be economically unsustainable in the near future.

As with the conventional market, organic apple sales are cultivar specific. For example, organic 'Golden Delicious' apples received some of the lowest premiums in 2000, followed by 'Red Delicious', while 'Fuji' and 'Gala' received around a 50% premium, and 'Pink Lady', a cultivar in high demand, received an average premium of 91% in 2000 (Figure 2). Whether the decline in price premiums for 'Golden Delicious' is a trend and sign of the future for other cultivars is yet to be determined; however, it is likely, if production continues to soar. As returns on organic apples decline, the profit margin for organic orchard operations becomes increasingly slim. Organic growers who do not use the latest available technologies, such as new organically certified pesticides, laborsaving weed-control tools, and chemical thinning, would have a difficult time maintaining an economically sustainable enterprise.

Lower organic price premiums can be directly correlated with increases in plantings and production, but also to industry consolidation (Dimitri and Richman, 2000). As with many other commodities, large fruit packing and marketing companies are dedicating packing plants solely to organic fruit, ensuring uninterrupted organic sales and preventing cross-contamination from conventional fruit. Pac Organic Fruit has recently forged an alliance with Snokist Growers Co-Op (Yakima, Washington), one of the largest conventional fruit packing firms, to cooperatively pack organic fruit (Offner, 2003). Stemilt Growers, Inc. (Wenatchee, Washington), the largest apple packer in the US, recently purchased a packinghouse that will be exclusively dedicated to organic fruit (Warner, 2003). With industry leaders from the conventional market expanding their organic holdings and providing buyers with convenience and consistency, smaller marketing firms will likely find it difficult to compete and may be usurped by the larger operations with more efficient economies of scale.

To further complicate the situation, an organic grower cannot automatically be assured of finding a buyer, since, like the conventional market, the organic market is very competitive and subject to severe price swings. We have heard of organic apples receiving higher prices in the conventional over the organic marketplace, because the smaller organic apple market is more readily flooded with excess fruit than the conventional. Nevertheless, a cultivar marketed through the right channels, at the right time, will likely receive adequate premiums.

European Demand

Janice Zygmont (2000), formerly of the USDA Foreign Agricultural Service, stated that Europe was the biggest importer of US organic goods in 1999, with the UK being the leading importer in Europe, accounting for US$32.5 million, followed by Germany at more than US$22 million. Organic markets in individual EU member states are extremely variable, growing anywhere from 0-40% annually (Zygmont, 2000; Willer and Richter, 2003). Thus, each country needs to be evaluated individually by marketers.

It is difficult to assess the market for individual commodities as no central clearinghouse for organic sales information has been established within the EU. Several publications have assessed each country within the EU and we have documented a generalized overview of the EU marketplace (Table 2).

In the past few years, increasing demand in the UK at 40% a year has been outpacing supply, which is growing at 25% annually (Zygmont, 2000). Of that growth in supply, fresh produce accounted for about 50% of total organic sales. This represents a significant market potential for US fruit, when you consider that 90% of all organic apples sold in the UK are imported. According to one industry source, Washington State's organic apples represent one-third of all organic apples imported into the UK (Anonymous, 2002). This is backed by sales figures from Pacific Organic Produce, for which the UK represents their largest EU export destination, followed by Germany and Holland.

For Pacific Organic Produce, newer cultivars, such as ‘Pink Lady,’ command a high price premium since availability is currently limited. Pacific Organic Produce sells the greatest volume of ‘Braeburn,’ ‘Gala,’ and ‘Fuji’ apples in small fruit sizes (carton counts of 113 to 138 fruit per 42-pound carton) to Europe. Apples are often re-graded according to each country’s size standards and transferred into bags or punnets by the importing buyer before retail sale. For example, ‘Gala’ apples are sold as small as 198 fruit per carton in the UK, where they are then repackaged into plastic bags. However, larger retailers, such as the Wal-Mart subsidiary, ASDA (Leeds, UK), the UK’s second largest grocery store chain, do make special demands, such as requiring fruit to be bagged before shipping. The potential to sell smaller fruit to the EU is an excellent complement to the domestic market, which tends to command higher prices for larger fruit.

Conclusions

Although European demand for organic apples is strong, current US and EU regulations prevent quick sales. For example, it can take between three and six months to get all the paperwork in order and make the transportation arrangements when developing new markets or adding new buyers to existing markets. For Pacific Organic Produce, many European buyers require a complete list of orchard management practices and materials. When exporting to the UK, for example, handlers must supply detailed records from every grower, including their production tonnage, date of first certification, and their most recent farm inspection report. This information is passed on to the European certifier to verify that the practices meet the European standards. Occasionally, Pacific Organic Produce has even been asked to supply records of materials applied by their growers in past growing seasons to gain approval from a foreign certifier. Clearly, very thorough record keeping will help facilitate the export process.

Additionally, the number of certifiers involved in the international organic apple trade is constantly growing. Growers and marketers are in a constant struggle to stay abreast of current regulations. Buyers may desire to have one certification standard met in one year, but change the requirements the next. Thus, to enhance profitability, organic growers and marketers need to target a wider range of consumers by exploring new markets, increasing sales to existing European markets, and developing sales strategies that satisfy the buyer. Pac Organic, for example, is developing biodegradable packaging and small fruit packs that target children and home delivery businesses, and promote small family farmers by packing growers' fruit in separately labeled boxes. At the same time, certification standards between nations, and perhaps more importantly, between sellers and buyers must be uniform in order to allow smooth trade and consumer acceptance.

If organic growers and marketers plan ahead and understand the multitude of regulations involved, the European market represents a promising destination for US organic fruit. European demand is strong and growing, although Europe likely will be unable to meet consumer demand for organic apples. However, competition in organic fruit production will also be increasing from France, Germany, Italy, and Israel in the Northern hemisphere, and Argentina, Chile, New Zealand, and Australia in the Southern hemisphere. As in the conventional market, China is also a potentially significant player, particularly for apples, but as of now Chinese organic fruit has not been regularly seen in the marketplace. These are all examples of the potential for saturation in the market and, as a result, lower profitability. Organically managed orchards provide greater challenges for the grower, while the monetary incentives, such as price premiums, have declined over the past five years. Price premiums fluctuate year-to-year making it difficult to say whether premiums will continue declining or are reaching a stable price. Also, additional bureaucratic and regulatory work is needed to certify and export organic produce, which increases production costs.

We must also ask whether it is sustainable to ship organic apples halfway around the globe to meet European demand. With the current political instability in oil producing regions and rising concerns about the effects of fossil fuels on global warming, we must remember that most organic apples are shipped to Europe by diesel-powered freightliners. At some point these concerns will likely be included in organic certification schemes, as “buy-local” labeling campaigns already exist in the marketplace.

The future will see continued growth in the organic market, but most likely at a slower rate, at least in the near term, than has occurred thus far. Many growers who think organic certification is a good business move, but who are not committed to its core values, may find the additional challenges that organic systems demand difficult and are therefore unlikely to remain in the organic market long. Nevertheless, food safety scares, public distrust of genetically modified crops, and possible health benefits from eating organic produce will all help to increase organic food sales. In the end, the more land area that is under organic farm management will result in more options available for growers, greater environmental benefits accruing to society, and more choices for consumers in the marketplace.

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Table 1. An abbreviated list of allowable practices and materials that potentially impact organic apple orchard management under the United States Department of Agriculture National Organic Program (NOP) and European Economic Commission Regulation 2092/91. For the NOP all synthetic materials are prohibited, unless explicitly allowed; and all non-synthetic materials are allowed, unless explicitly prohibited. The National Organic Standards Board scientifically reviews materials under the guidance of Technical Advisory Panels consisting of scientists, policy makers, and industry leaders. The European Union code must explicitly list allowable materials, which are petitioned for by the member states. Source: Sustainable Strategies, 2002.

Practice/Material	**Allowable under USDA NOP**	**Allowable under EEC 2092/91**
Bone meal (degelatinized)	No	Yes
Buffer zone	Required	Not required
Composted animal excrements, including poultry manure and composted farmyard manure included	Yes	Yes
Elemental sulfur	Yes	Yes
Extract (aqueous solution) from *Nicotiana tobacum*	No	Yes
Fish meal and blood meal	Yes	Yes
Herbicides, soap based	Yes	No
Lime sulfur	Yes	Yes
Liquid fish products	Yes	No
Microorganisms (bacteria, viruses and fungi) e.g. *Bacillus thuringiensis*, Granulose virus etc.	Yes	Yes
Oil, horticultural	Yes	Yes
Plant oils (e.g. mint oil, pine oil, caraway oil)	No	Yes
Plastic, newspaper and recycled paper mulches	Yes, without glossy or colored inks	No
Pyrethroids (only deltamethrin and lambdacyhalothrin)	No	Yes
Seaweed and seaweed extracts	Yes	Yes
Sodium hypochlorite (liquid bleach)	Yes	No
Sodium nitrate (Chilean nitrate)	Yes, up to 20% of total nitrogen input	No
Transition period	Three years	Two years

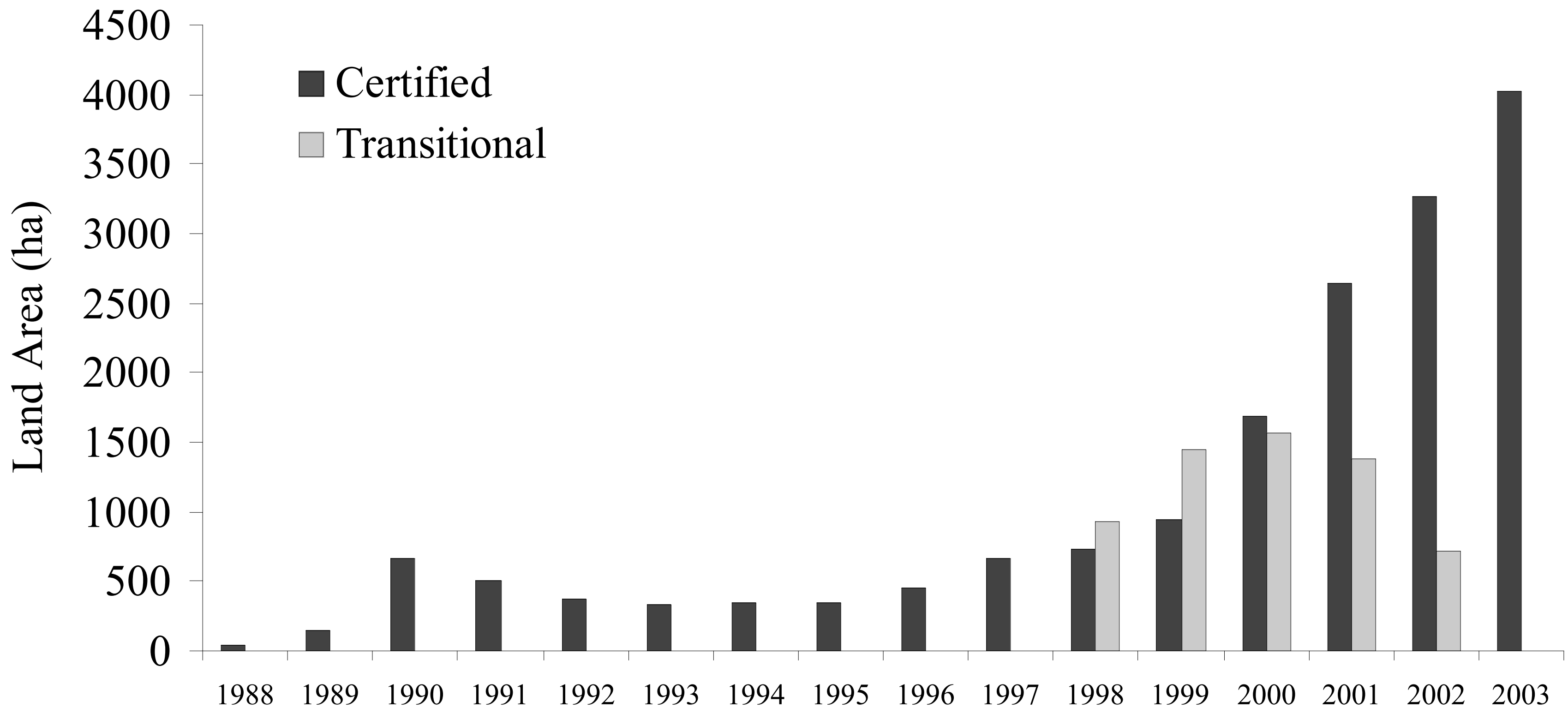
Table 2. Organic sales, production, and imports for key European Union member states and the United States.

Country	Total organic retail sales for 2003 (million US$)	Total land area in organic production for 2003 (hectares)	Domestic organic fruit production	Organic fruit and vegetable sales (Million US$)	Apple imports (metric tons)	Main importer of apples
Austria	325-375[z]	285,500[y]	6,000 tonnes[x] (1999)	29[x] (2000)	400[x] (1999)	Italy[x]
Belgium	200-250[z]	22,410[y]	612 ha (of which 101 are in transition)[x] (1999)	34[x] (2000)	650-700[x] (2000)	Netherlands, Argentina, New Zealand[x]
Denmark	325-375[z]	174,600[y]	197 ha (of which 66 are apples)[x] (1999)	Value not available. 2,000-2,500 tonnes[x] (2000)	1,750-2,250[x] (2000)	Italy, Germany, Netherlands, Argentina, United States, New Zealand[x]
France	1,200-1,300[z]	419,750[y]	8,210 ha (of which 3,121 are in transition and 748 are in apples)[x] (2000)	170[x] (1998)	1,814[x] (1999)	Italy[x]
Germany	2,800-3,100[z]	632,165[y]	2,710 ha (of which 393 are in pome fruit)[x] (1997/98)	378[x] (2000)	3,000[x] (2001)	Italy, Argentina, New Zealand[x]
Italy	1,250-1,400[z]	1,230,000[y]	474,000 tonnes[x] (2000)	264[x] (2000)	495[x] (2000)	Argentina[x]

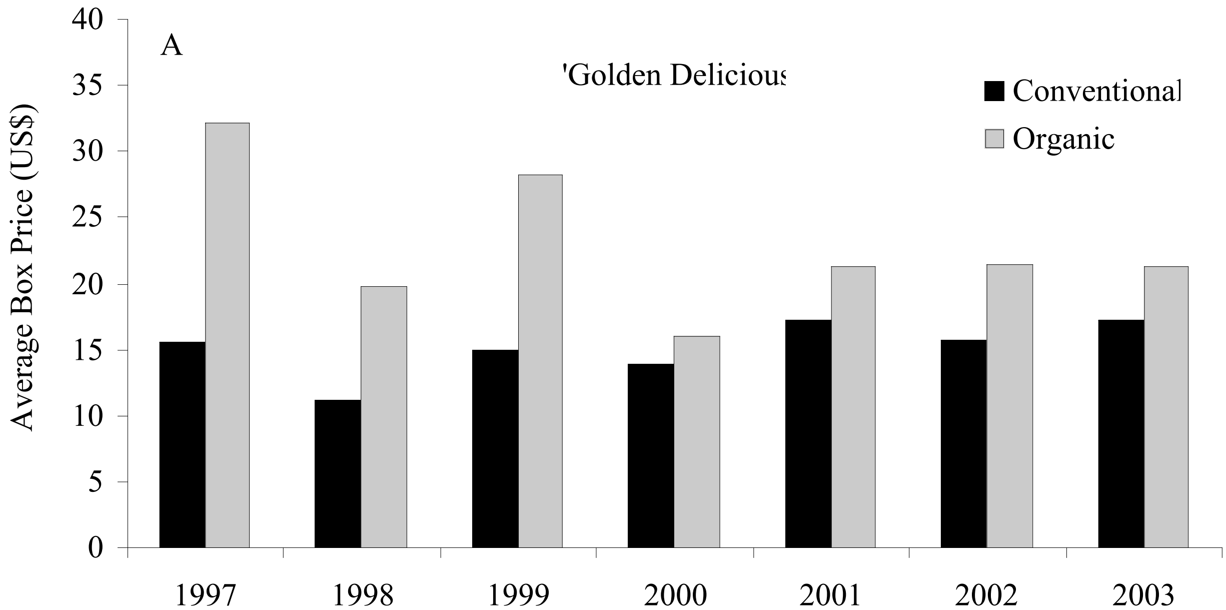
Sweden	350-400[z]	193,611[y]	65 ha[x] (2000)	31[x] (2000)	850-900 (includes pears)[x] 2000	Italy, France, Argentina, Chile[x]
The Netherlands	425-475[z]	38,000[y]	4,000 tonnes (of which 2,500 are apples) 260 ha (of which 180 are apple)[x] (1999)	Value not available. 40,000-45,000 tonnes[x] (1999)	2,500-3,500[x] (2000)	Chile, Argentina, Brazil[x]
United Kingdom	1,550-1,750[z]	679,631[y]	2,951 tonnes (of which 1000 are apples)[x] (1998/99) 811 ha[w] (2002)	267[x] (1999)	Quantity not available. 90% of organic apples are imported.[u]	US, Israel, Egypt, Turkey, other EU member states[x]
United States	11,000-13,000[z]	950,000[v]	10,010 ha (of which 3,414 are apples and 2,610 are apples within Washington State)[t] (2001)	2,250[s]	N/A	N/A

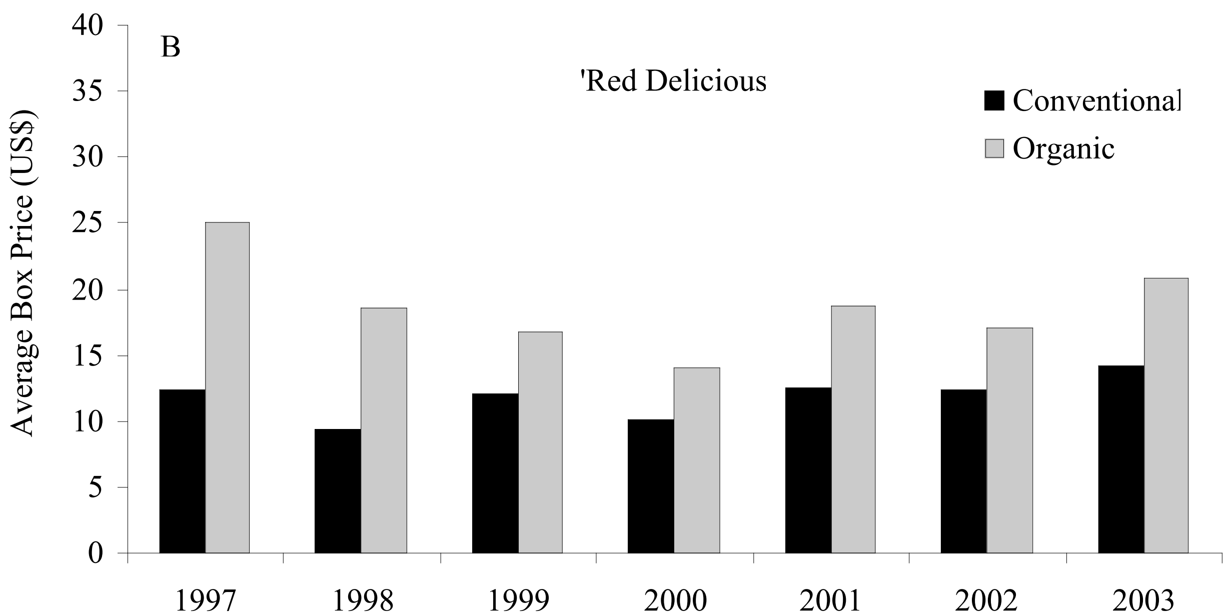
[z] Kortbech-Olesen, R. 2003.
[y] Willer, H. and T. Richter. 2003.
[x] FAO/ITC/CTA. 2001.
[w] DEFRA. 2003.
[v] Haumann, B. 2003.
[u] Zygmont, J. 2000.
[t] Granatstein, D. and E. Kirby. 2002a.
[s] Dimitri, C. and C. Greene. 2002.

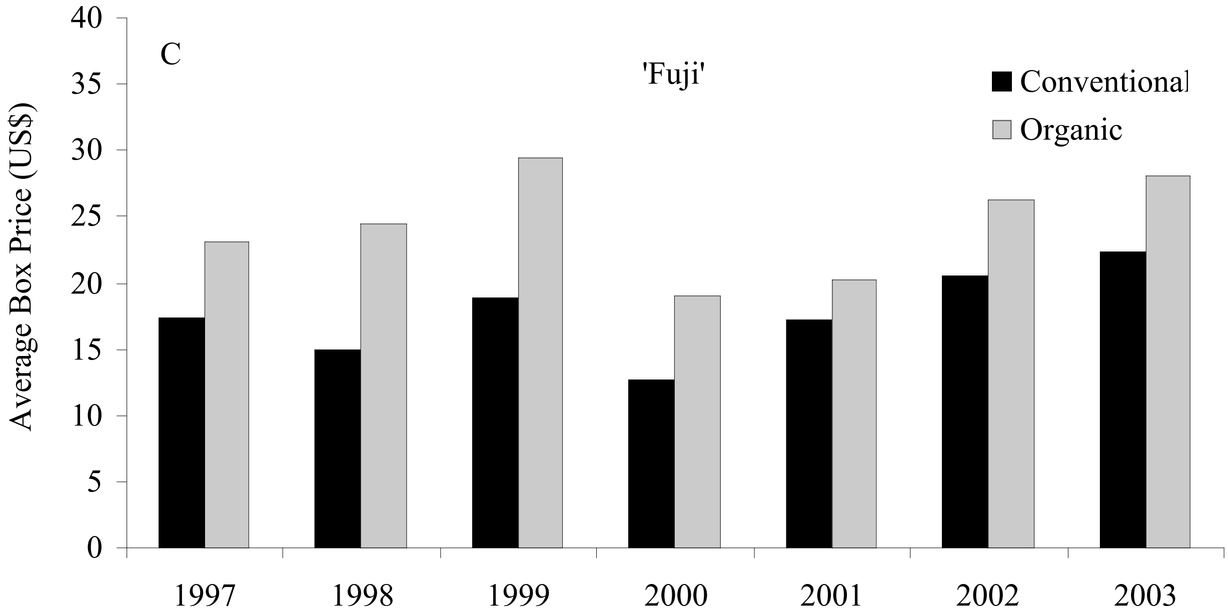
Figure 1. Total certified organic and transitional (farmed as organic) land area of planted apple orchards in Washington State. Note: 2003 data are projected, not actual. Source: Granatstein and Kirby, 2002a; Granatstein and Kirby, 2002b.



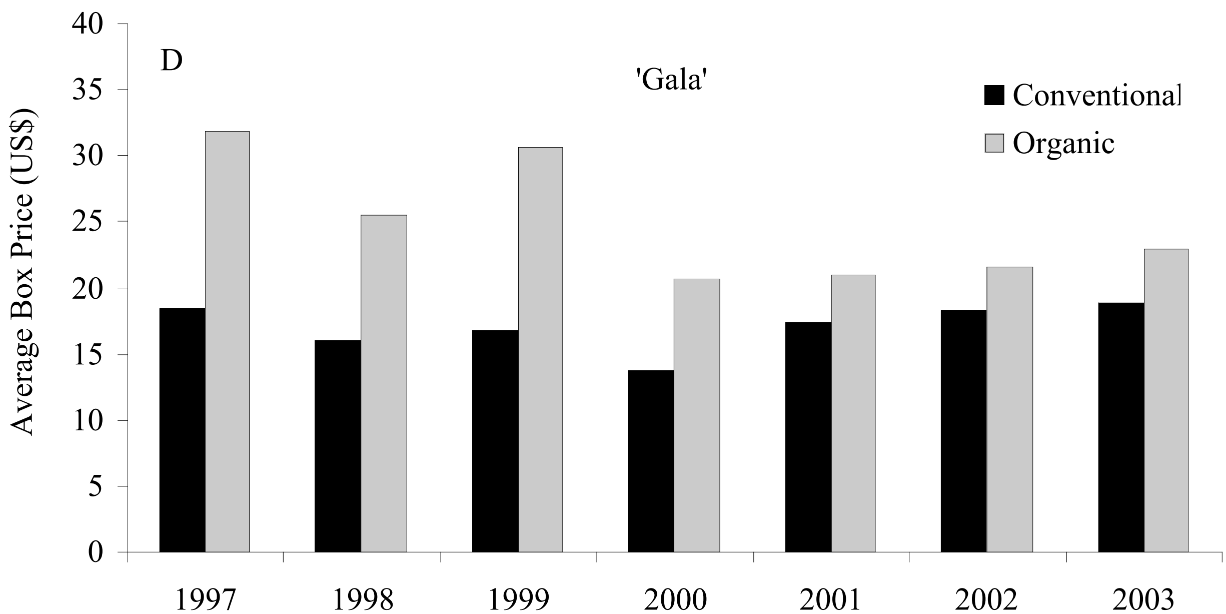
Figures 2A-E. Average annual free on board (FOB) market price per 42-lb box of 'Golden Delicious' (A), 'Red Delicious' (B), 'Fuji' (C), 'Gala' (D), and 'Pink Lady' (E) apple cultivars. Data represent the majority of the total Washington State tree fruit sales averaged over the course of the entire marketing season (September through August). The 2003 data are only through December 31, 2003. Source: Washington Growers Clearinghouse Association, 2004.



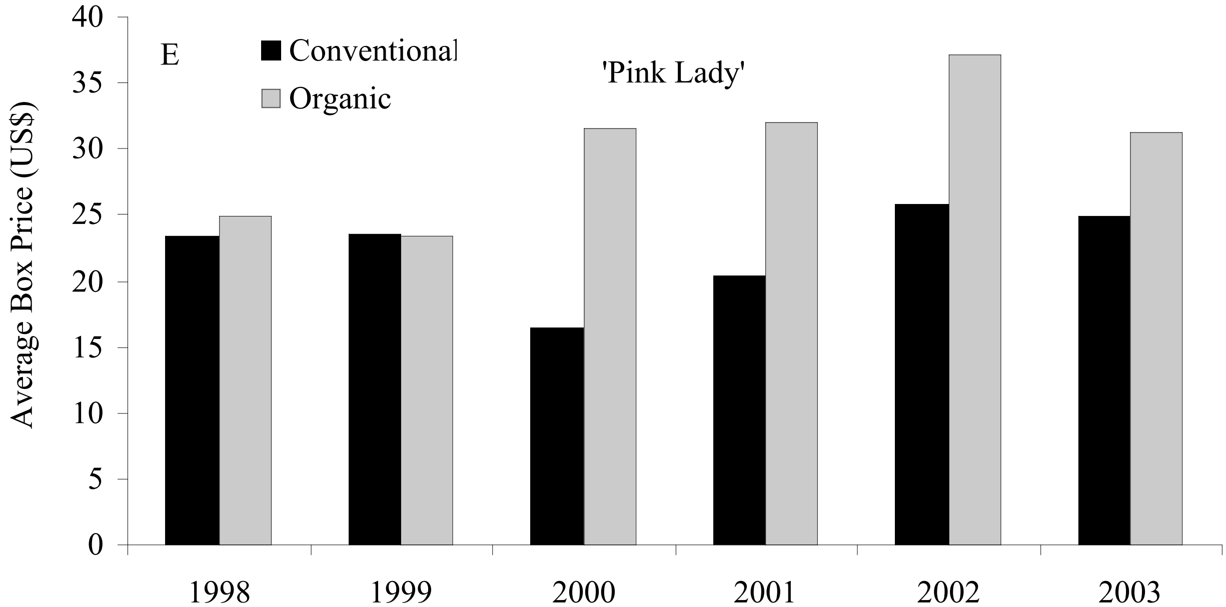




C
'Fuji'
Conventional
Organic
Average Box Price (US$)
0
5
10
15
20
25
30
35
40
1997
1998
1999
2000
2001
2002
2003



D
'Gala'
Conventional
Organic
Average Box Price (US$)
0
5
10
15
20
25
30
35
40
1997
1998
1999
2000
2001
2002
2003



40
35
30
25
20
15
10
5
0
Average Box Price (US$)
E
Conventional
Organic
'Pink Lady'
1998
1999
2000
2001
2002
2003

CHAPTER THREE

ORCHARD PRODUCTIVITY AND APPLE FRUIT QUALITY OF ORGANIC, CONVENTIONAL, AND INTEGRATED FARM MANAGEMENT SYSTEMS

Abstract

Since 1994, the effects of organic (ORG), conventional (CON), and integrated (INT) apple (*Malus domestica* Borkh.) farm management systems have been studied in the Yakima Valley of Washington State. In years nine and ten of this long-term study, we compared the horticultural productivity and fruit quality of these three farming systems. Four replicated blocks of 'Galaxy Gala' apple trees, located on a commercial orchard with matched soil type, plant age, and all other conditions except management, were used for the comparisons. Crop yields were lowest in the ORG system in the first year of the study, but highest in the second year, reflecting inconsistent cropping because the technologies available for the ORG system limited satisfactory crop load management. Pests and weeds were more difficult to control in the ORG system, and may have contributed to the inconsistent productivity of the ORG system. The lower productivity in the ORG system also may have been influenced by the lower nitrogen, and deficient zinc concentrations in the ORG trees. However, organic apples had 6-10 N higher flesh firmness than conventional apples, and 4-7 N higher than integrated apples. Additionally, consumers consistently rated organic apples to be of better overall acceptability, firmness, and having better textural properties. However, consumer panels were unable to detect differences in the flavor volatiles, soluble solids concentration, and titratable acidity that were measured in fruit from these farming systems. Total antioxidant activity was 10-15% higher in the ORG apples than CON apples and 5-12% higher than INT apples. The CON and INT apple farm management

systems were more similar to each other than either was to the ORG system throughout this study.

1. Introduction

Around the world, there has been a great expansion in the number of growers and the total land area utilizing organic and integrated farm management systems in apple (*Malus domestica* Borkh.) orchards, contributing to increased consumer demand for healthier and more environmentally sustainable agricultural products. Media coverage, expanded shelf-space in retail venues, direct-marketing approaches, such as farmers' markets and community-supported agriculture, and food safety scares have all fostered international household recognition of organic (Dimitri and Richman, 2000; Wier and Calverley, 2002; Canavari et al., 2002) and integrated products, including apples (Sansavini, 1997; Manhoudt et al., 2002). Additionally, studies have shown that current conventional apple systems negatively affect agroecosystems and the environment at large (Aigner et al., 2003), agricultural workers and their families (Fenske et al., 2000; Curl et al., 2002b), and potentially, the health of consumers (Baker et al., 2002; Curl et al., 2002a). A growing body of resources and technologies are now available for organic apple production (Edwards, 1998; Swezey et al., 2000), many of which are transferable to integrated apple production. Both organic and integrated production systems strive for sustainability by minimizing environmental degradation, improving soil quality, and maximizing productivity, as well as economic returns (Reganold et al., 2001). The research discussed below took place in Washington State, the premier organic apple growing region in the US, with more than 2,600 certified hectares representing approximately 40% of the total land area of US certified organic apples (Granatstein and Kirby, 2002).

The term “organic,” as well as the practices used and the products labeled as such, are regulated according to standards drawn up by various public, private, and non-profit organizations around the world. In 2002, the United States Department of Agriculture (USDA) centralized the US organic code under the National Organic Program (NOP), giving specific meaning to the term “organic” for products grown and sold within the US (Federal Register, 2000). It should be noted, however, that there are a wide spectrum of management practices used in organic systems, all of which may pass organic certification. In other words, not all organic apple orchards are managed alike, just as not all conventional or integrated apple orchards are managed alike. Differences in geography, cultivars, rootstocks, soils, microclimate, and growers’ personal preferences are included in the decision-making process of a farming system.

In the US, integrated apples have yet to attain the same widespread consumer visibility as organic apples, and no production statistics exist to evaluate the US land area under integrated farm management for apple orchards. However, some labeling schemes for apples grown with integrated management practices within the US are emerging, such as Responsible Choice developed by Stemilt Growers, Inc. (2004), the Food Alliance (2001) in the Northwest, and CORE Values (2004) in the Northeast. In other countries, particularly New Zealand and many European Union (EU) member-states, integrated farm management has become the standard agricultural practice, while conventional management is largely being phased out, with the belief that an integrated agricultural system represents the middle ground between the constraints of certified organic production and the negative impacts of conventional agriculture (Sansavini, 1997; Morris and Winter, 1999).

Results from long-term studies comparing the effects of organic and integrated to conventional farm management have shown that organic systems had equal to slightly lower yields in a range of crops than conventional systems, but that organic and integrated systems generally had greater economic and environmental sustainability and energy efficiency (Smolik et al., 1995; Drinkwater et al., 1998; Reganold et al., 2001; Mäder et al., 2002; Porter et al., 2003). The majority of these studies focused on agronomic crops or crop rotations and only the Reganold et al. (2001) study on apple orchards investigated the effects of farm management in a perennial horticultural cropping system.

The results from this paper are a continuation of the Reganold et al. (2001) study and at ten years of age represented what was perhaps the longest running trial comparing farm management systems for a perennial horticultural crop. Since 1994, Washington State University researchers have examined and compared organic, conventional, and integrated apple orchard systems in the Yakima Valley of Washington State. To date, research from this study found that the organic and integrated systems had higher soil quality and lower environmental impacts than the conventional system. Organic apples were also found to be the most profitable, due to price premiums. The organic system was more energy efficient and ranked first in overall sustainability, followed by the integrated, then the conventional system (Glover et al., 2000; Reganold et al., 2001; Glover et al., 2002).

While other shorter-term studies compared transitional organic and conventional apple orchards in California (Caprile et al., 1994; Vossen et al., 1994; Werner, 1997; Swezey et al., 1998), few have compared the harvest or post-harvest fruit quality of organically and conventionally grown apples (DeEll and Prange, 1992; DeEll and Prange, 1993; Weibel et al., 2000; Reganold et al., 2001). Additionally, none have fully explored nutritional quality differences between apples grown with organic, conventional, and integrated farm management systems, while research into antioxidants in other perennial horticultural crops have had mixed results (Carbonaro and Mattera, 2001; Carbonaro et al., 2002; Lombardi-Boccia et al., 2004). Several reviews of studies comparing the nutritional quality of organic and conventional produce have been inconclusive (Woese et. al., 1997; Brandt and Mølgaard, 2001; Heaton, 2001; Worthington, 2001; Bourn and Prescott, 2002), although some authors do suggest a slight nutritional gain for organically produced fruits and vegetables (Brandt and Mølgaard, 2001; Heaton, 2001; Worthington, 2001). However, most of these authors have pointed to significant flaws in comparative studies, such as not matching growing conditions, soil types, plant age, plant varieties, harvest dates, and post-harvest treatments. The current study matched all of these factors in order to ascertain differences in fruit quality between farm management systems.

The purpose of this study was to measure the effects of organic, conventional, and integrated 'Gala' apple production systems on orchard productivity and fruit quality. Measurements of crop yield, tree growth, weight distributions and color grades of marketable fruit, percentages of unmarketable fruits, cullage classifications, and plant and soil mineral concentrations were used to evaluate orchard productivity. Fruit internal ethylene concentrations and evolution, fruit respiration, analytical measurements of fruit maturity and quality, consumer sensory panels, and a total antioxidant activity were used to evaluate fruit quality.

2. Methods

2.1. Study area

Located on a 20 ha commercial, conventional apple orchard in the Yakima Valley of Washington State, USA (latitude 46°25´N, longitude 120°16'W), the 1.7 ha study area was planted as a randomized complete block design with four replications in 1994. Each block contained the three treatment plots: organic (ORG), conventional (CON), and integrated (INT).

Each 0.14 ha plot consisted of four rows of trees spaced at 1.4 m within rows and 3.2 m between rows for a density of 2240 trees/ha. Approximately 80 trees per row were trained on a three-wire trellis system. The study site has been described in Glover et al. (2000) and Reganold et al. (2001), with the latter containing a site map. However, russeting caused a high percentage of unmarketable fruit and due to the market demands for newer cultivars, the research site was top-grafted from 'Golden Delicious' to 'Galaxy Gala' apples. One half of the orchard (every other tree) was grafted in 1999, with the remaining half grafted in 2000. The rootstock remained EMLA.9, with 'Golden Delicious' as an interstock trunk for each tree. In mid-summer 2003 an over-tree evaporative cooling system was installed to reduce the incidence of sunscald, a prevalent physiological disorder for 'Gala' apples caused by excessive heat and solar radiation (Andrews and Johnson, 1996).

2.2. Farm management treatments

Previous years' (1994-1999) farm management practices have been described elsewhere (Glover et al., 2000; Reganold et al., 2001). In 2000, the newly grafted trees were not yet bearing fruit and in 2001 a hailstorm caused complete crop failure. For 2002 and 2003, the research team recommended orchard management strategies for each treatment. A licensed Pest Control Advisor (PCA) made pesticide recommendations for all three systems based upon modeling, trapping, and monitoring for insects and diseases. Final decisions on the materials to be used were made by orchard personnel. ORG farm management followed the USDA NOP (Federal Register, 2000) and the Washington State Department of Agriculture (WSDA) Organic Food Program (WSDA, 2004) certification guidelines and amendments. The CON treatment followed the practices used for the remainder of the conventional apple blocks on the farm, which reflects the practices of conventional, commercial apple orchards in Washington State. INT management combined practices from both ORG and CON farm management. During the course of this two-year study, the orchard ownership was actively trying to sell the ranch, including the research site. In 2003, the ownership was unable to provide as much additional financial support as in past seasons, and so the research team contracted the spray applications in the ORG and INT plots in that year through the PCA's company (Wilbur-Ellis Co, Yakima, WA) and additional labor through a local grower. After ten years of research supported in part by a privately owned commercial orchard, this long-term experiment ended after the 2003 growing season.

Full bloom was observed on April 18, 2002 and April 15, 2003. In 2002, chemical flower thinning in the organic system was accomplished by one application of calcium polysulfide (lime sulfur), while the CON and INT systems utilized one application of carbaryl (Sevin®, Bayer CropScience, Research Triangle Park, North Carolina) (Table 1A). In 2003, two applications of calcium polysulfide (lime sulfur) + fish oil (Crocker's Fish Oil, Quincy, Washington) + petroleum oil (Superior Oil N.W., Wilbur-Ellis, San Francisco, California) were used for thinning flowers in all three systems (Table 1B). Two chemical post-bloom thinning applications were made in the CON and INT systems in 2002 and for the CON system in 2003 (Tables 1A-B). Fruit were also removed by hand thinning in all three systems 27 and 42 days after full bloom (DAFB) in 2002 and 2003, respectively.

In the spring of 2002, weeds in the tree-rows of the ORG system were controlled thermally by use of a liquid petroleum burner mounted onto an all-terrain vehicle. However, this device caused leaf damage to the lower canopy and was used only twice. For the remainder of 2002, two mowing events controlled weeds in the ORG tree-rows. Three mechanical soil tillage and one mowing event controlled weeds in the ORG system for 2003. Synthetic herbicides were used to control tree-row weeds in the CON and INT systems both years. The alleyways of all three systems were regularly mowed throughout the growing season.

In the fall of 2001, the ORG and INT alleyways were rototilled in preparation for planting a cover crop mix of *Lolium multiflorum* (winter rye grass), *Vicia villosa* (hairy vetch), and *Trifolium repens* (Dutch white clover) at rates of 112, 45, and 22 kg ha^{-1}, respectively. *T. repens* was broadcast over the existing vegetation in the ORG and INT plots a second time, in the spring of 2003, at a rate of 42 kg ha^{-1}. The cover crop was deemed an appropriate method of fulfilling section §205.201 of the NOP, which requires organic operations to maintain or improve soil quality (Federal Register, 2000). No ground fertilization or soil amending occurred for any system in 2002. In 2003, all three systems received 168 kg ha^{-1} of actual nitrogen (N), in the form of blood meal for the ORG system, and ammonium sulfate for the CON and INT systems, in split applications of 112 kg N ha^{-1} on April 12 and 56 kg N ha^{-1} on May 27.

Pheromone mating disruption (PMD, Isomate C+, Pacific Biocontrol Co., Vancouver, Washington) was employed in all three systems to control the key apple pest, codling moth (*Cydia pomonella* L.), at rates of 494 ties ha^{-1} in 2002 and 988 ties ha^{-1} in 2003. A list of all other agrochemical inputs can be found in Tables 1A-B.

2.3. Orchard productivity

Twelve sample trees were randomly selected in the spring of each year from the middle two rows of each experimental plot, excluding the first 20 trees from each end of the sample rows, and used for all horticultural evaluations that season.

2.3.1. Crop yields and tree growth

Two harvests were conducted each year, as is the common commercial practice with 'Gala' apples, in coordination with the harvests conducted by the farm management (130 and 137 DAFB in 2002, and 124 and 127 DAFB in 2003). During the first harvest, apples were visually inspected for appropriate green to yellow background color development, an indication of maturity, as chlorophyll breaks down rapidly in 'Gala' apples near the optimum harvest date (Plotto et al., 1995). The second harvest accounted for the majority of the harvested apples each season. Calculations of yield, yield efficiency, crop load, average fruit weight, and amount of unmarketable fruit were made by counting and weighing all of the fruit from each of the 144 sample trees.

Tree growth was assessed by calculating the trunk cross-sectional area (TCSA) from measurements of trunk circumference at 20 cm above the rootstock-'Golden Delicious' graft union, assuming a circular geometry for the 'Golden Delicious' trunk. Measurements of the 'Gala' TCSA were also taken from 20 cm above the 'Golden Delicious'-'Gala' graft union, and showed the same statistical results as the 'Golden Delicious' TCSA related data. Only 'Golden Delicious' TCSA data are shown so comparisons can be made to previous results from this study site. Return bloom was calculated by floral intensity (ratio of total flower buds to total flower + vegetative buds) when the buds could easily be differentiated each spring on three branches of each sample tree.

2.3.2. Color grade, weight distribution, cullage analyses

For both years, apples from the two harvests were brought to the USDA-Agricultural Research Service Tree Fruit Research Laboratory (Wenatchee, Washington) where fruit were sorted for size and graded for color using a demonstration model AWETA sorter interfaced to a computer running AWESORT software (v.2.28, Nootdorp, The Netherlands). The sorter was programmed to follow USDA (Federal Register, 1981) and Washington State color and size standards (WAC, 2003). Fruit with 66% red blush area were considered to be Washington Extra Fancy (WaXF), the highest color grade standard. Washington Fancy (WaF) contained 33%, and U.S. No. 1 contained 25% red blush areas, respectively. Due to the high red coloring that is typical for the 'Galaxy Gala' strain, and as is common practice in the apple industry for marketing purposes, apples were further segregated into WaXF#1 and WaXF#2 with 80 and 50% red blush areas, respectively. As fruits were loaded onto the conveyor belt for sorting and grading, each apple was visually inspected for injury and damage as described in WAC 16-403-265 and 16-403-266 (WAC, 2003). The unmarketable injured and damaged apples were not sorted in the AWETA, but brought back to the Fruit Biology Laboratory at Washington State University (WSU, Pullman, Washington) for visual inspection and segregation into various cullage categories. Fruit weight distribution and grade classifications are reported as a percentage of 1829 (ORG), 2907 (CON), and 2584 (INT) apples in 2002 and 2812 (ORG), 4376 (CON), and 2845 (INT) apples in 2003, which correspond only to the numbers of marketable fruits sorted in the AWETA. Cullage categories are reported as a percentage of 1459 (ORG), 913 (CON), and 1168 (INT) apples in 2002 and 774 (ORG), 972 (CON), and 753 (INT) apples in 2003, which correspond only to the numbers of fruits that were deemed unmarketable.

2.3.3. Plant tissue mineral analyses

Leaf mineral concentrations were conducted on a pooled sample of 100 mid-terminal shoot leaves per plot taken from mid-canopy height. Fruit mineral concentrations were conducted on 15 whole fruits from each experimental plot. Both leaf and fruit mineral samples were collected two weeks prior to harvest. Analyses were performed by commercial laboratories (Soiltest Farm Consultants, Inc., Moses Lake, Washington in 2002 and Cascade Analytical, Inc., Wenatchee, Washington in 2003) using standard methods (Gavlak et al., 1994; WSALPT, 1997).

2.3.4. Soil analyses

Soil sampling occurred within the same sample area as the horticultural measurements, but midway between trees and within the tree-row. Three soil cores, separated into three depths (0-7.5, 7.5-15, and 15-30 cm) were taken from random sites within the above defined area in each experimental plot and pooled into a single observation. One pooled soil sample, at each depth range, was used for measurements of mineral concentrations, organic matter, and soil chemical properties, and another pooled sample for bulk density, porosity, and water-filled pore space. Mineral analyses were performed by a commercial laboratory (Soiltest Farm Consultants, Inc., Moses Lake, Washington) using methods for each soil analysis according to Glover et al. (2000). Soil samples were collected on June 17, 2002 and September 17, 2003. The later date in 2003 was due to persistently wet soils caused by the use of the over-tree evaporative cooling system during the summer months.

2.4. Fruit quality analyses

2.4.1. Storage and shelf-life treatments

Apple fruit quality was assessed at both harvests, after three months of refrigerated regular atmosphere (RA3) storage (ambient oxygen levels, 0-1 °C), after three months of controlled atmosphere (CA3) storage (1.5-2% oxygen, 0-1 °C), and after six months of CA storage (CA6). From each experimental plot, one box of medium-sized (161-204 g) WaXF apples was used for harvest and post-harvest measurements. WaXF apples from the second harvest were used for storage trials, because this is the main harvest for this multiple-harvested cultivar. When removed from storage, apples were placed in the laboratory under prevailing temperature conditions (approximately 22 °C) for 24 hours before analyses were conducted. To test apples at a physiological stage in which they would likely be consumed, a shelf-life study was conducted where apples were left under prevailing laboratory conditions for seven days. Measurements of flesh firmness, percent moisture (2003 only), starch index (SI), soluble solids concentration (SSC), titratable acidity (TA), purgeable volatiles, internal ethylene concentration (IEC), respiration, ethylene evolution, the hydrophilic and lipophilic contributions to total antioxidant activity (TAA), and consumer acceptability were analyzed at harvest, after each storage treatment, and for most measurements, before and after the shelf-life treatment.

2.4.2. Internal ethylene, ethylene evolution, and fruit respiration

In 2002, IEC was analyzed by taking a 1 mL gas sample from the core-space of a whole apple and directly injecting it into a Shimadzu G8A gas chromatograph (Shimadzu Corp., Kyoto, Japan) as described in Fellman et al. (2003). In 2003, 0.5 mL of gas from the core-space was analyzed for IEC using an HP 5890A gas chromatograph (Hewlett-Packard Co., Palo Alto, California) equipped with a 0.53 mm x 30 m x 3 μm J&W CarbonPLOT column (J&W Scientific, now Agilent Technologies, Avondale, Pennsylvania). The packed injector, oven, and flame ionization detector had temperatures of 100 °C, 100 °C, and 200 °C, respectively. Five apples from each experimental plot were used for IEC.

For measurements of respiration and ethylene evolution, five apples from each experimental plot were weighed and placed inside 18 L sealed Plexiglas chambers supplied with ethylene-free air at a flow rate of approximately 100 mL min^{-1}. The carbon dioxide and ethylene concentrations from each chamber were automatically measured every eight hours using an HP 5890A gas chromatograph (Hewlett-Packard Co., Palo Alto, California) equipped with a thermal conductivity detector, a 0.53 mm x 30 m GS-Q PLOT column (Agilent Technologies, Avondale, Pennsylvania), and an electronic switching valve. Oven, injector, and detector temperatures were set at 30 °C, 90 °C and 200 °C, respectively. The helium carrier gas flow rate was 8 mL min^{-1}. A brief description of this apparatus is available (Patterson and Apel, 1984).

2.4.3. Analytical measurements of fruit quality

In 2002, many of the maturity and quality parameters were conducted in the Post-Harvest Physiology Laboratory at WSU, but by 2003 the Fruit Biology Laboratory was updated to conduct many of these measurements. At both days one and seven of the shelf-life test, ten apples were sub-sampled from the box of apples from each experimental plot, individually weighed, ensuring they were of approximately the same size, and analyzed for flesh firmness, moisture content, SI, SSC, and TA. A composite juice sample, from these ten apples, was used for purgeable volatile analyses. Flesh firmness was averaged from two measurements taken at the equator of each apple, after removing the peel, with a Topping penetrometer (Topping, 1981) in 2002 and a Güss Fruit Texture Analyzer (FTA) interfaced to a computer running FTA software (v.5.00, Strand, South Africa) in 2003, both using a standard, cylindrical 11.1 mm diameter head. Percent moisture was found by weighing a 2 cm long cylindrical piece of flesh tissue (no. 9 cork borer, 1.5 cm diameter), removed from each of the ten apples' equators and from directly beneath the peel, before and after 24 hours at 80 °C (Nielsen, 1998). SI was determined by staining the stem-side of an equatorial cross-section of the apple with iodine (I_2-KI) solution and visually rating the color change (1 = 100% staining; 6 = 0%) on a 'Gala'-specific SI chart developed by Cascade Analytical, Inc. (Wenatchee, Washington). The remainder of the apple was then juiced (Champion Juicer, Lodi, California). A juice aliquot was taken to measure SSC using a Reichert ABBE Mark II refractometer (AO Scientific Instruments, Keene, New Hampshire) in 2002 and an ATAGO PR-101 refractometer (ATAGO Co., LTD., Tokyo, Japan) in 2003 and reported as °Brix. TA was found by adding a 10 mL juice aliquot to 100 mL of deionized water and titrating against a 0.1 N KOH solution to an end-point of pH 8.1 using a Metrohm 672 autotitrator (Herisau, Switzerland) in 2002 and a Schott Titroline *easy* autotitrator (Mainz, Germany) in 2003. Malic acid equivalency was calculated by multiplying the volume of titrant used by the malic acid factor (% w/v malic acid in 1 N solution multiplied by KOH normality). Determining purgeable volatiles followed the procedure described by Fellman et al. (1993), where a 2.5 mL sample of composite juice diluted 1:1 with distilled deionized water was analyzed using purge-and-trap cryofocusing techniques.

2.4.4. Consumer acceptance panels

Consumer acceptance panels were conducted at the Food Science and Human Nutrition Sensory Laboratory at WSU. Forty-eight untrained consumer panelists judged apples at harvest, after each storage period, and after a shelf-life period (except for the 2002 harvest). Overall acceptability, texture, and flavor were rated on a 9-point hedonic scale (1 = dislike extremely; 5 = neither like/dislike; 9 = like extremely), while firmness, sweetness, and tartness were rated on a 9-point intensity scale (1 = very soft, not at all sweet, or not at all tart, respectively; 9 = very hard, extremely sweet, or extremely tart, respectively). Unpeeled apples, at room temperature, were quartered and cored. Each quarter was sliced (stem to calyx) into three equal parts, placed on a white plate identified with a random code, and immediately served to a panelist. Each panelist judged all three treatments from one block separately and in a randomized order, with a total of 12 panelists per block. Panelists were provided water and crackers for rinsing and palate cleansing. All sessions were conducted in individual sensory panel booths under white light.

2.4.5. Total antioxidant activity

By adapting the methods of Cano et al. (1998) and Arnao et al. (2001) to apple tissue, TAA was performed on both the peel and flesh of four apples per experimental plot at harvest and at each storage period after the shelf-life. Peel tissue was collected from a 4 cm band around the apple's equator by knife, being careful not to remove flesh tissue. Flesh tissue was collected by removing a 5 mm thick slice (stem to calyx) from each quarter of the peeled apple. Tissue was finely ground by mortar and pestle in liquid N_2 (-196 °C) and stored at -80 °C until the time of assay. Hydophilic (HAA) and lipophilic antioxidant activities (LAA) were measured for both peel and flesh tissue. The chemicals 2,2'-azino-bis-(3-ethylbenzthiazoline-6-sulfonic acid) in the crystallized diammonium salt form (ABTS), 6-hydroxy-2,5,7,8-tetramethylchroman-2-carboxylic acid (Trolox), and horseradish peroxidase (HRP) were obtained from Sigma-Aldrich Chemical Co. (St. Louis, Missouri). While, 2-(4-morpholino)-ethano suffonic acid (MES) was purchased from FisherScientific (Fair Lawn, New Jersey).

Extractions were performed by grinding (T-line Laboratory Stirrer, Montrose, Pennsylvannia, fitted with a glass pestle) 100 mg of tissue in ice-cold grinding buffers consisting of 700 μL of 50 mM MES (pH 6.0) and 700 μL of 100% ethyl acetate for 45 sec. Samples were then centrifuged at 13,250 g for 10 min at 4 °C. The aqueous phase was collected to measure HAA. The organic phase was collected to measure LAA. The reaction medium was mixed in glass cuvettes containing 10 µL of 3.3 U μL^{-1} HRP, 40 µL of 1 mM H_2O_2, 100 µL of 15 mM ABTS, and either 830 µL (for peel) or 810 µL (for flesh) of either 50 mM $NaPO_4$ (pH 7.5) for HAA or 100% ethanol for LAA. The reaction was monitored at 734 nm on a HP 8453 UV-visible spectrophotometer (Agilent Technologies, Avondale, Pennsylvania) interfaced to a computer running UV-Visible ChemStation software (v.A.08.03 [71], Agilent Technologies, Avondale, Pennsylvania) until a stable absorbance was obtained. Then 20 µL of peel extract or 40 µL of flesh extract was added to the reaction medium and the decrease in absorbance was measured after 180 sec. The final volume for all assays was 1 mL. A solution of Trolox, an analog of vitamin E and a strong antioxidant, was prepared daily to create dose response standard curves. TAA is the total of HAA + LAA and is expressed as µmol TAA g^{-1} FW. Since apples contain considerably more flesh than peel tissue, an estimate of TAA for a 200 g apple was calculated based on a ten-apple sample. A 200 g apple, minus the core tissue, would contain on average 16 g of edible peel tissue and 154.4 g of edible flesh tissue.

2.5. Statistical analyses

All data were subjected to an analysis of variance (ANOVA) utilizing the SAS System for Windows (v.8.01, Cary, North Carolina). Orchard productivity and harvest fruit quality data were analyzed as a randomized complete block design. Mean separation was by Fisher's protected Least Significant Difference (LSD) at the 5% level of probability, unless otherwise noted.

Post-harvest analyses were analyzed as a split-split-plot. The main effects were the farm management treatments (ORG, CON, INT). The first split was for the storage treatments (RA3, CA3, CA6) and the second split was for the shelf-life treatments (1, 7 days). Harvest data were not included in the split-split-plot design. The model was *Response variable = Treatment Storage Shelf-life Treatment*Storage Treatment*Shelf-life Storage*Shelf-life Treatment*Storage*Shelf-life*. *Block* was a random effect and so, *Block*Treatment Block*Treatment*Storage*, and *Block*Treatment* Storage*Shelf-life* were also considered random effects. For TAA, there was no shelf-life treatment, and so the design was a split-plot with a similar model as explained above, but without the *Shelf-life* interactions. Additionally, all apples used for TAA were from the same harvest, so harvest data were analyzed in the split-plot model. Interactions significant at the 5% level of probability between the main effects and storage or the main effects and shelf-life were further explored using contrast statements. Interactions between storage and shelf-life were not explored in this study as the objective was to determine differences involving the main effects. Mean separations of the interactions were at the 5% level of probability.

3. Results and Discussion

3.1. Orchard productivity

3.1.1. Crop yields and tree growth

In 2002, crop yields in the CON system were significantly higher than those in the ORG and INT systems, and INT yields were significantly higher than ORG yields (Table 2). However, in 2003, ORG yields were significantly higher than both CON and INT yields. ORG yields increased 2.3 times from 2002 to 2003 indicating that this system was likely falling into a pattern of biennial bearing, where apple trees produce light crops one year followed by heavy crops the next. Since CON and INT yields were more consistent between years than were ORG yields, it is less likely that tree size solely accounts for the differences in yields between farm management systems. Evidence indicates that biennial bearing occurs when gibberellins (GA), synthesized in seeds, inhibit flower initiation in proximal buds (Buban and Faust, 1982). A tree with a high crop load will contain many more fruits, and therefore seeds, that inhibit flower bud formation. Conversely, when a tree has a low crop load, there are less seeds, and thus more flower buds are formed. This was seen in the high return bloom for the ORG system, which had a significantly lower crop density in 2002, where crop load is expressed on unit tree size, and higher floral intensity in 2003 than the other systems (Table 2).

Because of the lack of effective organically certified chemical thinners, biennial bearing has been cited as one of the technological barriers for organic apple production (Vossen et al., 1994; Swezey et al., 1998; Glover et al., 2000; Reganold et al., 2001). In this study chemical flower thinning occurred in the ORG system in both years, but chemical post-bloom thinners, which are still under development for organic apple production, were only used in the CON and INT systems in 2002 and in the CON system in 2003 (Table 1). Hand thinning occurred after the post-bloom chemical thinning applications and on the same date for all three systems within each year. The timing of hand thinning may have been appropriate for the systems using post-bloom thinners, but was likely too late to positively affect return bloom in the ORG system.

Additionally, although there was no harvestable crop in 2001, and so crop load was not measured, a crop still existed that would have impacted the 2002 floral intensity (Table 2). The ORG system was solely relying on hand thinning in 2001 for reducing crop load, and so it is plausible that the ORG trees were sent into a biennial bearing pattern in this first year of production after the grafting event. It may be especially important for organic production systems to have the necessary labor on-site for proper crop load management and thus, labor shortages may have more impact on organic apple systems when hand thinning cannot be completed soon enough to avoid floral inhibition by GA.

Lower yields in the ORG system were also noted in the early years of this study when the ‘Golden Delicious’ trees first came into bearing; however, after five years of production, there were no differences in cumulative yields (Reganold et al., 2001). The lack of early yields in the ORG system may relate to the lack of readily available nitrogen (N) fertilizers for organic production. Calcium nitrate ($Ca(NO_3)_2$) was applied at a rate of 254 kg ha^{-1} or 39.4 kg ha^{-1} of actual N banded in the tree row to the CON and INT systems in June 2000 when the newly grafted trees would have benefited from fertilization (Neilsen et al., 2001). The ORG system did not receive N fertilizer application until 2003, with the previous N application to this system in 1995 (Reganold et al., 2001).

In the spring of 2002, CON trees were larger as measured by TCSA than ORG trees, and INT trees were similar in size to both treatments (Figure 1). No statistical sdifferences were seen between systems in the percent change for TCSA during the course of this two-year study of the ‘Gala’ grafts, and so by the end of the 2003 growing season, TCSA’s of CON trees were still larger than ORG trees and as large as the INT trees (Figure 1). TCSA measurements on these same trees from 1994 to 1999 showed no difference between systems (Reganold et al., 2001), and so the lack of N applications in the ORG system likely resulted in the tree size differences seen in the current study. The ability to use readily available N fertilizers may be an advantage for conventional and integrated orchard systems, as organically certified fertilizers, such as composted manures, are bulky and difficult to apply in orchards without specialized equipment or sufficient labor, and more readily available N fertilizers that are organically certified, such as Chilean nitrate, are restricted by the NOP to 20% of the total N input (Federal Register, 2000). However, the negative impacts of N in highly soluble formulations applied in the CON and INT systems must be taken into account (Weinbaum et al., 1992; Neilsen and Neilsen, 2002). For example, it has been shown that only 22% of applied N is taken up by young apple trees (Neilsen et al., 2001), potentially leaving the remaining N to leach from the root zone.

3.1.2. Color grade, weight distribution, and cullage analyses

The ORG system had significantly larger average fruit weight in 2002 and significantly smaller average fruit weight in 2003 than the other two systems (Table 2). This follows the trend for crop densities and yield efficiencies, where total crop weight is expressed on unit tree size, and as lower yield efficiencies and crop densities tend to produce larger fruit and higher efficiencies and densities produce smaller fruit (Table 2). Smaller fruit size and reduced tree size in the organic 'Gala' trees in 2003 probably resulted from late fruit thinning, as it has been shown that delaying thinning in 'Gala' trees by four or more weeks after full bloom significantly reduced fruit size and leaf area (McArtney et al., 1996).

There were no statistical differences between systems for fruit weight distributions in 2002 at the 5% level, and relatively little significance at the 10% level for 2002 (Figure 2A). However, in 2003 there were statistically more ORG fruit in the smaller weight classes (≤ 160 g) and less ORG fruit in the middle and larger weight classes (≥ 161 g) (Figure 2B). Even though yields were 35-37% higher in the ORG system than in the CON and INT systems in 2003, the fact that 50% of the ORG fruit fell into the smaller sizes compared with 24 and 15% for the CON and INT systems, respectively, would have a profound negative effect on the financial returns to the ORG system as larger fruit usually commands a better price in the marketplace (Washington State Growers Clearinghouse, 2004).

There were no significant treatment differences for color grade in either year at either the 5 or 10% significance level. In 2002, 98-99% of the apples were graded as WaXF, with most apples in the WaXF#1 color grade. In 2003, even though 86-92% of the apples from all systems graded as WaXF, about half as many apples fell in the #1 category of the WaXF grade in 2003 compared to 2002. This is despite the fact that in 2002 the ethylene biosynthesis inhibitor aminoethoxyvinylglycine (AVG), marketed as ReTain© (Valent U.S.A. Corp., Walnut Creek, CA), was applied to all three systems. AVG may have caused the 2002 harvest to be six days later than in 2003, as calculated from the full bloom date, by causing a delay in the autocatalytic ethylene production that is associated with climacteric fruit ripening (Kidd and West, 1925). While AVG can reduce red coloration in 'Gala' apples (Wang and Dilley, 2001), fewer highly colored WaXF#1 apples in 2003 most likely relates to the hotter growing conditions that existed that year, causing fruit to mature before full color development was attained. Color development for many apple cultivars requires cool temperatures as the fruit matures (Saure, 1990).

In 2003, no significant differences existed for the percent of total yield that was unmarketable due to defects, even though 10% more were unmarketable in the ORG system (Table 2). This non-significant difference still would have likely reduced the profitability of the ORG system. In 2002, the largest percentage (37-50%) of culled fruit was due to russeting, caused by early season frost events (Figure 3A). There was significantly more cullage in the total pest damage category (which primarily included Western flower thrip [*Frankliniella occidentalis*] and codling moth) in the ORG system than in the CON or INT systems in 2003, but in 2002 there was no significant difference at the 5% level in this cullage category (Figures 3A-

B). This is contrary to previous reports from this study site (Reganold et al., 2001), but similar to reports from California (Caprile et al., 1994; Vossen et al., 1994), and despite the fact that the ORG and INT systems received the same insecticide treatments in 2003 (Tables 1A-B). In 2002, more ORG apples contained codling moth damage than the other two systems, but no difference among systems occurred for 2003 (Figures 3A-B). Overall, better control of codling moth occurred in 2003, possibly because of application of the full label rate of PMD. In 2003, an unidentified spray application (likely herbicide, because it was the only spray applied to the INT system and not the ORG) caused considerable damage to fruit in the CON and INT systems (Figure 3B). Latent spray damage also caused a high percentage of cullage to CON and INT fruit emerging from six months of CA storage. In 2003, apple scab, caused by *Venturia inaequalis*, emerged as a fruit cullage factor, even though its incidence is rare in arid, central Washington state (Figure 3B).

3.1.3. Plant tissue mineral analyses

In apple trees, zinc (Zn) and boron (B) are necessary for proper flower development, fruit set and development, and for maintaining high fruit quality (Neilsen and Neilsen, 1994; Stover et al., 1999; Peryea et al., 2003), and thus both minerals are commonly applied to apple orchards in central Washington, as both are known to be deficient in central Washington soils (Martin, 2004). However in this experiment, Zn was not applied in the ORG system during the 1997-2002 seasons, and B was not applied to any of the systems during 2000-02 seasons. The missed applications in prior years likely had detrimental effects to all three systems, but especially to the ORG system since neither Zn nor B applications were made. In 2003, Zn and B applications were made to all three systems, which will likely correct these deficiencies (Table 1B).

For each nutrient, the critical nutrient range (CNR) is the concentration above which the plant is likely supplied with ample nutrient for growth and below which the plant is likely deficient resulting in sub-optimal growth. The CNR for B in the mid-shoot leaf tissue of apple trees is 20-25 ppm (Dow, 1980). All three systems were within the CNR for B in 2002, and the ORG and INT systems were above B's CNR in 2003 (Table 3). It is difficult to determine the effect of the missed B applications since the B concentrations were never below the CNR, but the continued application of B is recommended for all three systems to maintain proper return bloom.

Zinc is one of the most important micronutrients in apple production, with a CNR of 15-20 ppm (Dow, 1980). Leaf tissue analyses in this study showed Zn to be below the CNR in the ORG trees in 2002, but within or above the CNR in the CON and INT trees (Table 3). All three systems were within the CNR for Zn in 2003. Symptoms of Zn deficiency, including small thin chlorotic leaves, leaf rosetting, and branches with sections of non-bearing "blind" wood (Swietlik, 2002; Martin, 2004), were observed in the ORG system both seasons, but not in the other two systems. It has been reported that even with low Zn leaf concentrations, symptoms of Zn deficiency are a prerequisite of yield reductions and poor growth (Swietlik, 2002), which may have contributed to the low ORG yields in 2002 and the smaller tree size observed for the ORG system throughout this study.

Although all systems were within the nitrogen CNR of 1.7-2.0 (Dow, 1980), N leaf levels were significantly higher in the CON and INT systems than the ORG system in 2002, but no difference was seen in 2003 despite the differences in fertilizers applied (Table 3). These results may reflect the application of fish emulsion fertilizer in the ORG and INT systems in 2003 (Table 1). Leaf manganese (Mn) levels were considerably lower in the ORG system in 2002 and in the ORG and INT systems in 2003 (Table 3). This was not seen in previous results from this study site (Reganold et al., 2001). Nonetheless, for Mn all three treatments were within or above the CNR of 25-30 ppm and below the excess level of 200 ppm in both years (Dow, 1980). All other leaf mineral nutrient levels were within their CNRs (Dow, 1980) and therefore, statistical differences among them may not be physiologically important. Whether fruit is grown by organic, conventional, or integrated apple farm management systems, determining deficiencies by annual sampling for macro- and micronutrients and taking corrective actions to alleviate deficiencies is necessary for proper productivity.

Fruit tissue N levels were statistically higher in the INT system compared to the ORG system in 2002, and higher in the CON and INT systems compared to the ORG system in 2003 (Table 4). Increased N status in fruit trees is known to increase fruit size, but along with lower Ca and P concentrations, delays color development, reduces fruit firmness, and increases post-harvest disorders (DeEll and Prange, 1993; Stiles, 1994). Fruit Ca showed slight differences in 2002, and no difference in 2003, despite the lack of Ca applications in the ORG and INT systems in 2003 (Table 3). The absence of differences may be due to 'Gala' apple trees being good accumulators of Ca (Neilsen et al., 1999). No differences were seen in Zn or B fruit tissue samples in 2002, but in 2003, fruit B concentration was higher in the ORG and INT apples than the CON apples, matching the results from the leaf tissue analyses (Tables 3, 4). However, no observable symptoms of Zn or B deficiency were seen in harvested fruit from any system in either 2002 or 2003.

Several studies have reported organic apple trees to have higher phosphorus (P) status (DeEll and Prange, 1993; Werner, 1997, Weibel et al., 2000). Werner (1997) suggested that higher P status may be due to increased colonization of mycorrhizal fungi in ORG apple orchards, which we did not measure in this study. Higher leaf P concentrations were found in the ORG trees in 2003 (Table 3), but not in 2002, and no differences were found for fruit P in either year (Table 4). Soil P was the same for all three systems in the 0-7.5 cm depth, but was slightly higher in the INT system than the other two at the 7.5-15 cm depth in 2002 and at the 15-30 cm depth in 2003 (Table 5). Unlike these other studies, we found no consistent treatment effect on the P status in the ORG system.

3.1.4. Orchard floor and soil analyses

Weed control continues to be a technological barrier for organic orchard systems (Walsh et al., 1996). In over ten years of experiments at this study site, researchers have attempted to control weeds in the ORG system with bark mulches, landscape fabric, a surface weed cultivator, mowing, a weed burner, a rototiller, and hand hoeing (Reganold et al., 2001). None have proved to be as reliable as the chemical herbicides used in the CON and INT treatments, and in this respect an integrated farming system, with less restrictions on the allowable materials, may prove to have an advantage over certified organic systems. The specialized equipment that organic growers employ to effectively control weeds were not owned by the management of the commercial orchard and hired equipment often proved incompatible with the existing orchard planting/training system. For example, the thermal weed control device used in 2001 and Spring 2002 was very effective at a neighboring organic apple orchard because it was custom designed for a Tatura (“V”) trellis, which allows for heat dissipation up through the center of the training system and not into the tree canopy. However, the vertical training of the experimental orchard put the lower canopy in direct line with the rising heat of the propane burners. Lack of effective weed control in the ORG system would increase competition for water and nutrients, thus reducing availability to the ORG trees (Merwin and Stiles, 1994; Walsh et al., 1996; Neilsen and Hogue, 2000; Neilsen and Neilsen, 2002). However, Neilsen et al. (1999) also note that while grass grown under orchard trees can decrease growth and yield in younger trees, 'Gala' apple fruit firmness can be increased.

Soil mineral analyses for total N, NO_3-N, and extractable P were all within thresholds developed by Glover et al. (2000) and reflect the high quality of soil at the study site. No differences between treatments were seen in the 0-7.5 cm depth for NO_3-N. Although not statistically analyzed, between 2002 and 2003 NO_3-N concentrations increased 2, 3.8, and 2.7 times at the 0-7.5 cm depth for the ORG, CON, and INT systems, respectively (Table 5), likely due to the 2003 fertilizer applications. It is surprising that all three systems had similar soil NO_3-N concentrations in 2003, despite ammonium sulfate being a more readily available N source than the blood meal applied in the ORG system. Difference in NO_3-N levels between years may also reflect sampling soil several weeks after continuous water use from the evaporative cooling system leached the more soluble ammonium sulfate fertilizer from the root-zone. Additionally, the greater N needed for the larger ORG crop load in 2003.

This study was not meant to assess the effects of cover crops in orchard systems, and so alleyway soil parameters were not measured. However, the addition of N-fixing cover crops to the alleyways of the ORG and INT systems, may explain the higher levels of total N in those systems' soil in 2002, even though NO_3-N levels within the tree rows were not greatly affected.

Although some significant differences were seen among systems for bulk density, porosity, cation exchange capacity, pH, and electrical conductivity, all were within the thresholds developed by Glover et al. (2000) (Table 6). To maintain the high soil quality of the ORG and INT orchard systems previously reported (Glover et al., 2000; Reganold, 2001), or to improve the soil quality of the CON system, especially when employing tillage for weed control, the addition of a soil amendment in the form of either compost or an organic mulch may be necessary in addition to organic fertilizers, such as blood meal. The addition of compost to the organic system would also address NOP requirements for soil quality maintenance or improvement (Federal Register, 2000).

3.2. Fruit Quality Analyses

3.2.1. Harvest parameters

In 2002, apples from all three systems were within an acceptable maturity based upon IEC (Figure 4A) and SI (Table 7), both good predictors of determining the acceptable maturity for harvesting and storing ‘Gala’ apples (Plotto et al., 1995; Mattheis et al., 1998). In 2003, however, IEC was significantly higher for CON and INT apples than ORG apples (Figure 4B), even though SI showed sufficient starch hydrolysis (Table 7). Despite the differences in IEC at the 2003 harvest, both years showed similar trends between treatments at harvest for fruit ethylene evolution (Figures 5A-B) and respiration rates (Figures 6A-B). Only for fruit harvested in 2003 was the autocatalytic rise in ethylene production clearly seen at approximately day six for all three systems (Figure 5B), and so it is likely that all three treatments were harvested within similar maturities in that year.

In both 2002 and 2003, the IEC was several times larger in apples emerging from RA3 storage than from either CA3 or CA6 storages, and at CA3 the IEC was higher than at CA6 (Figures 4A-B). Apples from all three systems had much higher IEC in 2002 than they did in 2003, reflecting differences in harvest maturities between years. The lower IEC at CA6 is typical for ‘Gala’ apples, which tend to lose viability after prolonged storage (Plotto et al., 1995). In

2002, ORG apples had lower IECs than either CON or INT apples for RA3 and CA3, and lower IECs than CON apples for CA6 (Figure 4A). In 2003, the only storage difference in IEC between systems was at RA3, with ORG and INT apples having lower IEC than CON apples (Figure 4B).

3.2.2. Analytical measurements of fruit quality

ORG apples were firmer than INT apples at both harvests and after the seven-day shelf-life in 2002, and firmer than CON apples at both harvests and after the shelf-life in 2003 (Table 8). Out of storage ORG apples were firmer than CON and INT apples in both years (Figure 7). On average, the 2002 ORG apples from the storage treatments were 6.51 and 7.38 N firmer than CON and INT apples, respectively. For the 2003 storage apples, ORG fruit were 11.2 and 5.75 N firmer than CON and INT apples, respectively (Figure 7). These are perceivable differences for consumers (Harker et al., 2002a), as determined in the consumer panels conducted in this study (Table 9). Washington State requires a minimum firmness of 48.93 N to ship 'Gala' apples (WAC, 2003). After six months of CA storage in 2002, 10% of the ORG apples were below the minimum, as opposed to 36 and 58% of CON and INT apples, respectively, showing better long-term storability for ORG apples. The higher percent of shippable ORG fruit would be economically valuable to producers. Higher firmness in organic apples after storage was also seen for 'Golden Delicious' apples (Weibel, 2000; Reganold et al., 2001), but not for 'Cortland' or 'McIntosh' apples (DeEll and Prange, 1992).

Higher fruit N concentrations, lower Ca concentrations, lower ratio of N:Ca, increased ethylene production, and lower moisture content all lead to the loss of cell-to-cell adhesion, and thus the loss of flesh firmness in apples (Johnston et al., 2002). Higher fruit N levels in CON and INT apples correlated with the loss of firmness in both years, while Ca levels were relatively equal among treatments both years (Table 4). The N:Ca ratio was lower for ORG apples in both years, reflecting their lower N status. Other fruit mineral concentrations and their ratios were not consistently good predictors of flesh firmness in this study (Table 4). Additionally, the greater weed competition in the ORG plots may have had an effect on N status in the ORG system (Neilsen et al., 1999), and thus the increased firmness of ORG fruit. Although the exact relationship between flesh firmness and ethylene has not been fully explained (Johnston et al., 2002), the IEC of ORG fruit was almost always lower throughout the storage trials in both years (Figures 4A-B), correlating well with the results for flesh firmness. The lower IEC for ORG apples may also relate to the lower N concentrations in ORG fruit (Fallahi et al., 2001). Percent moisture decreased over time in the storage treatments for all systems, but few differences were seen among farm management systems, and no consistent differences were evident that would explain the differences seen in firmness (Data not shown).

At both 2002 harvests, SSCs were higher in ORG apples than INT apples, and higher than CON apples at the second harvest both before and after the shelf-life (Table 8). However, at harvest in 2003 CON apples had higher SSCs than ORG apples, and INT apples were intermediate after the shelf-life and at the second harvest (Table 8). After the storage treatments, there were no consistent farm management effects for SSC in 2002, but in 2003 a significant interaction occurred between farm management system and shelf-life (Tables 10A-B), which showed that CON apples had consistently higher SSC than ORG and INT apples immediately out of storage and after the shelf-life, and that INT apples had higher SSC than ORG apples after the shelf-life (Figure 8A). However, in both years differences in SSC among systems were usually less than one ºBrix, which may reflect the lack of perceivable differences in sweetness found by the consumer panelists (Harker et al., 2002b; Table 9). Given the inconsistent results in the two years of this study, and the small magnitude of differences that were found, farm management systems had no consistent effect on SSC. This is different than other comparative studies of organic and conventional apples, where more often than not, organic apples had higher SSC (DeEll and Prange, 1992; Reganold et al., 2001).

Although year-to-year differences were not statistically analyzed, TA appeared to be higher in 2002 than 2003 for all three farming systems (Table 8). There were no farm management system differences at either harvest before the shelf-life in 2002, but after seven days, TA was higher in INT apples than ORG and CON apples and higher in ORG apples than in CON apples (Table 8). INT apples also had higher TA than ORG apples in 2003 at both harvests and after the shelf-life period, and CON apples had higher TA than ORG apples after the shelf-life period for the first harvest and immediately after the second harvest (Table 8). During the 2002 storage trials, ORG apples had statistically higher TA than either CON or INT apples at 0.446, 0.412 and 0.403%, respectively, but there was no difference between CON and INT apples (Table 8). In 2003, there was a highly significant interaction between farm management system and shelf-life treatments (Table 10B). Exploration of this interaction showed that CON and INT apples had consistently higher TA after the seven-day shelf-life period than did ORG apples (Figure 8B). Interestingly, consumer panelists found ORG apples to be tarter than CON apples out of storage in 2003 (Figure 9). As with SSC, no clear effects of farm management system were observed for TA, as the results were inconsistent between years and the magnitude of differences small (Harker et al., 2002b). In other comparative studies, conventional and integrated 'Golden Delicious' apples were found to have higher TA than organic apples (Reganold et al., 2001), but no differences were seen in 'Cortland' or 'McIntosh' apples (DeEll and Prange, 1992).

The ratio of SSC:TA can be used as an assessment of the relative sweetness and tartness of apples (Harker et al., 2002b). In 2002, there were no differences in SSC:TA ratios among farming systems at the first harvest, whereas, before the shelf-life period at the second harvest INT apples had higher SSC:TA ratios than did ORG or CON apples, but after the shelf-life period CON apples were highest, followed by ORG and then INT apples (Table 8). In 2003, CON apples were consistently higher for this ratio at harvest than INT apples, with ORG apples being intermediate (Table 8). No interactions occurred between farm management systems and either storage or shelf-life treatments in either year (Tables 10A-B). Throughout the 2002 storage trials CON and INT apples had statistically higher SSC:TA ratios than ORG apples, while ORG and CON apples had higher SSC:TA ratios than INT apples in 2003 (Figure 10). Despite the high SSC:TA ratios for CON apples in both years, no clear pattern of differences emerged for ORG or INT apples. Additionally, consumer panelists were unable to detect that CON apples were sweeter in either year (Table 9).

The volatile compounds responsible for the distinctive fruity flavor of 'Gala' apples, particularly the esters butyl acetate, hexyl acetate, and 2-methylbutyl acetate, were found in apples from all three systems (Data not shown) (Mattheis et al., 1998; Plotto et al., 1999; Plotto et al., 2000). Numerous aldehydes, produced in less mature fruit, and alcohols, a key substrate for ester production, were also quantified (Fellman et al., 2000). The alcohols (i.e., 1-butanol, 1-hexanol, ethanol, and 2-methyl-1-butanol), aldehydes (i.e., hexanal, propanal, 2-methyl-1-butanal), and esters (i.e., butyl acetate, ethyl acetate, ethyl butyrate, hexyl acetate, 2-methylbutyl acetate, 2-methyl-1-propyl acetate, and propyl acetate) were grouped together and the total production of these three classes of volatile compounds was also analyzed. No differences between farm management systems were noted for alcohols, esters, or total volatile production at harvest in 2002, but there were more aldehydes in ORG apples, signifying that ORG apples may have been slightly less ripe (Table 11). CON fruit produced significantly more total volatiles out of storage than either ORG or INT fruit (Figure 11). Also in 2002, a three-way interaction for aldehydes (Table 10A) showed that ORG and INT fruit increased in aldehyde concentration from day one to seven of the shelf-life trial, but the CON fruit did not (Figure 12A). No significant farm management or storage treatment effects were seen for aldehyde production between RA3 and CA3, but all three systems did result in significantly higher production of aldehydes between CA3 and CA6 (Figure 12A). There were also significantly more aldehydes in the CA6 ORG fruit than the CA6 INT fruit (Figure 12A). A three-way interaction for esters in 2002 (Table 10A) revealed that CON fruit had the most esters at both one and seven days of the shelf-life trial, but that the shelf-life period had little effect in any of the farming systems (Figure 12B). Additionally, the CON fruit had consistently higher ester production at all storage treatments, regardless of shelf-life, and similar to aldehyde production, ester production was lowest at CA6 for all farm management systems (Figure 12B).

The 2003 harvest measurements of volatile production also showed significantly greater concentrations of esters and total volatiles for CON apples (Table 11). In the 2003 storage trials, there were farm management by storage treatment interactions for the esters and the total production of volatiles (Table 10). Similar to 2002, the 2003 CON apples produced more esters and total volatiles at RA3, but not at CA6 for the esters or at either CA3 or CA6 for total volatile production (Figure 13). Additionally, for all systems there were less esters and total volatiles at CA3 and CA6 than at RA3 (Figure 13).

Higher N status in fruit can increase volatile production in apples (Fellman et al., 2000). However, higher fruit N levels before harvest (Table 4) were not always associated with increased volatile production at harvest or after storage (Table 11). Fruit maturity also affects volatile production, with apples producing more volatiles, particularly esters, as they approach full maturity (Fellman et al., 2000). Although CON apple IEC was consistently higher than ORG apples out of storage, the IEC pattern between CON and INT apples was less clear (Figures 4A-B), and did not always match the results for volatile production. Thus, it is likely that many interacting factors were responsible for the differences in volatile production. Additionally, consumer ratings of flavor did not relate well with the greater production of volatiles in CON fruit. Either all three treatments were within a similar perception range for these components of flavor, even though statistical differences were found, or that other fruit quality parameters, such as SSC and TA, interfered with these untrained panelists' responses to flavor composition.

3.2.3. Consumer acceptability

At harvest in 2002, consumers detected no differences in any of the rated attributes (Table 9). An exploration of the 2002 three-way interaction for overall acceptability (Figure 14A) revealed that ORG and INT apples maintained overall acceptability over the course of the shelf-life, regardless of the storage treatment, while CON apples declined in overall acceptability after seven days (Figure 14A). Additionally, for CA6 when days one and seven of the shelf-life were considered together, consumers perceived ORG apples more acceptable than INT apples (Figure 14A). At the 2003 harvest, before the shelf-life period, consumers judged INT and CON apples to be of overall better acceptability and sweetness, respectively, than ORG fruit, but ORG apples were judged to be firmer than CON apples (Table 9). In the 2003 storage trials, ORG and INT apples were statistically rated higher for overall acceptability than CON apples (Figure 9**).**

Throughout this two-year study, consumers, more often than not, found ORG and INT apples more acceptable than CON apples.

Seven days after harvest in 2003, panelists were able to differentiate that ORG were firmer than CON apples (Table 9). ORG apples were always firmer than INT apples before the shelf-life period for the 2002 storage trials (Figure 14D). In the 2003 storage trails, ORG apples in 2003 were statistically judged the firmest and INT apples firmer than CON apples (Figure 9). No differences were found in texture at harvest (Table 9), but in 2002, CON apples lost their texture over the shelf-life, regardless of storage treatment, while apples from the other two systems maintained their texture (Figure 14B). In 2003, out of storage, ORG and INT apples were statistically rated to have better texture than CON apples (Figure 9). Similar to the analytical measurement of firmness, consumer ratings consistently found ORG apples the firmest and having the best texture, but no clear trend emerged for the other two systems. Additionally, these findings support the work by Harker et al. (2002a) that consumers can differentiate differences in flesh firmness and texture even when analytical measurements cannot.

Consumers detected few harvest differences for flavor, sweetness, or tartness in either year (Table 9) and found inconsistent differences out of storage for flavor and tartness (Figures 9, 14C). In the 2002 storage trials, consumers found CON fruit to lose flavor over the shelf-life, but no consistent results were found among the storage treatments in that year (Figure 14C). The higher volatile production seen in CON apples was not perceptible by these untrained panelists.

Overall, these panels showed a trend toward ORG fruit being more acceptable, especially after the shelf-life, when consumers would likely eat these apples. In 2002, CON fruit were often rated as high as ORG fruit, but in 2003 INT fruit rated better than CON fruit. The most notable patterns occurred for firmness and texture, both of which were rated highest for ORG apples. In trials by Reganold et al. (2001), consumers were unable to detect differences in the overall acceptability, firmness, or texture of 'Golden Delicious' apples from the three farm management systems. However, those evaluations did find organic apples to be sweeter after six-months of CA storage, but they also found integrated apples to be of better flavor (Reganold et al., 2001). Based on sensory panels, DeEll and Prange (1992) found that organic 'McIntosh' apples were firmer at harvest than conventional apples, but not out of storage, which may have been due to the poor storability of that variety more so than the farm management system.

3.2.4. Total antioxidant activity

The greater TAA of ORG apples was perhaps the most consistent result found in this study. TAA included both hydrophilic antioxidants, such as ascorbic acid and flavonoids, and lipophilic antioxidants, such as carotenoids and tocopherol. Regular consumption of antioxidants aids in disease prevention, and numerous studies have shown the important antioxidants commonly found in apples to be associated with the prevention of heart disease (Knekt et al., 1996; Cooper et al., 1999a) and lung cancer (Hertog et al., 1992; Knekt et al., 1997; Copper et al., 1999b), and that the consumption of fresh fruit may be more effective than dietary supplements (Wang et al., 1996; Eberhardt et al., 2000).

There were no farm management by storage treatment (including apples analyzed at harvest) interactions in either year, but from harvest to RA3 to CA3 to CA6 there was a lowering effect on LAA and flesh TAA in 2002 and on both phases and both tissue types in 2003 (Table 10A-B). In 2002, when harvest and all storage treatment analyses were averaged together, ORG fruit had statistically higher HAA, peel TAA, flesh TAA, and peel + flesh TAA than both CON and INT apples, and higher LAA than INT apples (Figure 15A). For 2003, ORG fruit had greater

HAA, peel TAA, and peel + flesh TAA than CON fruit, but not INT fruit (Figure 15B). In 2002 there was also a significant main effect mean for the estimated 200 g apple (Table 10A), which showed that at 965 µmol FW, ORG apples had significantly higher TAA than CON or INT apples at 825 and 726 µmol FW, respectively. On average in 2002, ORG apples had 15 and 25% higher TAA per 200 g apple than CON and INT apples, respectively. While there was no main effect for the 200 g apple in 2003 (Table 10B), ORG apples did have 12 and 7% higher TAA per 200g apple than CON and INT apples, respectively. In 2002, CON apples had 12% more TAA per 200 g apple than INT apples, but in 2003, INT apples had 4% higher TAA per 200 g apple than CON.

Some recent studies comparing growing systems with other perennial horticultural crops have found higher concentrations of polyphenolic compounds and other antioxidants in pears (*Pyrus communis* L.) and peaches (*Prunus persica* L.) (Carbonaro and Mattera, 2001; Carbonaro et al., 2002). However, for yellow plums (*Prunus domestica* L.), conventional fruit had higher concentrations of polyphenols and quercetin, while other flavonoids and several vitamins were higher in organic fruit (Lombardi-Boccia et al., 2004). Our results show ORG apples to have higher TAA, but we did not explore the specific antioxidants that contribute to TAA.

Both abiotic stresses, such as UV-radiation, low temperatures, and nutrient deficiencies, and biotic stresses, such as pest and pathogen attack, induce the production of antioxidants in plants (Matsuki, 1996), but few studies look at the effects of farm management practices on fruit antioxidants. There were no differences seen for sunscald, as a fruit cullage factor, in either year (Figures 3A-B), but that does not necessarily mean that the ORG fruit were exposed to less solar radiation, only that we were not able to detect differences in symptoms among the farm management systems. The smaller ORG trees had a smaller canopy, and thus may have had more sun-exposed fruits. There was significantly more total pest damage in the ORG system in 2003, but not in 2002, so insect-plant interactions were not a clear cause. Other factors that have been shown to affect antioxidants, such as crop load (Stopar et al., 2002), placement of fruit within the tree canopy (Reay and Lancaster, 2001), and soil organic matter (Wang and Lin, 2003) varied between the two years, and so no conclusive effects could be made about those factors either. One plausible explanation is that glyphosate, an herbicide applied only to CON and INT plots, inhibits the necessary enzyme, 5-enolpyruvyl skimimate-3-phosphate synthase, in the flavonoid biosynthetic pathway (Lydon and Duke, 1989; Daniel et al. 1999) (Table 1A-B). A second explanation, given by Awad and de Jager (2002), is that increased fruit N levels correlated with reduced apple skin flavonoid concentrations, which may explain partially higher TAA in ORG apples in this study (Table 4), but as with other nitrogen-related fruit quality measurements, N status was not always associated with increased TAA. Additional research is needed to determine causes of higher TAA in ORG fruit. Also, further analyses should be conducted in order to identify the specific antioxidants that contribute to higher TAA levels.

Despite studies that suggest health benefits from increased consumption of antioxidants, the National Academy of Sciences' Institute of Medicine did not find enough available literature to recommend a dietary reference intake (IOM, 1998), and so it is difficult to ascertain how great a benefit the additional TAA seen in ORG fruit would be to human health. However, since only 20% of the US population (2 years old and older) is meeting the recommended daily servings for fruits and only 36% for vegetables (USDA-ERS, 2000), any additional nutritional value gained through the consumption of organic produce would potentially be beneficial.

4. Conclusions

The organic apple farm management system had significant production limitations in regard to crop load, pest management, weed control, and fertility and soil management. The biennial bearing pattern exhibited in the ORG system would have negatively impacted the economic returns for the ORG system both years. In 2002 there were significantly less fresh marketable fruit and in 2003 a significant proportion of the fresh fruit would have been unmarketable due to the small size. However, as no differences were seen in color grade between systems, properly timed chemical and hand thinning in the ORG system would likely correct the biennial bearing pattern resulting in similar yields and pack outs among the systems, and thus similar economic returns could be expected amongst the systems. Tree growth was the same for all three systems from Spring 2002 to Fall 2003, and so it is likely that the ORG trees were smaller throughout this study because of the fertilizer application to the CON and INT trees in 2000. Supplying N to the newly grafted apple trees proved to be advantageous for the CON and INT systems, but if N had been applied to the ORG system at the same time and rate, tree size may not have been significantly different. Similarly, annual zinc and boron applications would have corrected for the zinc deficiency in the ORG system and the low zinc and boron leaf concentrations seen in all three systems.

While pests appeared to more difficult to control in the ORG system, our experimental plots may have been too small and too close together to provide for adequate habitat for the beneficial insects that organic growers typically rely upon to control pests. This study site was originally designed to test soil and horticultural parameters, for which the plot size is adequate, but entomologists tend to use much larger plots when comparing the effects of farm management systems upon insect populations. The lack of specialized equipment for weed control in this experiment was regrettable, but exemplified the difficulty of controlling weeds in organic production systems. However, as organic apple acreage has increased, new products and technologies for organic production have been developed.

ORG apples were firmer, had better texture, and were of higher overall acceptability as measured by analytical and sensory evaluations, but no clear trends emerged for CON or INT apples. Few clear trends emerged for the flavor parameters of SSC, TA, or SSC:TA, but the CON apples had higher flavor volatile production. However, consumers were unable to differentiate among systems for the parameters of flavor, sweetness, or tartness, and so while statistical differences were found for fruit volatile production, all three systems may have been within a similar range of perception by human subjects. Overall ORG apples tended to store better, because of the increased firmness. ORG apples also had higher TAA, and more research is needed to determine the particular antioxidants that contributed to the higher TAA. This would also help elucidate the health benefits, as not all antioxidants are equal in either their bioavailability or efficacy. Nitrogen status in the trees was one likely cause of many of the fruit quality differences seen in this study, but these results were not always consistent, especially between the CON and INT systems. Further explorations into whether plants grown by different farm management systems employ different mechanisms for N uptake are needed, as are studies into the differences in soil and plant N-cycling among farm management systems.

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Tables 1A-B. Agrochemical product applications, intended purposes, rates/ha, and concentration of active ingredients (a.i.)/ha used in organic, conventional, and integrated apple farm management systems for 2002 (A) and 2003 (B). Note: Three applications of the herbicide glyphosate were used for weed control in the conventional and integrated systems in 2003, but application dates and rates were unavailable.

1A	Date	Product Name	Chemical Name	Purpose[z]	Rate/ha	a.i./ha
Organic	29-Mar	Kocide DF	Copper hydroxide	B	6.73 kg	4.13 kg
	1-Apr	Lime Sulfur	Calcium polysulfide	F	93.54 l	27.13 l
	1-Apr	Supreme Oil	Petroleum oil	I/F	46.77 l	46.30 l
	14-Apr	Lime Sulfur	Calcium polysulfide	F	74.83 l	21.70 l
	15-Apr	Mycoshield	Oxytetracycline	B	1.12 kg	0.35 kg
	16-Apr	Dipel 2X	*Bacillus thuringiensis*	I	2.24 kg	0.14 kg
	16-Apr	Golden Dew	Micronized sulfur	F	11.21 kg	10.31 kg
	24-Apr	Lime Sulfur	Calcium polysulfide	T	56.12 l	16.27 l
	26-Apr	Mycoshield	Oxytetracycline	B	1.12 kg	0.35 kg
	10-May	Dipel 2X	*Bacillus thuringiensis*	I	2.24 kg	0.14 kg
	10-May	Mycoshield	Oxytetracycline	B	1.12 kg	0.35 kg
	27-May	Mycoshield	Oxytetracycline	B	1.12 kg	0.35 kg
	27-Jun	Dipel 2X	*Bacillus thuringiensis*	I	2.24 kg	0.14 kg
	27-Jun	Metalosate Calcium	Chelated calcium	N	4.68 l	0.28 l
	27-Jun	Saf-T-Oil	Petroleum oil	I/F	14.03 l	11.22 l
	30-Jun	Mycoshield	Oxytetracycline	B	1.12 kg	0.35 kg
	15-Jul	Dipel 2X	*Bacillus thuringiensis*	I	2.24 kg	0.14 kg
	15-Jul	Metalosate Ca	Chelated calcium	N	4.68 l	0.28 l
	24-Jul	Dipel 2X	*Bacillus thuringiensis*	I	2.24 kg	0.14 kg
	24-Jul	Metalosate Calcium	Chelated calcium	N	0.56 l	0.03 l
	24-Jul	ReTain	Aminoethoxyvinylglycine	PGR	4.68 l	0.70 l
	24-Jul	Saf-T-Oil	Petroleum oil	I/F	14.03 l	11.22 l
Conventional	1-Apr	Supreme Oil	Petroleum oil	I/F	46.77 l	46.30 l
	1-Apr	Kocide DF	Copper hydroxide	B	6.73 kg	4.13 kg
	1-Apr	Lorsban 4E	Chlorpyrifos	I	4.68 l	2.10 l
	1-Apr	Procure	Triflumizole	F	0.58 l	0.29 l
	1-Apr	Zinc 10%	Zinc sulfate	N	9.35 l	0.94 l
	13-Apr	Lime Sulfur	Calcium polysulfide	F	74.83 l	21.70 l
	13-Apr	Rally	Myclobutanil	F	0.37 l	0.15 l
	15-Apr	Mycoshield	Oxytetracycline	B	1.12 kg	0.35 kg
	24-Apr	Captec 4L	Captan	F	3.51 l	1.31 l
	24-Apr	Guthion 50WSP	Azinphos-methyl	I	2.24 kg	1.12 kg
	24-Apr	Manzate 200DF	Mancozeb	F	6.73 kg	5.05 kg
	24-Apr	Sevin 4F	Carbaryl	T	4.68 l	2.01 l
	26-Apr	Mycoshield	Oxytetracycline	B	1.12 kg	0.35 kg
	6-May	Ethrel	Ethephon	T	2.34 l	0.51 l
	6-May	K-Salt Fruit Fix 200	1-Naphthalene acetic acid	T	0.15 l	0.01 l
	10-May	Mycoshield	Oxytetracycline	B	1.12 kg	0.35 kg
	10-May	Manzate	Mancozeb	F	6.73 kg	5.05 kg
	13-May	Roundup	Glyphosate	H	3.51 l	1.44 l
	21-May	Agrimycin 17	Streptomycin	B	1.68 kg	0.29 kg
	21-May	K-Salt Fruit Fix 200	1-Naphthalene acetic acid	T	0.07 l	0.00 l
	21-May	Mycoshield	Oxytetracycline	B	1.12 kg	0.35 kg
	21-May	Sevin 4F	Carbaryl	T	2.34 l	1.01 l

	27-May	Mycoshield	Oxytetracycline	B	1.12 kg	0.35 kg
	8-Jun	Bayleton	Triademifon	F	0.58 l	0.29 l
	8-Jun	Provado	Imidacloprid	I	0.58 l	0.10 l
	13-Jun	Imidan 50W	Phosmet	I	5.6 kg	2.80 kg
	24-Jun	Diuron	Diuron	H	3.51 l	1.43 l
	24-Jun	Roundup	Glyphosate	H	3.51 l	1.44 l
	24-Jun	Simazine 4L	Simazine	H	4.68 l	1.87 l
	1-Jul	Mora-Leaf Calcium	Calcium chloride	N	6.73 kg	6.33 kg
	12-Jul	Confirm 2F	Tebufenozide	IGR	1.17 l	0.27 l
	12-Jul	Mora-Leaf Calcium	Calcium chloride	N	6.73 kg	6.33 kg
	17-Jul	Roundup	Glyphosate	H	3.51 l	1.44 l
	24-Jul	ReTain	Aminoethoxyvinylglycine	PGR	4.68 l	0.70 l
	3-Aug	Imidan 50W	Phosmet	I	5.88 kg	2.94 kg
	20-Aug	Roundup	Glyphosate	H	3.51 l	1.44 l
	16-Oct	Roundup	Glyphosate	H	3.51 l	1.44 l
Integrated	29-Mar	Kocide DF	Copper hydroxide	B	6.73 kg	4.13 kg
	1-Apr	Lime Sulfur	Calcium polysulfide	F	93.54 l	27.13 l
	1-Apr	Supreme Oil	Petroleum oil	I/F	46.77 l	46.30 l
	14-Apr	Lime Sulfur	Calcium polysulfide	F	74.83 l	21.70 l
	15-Apr	Mycoshield	Oxytetracycline	B	1.12 kg	0.35 kg
	16-Apr	Dipel 2X	*Bacillus thuringiensis*	I	2.24 kg	0.14 kg
	16-Apr	Golden Dew	Micronized sulfur	F	11.21 kg	10.31 kg
	24-Apr	Manzate 200DF	Mancozeb	F	6.73 kg	5.05 kg
	24-Apr	Sevin 4F	Carbaryl	T	4.68 l	2.01 l
	26-Apr	Mycoshield	Oxytetracycline	B	1.12 kg	0.35 kg
	6-May	Ethrel	Ethephon	T	2.34 l	0.51 l
	6-May	K-Salt Fruit Fix 200	1-Naphthalene acetic acid	T	0.15 l	0.01 l
	10-May	Mycoshield	Oxytetracycline	B	1.12 kg	0.35 kg
	10-May	Manzate	Mancozeb	F	6.73 kg	5.05 kg
	13-May	Roundup	Glyphosate	H	3.51 l	1.44 l
	21-May	Agrimycin 17	Streptomycin	B	1.68 kg	0.29 kg
	21-May	K-Salt Fruit Fix 200	1-Naphthalene acetic acid	T	0.07 l	0.00 l
	21-May	Sevin 4F	Carbaryl	T	2.34 l	1.01 l
	27-May	Mycoshield	Oxytetracycline	B	1.12 kg	0.35 kg
	27-Jun	Dipel 2X	*Bacillus thuringiensis*	I	2.24 kg	0.14 kg
	27-Jun	Metalosate Calcium	Chelated calcium	N	4.68 l	0.28 l
	27-Jun	Saf-T-Oil	Petroleum oil	I/F	14.03 l	11.22 l
	12-Jul	Confirm 2F	Tebufenozide	IGR	1.17 l	0.27 l
	12-Jul	Mora-Leaf Calcium	Calcium chloride	N	6.73 kg	6.33 kg
	15-Jul	Dipel 2X	*Bacillus thuringiensis*	I	2.24 kg	0.14 kg
	15-Jul	Metalosate Ca	Chelated calcium	N	4.68 l	0.28 l
	17-Jul	Roundup	Glyphosate	H	3.51 l	1.44 l
	24-Jul	Dipel 2X	*Bacillus thuringiensis*	I	2.24 kg	0.14 kg
	24-Jul	Metalosate Calcium	Chelated calcium	N	0.56 l	0.03 l
	24-Jul	ReTain	Aminoethoxyvinylglycine	PGR	4.68 l	0.70 l
	24-Jul	Saf-T-Oil	Petroleum oil	I/F	14.03 l	11.22 l
	26-Jul	Roundup	Glyphosate	H	3.51 l	1.44 l
	20-Aug	Roundup	Glyphosate	H	3.51 l	1.44 l
	16-Oct	Roundup	Glyphosate	H	3.51 l	1.44 l

1B	Date	Product Name	Chemical Name	Purpose	Rate/ha	a.i./ha
Organic	23-Mar	Lime Sulfur	Calcium polysulfide	F	74.83 l	21.70 l
	23-Mar	Supreme Oil	Petroleum oil	I	28.06 l	27.78 l
	7-Apr	Mycoshield	Oxytetracycline	B	1.12 kg	0.35 kg
	18-Apr	Crockers Fish Oil	Fish oil	T	18.71 l	18.34 l
	18-Apr	Lime Sulfur	Calcium polysulfide	T	23.38 l	6.78 l
	18-Apr	Superior Oil N.W.	Petroleum oil	T	4.68 l	4.63 l
	21-Apr	Crockers Fish Oil	Fish oil	T	18.71 l	18.34 l
	21-Apr	Lime Sulfur	Calcium polysulfide	T	18.71 l	5.43 l
	21-Apr	Superior Oil N.W.	Petroleum oil	T	4.68 l	4.63 l
	22-Apr	Dipel 2X	*Bacillus thuringiensis*	I	2.24 kg	0.14 kg
	22-Apr	Pronatural Zinc	Zinc	N	2.34 l	0.14 l
	22-Apr	Serenade	*Bacillus subtilis*	F/B	6.73 kg	0.67 kg
	22-Apr	Spraybor	Sodium borate	N	5.6 kg	0.92 kg
	25-Apr	Mycoshield	Oxytetracycline	B	1.12 kg	0.35 kg
	20-May	Entrust	Spinosad	I	0.15 l	0.12 l
	20-May	Mermaid`s OrganicFish Fertilizer WP	Fish emulsion (N-P-K)	N	3.36 kg	.34 kg .034 kg .034 kg
	20-May	Pronatural Zinc	Zinc	N	1.17 l	0.07 l
	20-May	Superior Oil N.W.	Petroleum oil	I	9.35 l	9.26 l
	19-Jun	Superior Oil N.W.	Petroleum oil	I	9.35 l	9.26 l
	26-Jul	Entrust	Spinosad	I	0.15 l	0.12 l
	26-Jul	Superior Oil N.W.	Petroleum oil	I	9.35 l	9.26 l
Conventional	23-Mar	Lime Sulfur	Calcium polysulfide	F	74.83 l	21.70 l
	23-Mar	Lorsban 50W	Chlorpyrrifos	I	4.68 l	2.34 l
	23-Mar	Procure 50WS	Triflumizol	F	0.58 l	0.29 l
	23-Mar	Solubor DF	Boron	N	3.36 kg	0.59 kg
	23-Mar	Supreme Oil	Petroleum oil	I	28.06 l	27.78 l
	23-Mar	Zinc 10%	Zinc sulfate	N	9.35 l	0.94 l
	7-Apr	Mycoshield	Oxytetracycline	B	1.12 kg	0.35 kg
	18-Apr	Crockers Fish Oil	Fish oil	T	18.71 l	18.34 l
	18-Apr	Lime Sulfur	Calcium polysulfide	T	23.38 l	6.78 l
	18-Apr	Superior Oil N.W.	Petroleum oil	T	4.68 l	4.63 l
	21-Apr	Crockers Fish Oil	Fish oil	T	18.71 l	18.34 l
	21-Apr	Lime Sulfur	Calcium polysulfide	T	18.71 l	5.43 l
	21-Apr	Superior Oil N.W.	Petroleum oil	T	4.68 l	4.63 l
	22-Apr	Sevin 4F	Carbaryl	T	4.68 l	2.01 l
	23-Apr	Dithane	Mancozeb	F	6.73 kg	5.38 kg
	23-Apr	Rally 40W	Myclobutanil	F	0.37 l	0.15 l
	23-Apr	Success	Spinosad	I	0.44 l	0.10 l
	25-Apr	Mycoshield	Oxytetracycline	B	1.12 kg	0.35 kg
	6-May	Dithane	Mancozeb	F	6.73 kg	5.38 kg
	12-May	K-Salt Fruit Fix 200	1-Naphthalene acetic acid	T	0.15 l	0.01 l
	12-May	Sevin 4F	Carbaryl	T/I	2.34 l	1.01 l
	18-May	Assail 70WP	Acetamidine	I	0.25 l	0.18 l
	18-May	Superior Oil N.W.	Petroleum oil	I	9.35 l	9.26 l
	8-Jun	Mora-Leaf Calcium	Calcium chloride	N	6.73 kg	6.33 kg
	18-Jun	Ethrel	Ethephon	T	2.34 l	0.51 l
	18-Jun	Guthion 50WSP	Azinphos-methyl	I	2.24 kg	1.12 kg
	18-Jun	Last Call	Permethrin	I	0.39 l	0.02 l

	15-Jul	Guthion 50WSP	Azinphos-methyl	I	2.24 kg	1.12 kg
	15-Jul	Mora-Leaf Calcium	Calcium chloride	N	6.73 kg	6.33 kg
	6-Aug	Guthion 50WSP	Azinphos-methyl	I	2.24 kg	1.12 kg
	6-Aug	Mora-Leaf Calcium	Calcium chloride	N	6.73 kg	6.33 kg
Integrated	23-Mar	Lime Sulfur	Calcium polysulfide	F	74.83 l	21.70 l
	23-Mar	Supreme Oil	Petroleum oil	I	28.06 l	27.78 l
	7-Apr	Mycoshield	Oxytetracycline	B	1.12 kg	0.35 kg
	18-Apr	Crockers Fish Oil	Fish oil	T	18.71 l	18.34 l
	18-Apr	Lime Sulfur	Calcium polysulfide	T	23.38 l	6.78 l
	18-Apr	Superior Oil N.W.	Petroleum oil	T	4.68 l	4.63 l
	21-Apr	Crockers Fish Oil	Fish oil	T	18.71 l	18.34 l
	21-Apr	Lime Sulfur	Calcium polysulfide	T	18.71 l	5.43 l
	21-Apr	Superior Oil N.W.	Petroleum oil	T	4.68 l	4.63 l
	22-Apr	Dipel 2X	*Bacillus thuringiensis*	I	2.24 kg	0.14 kg
	22-Apr	Pronatural Zinc	Zinc	N	2.34 l	0.14 l
	22-Apr	Serenade	*Bacillus subtilis*	F/B	6.73 kg	0.67 kg
	22-Apr	Spraybor	Sodium borate	N	5.6 kg	0.92 kg
	25-Apr	Mycoshield	Oxytetracycline	B	1.12 kg	0.35 kg
	20-May	Entrust	Spinosad	I	0.15 l	0.12 l
	20-May	Mermaid`s OrganicFish Fertilizer WP	Fish emulsion (N-P-K)	N	3.36 kg	.34 kg .034 kg .034 kg
	20-May	Pronatural Zinc	Zinc	N	1.17 l	0.07 l
	20-May	Superior Oil N.W.	Petroleum oil	I	9.35 l	9.26 l
	19-Jun	Superior Oil N.W.	Petroleum oil	I	9.35 l	9.26 l
	26-Jul	Entrust	Spinosad	I	0.15 l	0.12 l
	26-Jul	Superior Oil N.W.	Petroleum oil	I	9.35 l	9.26 l

[z] B = bactericide; I = insecticide; IGR = insect growth regulator; F = fungicide; N = nutrient; PGR = plant growth regulator; T = thinning.

Table 2. Crop yields, floral intensity, yield efficiency, crop density, average fruit weight, and percent of unmarketable fruit in organic, conventional, and integrated apple farm management systems in 2002 and 2003.

	Year	Organic	Conventional	Integrated
Yield	2002	15.28 a[z]	46.28 b	30.13 c
(Mg/ha)	2003	56.50 a	35.70 b	36.96 b
Floral intensity	2002	0.29 a	0.67 b	0.45 c
(flower buds/total buds)	2003	0.81 a	0.59 b	0.68 c
Crop density	2002	0.80 a	2.43 b	1.64 c
(no. of fruit/ cm^2 TCSA)	2003	3.23 a	1.59 b	1.57 b
Yield efficiency	2002	0.14 a	0.40 b	0.25 c
(kg/cm^2 TCSA)	2003	0.49 a	0.29 b	0.30 b
Average fruit size	2002	0.176 a	0.168 b	0.164 b
(kg)	2003	0.158 a	0.188 b	0.196 b
Unmarketable culls	2002	—	—	—
(%)	2003	42 a	33 a	31 a

[z] Differences among treatments within each year followed by different letters are significant at the 0.05 level (LSD).

Table 3. Leaf mineral concentrations of organic, conventional, and integrated apple farm management systems for 2002 and 2003.

	Year	Organic	Conventional	Integrated
Total Nitrogen (%)	2002	2.46 a[z]	2.67 b	2.67 b
	2003	2.44 a	2.54 a	2.61 a
Phosphorus (%)	2002	0.24 a	0.23 a	0.22 a
	2003	0.22 a	0.18 b	0.19 b
Potassium (%)	2002	1.53 a	1.63 a	1.66 a
	2003	1.49 a	1.48 a	1.55 a
Sulphur (%)	2002	0.15 a	0.20 b	0.18 c
	2003	0.19 a	0.21 b	0.20 ab
Calcium (%)	2002	1.30 a	1.94 b	1.62 a
	2003	1.94 a	2.00 a	1.79 a
Magnesium (%)	2002	0.25 a	0.33 b	0.31 b
	2003	0.33 a	0.36 a	0.35 a
Boron (ppm)	2002	23.25 a	24.50 a	25.00 a
	2003	28.00 a	24.50 b	27.00 ab
Zinc (ppm)	2002	11.50 a	20.25 b	17.00 c
	2003	17.25 a	17.75 a	17.50 a
Manganese (ppm)	2002	48.50 a	106.25 b	95.00 b
	2003	49.75 a	81.50 b	46.75 a
Copper (ppm)	2002	7.25 a	7.75 ab	8.50 b
	2003	7.25 a	6.25 b	7.75 a
Iron (ppm)	2002	265.25 a	238.75 a	262.75 a
	2003	128.25 a	101.00 b	117.75 ab

[z] Differences among treatments within each year followed by different letters are significant at the 0.05 level (LSD).

Table 4. Fruit mineral concentrations of organic, conventional, and integrated apple farm management systems for 2002 and 2003.

	Year	Organic	Conventional	Integrated
Total Nitrogen (%)	2002	0.25 a[z]	0.27 ab	0.29 b
	2003	0.31 a	0.41 b	0.35 c
Phosphorus (%)	2002	0.07 a	0.07 a	0.07 a
	2003	0.08 a	0.09 a	0.08 a
Potassium (%)	2002	0.85 a	0.87 a	0.88 a
	2003	0.84 a	0.91 b	0.86 ab
Calcium (%)	2002	0.03 ab	0.04 a	0.03 b
	2003	0.03 a	0.03 a	0.03 a
Magnesium (%)	2002	0.04 a	0.04 a	0.04 a
	2003	0.03 a	0.03 a	0.03 a
Boron (ppm)	2002	11.75 a	10.50 a	10.75 a
	2003	17.60 a	12.93 b	17.33 a
Zinc (ppm)	2002	4.50 a	7.00 a	5.25 a
	2003	1.08 a	0.98 a	0.90 a
Nitrogen:Calcium	2002	8.25 a	7.34 a	10.67 b
	2003	11.05 a	13.90 b	11.99 a
Magnesium:Calcium	2002	1.33 a	1.17 a	1.50 a
	2003	1.12 a	1.14 a	1.13 a
Magnesium +	2002	29.58 ab	25.46 b	34.54 a
Potassium:Calcium	2003	30.89 a	32.07 a	30.64 a
Nitrogen:Phosphorus	2002	3.54 a	3.93 a	3.96 a
	2003	3.91 a	4.80 a	4.40 a

[z] Differences among treatments within each year followed by different letters are significant at the 0.05 level (LSD).

Table 5. Soil mineral concentrations at three depths in organic (ORG), conventional (CON), and integrated (INT) apple farm management systems in 2002 and 2003.

	Soil Depth (cm)	2002			2003		
		ORG	CON	INT	ORG	CON	INT
Total nitrogen	0-7.5	1955.0 a[z]	1242.5 b	1755.0 a	1532.5 a	1332.5 a	1505.0 a
(ppm)	7.5-15	1165.0 a	1060.0 a	1290.0 a	1075.0 a	980.0 a	1085.0 a
	15-30	712.5 a	865.0 b	872.5 b	802.5 a	755.0 a	737.5 a
Nitrate-nitrogen	0-7.5	9.8 a	5.8 a	10.8 a	29.8 a	27.8 a	39.8 a
(ppm)	7.5-15	5.3 a	4.3 a	7.8 b	6.5 a	13.3 b	8.8 ab
	15-30	4.0 a	6.5 a	6.5 a	8.0 a	14.3 b	9.0 ab
Ammonia-nitrogen	0-7.5	3.3 a	2.5 a	5.0 a	25.0 a	14.3 a	35.5 a
(ppm)	7.5-15	2.5 a	3.0 a	2.3 a	3.3 a	5.0 a	4.3 a
	15-30	2.5 a	2.5 a	1.5 a	4.0 a	6.5 a	3.8 a
Phosphorus	0-7.5	51.0 a	43.3 a	56.3 a	39.3 a	43.8 a	45.0 a
(ppm)	7.5-15	37.3 a	37.5 a	54.5 b	35.8 a	37.3 a	44.8 b
	15-30	30.3 a	30.5 a	43.0 a	25.5 a	27.5 ab	33.8 b
Potassium	0-7.5	665.3 a	479.8 a	577.8 a	459.3 a	454.0 a	454.5 a
(ppm)	7.5-15	439.8 a	338.0 a	469.8 a	399.8 a	361.5 a	430.8 a
	15-30	377.5 ab	307.5 a	434.5 b	343.3 a	298.5 a	370.3 a
Sulfur	0-7.5	6.8 a	24.3 b	5.0 a	10.0 a	12.5 b	9.8 a
(ppm)	7.5-15	9.5 ab	21.0 b	6.0 a	7.5 a	10.8 b	9.0 ab
	15-30	17.8 a	13.5 a	17.3 a	9.8 a	16.3 a	8.0 a
Boron	0-7.5	0.7 a	0.9 a	0.4 a	1.3 ab	2.3 b	0.9 a
(ppm)	7.5-15	0.6 a	0.8 a	0.4 a	1.0 a	1.0 a	1.1 a
	15-30	1.1 a	0.5 a	0.3 a	1.0 a	0.9 a	1.1 a
Zinc	0-7.5	2.5 ab	3.3 b	0.2 a	3.3 a	5.8 b	6.0 b
(ppm)	7.5-15	2.1 a	2.1 a	0.1 b	1.9 a	2.1 a	2.7 a
	15-30	2.0 a	0.9 a	0.8 a	1.1 a	1.3 a	1.5 a
Manganese	0-7.5	2.9 a	5.8 a	4.3 a	5.5 a	8.0 a	8.0 a
(ppm)	7.5-15	3.2 a	4.4 a	3.5 a	3.7 a	4.3 a	4.5 a
	15-30	3.9 a	4.4 a	7.6 a	3.2 a	3.5 a	3.2 a
Copper	0-7.5	2.6 a	4.0 a	1.5 a	5.7 a	5.3 a	6.2 a
(ppm)	7.5-15	2.2 a	3.1 a	1.5 a	4.0 a	3.0 b	3.8 a
	15-30	2.5 a	1.8 a	1.6 a	3.0 a	2.8 a	3.0 a
Iron	0-7.5	26.3 a	43.0 a	30.3 a	52.8 a	71.5 a	58.8 a
(ppm)	7.5-15	80.0 a	33.0 a	22.0 a	46.5 a	61.0 a	66.0 a
	15-30	59.0 a	30.5 a	144.0 a	35.0 a	37.3 a	45.0 a
Calcium	0-7.5	10.4 a	11.3 a	10.7 a	11.1 a	11.5 a	11.1 a
(meq/100g)	7.5-15	9.4 a	10.2 a	10.1 a	11.2 a	12.4 a	10.3 a
	15-30	9.8 a	11.7 a	9.1 a	10.9 a	13.5 a	9.8 a

Magnesium (meq/100g)	0-7.5	4.3 a	4.4 a	4.1 a	4.4 a	3.9 a	4.1 a
	7.5-15	4.1 a	4.0 a	4.0 a	4.6 a	4.0 b	4.0 b
	15-30	4.2 a	4.1 a	3.9 a	4.4 a	4.1 a	4.1 a
Sodium (meq/100g)	0-7.5	0.2 a	0.1 a	0.1 a	0.2 a	0.1 b	0.1 b
	7.5-15	0.2 a	0.1 a	0.1 a	0.2 a	0.1 a	0.2 a
	15-30	0.2 a	0.2 a	0.1 a	0.2 a	0.1 b	0.2 ab

[z] Differences among treatments within each year followed by different letters are significant at the 0.05 level (LSD).

Table 6. Chemical and physical soil properties at three depths in organic (ORG), conventional (CON), and integrated (INT) apple farm management systems in 2002 and 2003.

	Soil Depth (cm)	**2002**			**2003**		
		ORG	**CON**	**INT**	**ORG**	**CON**	**INT**
Organic matter (%)	0-7.5	3.4 a[z]	2.2 b	3.1 a	2.1 a	2.0 a	2.4 a
	7.5-15	2.2 a	1.7 b	2.3 a	1.6 a	1.6 a	1.9 a
	15-30	1.4 a	1.4 a	1.4 a	1.3 ab	1.2 b	1.3 a
Cation exchange capacity (meq/100g)	0-7.5	17.1 a	15.6 a	16.5 a	17.4 a	16.8 a	16.0 a
	7.5-15	16.8 a	14.6 a	15.2 a	17.0 a	16.3 a	15.9 a
	15-30	15.1 a	15.4 a	14.9 a	17.4 a	15.5 a	15.8 a
pH	0-7.5	6.9 a	7.2 b	6.9 a	6.4 a	6.3 a	6.3 a
	7.5-15	6.9 a	6.9 a	6.7 a	6.6 a	6.3 a	6.2 a
	15-30	7.0 a	6.9 a	6.7 a	6.6 a	6.5 a	6.3 a
Electrical conductivity (mmhos/cm)	0-7.5	0.6 a	0.5 a	0.6 a	1.0 a	0.8 a	1.1 a
	7.5-15	0.5 a	0.3 a	0.5 a	0.4 a	0.6 a	0.5 a
	15-30	0.4 a	0.5 ab	0.5 b	0.4 a	0.5 a	0.4 a
Bulk density (Mg/m^3)	0-7.5	1.15 a	1.26 a	1.29 a	1.11 a	1.21 a	1.13 a
	7.5-15	1.23 a	1.3 a	1.24 a	1.34 a	1.23 a	1.24 a
	15-30	1.15 a	1.12 a	1.16 a	1.12 a	1.19 b	1.22 c
Porosity (%)	0-7.5	57 a	52 a	51 a	58 a	55 b	57 ab
	7.5-15	54 a	51 a	53 a	50 a	54 a	53 a
	15-30	57 a	58 a	56 a	58 a	55 b	54 c
Water-filled pore space (%)	0-7.5	58 a	61 a	66 a	32 a	37 a	37 a
	7.5-15	60 a	65 a	58 a	54 a	47 a	50 a
	15-30	47 a	47 a	52 a	37 a	42 b	48 ab

[z] Differences among treatments within each year followed by different letters are significant at the 0.05 level (LSD).

Table 7. Starch index for apples in organic (ORG), conventional (CON), and integrated (INT) farm management systems in 2002 and 2003.

	2002			2003		
	ORG	CON	INT	ORG	CON	INT
First harvest	4.0 a[z]	4.3 ab	4.5 b	3.5 a	4.3 b	3.5 a
Second harvest	4.1 a	4.3 a	4.5 a	4.4 a	4.8 b	4.4 a

[z] Differences among treatments within each year followed by different letters are significant at the 0.05 level (LSD).

Table 8. Flesh firmness, soluble solid concentration (SSC), titratable acidity (TA), and the ratio of SSC:TA of apples from organic (ORG), conventional (CON), and integrated (INT) farm management systems measured at two harvests, after three storage treatments, and before and after a seven day shelf-life in 2002 and 2003.

Time of analysis	Shelf-life Day	Analytical Measurement	2002 ORG	2002 CON	2002 INT	2003 ORG	2003 CON	2003 INT
First harvest	1	Firmness (N)	79.44 a[z]	76.50 b	73.10 c	82.15 a	72.82 b	81.35 a
		SSC (ºBrix)	13.4 a	13.3 ab	13.1 b	11.8 a	12.4 b	12.3 ab
		TA (%)	0.57 a	0.57 a	0.56 a	0.36 a	0.36 a	0.39 b
		SSC:TA	23.8 a	24.1 a	23.6 a	33.0 ab	34.4 a	31.4 b
	7	Firmness (N)	—	—	—	70.05 a	61.81 b	67.31 a
		SSC (ºBrix)	—	—	—	12.3 a	13.3 b	12.7 c
		TA (%)	—	—	—	0.32 a	0.33 b	0.34 b
		SSC:TA	—	—	—	39.6 ab	40.1 a	38.0 b
Second harvest	1	Firmness (N)	78.59 a	77.77 a	71.96 b	78.42 a	71.15 b	76.70 a
		SSC (ºBrix)	14.5 a	14.1 b	14.0 b	11.2 a	12.4 b	11.8 c
		TA (%)	0.60 a	0.58 a	0.51 a	0.35 a	0.38 b	0.39 b
		SSC:TA	24.2 a	24.8 a	27.8 b	32.2 a	33.4 a	30.7 b
	7	Firmness (N)	70.55 a	64.10 b	63.92 b	—	—	—
		SSC (ºBrix)	15.0 a	13.9 b	14.5 c	—	—	—
		TA (%)	0.49 a	0.42 b	0.55 c	—	—	—
		SSC:TA	30.9 a	33.3 b	26.5 c	—	—	—
Regular atmosphere three months	1	Firmness (N)	64.44 a	56.98 b	59.01 b	67.66 a	58.71 b	65.17 c
		SSC (ºBrix)	13.5 a	13.3 a	13.4 a	12.3 a	12.6 b	12.1 a
		TA (%)	0.44 a	0.40 b	0.39 b	0.31 a	0.32 a	0.33 b
		SSC:TA	31.1 a	33.4 b	34.9 c	39.8 a	39.7 a	36.7 b
	7	Firmness (N)	57.72 a	51.70 b	50.92 b	63.25 a	55.24 b	58.53 c
		SSC (ºBrix)	14.2 a	13.4 b	13.4 b	14.8 a	12.9 a	12.4 a
		TA (%)	0.39 a	0.35 b	0.35 b	0.27 a	0.29 a	0.28 a
		SSC:TA	36.2 a	38.1 b	38.3 b	57.2 a	45.5 a	44.2 a
Controlled atmosphere three months	1	Firmness (N)	64.49 a	57.02 b	56.50 b	78.33 a	65.88 b	73.33 c
		SSC (ºBrix)	14.0 a	13.7 b	13.6 b	12.0 a	12.7 b	12.3 c
		TA (%)	0.50 a	0.45 b	0.44 b	0.36 a	0.37 a	0.37 a
		SSC:TA	28.3 a	30.4 b	31.4 b	33.6 a	34.3 a	33.8 a

	7	Firmness (N)	60.86 a	53.91 b	52.85 b	79.39 a	64.74 b	73.58 c
		SSC (ºBrix)	14.1 a	13.6 b	13.7 b	12.1 a	13.2 b	12.6 c
		TA (%)	0.44 a	0.41 b	0.40 b	0.32 a	0.35 b	0.36 b
		SSC:TA	32.4 a	33.6 b	34.5 b	38.3 a	37.9 a	34.9 b
Controlled atmosphere six months	1	Firmness (N)	57.27 a	51.68 b	50.66 b	77.22 a	70.08 b	75.31 a
		SSC (ºBrix)	14.3 a	13.7 b	13.6 b	12.4 a	12.7 b	12.2 c
		TA (%)	0.47 a	0.44 b	0.43 c	0.34 a	0.35 a	0.35 a
		SSC:TA	30.6 a	31.0 a	32.1 b	36.7 a	36.8 a	34.7 b
	7	Firmness (N)	56.51 a	50.96 b	47.10 c	75.86 a	62.98 b	68.60 c
		SSC (ºBrix)	14.1 a	13.8 ab	13.7 b	12.1 a	13.0 b	12.8 b
		TA (%)	0.44 a	0.41 b	0.41 b	0.31 a	0.35 b	0.35 b
		SSC:TA	32.4 a	33.6 a	33.3 a	39.1 a	37.6 b	37.1 b

[z] Differences among treatments within each year followed by different letters are significant at the 0.05 level (LSD).

Table 9. Consumer sensory panelist ratings of overall acceptability, texture, flavor, firmness, sweetness, and tartness of apples from organic (ORG), conventional (CON), and integrated (INT) apple farm management systems measured at two harvests, after three storage treatments, and before and after a seven day shelf-life in 2002 and 2003. Ratings of overall acceptability, texture, and flavor were based on a 9-point hedonic scale (1=dislike extremely; 9=like extremely). Ratings of firmness, sweetness, and tartness were based on a 9-point intensity scale (1=very soft, not at all sweet, or not at all tart, respectively; 9=very hard, extremely sweet, or extremely tart, respectively).

Time of analysis	Shelf-life		2002			2003		
	Day	Measurement	ORG	CON	INT	ORG	CON	INT
First harvest	1	Overall	—	—	—	6.2 a^{z}	6.5 ab	6.8 b
		Texture	—	—	—	6.5 a	6.3 a	6.7 a
		Flavor	—	—	—	5.9 a	6.2 a	6.5 a
		Firmness	—	—	—	6.8 a	6.1 b	6.4 ab
		Sweetness	—	—	—	5.0 a	5.8 b	5.6 ab
		Tartness	—	—	—	4.9 a	4.5 a	4.6 a
	7	Overall	—	—	—	6.7 a	6.5 a	6.3 a
		Texture	—	—	—	6.8 a	6.4 a	6.2 a
		Flavor	—	—	—	6.6 a	6.3 a	6.3 a
		Firmness	—	—	—	6.1 a	5.5 b	5.6 ab
		Sweetness	—	—	—	5.5 a	5.5 a	5.8 a
		Tartness	—	—	—	4.5 a	4.2 a	4.2 a
Second harvest	1	Overall	6.8 a	6.7 a	7.0 a	—	—	—
		Texture	6.8 a	6.8 a	6.9 a	—	—	—
		Flavor	6.6 a	6.5 a	6.8 a	—	—	—
		Firmness	6.6 a	6.4 a	6.2 a	—	—	—
		Sweetness	5.6 a	5.8 a	6.0 a	—	—	—
		Tartness	4.7 a	4.3 a	4.4 a	—	—	—
Regular atmosphere three months	1	Overall	5.9 a	6.6 b	6.3 ab	6.8 a	5.8 b	6.0 b
		Texture	5.9 a	6.3 a	6.0 a	7.0 a	6.0 b	6.1 b
		Flavor	5.6 a	6.5 b	6.2 ab	6.4 a	5.8 b	5.9 ab
		Firmness	5.4 a	5.1 a	5.3 a	6.5 a	5.5 b	5.8 b
		Sweetness	5.4 a	6.1 b	5.8 ab	5.9 a	5.5 ab	5.3 b
		Tartness	4.0 a	3.9 a	3.8 a	4.8 a	4.0 b	3.9 b
	7	Overall	6.1 a	5.4 b	5.0 b	5.9 a	5.3 a	5.4 a
		Texture	6.1 a	5.2 b	5.0 b	5.8 a	5.1 a	5.3 a
		Flavor	6.4 a	5.4 b	5.2 b	5.7 a	5.3 a	5.7 a
		Firmness	5.4 a	4.6 b	4.1 b	5.0 a	4.6 a	4.6 a
		Sweetness	5.5 a	5.1 a	5.1 a	5.8 a	5.6 a	5.5 a
		Tartness	4.3 a	3.6 ab	3.5 b	3.9 a	3.6 a	3.8 a

Controlled atmosphere three months	1	Overall	6.4 a	6.1 a	6.2 a	6.7 a	6.3 a	6.7 a
		Texture	6.6 a	6.0 a	6.0 a	6.9 a	6.2 b	7.1 a
		Flavor	6.2 a	6.0 a	6.1 a	6.5 a	6.0 a	6.3 a
		Firmness	6.0 a	5.6 ab	5.3 b	7.0 a	5.4 b	6.6 a
		Sweetness	5.7 a	5.3 a	5.5 a	5.4 a	5.3 a	5.3 a
		Tartness	4.0 a	4.1 a	3.7 a	4.8 a	4.4 a	5.0 a
	7	Overall	5.9 a	6.1 a	6.9 b	6.2 ab	5.7 b	6.5 a
		Texture	5.7 a	5.8 a	6.8 b	6.6 a	6.0 b	6.8 a
		Flavor	5.9 a	5.9 a	6.6 b	6.0 a	5.7 b	6.3 ab
		Firmness	4.8 a	5.3 a	6.1 b	6.6 a	5.8 a	6.4 a
		Sweetness	5.5 a	5.5 a	5.9 a	5.3 a	5.7 a	5.6 a
		Tartness	3.9 a	4.0 a	4.5 a	4.5 a	4.0 a	4.5 a
Controlled atmosphere six months	1	Overall	6.2 a	6.1 a	5.8 a	6.3 ab	5.7 b	6.5 a
		Texture	5.9 a	5.8 ab	5.1 b	6.7 a	5.5 b	6.6 a
		Flavor	6.3 a	6.0 a	6.0 a	5.9 ab	5.5 b	6.2 a
		Firmness	5.3 a	5.0 a	4.7 a	6.7 a	5.1 b	6.3 a
		Sweetness	5.6 a	5.7 a	5.7 a	5.1 a	5.2 a	5.1 a
		Tartness	4.5 a	4.4 a	4.1 a	5.1 a	4.3 b	5.0 ab
	7	Overall	6.3 a	5.6 b	5.1 b	6.3 a	5.9 a	6.1 a
		Texture	6.0 a	5.4 ab	4.8 b	6.6 a	5.8 b	6.3 ab
		Flavor	5.9 a	5.5 ab	5.2 b	6.0 a	5.7 a	6.1 a
		Firmness	5.6 a	4.9 ab	4.4 b	6.3 a	5.2 b	5.9 a
		Sweetness	5.9 a	5.3 ab	5.1 b	5.2 a	5.4 a	5.0 a
		Tartness	4.8 a	3.9 b	3.8 b	5.0 a	4.5 a	4.8 a

[z] Differences among treatments within each year followed by different letters are significant at the 0.05 level (LSD).

Tables 10A-B. Probability values of main effects, sub-plots, and interactions for analytical measurements of fruit quality, consumer sensory panels, volatiles, and antioxidant activities in 2002 (A) and 2003 (B).

10A	**Treatment**	**Storage**	**Shelf-life**	**Treatment* Storage**	**Treatment* Shelf-life**	**Storage* Shelf-life**	**Treatment* Storage* Shelf-life**
Firmness	0.0017	<.0001	<.0001	0.2345	0.1845	0.0004	0.8244
SSC	0.2103	0.0023	0.084	0.7404	0.5763	0.2587	0.1612
TA	0.0029	<.0001	<.0001	0.6613	0.1581	0.016	0.85
SSC:TA	0.0301	<.0001	<.0001	0.2849	0.2473	0.0024	0.7939
Overall acceptability	0.3319	0.0361	0.0141	0.0833	0.2966	0.0599	0.0296
Texture	0.119	0.0059	0.0455	0.0507	0.4658	0.2724	0.025
Flavor	0.6032	0.2092	0.0412	0.2926	0.2237	0.2313	0.0389
Firmness	0.0871	0.0054	0.0363	0.0595	0.9126	0.2826	0.0034
Sweetness	0.7614	0.8555	0.1244	0.4365	0.3001	0.073	0.1444
Tartness	0.2369	0.1829	0.9318	0.4354	0.261	0.4644	0.4008
Alcohols	0.0665	<.0001	0.4052	0.699	0.7796	0.0126	0.8524
Aldehydes	0.4402	<.0001	0.0007	0.099	0.0062	0.492	0.0021
Esters	0.0027	<.0001	0.1715	0.1636	0.3431	0.3563	0.0168
Total volatiles	0.0068	<.0001	0.4782	0.2067	0.4508	0.097	0.1747
HAA	0.0048	0.9199		0.9399			
LAA	0.0138	0.0244		0.6924			
Peel TAA	0.0025	0.2706		0.8699			
Flesh TAA	0.0317	0.0137		0.5033			
Peel + Flesh TAA	0.0035	0.9804		0.91			
TAA 200 g apple^{-1}	0.0112	0.3994		0.8251			

10B	Treatment	Storage	Shelf-life	Treatment* Storage	Treatment* Shelf-life	Storage* Shelf-life	Treatment* Storage* Shelf-life
Firmness	<.0001	<.0001	0.882	0.1439	0.6101	<.0001	0.1437
SSC	0.0119	0.4599	0.0005	0.1601	0.0202	0.7105	0.4157
TA	0.0353	<.0001	<.0001	0.9072	0.0035	0.0001	0.0527
SSC:TA	<.0001	<.0001	<.0001	0.1442	0.1522	0.0026	0.3704
Overall acceptability	0.0144	0.0036	0.0102	0.8074	0.2918	0.0562	0.2859
Texture	0.0019	0.0005	0.0002	0.7732	0.1345	0.0008	0.1695
Flavor	0.0382	0.048	0.044	0.5276	0.8518	0.4992	0.8786
Firmness	0.0011	0.002	<.0001	0.2629	0.5811	<.0001	0.3659
Sweetness	0.511	0.0633	0.3706	0.8503	0.4468	0.5445	0.7982
Tartness	0.0252	0.0004	0.0042	0.8203	0.4836	0.0793	0.4014
Alcohols	0.1454	0.0001	0.2874	0.1087	0.2993	0.1153	0.4211
Aldehydes	0.3126	0.0053	0.0052	0.2822	0.0573	<.0001	0.2985
Esters	<.0001	<.0001	0.0002	<.0001	0.8106	<.0001	0.4091
Total volatiles	0.0206	<.0001	0.0489	0.0053	0.297	0.0005	0.3647
HAA	0.044	<.0001		0.8242			
LAA	0.3007	0.0007		0.1654			
Peel TAA	0.0278	<.0001		0.7803			
Flesh TAA	0.2589	<.0001		0.9542			
Peel + Flesh TAA	0.0438	<.0001		0.9357			
TAA 200 g apple^{-1}	0.0931	<.0001		0.5471			

Table 11. Purgeable volatile concentrations of apples from organic (ORG), conventional (CON), and integrated (INT) farm management systems measured at two harvests, after three storage treatments, and before and after a seven day shelf-life in 2002 and 2003.

Time of analysis	Shelf-life (day)	Chemical classification	2002 ORG	2002 CON	2002 INT	2003 ORG	2003 CON	2003 INT
First harvest	1	Alcohols (ng mL^{1})	—	—	—	220.4 a[z]	514.4 a	315.8 a
		Aldehydes(ng mL^{1})	—	—	—	525.3 a	532.1 a	396.3 a
		Esters (ng mL^{1})	—	—	—	727.2 a	1524.9 b	570.6 a
		Total volatiles (ng mL^{1})	—	—	—	1476.5 a	2576.8 b	1286.7 a
	7	Alcohols (ng mL^{1})	—	—	—	980.4 a	1359.6 a	1156.8 a
		Aldehydes(ng mL^{1})	—	—	—	477.4 a	490.6 a	358.8 a
		Esters (ng mL^{1})	—	—	—	1968.0 a	3231.5 b	1624.7 a
		Total volatiles (ng mL^{1})	—	—	—	3431.1 a	5087.0 b	3144.9 a
Second harvest	1	Alcohols (ng mL^{1})	453.1 a	417.5 a	583.9 a	405.4 a	876.0 a	494.9 a
		Aldehydes(ng mL^{1})	179.5 a	95.3 b	104.3 b	708.6 a	298.5 a	328.4 a
		Esters (ng mL^{1})	486.8 a	633.9 a	626.7 a	459.9 a	1185.3 b	513.5 a
		Total volatiles (ng mL^{1})	1123.2 a	1149.5 a	1318.2 a	1575.7 a	2362.1 a	1339.4 a
	7	Alcohols (ng mL^{1})	883.4a	735.9 a	1134.0 a	—	—	—
		Aldehydes(ng mL^{1})	181.9 a	190.4 a	253.2 b	—	—	—
		Esters (ng mL^{1})	1349.0a	1502.3 a	1749.5 a	—	—	—
		Total volatiles (ng mL^{1})	2420.5 a	2436.4 a	3144.4 a	—	—	—
Regular atmosphere 3 months	1	Alcohols (ng mL^{1})	605.0 a	928.3 a	993.8 a	764.2 a	1524.0 b	859.3 a
		Aldehydes(ng mL^{1})	193.3 a	220.2 a	222.5 a	315.9 a	323.5 a	297.9 a
		Esters (ng mL^{1})	747.6 a	1663.1 b	1499.3 b	696.3 a	1879.1 b	640.8 a
		Total volatiles (ng mL^{1})	1555.1 a	2818.7 b	2724.1 b	1782.1 a	3732.5 b	1803.6 a
	7	Alcohols (ng mL^{1})	873.5 a	1213.3 a	1047.5 a	885.1 a	3236.3 a	1069.0 a
		Aldehydes(ng mL^{1})	267.6 a	253.3 a	269.2 a	250.9 a	248.6 a	201.6 a
		Esters (ng mL^{1})	1007.0 a	1623.0 b	886.0 a	1384.9 a	2395.3 b	1255.6 a

		Total volatiles (ng mL^{1})	2164.8 a	3108.4 b	2211.0 a	2526.3 a	5886.2 a	2531.5 a
Controlled atmosphere 3- months	1	Alcohols (ng mL^{1})	648.7 a	1192.7 a	891.1 a	268.5 a	387.4 a	370.6 a
		Aldehydes(ng mL^{1})	172.7 a	244.0 a	238.0 a	305.2 a	312.5 a	299.1 a
		Esters (ng mL^{1})	802.4 a	1722.8 b	1087.9 a	283.0 a	654.6 b	394.8 a
		Total volatiles (ng mL^{1})	1631.2 a	3168.9 a	2224.4 a	861.8 a	1360.1 b	1070.0 ab
	7	Alcohols (ng mL^{1})	535.4 a	798.6 a	594.4 a	163.6 a	319.5 b	142.6 a
		Aldehydes(ng mL^{1})	242.9 a	284.8 a	278.1 a	290.8 a	255.8 a	273.7 a
		Esters (ng mL^{1})	871.5 a	1460.4 b	1125.5 ab	165.8 a	386.8 b	218.4 a
		Total volatiles (ng mL^{1})	1659.3 a	2552.3 a	2008.1 a	625.8 a	969.3 b	640.3 a
Controlled atmosphere 6 months	1	Alcohols (ng mL^{1})	225.9 a	620.3 b	203.1 a	54.2 a	13.0 b	26.2 ab
		Aldehydes(ng mL^{1})	474.5 a	530.9 a	309.8 b	220.9 a	205.1 a	212.9 a
		Esters (ng mL^{1})	430.5 a	773.8 a	377.6 a	53.7 a	52.7 a	62.9 a
		Total volatiles (ng mL^{1})	1142.0 a	1933.6 b	897.0 a	334.0 a	276.7 a	308.0 a
	7	Alcohols (ng mL^{1})	301.8 a	432.2 a	196.5 a	19.3 a	22.6 ab	25.7 b
		Aldehydes(ng mL^{1})	608.9 a	415.4 b	503.8 ab	295.8 a	185.0 b	271.6 a
		Esters (ng mL^{1})	427.7 a	819.2 b	441.5 a	20.9 a	198.1 b	22.7 a
		Total volatiles (ng mL^{1})	1345.2 a	1672.0 a	1148.8 a	341.4 a	411.0 a	326.1 a

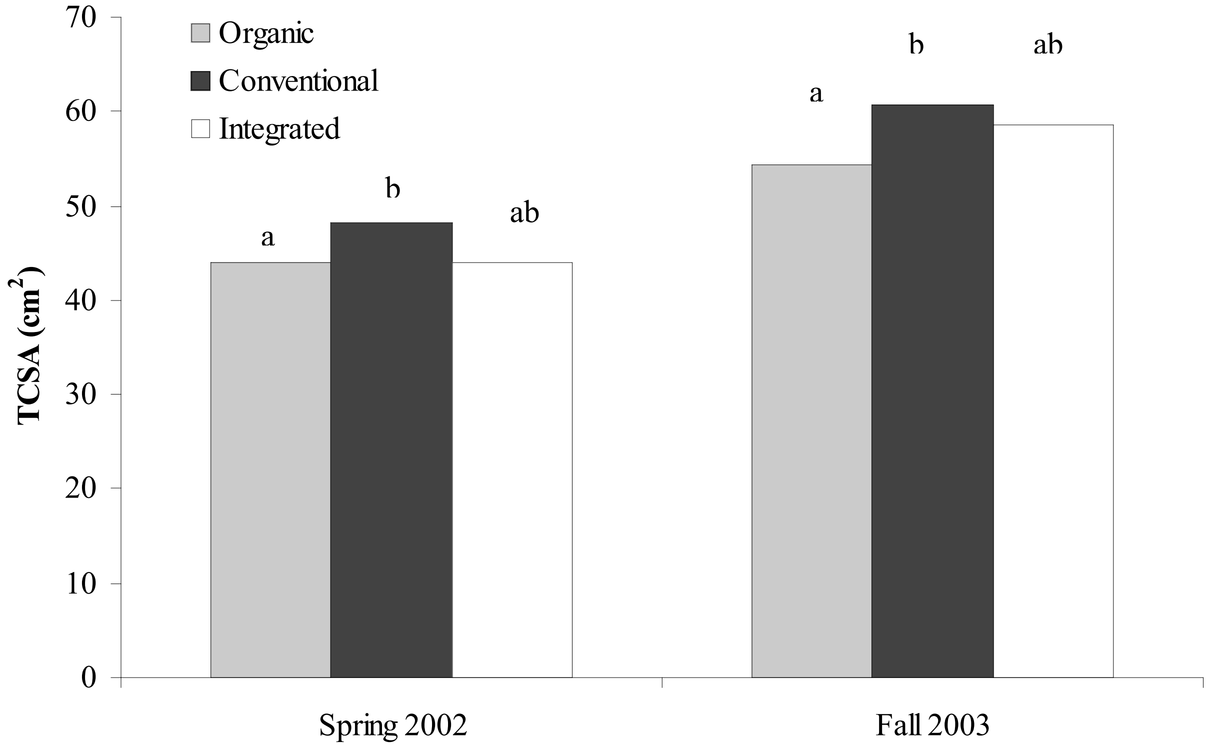
[z] Differences among treatments within each year followed by different letters are significant at the 0.05 level (LSD).

Table 12. Hydrophilic antioxidant activity (HAA), lipophilic antioxidant activity (LAA), and total antioxidant activity (TAA) of peel and flesh tissue of apples from organic (ORG), conventional (CON), and integrated (INT) apple farm management systems measured at harvests, three storage treatments, and after a seven day shelf-life in 2002 and 2003. The 2003 CA6 fruit are still to be measured.

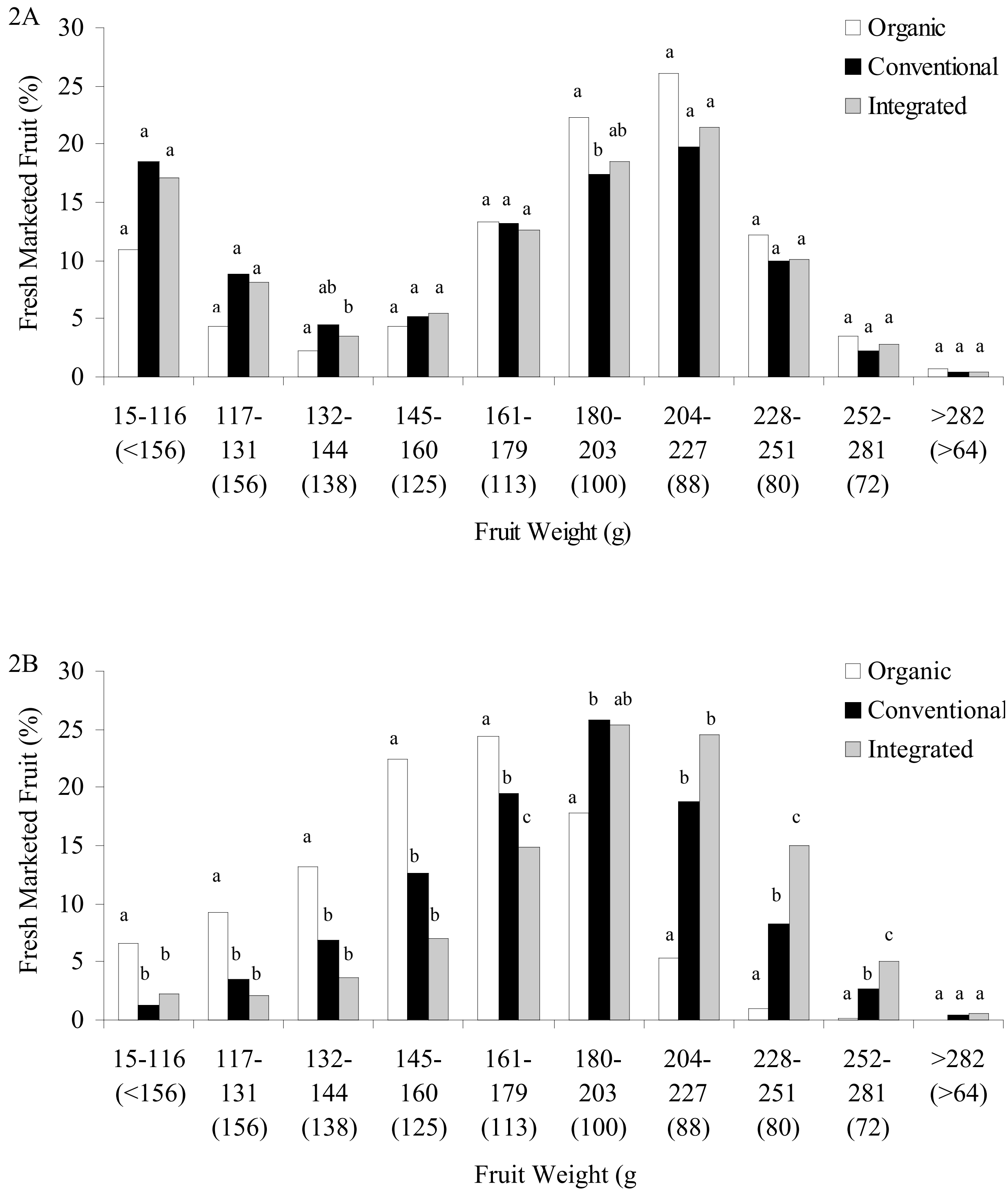
Time of analysis	Measurement	2002 ORG	2002 CON	2002 INT	2003 ORG	2003 CON	2003 INT
Harvest	HAA (µmol g^{-1} FW)	16.59 a[z]	13.89 ab	11.64 b	17.62 a	15.58 b	16.66 ab
	LAA (µmol g^{-1} FW)	7.33 a	6.62 a	6.80 a	12.52 a	11.48 a	11.72 a
	Peel (µmol TAA g^{-1} FW)	19.77 a	17.05 ab	15.30 b	25.43 a	23.14 a	24.17 a
	Flesh (µmol TAA g^{-1} FW)	4.15 a	3.45 ab	3.14 b	4.62 a	3.92 b	4.22 ab
	Total (µmol TAA g^{-1} FW)	23.92 a	20.50 ab	18.43 b	30.14 a	27.06 a	28.38 a
	Total TAA (µmol TAA 200 g $apple^{-1}$ FW)	957.08 a	805.27 ab	728.84 b	1121.59 a	975.36 b	1037.49 ab
Regular	HAA (µmol g^{-1} FW)	15.29 a	12.15 b	9.65 c	16.25 a	13.59 b	14.64 ab
	LAA (µmol g^{-1} FW)	9.58 a	7.89 b	7.07 b	11.38 a	10.44 a	10.75 a
atmosphere	Peel (µmol TAA g^{-1} FW)	20.72 a	16.34 b	13.46 c	23.67 a	19.89 b	21.79 ab
	Flesh (µmol TAA g^{-1} FW)	4.15 a	3.70 ab	3.26 b	3.97 a	4.13 a	3.65 a
three months	Total (µmol TAA g^{-1} FW)	24.87 a	20.04 b	16.72 c	27.64 a	24.04 a	25.39 a
	Total TAA (µmol TAA 200 g $apple^{-1}$ FW)	972.56 a	833.28 b	718.75 c	991.40 a	958.15 a	912.04 a
Controlled	HAA (µmol g^{-1} FW)	16.00 a	11.36 b	10.69 b	14.57 a	10.78 b	12.41 b
	LAA (µmol g^{-1} FW)	9.11 a	8.57 a	7.20 b	8.90 a	7.81 b	7.25 b
atmosphere	Peel (µmol TAA g^{-1} FW)	21.01 a	16.91 b	14.93 b	19.99 a	15.54 b	16.03 b
	Flesh (µmol TAA g^{-1} FW)	4.09 a	3.02 b	2.95 b	3.48 ab	3.05 b	3.62 a
three months	Total (µmol TAA g^{-1} FW)	25.11 a	19.93 b	17.88 b	23.46 a	18.59 b	19.65 b
	Total TAA (µmol TAA 200 g $apple^{-1}$ FW)	968.13 a	737.02 b	695.08 b	856.46 a	720.19 b	815.77 ab
Controlled	HAA (µmol g^{-1} FW)	14.28 a	12.70 a	10.67 b	—	—	—
	LAA (µmol g^{-1} FW)	7.75 ab	9.03 a	7.14 b	—	—	—
atmosphere	Peel (µmol TAA g^{-1} FW)	17.61 a	17.56 a	14.37 b	—	—	—
	Flesh (µmol TAA g^{-1} FW)	4.42 a	4.18 ab	3.45 b	—	—	—
six months	Total (µmol TAA g^{-1} FW)	22.03 a	21.73 a	17.82 b	—	—	—
	Total TAA (µmol TAA 200 g $apple^{-1}$ FW)	963.77 a	925.78 a	762.19 b	—	—	—

[z] Differences among treatments within each year followed by different letters are significant at the 0.05 level (LSD).

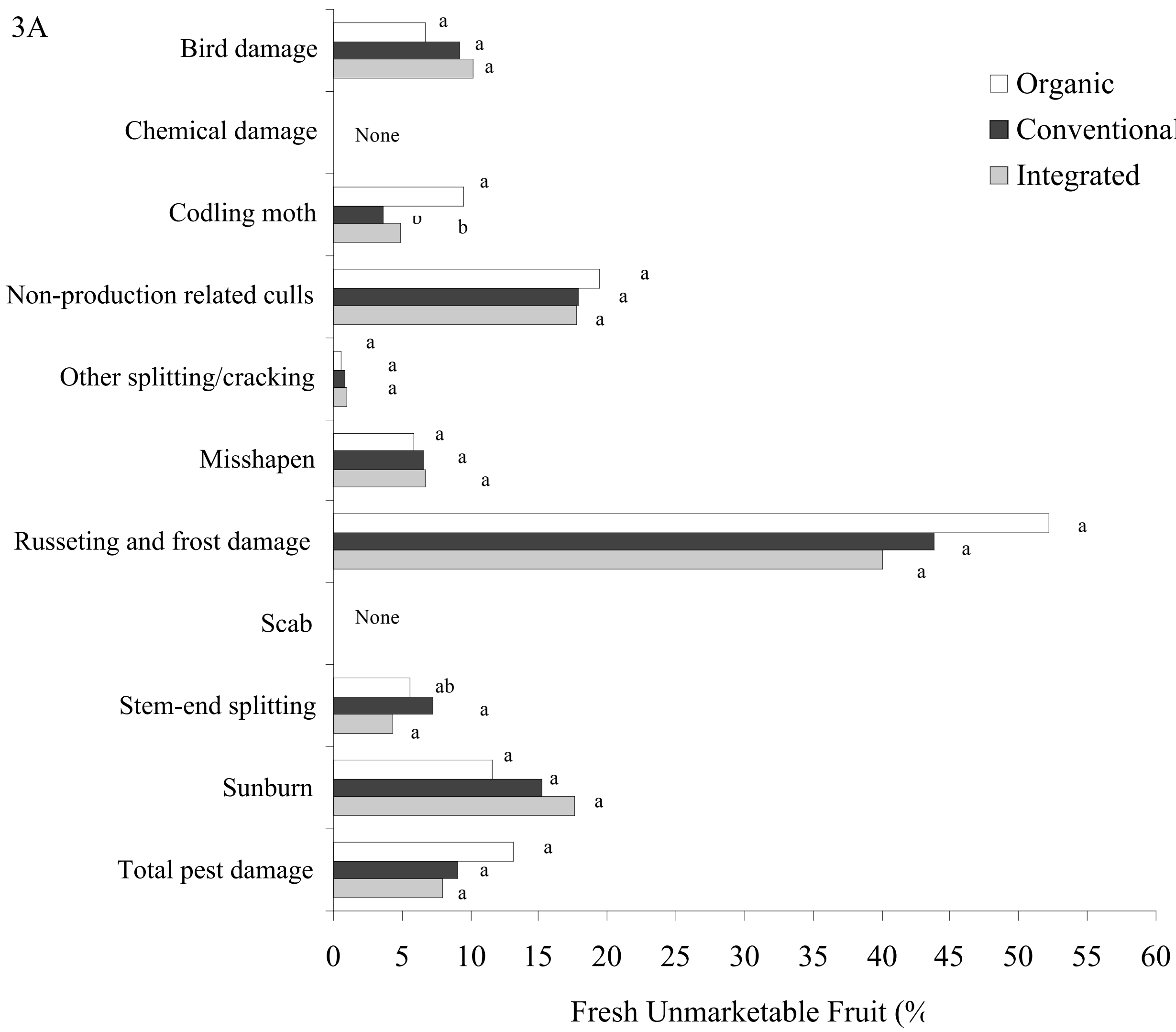
Figure 1. Trunk cross-sectional area of organic, conventional and integrated apple trees measured in Spring 2002 and Fall 2003. Differences among treatments within each year followed by different letters are significant at the 0.05 level (LSD).

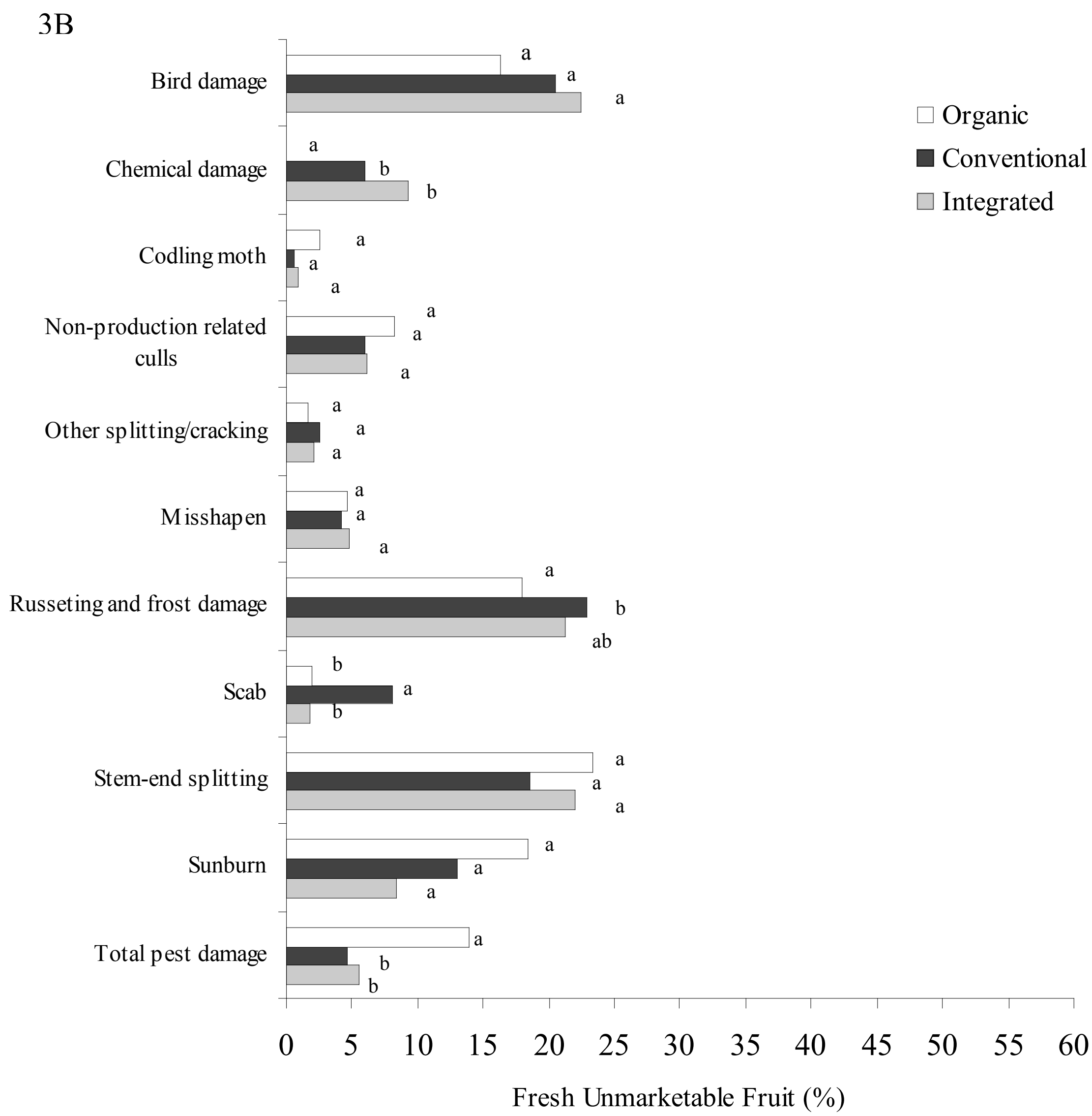


Figures 2A-B. Percentage of marketable apples in different weight classifications for organic, conventional, and integrated farm management systems in 2002 (A) and 2003 (B). Numbers in parentheses are standard box sizes, which represent the number of apples packed into a 42-pound box. Differences among treatments within each year followed by different letters are significant at the 0.10 level for 2002 and at the 0.05 level for 2003 (LSD).



Figures 3A-B. Percentage of fruit culls in various classifications for organic, conventional, and integrated apple farm management systems in 2002 (A) and 2003 (B). Total pest damage includes codling moth damage. Differences among treatments within each year followed by different letters are significant at the 0.05 level (LSD).

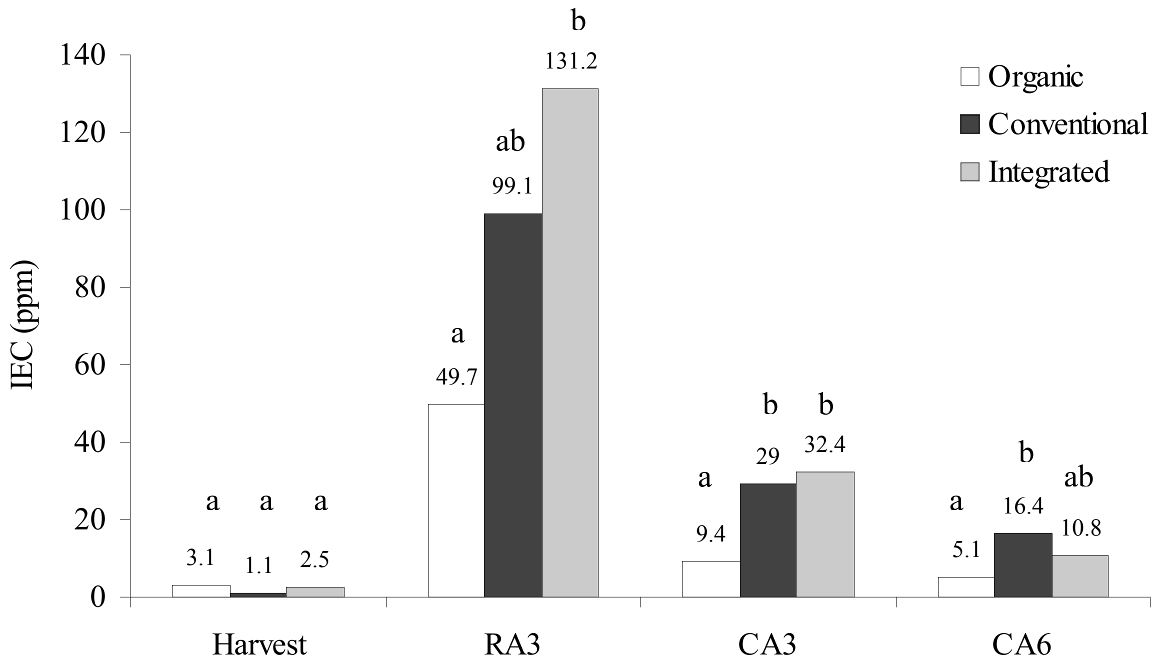




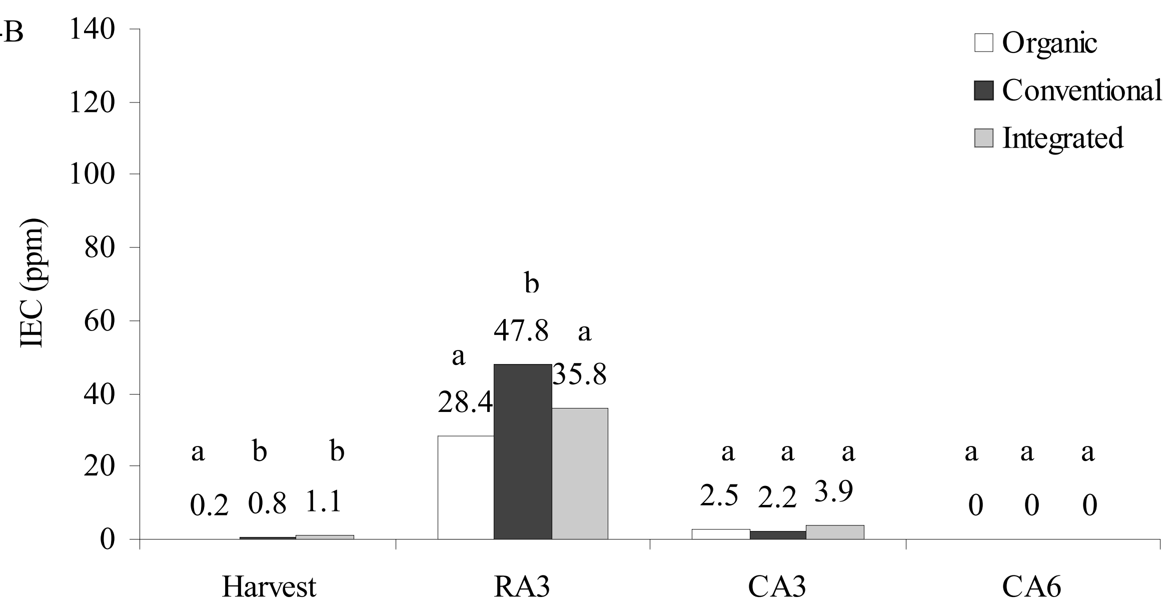
3B
Bird damage
Chemical damage
Codling moth
Non-production related culls
Other splitting/cracking
Misshapen
Russeting and frost damage
Scab
Stem-end splitting
Sunburn
Total pest damage
Organic
Conventional
Integrated
0
5
10
15
20
25
30
35
40
45
50
55
60
Fresh Unmarketable Fruit (%)

Figures 4A-B. Fruit internal ethylene concentration (IEC) for organic, conventional, and integrated apple farm management systems at the second harvest and after three months of regular atmosphere storage (RA3), three months of controlled atmosphere storage (CA3), and six months of controlled atmosphere storage (CA6) in 2002 (A) and 2003 (B). Differences among treatments within each year followed by different letters are significant at the 0.05 level (LSD).

4A

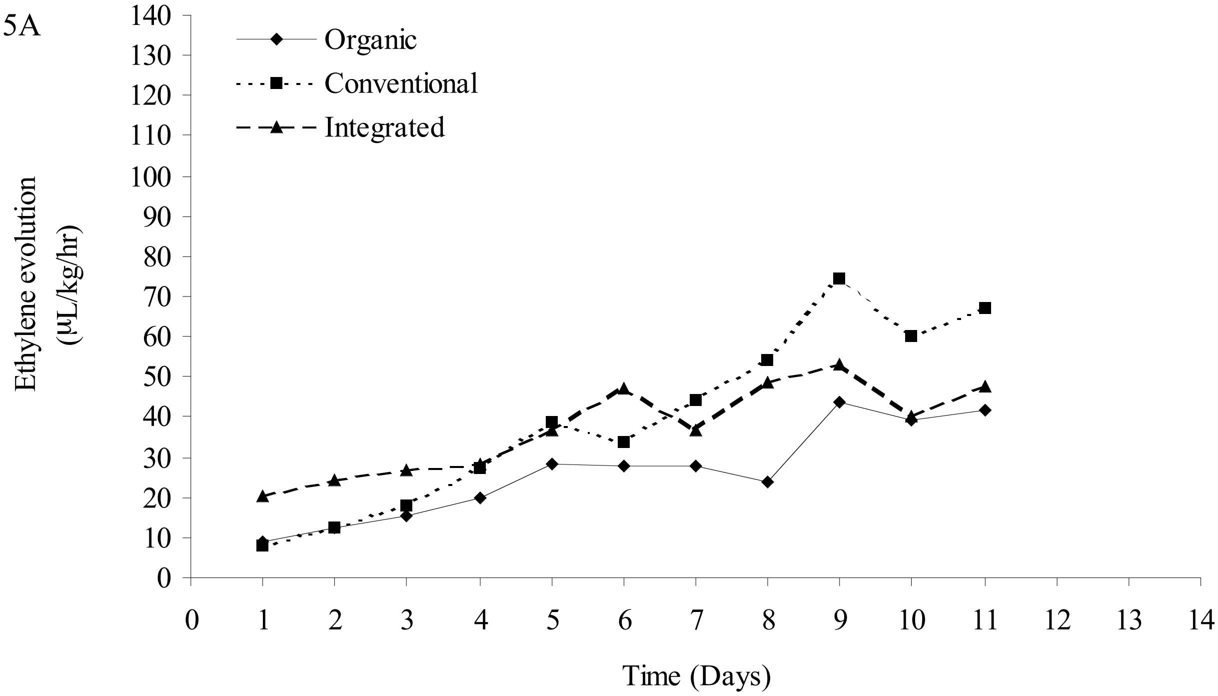


4B

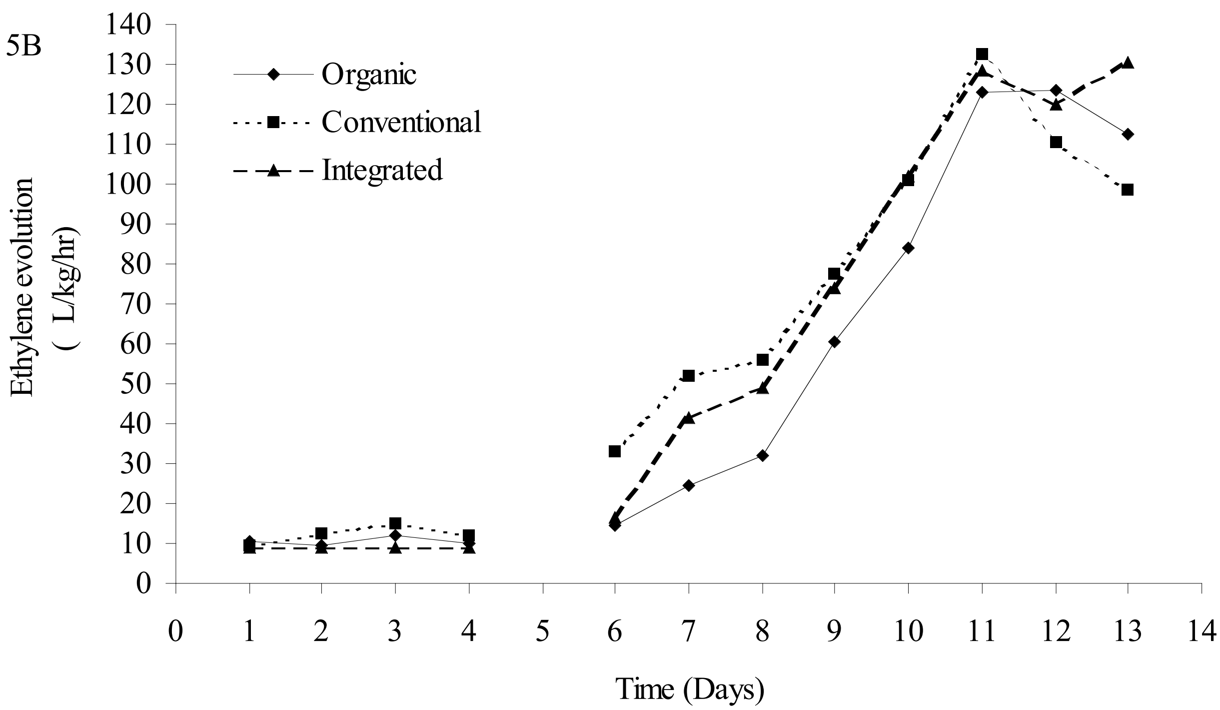


Figures 5A-B. Fruit ethylene evolution for organic, conventional, and integrated apple farm management systems at the second harvest in 2002 (A) and 2003 (B).

5A

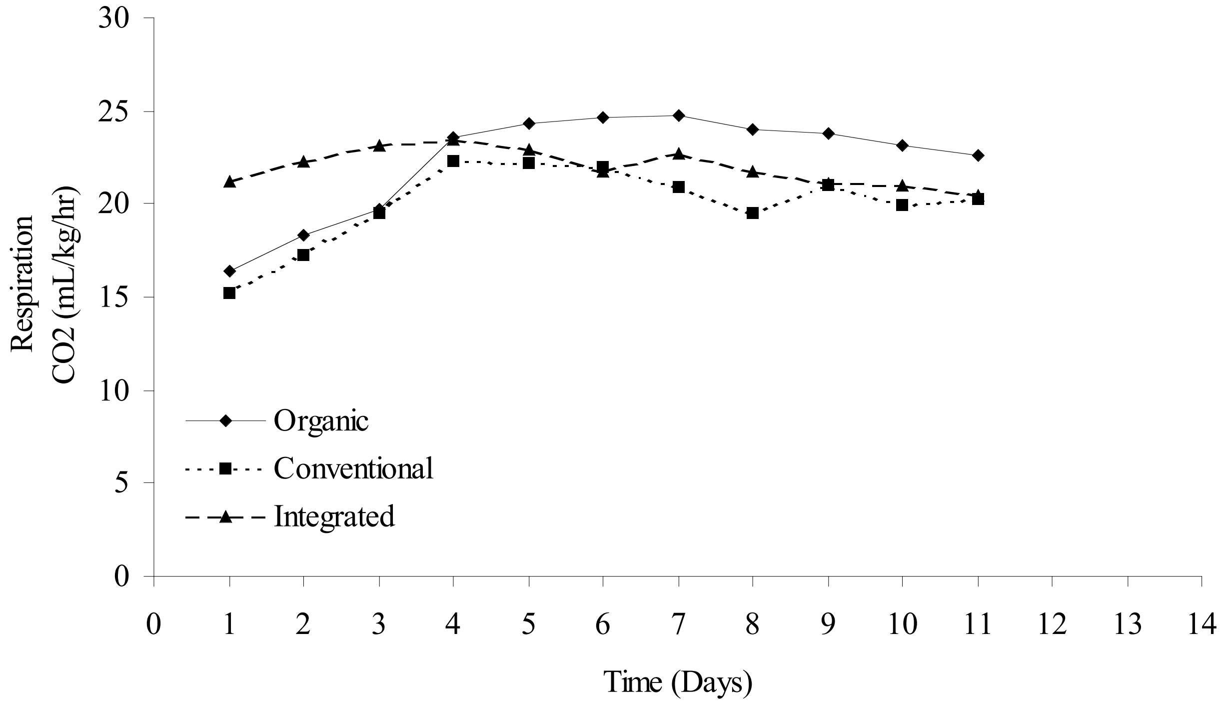


5B



Figures 6A-B. Fruit respiration rates for organic, conventional, and integrated apple farm management systems at the second harvest in 2002 (A) and 2003 (B).

6A



6B

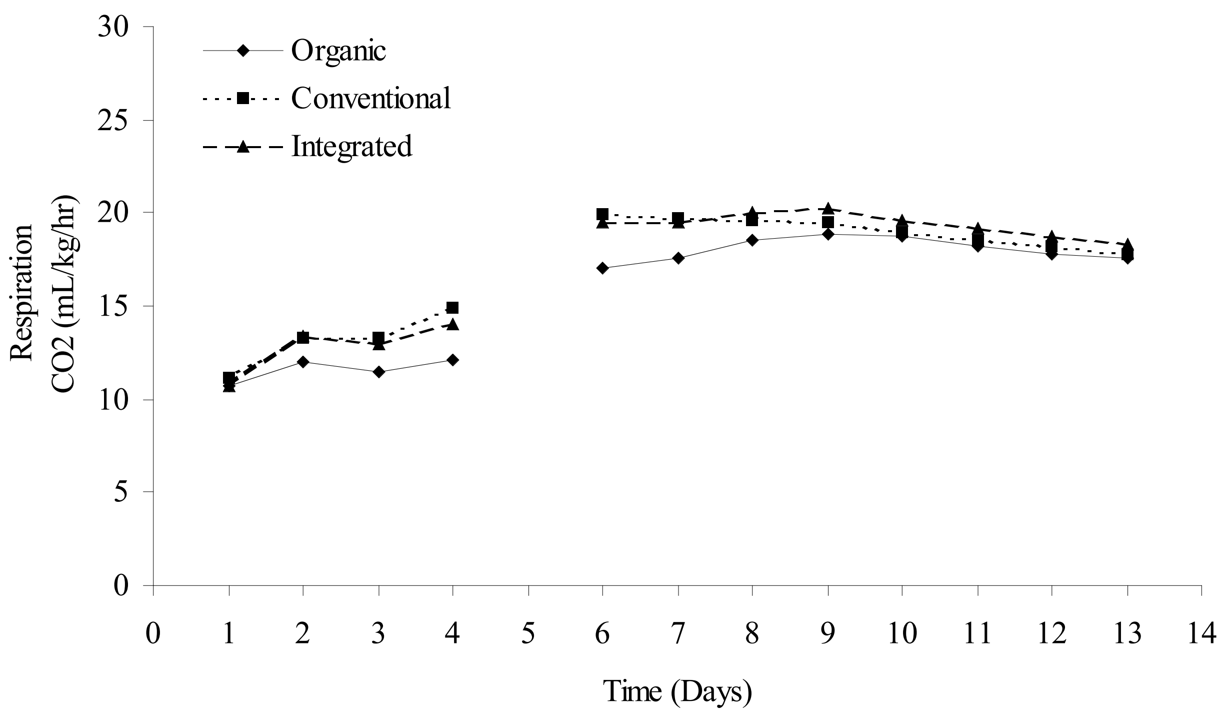
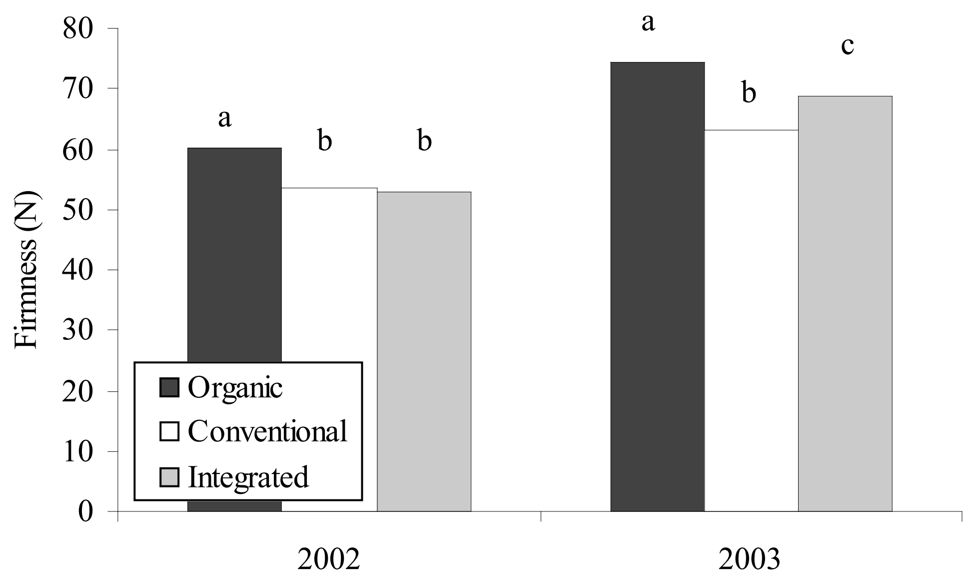
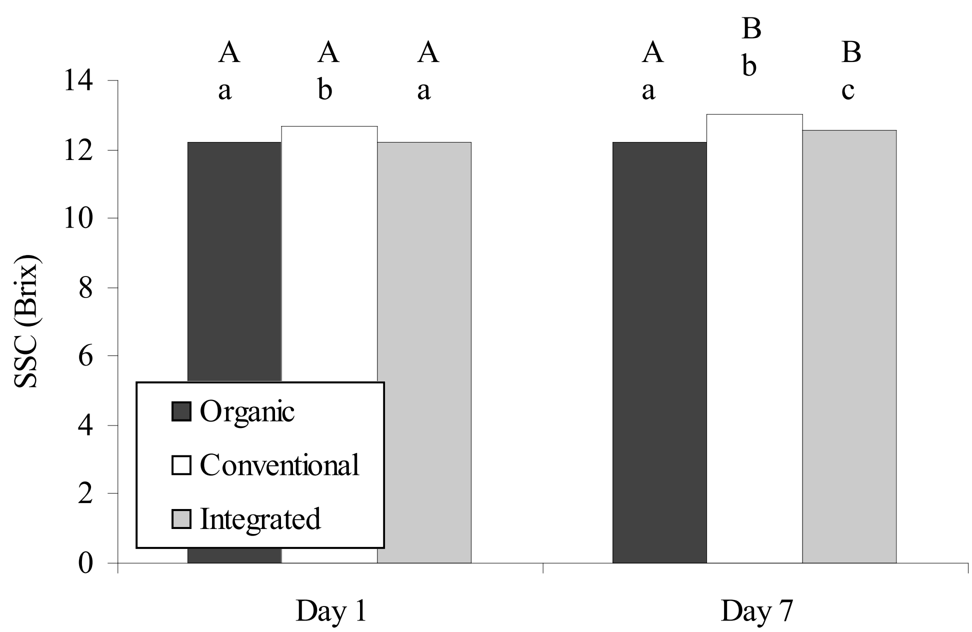


Figure 7. Main effect means for apple flesh firmness from organic, conventional, and integrated apple farm management systems measured after three storage treatments, and before and after a seven day shelf-life in 2002 and 2003. Differences among treatments within each year followed by different letters are significant at the 0.05 level (LSD).



Figures 8A-B. The interaction of apple farm management system*shelf-life for fruit soluble solids concentration (SSC) (A) and titratable acidity (TA) (B) measured after three storage treatments, and before and after a seven day shelf-life in 2003. Differences among treatments within each day followed by different lowercase letters are significant at the 0.05 level (LSD). Differences between days 1 and seven of the shelf-life within each apple farm management system followed by different uppercase letters are significant at the 0.05 level (LSD).

8A



8B

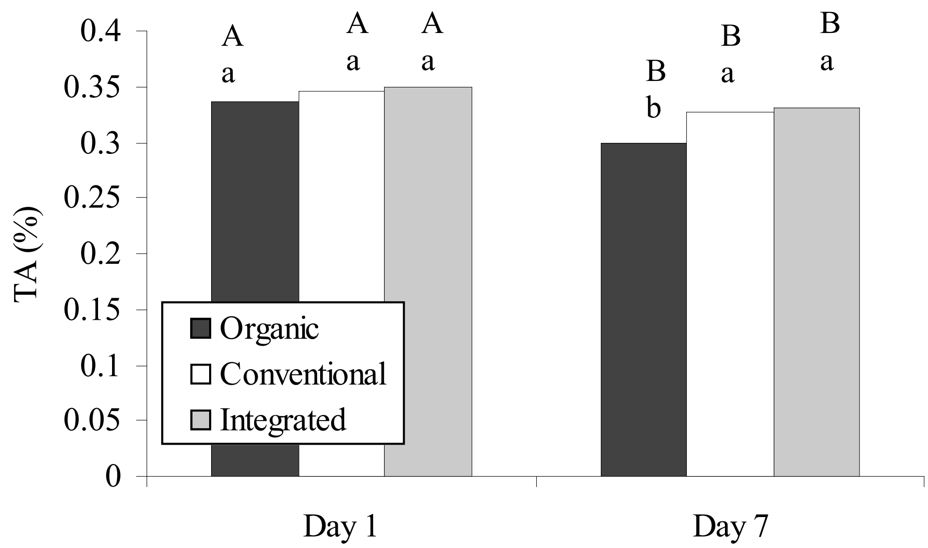


Figure 9. Main effect means for the consumer panelist evaluations of fruit overall acceptability, texture, flavor, firmness, and tartness from organic, conventional, and integrated apple farm management systems measured after three storage treatments, and before and after a seven day shelf-life in 2003. Differences within a measurement among treatments followed by different letters are significant at the 0.05 level (LSD).

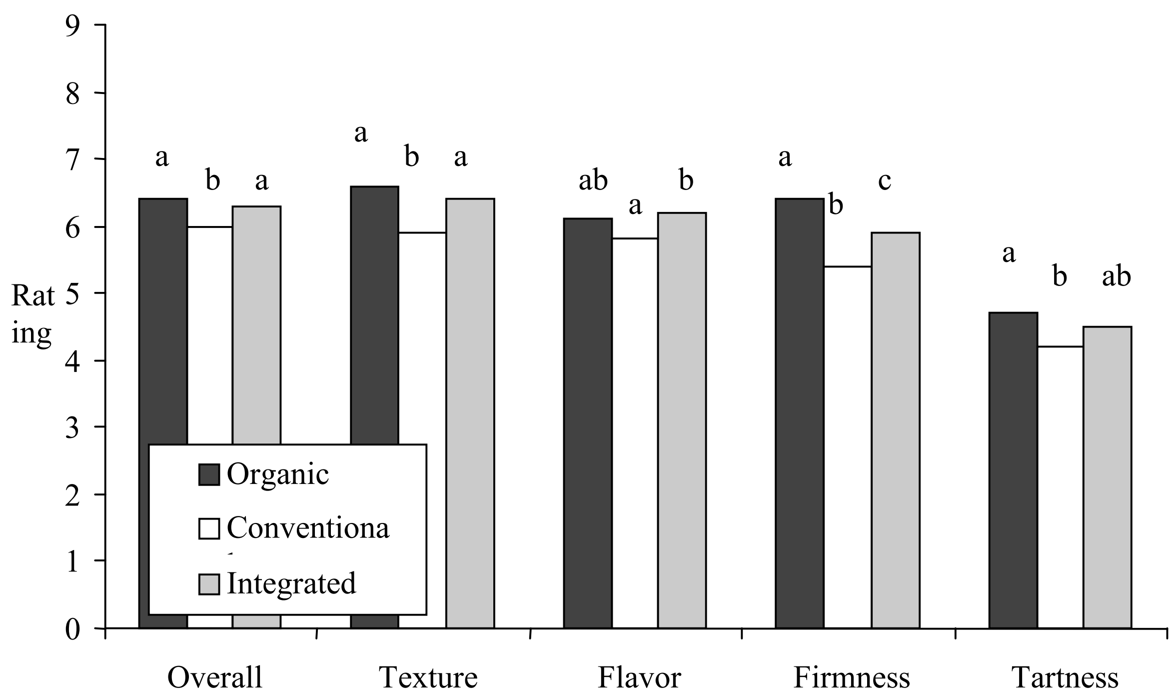


Figure 10. Main effect means for the ratio of soluble solids concentration to titratable acidity (SSC:TA) from organic, conventional, and integrated apple farm management systems measured after three storage treatments, and before and after a seven day shelf-life in 2002 and 2003. Differences among treatments within each year followed by different letters are significant at the 0.05 level (LSD).

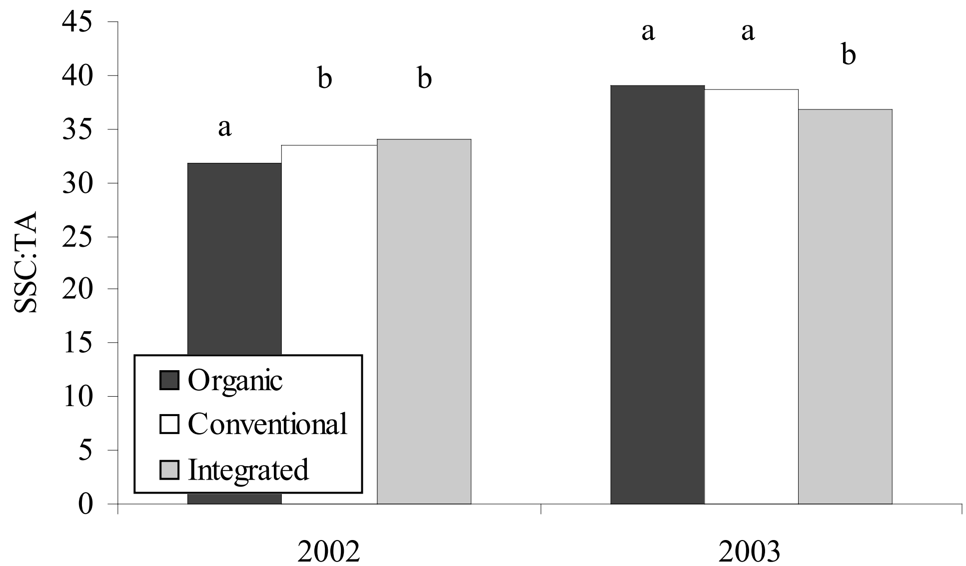
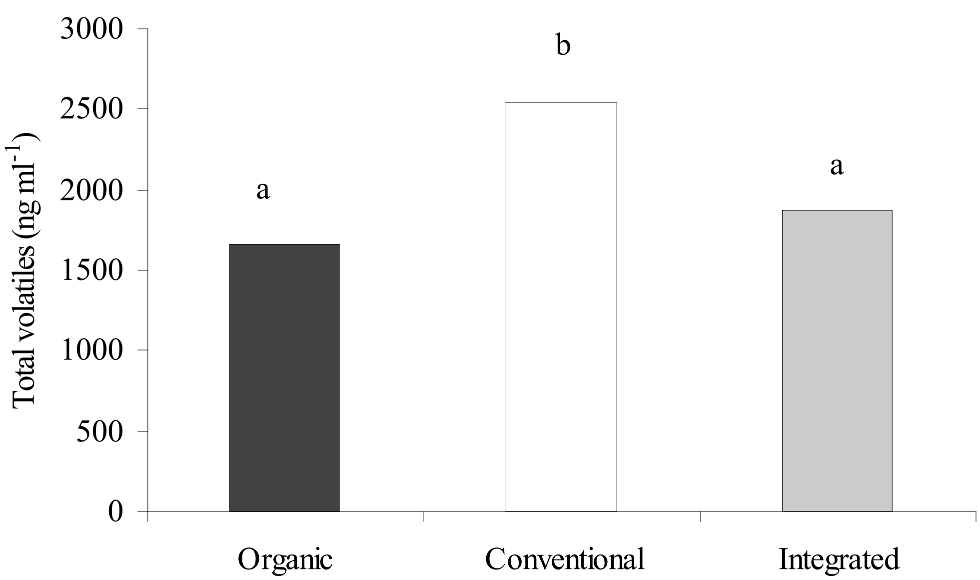
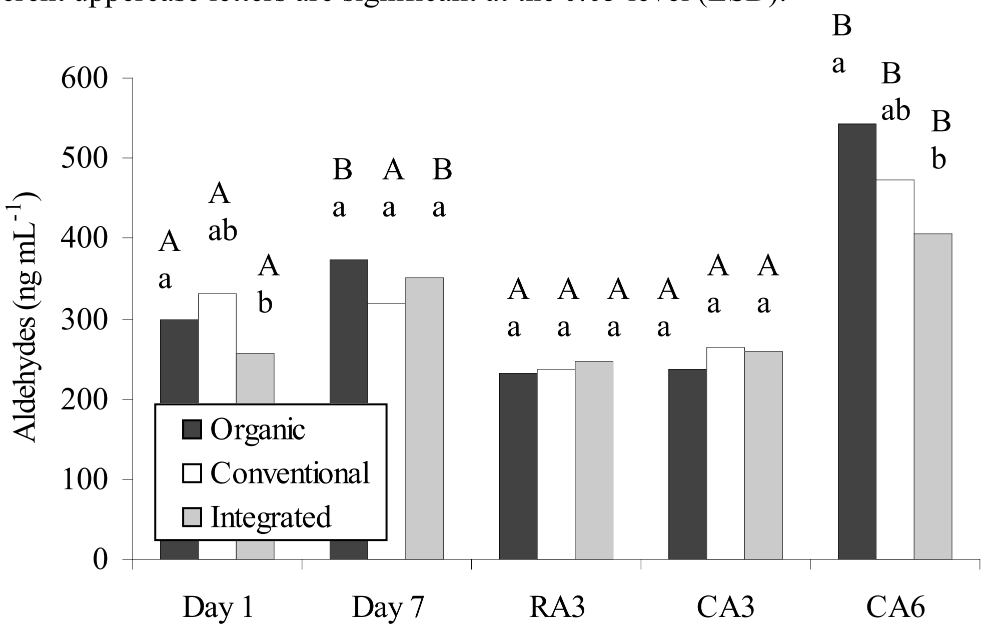


Figure 11. Main effect means for fruit total volatile production from organic, conventional, and integrated apple farm management systems measured after three storage treatments, and before and after a seven day shelf-life in 2002. Differences among treatments followed by different letters are significant at the 0.05 level (LSD).



Figures 12A-B. The 3-way interaction of apple farm management system*shelf-life*storage (RA3, CA3, CA6) for fruit aldehyde (A) and ester (B) volatile production measured after three storage treatments, and before and after a seven day shelf-life in 2002. Differences among treatments within each day or within each storage (RA3, CA3, CA6) followed by different lowercase letters are significant at the 0.05 level (LSD). Differences between days 1 and 7 of the shelf-life or between the different storages within each apple farm management system followed by different uppercase letters are significant at the 0.05 level (LSD).

12A



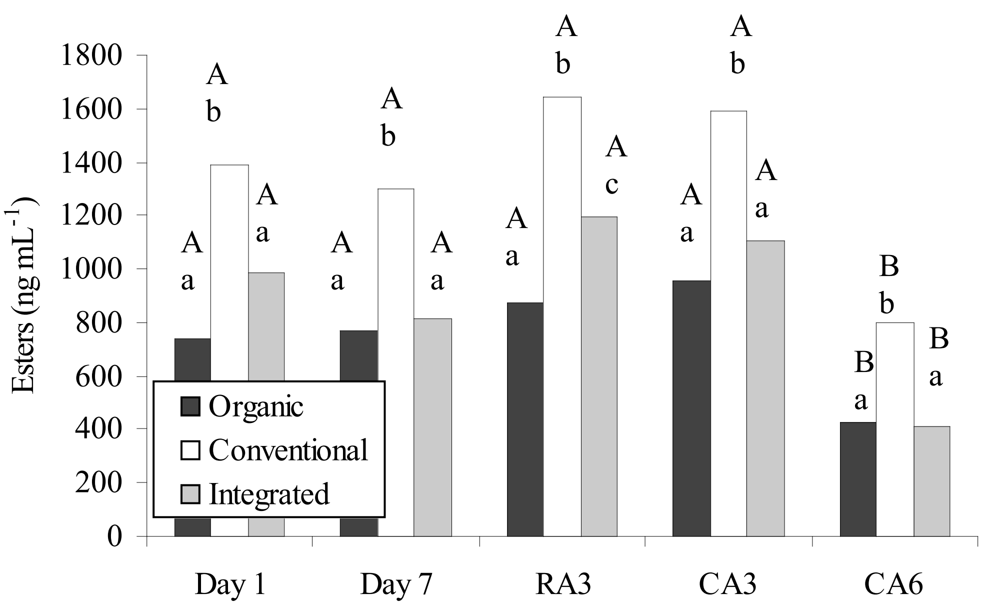
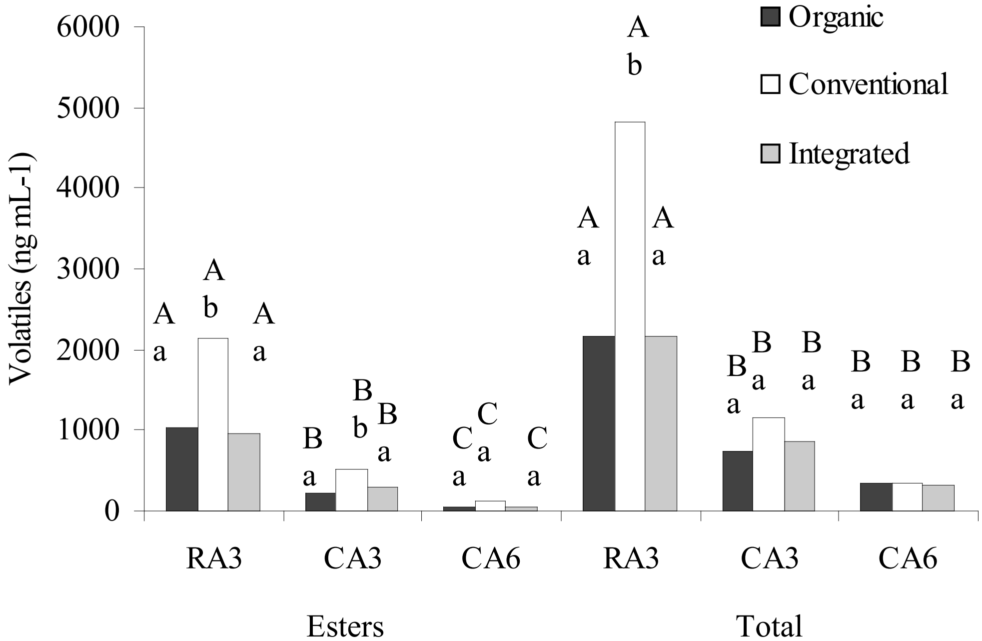
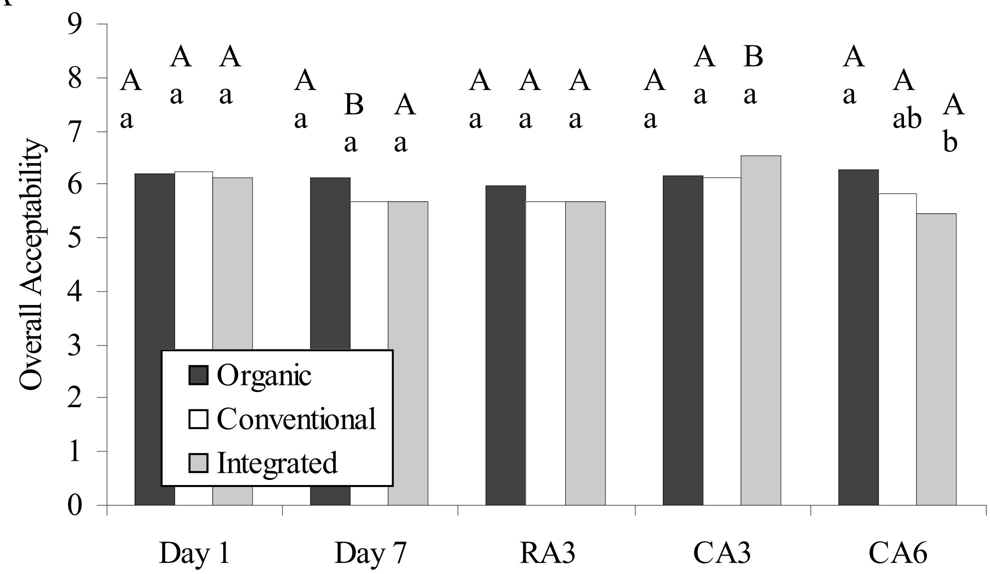


Figure 13. The interaction of apple farm management system*shelf-life for fruit ester and total volatile production measured after three storage treatments, and before and after a seven day shelf-life in 2003. Differences among treatments within each storage treatment (RA3, CA3, CA6) followed by different lowercase letters are significant at the 0.05 level (LSD). Differences between RA3, CA3, and CA6 within each apple farm management system followed by different uppercase letters are significant at the 0.05 level (LSD).

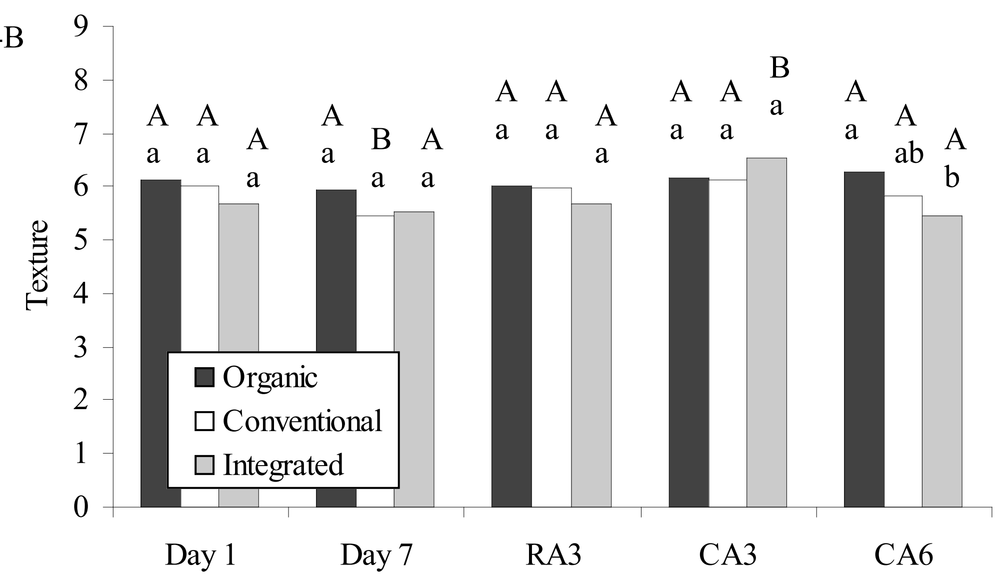


Figures 14A-D. The 3-way interaction of apple farm management system*shelf-life*storage treatment (RA3, CA3, CA6) for the consumer panelist measurement of fruit overall acceptability (A), texture (B), flavor (C), and firmness (D) measured after three storage treatments, and before and after a seven day shelf-life in 2002. Differences among treatments within each day or within each storage (RA3, CA3, CA6) followed by different lowercase letters are significant at the 0.05 level (LSD). Differences between days 1 and seven of the shelf-life or between the different storages within each apple farm management system followed by different uppercase letters are significant at the 0.05 level (LSD).

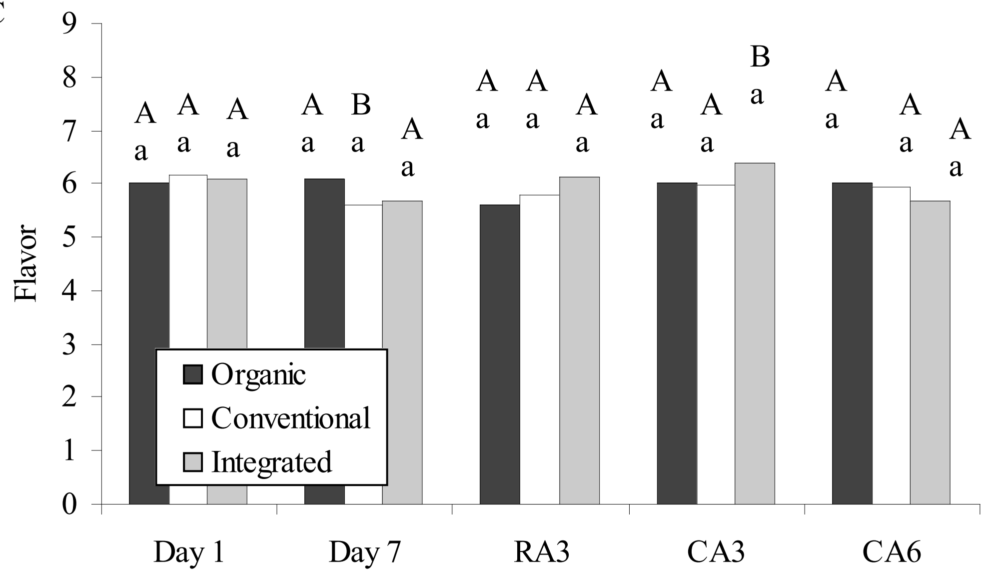
14A



14B



14C


A a
A a
A a
A a
B a
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A a
A a
B a
A a
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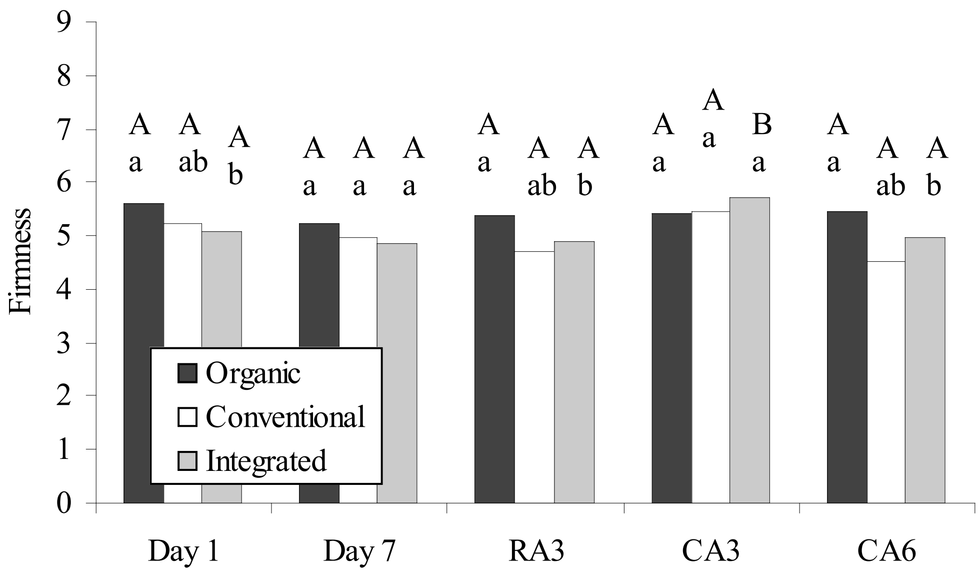
A a
9
8
7
6
5
4
3
2
1
0
Flavor
Organic
Conventional
Integrated
Day 1
Day 7
RA3
CA3
CA6

14D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A ab
A b
A a
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A ab
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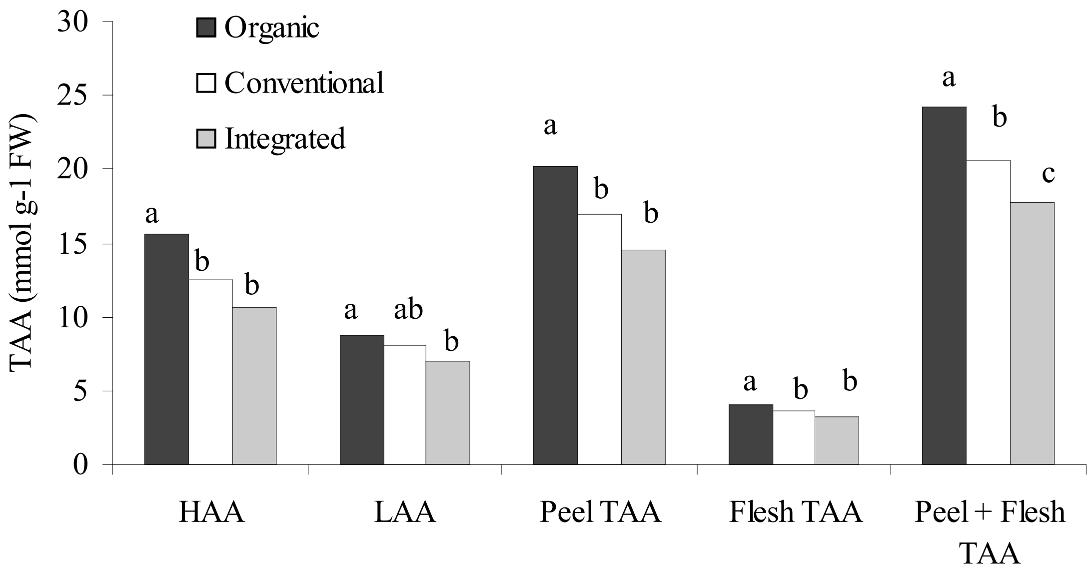
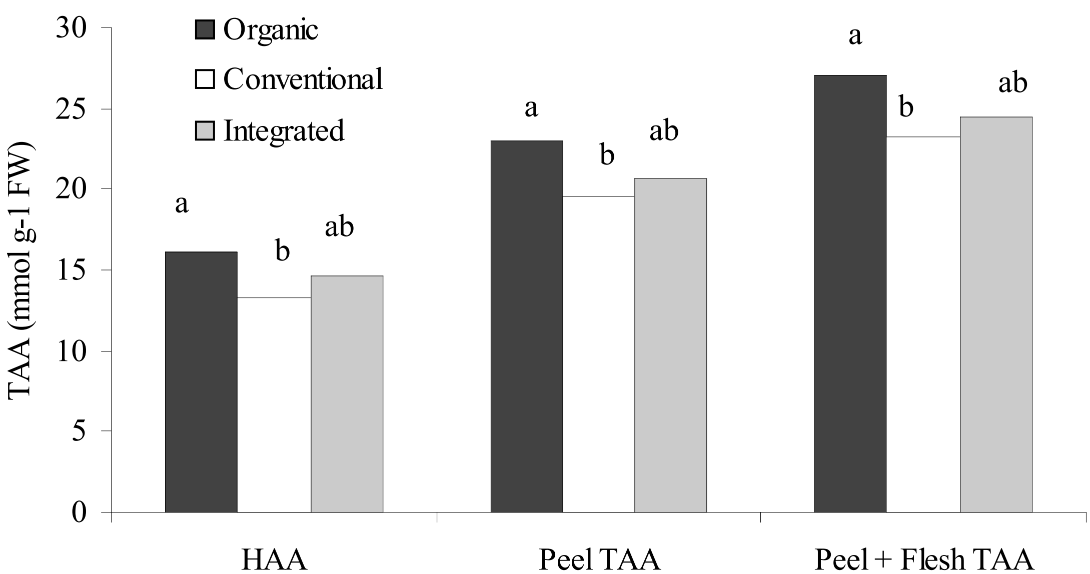
A a
A a
B a
A a
A ab
A b
9
8
7
6
5
4
3
2
1
0
Firmness
Organic
Conventional
Integrated
Day 1
Day 7
RA3
CA3
CA6

Figures 15A-B. Main effect means for hydrophilic (HAA), lipophilic (LAA), and total antioxidant activity (TAA) of fruit from organic, conventional, and integrated apple farm management systems measured at harvest and after three storage treatments in 2002 (A) and 2003 (B). Differences within a measurement among treatments followed by different letters are significant at the 0.05 level (LSD).

15A



15B



CHAPTER FOUR

GENERAL CONCLUSIONS

As the market for organic products continues to grow, both advocates and detractors must face the reality that organic agriculture is no longer exclusively a grassroots, philosophical movement. Organic agriculture is practiced around the world in more than 100 countries, and while this expansion has its benefits, it also has its detriments. The numerous certification bodies that I discussed in Chapter Two have caused growers to feel restricted in their production practices for fear of being denied access to international markets. Many growers have stated to me that certifiers are often more concerned with the specific materials that are allowed or disallowed than with upholding the philosophical principles of organic production, such as improving soil quality and reducing negative environmental effects. Although this is just anecdotal evidence, organic agriculture needs to ensure its integrity in the face of an ever-expanding capitalistic marketplace. However, organic agriculture is not exclusively practiced by farmers who are dedicated to its principles, and so certification is the means by which the consumer, and perhaps society, is protected from those growers who are only interested in the price premiums. Perhaps what is really needed is an agricultural plan that encompasses all farm management systems, not just organic. The European Union has already started to regulate the practices of all farms in its Common Agricultural Policy in order to manage the agrochemicals, fertilizers, and animal wastes that leave the agroecosystem and enter into the environment at large. The question is when will the US be politically ready for such a policy, because the negative environmental effects of current conventional farming practices, used on the majority US cropland, will only increase.

There are some other topics that were not discussed in this thesis that should be addressed in future research projects. Large tracts of land in less developed Southern hemisphere nations are being devoted to organic production, but the produce grown there is shipped thousands of miles to more wealthy countries in the Northern hemisphere. I believe that truly sustainable agriculture must foster local communities by providing an adequate supply of safe healthy food. Countries that grow organic crops for export should also be contributing to the local food system. Additionally, there is generally greater need for hand labor in the production of many organic crops, but farm worker rights are rarely part of the certification regulations. As organic agriculture continues to expand, social justice issues should be given the same importance as soil and crop quality and economic and environmental sustainability.

In the research described in Chapter Three, I learned the difficulties of on-farm research trials. The research site contained 12 plots that required constant micro-managing, but unfortunately the orchard staff often neglected such detailed management. The owners of the orchard were attempting to sell the ranch during the two-year period of this study, and so they were less committed to support the research than in past years. Even with the additional sprays that were contracted through Wilbur-Ellis during the second year of the study, the organic and integrated systems had minimal pest and disease control, and few foliar nutrients were applied. After touring numerous organic apple orchards throughout Washington State, I believe that many of the production difficulties that are documented in Chapter Three have already been overcome in other organic apple orchards in the state. Many commercial organic growers know how to effectively manage crop load with chemical and hand thinning, control codling moth with PMD and granulosis virus, and plant and soil fertility with cover crops and soil amendments. This leaves me to wonder if the higher quality of the organic apples in this study may have been even greater if the treatments had been managed like other knowledgeable, organic orchard operations. I don't believe that any of the farming systems in this study were producing at their full potential, but the organic and integrated systems were more often left without proper care. Because of these difficulties, the integrated system never lived up to the goal of being the middle ground between organic and conventional management. In the future, long-term comparative systems studies may want to use university land; assuming that the treatments could be controlled more effectively. The researchers would therefore be responsible for the entire cost of the project, and so large multi-disciplinary teams with multiple grant sources would be needed to financially support such a project.

Nonetheless, the results in Chapter Three lend good reason to delve further into the comparative study of organic and conventional produce quality. Although I make some attempts to elucidate the physiological reasons that higher antioxidant activities were found in organic fruit in this study, we did not control enough variables to find a root cause. Further research should test the hypothesis that glyphosate can alter flavonoid biosynthesis in the fruit of affected plants, as the cited references refer to flavonoid production in the leaves. Also, studies should look at the effects of nitrogen fertilization rates, soil organic matter, and the greater biological activity often found in organically managed soils in relationship to nutrients with the tree, fruit antioxidants, and other phytonutrients.