Organic Agriculture

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Abstract: Sustained high rates of growth in sales of certified organic products (OPs) in the U.S. and worldwide, averaging 20-25% yr^{-1} since 1990, have spurred concomitant growth and activities in production, processing, research, regulation and trade agreements, and exports. The global OP market value in 2001 is estimated to be $20B, and the OP share of total food sales is near 2% in the U.S. and 1-5% in EU countries. Processed OPs have shown particularly rapid growth, often over 100% yr^{-1}. Commercial certified organic agriculture (OA) has spread to over 130 countries worldwide.

Demand for OPs is driven by belief that OPs are more healthful, tasty, and environmentally friendly than conventional products (CPs). Evidence for these beliefs is reviewed. While many of the health claims for OPs remain unresolved, there is sufficient evidence to give OPs the edge in healthfulness. Comparative research is needed, particularly bioassays of animal health parameters, particularly reproduction, and analyses of the functional components of foods (nutraceuticals). OP/CP taste comparisons are often inconclusive, as cultivar and location are generally more important factors in taste than growing system.

Evidence for significant environmental amelioration via conversion to OA is overwhelming – pesticides are virtually eliminated and nutrient pollution substantially reduced. Loss of biodiversity, wind and water erosion, runoff, and fossil fuel use and greenhouse warming potential are all reduced in OA relative to comparable conventional agriculture (CA) systems.

The agroecological characteristics of OA are reviewed - weed, invertebrate, disease, and soil fertility management practices. Yield reductions of OA systems average 10-15% relative to CA, however these are generally compensated for by lower input costs and higher gross margins. Large-scale conversion to OA would not result in food shortages and could be accomplished with a reduction in meat consumption. OA systems consistently outperform CA in drought situations, out-yielding CA crops by up to 100%.

Also reviewed are: methodologies for comparing productivity and sustainability of OA/CA; the core concept that OA is a structurally different system than CA; the characteristics, sociology, and practices of U.S. organic farmers and farms; OA's origins, its pioneers, major institutions; international certification standards and the new (2000) USDA National Organic Program Final Rule; institutional and media support for and biases against OA; OA's increased involvement with social accountability and animal ethics.

Keywords: agriculture, organic agriculture, organic farming, organic food, sustainable agriculture, agroecology, agricultural ecology, crop systems, integrated pest management

Sections:

OA origins, history, and core values.

Organic agriculture (OA) movements in the major industrial countries - Britain, Germany, Japan, and the U.S. - emerged in the 1930's and 40's as an alternative to the increasing intensification of agriculture, particularly the use of synthetic nitrogen (N) fertilizers. Synthetic N began to become available after World War I when the infrastructure for the manufacture of explosives, based on the Haber-Bosch process for fixation of N, was converted to N fertilizer production (Morrison 1937). Synthetic N fixation enabled a 20-fold reduction in the volume and weight of fertilizer relative to manures, drastically reducing fertilizer transport and application costs per unit of N. A consequence of this process was that organic carbon (C] was decoupled from N and, along with the soil microbe community dependent on its energy, was essentially left out of the science of crop and soil fertility management for the next 50 years. Von Liebig's theory of the chemical basis for plant nutrition, in which N, P, and K are at the top of a list of elements necessary for plant growth, was used nearly exclusively as the theoretical basis of soil fertility well into the 1980's (Porceddu and Rabbinge 1997).

The scientific basis for crop soil management based on organic inputs was developed quite early. In the 1920's and 30's pioneering research on soil organic matter, the importance of organic carbon energy as the foundation for the soil microbial community, and the relation of this ecosystem to crop growth was done by Waksman (Conford 1988) and Albrecht (Albrecht and Walters 1975) in the U.S. and Chaboussou in France (Aubert 1996). These works were largely passed over in the prevailing approach to soil management in agriculture (Darwin 1945) (from the foreword by Albert Howard) in which the chemical basis for plant nutrition was substituted for the broader concept of an ecological basis for sustained crop production.

In Germany in the 1920's, Rudolf Steiner outlined what were to become the principles of Biodynamic Agriculture, an early and still active version of OA. The Biodynamic system uses specific compost preparation recipes, has a strong metaphysical component in its farm practices, and is considered to be "organic plus metaphysical" (Tate 1994). Currently approximately 1% of U.S. OFs are certified Biodynamic by the Demeter certification label (Mendenhall 2001).

The social and practical groundwork for the modern OA movement was laid in the 1940's in publications by Howard (Howard 1940) and Balfour (Balfour 1943) in the UK, and Rodale (Rodale 1945; Tate 1994) in the U.S., and centered on the importance of organic matter in agriculture. It is notable that the remarkable Charles Darwin's work on earthworms was foundational for OA pioneers' understanding organic matter dynamics in soils (Darwin 1945) (from the foreword by Howard). By the late 1940's, organizations such as the Soil Association in the U.K., Rodale's publishing house in the U.S., and the Bioland organic label in Germany were established as the first OA organizations. Hans Muller's work in Germany lead to the world's first organic certification label, Bioland, which still is active.[1] In Japan in the mid-1930's, Mokichi Okada developed Nature Farming which was seminal in Japanese OA.

The first use of the term "organic farming" was in 1940 by Lord Northbourne in his book *Look to the Land* (Scofield 1986). Northbourne used the term not only in reference to the use of organic materials for soil fertility, but also to the concept of designing and managing the farm as an organic or whole system, integrating soil, crops,

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[1] www.bioland.de

animals, and society. This systemic approach is at the core of OA today (Lampkin and Padel 1994a) and is fundamental to understanding the decisions of the OA community, such as its opposition to transgenic crops and foods, its discomfort with mainstream commercialization, and its recent steps toward inclusion of social and ethical issues in OA.

Definitions of OA are similar worldwide and focus on ecological principles as the basis for crop production and animal husbandry. According to the National Organic Standards Board, OA is:

"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" (ATTRA 1995).

A more detailed description of what constitutes organic practices follows in the review of the 2000 USDA National Organic Program (NOP). The term organic is also a labeling term that denotes products that have been produced in accordance with organic standards throughout production, handling, processing, and marketing (FAO 2000). The terms "biological agriculture" and "nature farming" are interchangeable with OA in Europe and Japan, respectively.

Definitions of OA are increasingly including social and ethical issues, i.e. fair labor practices, family farm viability, and animal ethics (IFOAM 2001a). A substantial portion of the public input during the USDA NOP comment period called for fair labor and other socially relevant guidelines (Haapala 2001). The increasing attention paid to ethics in animal production (Fölsch and Hörning 1996; Kiley-Worthington 1996; Hovi and Trujillo 2000) has influenced the development of livestock standards in OA, most recently in Europe with EU regulation 1804/99, which mandates standards for livestock production and animal welfare in OA.

Characteristics of organic farms and farmers in the U.S.[2]

In 1997 OF land comprised approximately 0.2% of total U.S. farms and farmland (Greene 2000). The average U.S. OF is 76 ha in size, half of the U.S. average, of which 70% is cropland compared to 34% for the average U.S. farm, the remainder being pasture. The number of certified OFs in the U.S. more than doubled from 1991-1997 to over 5,000 in 49 states, and in 2001 numbered more than 7,800 (OFRF 2001). OA land area grew by 30% yr^{-1} from 1991-1997 (Klonsky and Tourte 1998). The total number of organic farmers (both certified and non-certified) is increasing at a rate of 12% yr^{-1} in the U.S. and was reported by the USDA as 12,200 in 2000 (USDA 2000b).

More than 75% of certified OFs are less than 2.5 ha in size, compared to 35% of CFs (Greene 2000). Half of U.S. OFs gross less than $15,000. Vegetables are grown on 57% of OFs - the most common of which are tomatoes, sweet corn, lettuce, strawberries, onions, and carrots. Field crops are grown on 52% of OFs, wheat is the most common. Fruit and tree crops are grown on 40% of OFs, and 25% raise livestock. Vegetable crops account for 12% of OA cropland compared to 1% for CA. Half of the organic vegetables sold in the U.S. come from California (Klonsky and Tourte 1998; Greene 2000). In a situation similar to lesser developed countries, over half of California's organic products (OP) sales come from 2% of growers, while two-thirds of the 1,300 OFs accounted for

[2]Nearly all data on OA up to 2001 is from third party certifiers, which under-represent the total number of farmers, since only approximately half of OFs are certified. Nearly all of the larger OFs are certified, therefore acreage data is considered to be accurate (Klonsky 2000).

only 5% of total sales (Tourte and Klonsky Karen 1998). Of certified U.S. OFs, 75% are all organic, and 87% are single-family partnerships. On two-thirds of OFs, OPs earn less than half of net family income.

The U.S. produces 36% of the world's organic cotton (USDA-FAS 1998) and its acreage grew by 75% from 1998-1999 (Marquardt 2000), but organic cotton accounted for only 0.1% of U.S. cotton in 1997. Approximately 1/3 of U.S. culinary and medicinal herb acreage is organic.

Michigan leads the U.S. in organic livestock production (USDA 2000d). Organic dairy operations were lead by New York, followed by Wisconsin, Minnesota, Pennsylvania, California, and Maine (Greene 2000). The organic dairy products market is dominated by one company, Horizon, with 65% of the U.S. market (Depuis 2000). California is the leader in organic poultry products, followed by New York and Virginia (Greene 2000). Pigs and sheep are the other major organic livestock, followed by goats, fish, and bees.

Table 1: Nationally surveyed organic farmers rankings of constraints to production and research needs. (Walz 1999)

Of the respondents to a 1997 survey of U.S. organic farmers (Walz 1999) (the "OFRF" survey) 21% were female, 56% had college degrees, and the average age was 47.5 years. One Midwest study showed that half of both organic and conventional farmers had college degrees, however half of the degreed conventional farmers had majored in agriculture while only 9% of organic farmers had. The same study showed conventional farmers to be 14 years older than organic farmers (56 vs. 42 yr) (Duram 1997).

Constraints to production were ranked by organic farmers in the OFRF survey (Table 1-a). Cost of organically allowable inputs was the biggest perceived constraint to OF production. This was particularly severe with livestock producers, and as a result many OF livestock herds are fed conventional feeds and are not certified organic (Walz 1999). It is easier in the U.S. for organic farmers to keep conventional livestock than in the EU where manure inputs to OA must be from OA. Under the USDA Organic Rule manure from CA is allowed in OA.

Uncooperative or uninformed extension agents were also considered by organic farmers to be a constraint to productivity. Organic farmer information sources are primarily other farmers, private consultants and suppliers; organic certifiers, books and periodicals; and farmer-driven conferences (Fernandez-Cornejo *et al.* 1998).

Sociology of organic farmers.

Studies have shown that strong environment-oriented values are key to the adoption of OA, and that these have been stronger motivations than economics in farmers adopting OA (Padel and Lampkin 1994a; FAO 1998). Several studies have shown that, relative to their conventional counterparts, organic farmers have significantly greater concern for long-term farm sustainability, greater willingness to incur present risk for possible future benefits, greater awareness of and concern for environmental problems associated with agriculture, and scored higher on using conservation practices (Buttel *et al.* 1981; McCann *et al.* 1997). These studies, taken in combination with studies that report that OP consumers tend to have a distinct value system and way of life (Schifferstein and Ophuis 1998), indicate a culture of farmers and consumers at the core of OA. A 2000 survey of U.S. conventional farmers reported that, when asked the reasons for not using sustainable practices, 89% said that fear of loss of yields and profits was the chief concern, followed by "don't know how to do it" (36%), and "landlord won't allow" (17%) (Trusted-Brands 2000).

Motivational and philosophical differences between the two groups appear to be diminishing as markets for OPs continue to grow rapidly and growers more motivated by profits enter into OA (Lohr and Salomonsson 2000; Guthman 2001; Rigby and Caceres 2001). A study by Guthman (2001) focused on this trend. She reported that price premiums are the most often cited reason for conversion from CA to OA, a significant change from the studies above, done before the late-nineties. Many conversions are initiated by established organic growers who contract out for production. Increasingly onerous pesticide regulations are an additional oft cited motivation to convert to OA. These "johnny-come-lately" growers tend to de-emphasize farm-intrinsic agroecological techniques (i.e. crop rotations, careful timing of operations, more intensive management and vegetation design) and follow only the minimal criteria for organic certification by substituting organically-allowed inputs for conventional inputs. However, input substitution tends to be higher on high-rent land where growers cannot afford to take land out of production for rotations (Guthman 2001).

Markets and growth

Annual growth rates of certified OP sales in the U.S. have exceeded 20% since 1992 (NBJ 1999; USDA 2000d), and 25% in the European Union (EU)(FAO 1998) and Japan (NFM 1998b), reaching 36% in the U.S. in 1997 (NFM 1998b), and 55% in the UK in 1999 (Soil-Association 2001). The global OP market value in 2001 is estimated to be \$20B (Fuchshofen 2000; Willer 2001), with the U.S. and EU OP shares valued at \$6B (USDA 2000b) and \$8B (UNCTAD/WHO 1999), respectively in 2000, and Japan \$1.7B in 1997 (Lohr 1998). Global markets for OPs are projected to continue to grow at 5-40% yr^{-1} (Willer 2001) and in the U.S. 20-30% in the medium term (USDA 2000d). Projecting long-term market growth is difficult as little is known about OP demand elasticity and price response to OP supply increases (Midmore and Lampkin 1994; Lohr 1998).

The OP share of total food sales is near to 2% in the U.S. (USDA 2000d) and between 1% and 5% in various EU countries (Hamm 1998), and is projected by one source to grow to as much as 10% in the EU by 2006 (Hamm 1997), and by another source to 10-30% in the EU by 2005 (FAO 2000). The EU countries import an average of 50% of their OPs, with Japan averaging only slightly lower (NFM 1998a). The UK imported 75% of its OPs in 2000 (Soil-Association 2001).

Substantial information gaps exist for U.S. OP trade, as OPs have not been a commodity category in U.S. and world trade statistics, and adequate market surveys of potential OP export markets have been lacking (Fuchshofen 2000). The U.S. exports about 5% of its total OPs, valued at \$200-300 million (Fuchshofen 2000). The major non-NAFTA U.S. OP trade partners are the UK, Japan, Germany, Netherlands, Denmark, and France, and the major U.S. OP export products are soy and soy products, fresh and dried fruit, pulses, nuts, wild and regular rice, and frozen foods (Fuchshofen 2000).

Worldwide, over 130 countries produce certified OPs in commercial quantities (Kortbech-Olesen 2000). No single country dominates north-south OP trade, which was estimated to be 5% of total 1999 global OP trade. North-south trade is expected to expand substantially (Raunolds 2000). Annual per capita consumption of OPs is highest in Europe: Denmark ($114), Switzerland ($95), Austria ($48). The U.S. is 7th at $28, slightly less than Germany; Japan follows at $20 per person (Willer 2001).

Approximately 16 million ha of land worldwide was certified organic in 2000. The U.S., with 0.90 million ha is 4th in acreage after Australia (7.6 M), Argentina (3.0M), and Italy (0.96M). OA in Australia and Argentina consists largely of extensive rangeland, reflected in total sales of less than 5% of U.S. The aggregate EU OA area totals 2.7 million ha (Willer 2001).[3] OF land area in the EU as a proportion of total agricultural land is more than 10-fold higher than the U.S. at 3% in 2001 (Soil-Association 2001) and is projected to grow to 10% in 2007 (Reuters 1999). Sweden has set a target of converting 20% of its arable land to OA by 2005 (Bilefsky 2001). Subsidies for OFs for environmental impact reduction drive much of this growth and are reported to account for a 300% increase in OA area (Lampkin and Padel 1994b).

Growth of U.S. OP related industries – organic farms and farmland, handlers, processors, and manufacturers, has paralleled OP market growth at 20-24% yr^{-1} 1992 to 1997 (NFM 1998b). The structure of the OP industry in both the U.S. and EU is rapidly evolving from small entrepreneurial businesses into mass-market channels, with companies competing for both existing customers and new market sectors (Hartman-Group 1997). Expansion and consolidation of "whole foods" supermarkets, as well as increased sales of OPs by traditional supermarkets (Thompson 1998), and vertical integration of production, distribution, and retail (Merton 1998) have capacitated this growth. While natural food stores retain the bulk of U.S. OP retail market share at 62%, mainstream supermarket sales accounted for 31% in 1998 (NFM 1998b).

The fresh produce share of the OP market, accounting for nearly 2/3 in 1998, is expected to decline to just over 1/3 by 2003 due to more rapid growth of other OP sectors (Table 2). Processed OPs have shown particularly rapid growth, reaching 300% for some product classes in 1996-97 (NFM 1998b); frozen OPs averaged 68% growth from 1991-1996 (Glaser *et al.* 1998); and organic dairy 50-80% yr^{-1} during the late 1990s (Wyngate 1999). Meat and poultry growth rates were lower and difficult to assess owing to the inability to label these products as organic until 1999 (USDA 2000d).

Table 2. OP values, growth rates, and OP market shares for 1998 and projected shares for 2003. Source: (Datamonitor 1999).

Supply has been the primary factor limiting growth of OP wholesale and processed OP trade in the U.S. (NFM 1998b) and EU (Hamm 1997). This lack of supply may only be temporary, as the OFRF survey (Walz 1999) reported that 74% of U.S. organic farmers planned increases in OP volume marketed; 63% planned increases in market channels or buyers; 56% planned increases in cropland; and 39% planned increases in export sales. Another factor limiting growth of OP sales has been unwillingness of mass-market retail buyers and distributors to carry OPs, despite indications of consumer demand (Payson *et al.* 1994).

[3] The fact that EU has 3 times more OA land than the U.S. yet equal market value is likely due to the organic farm conversion subsidy programs in the EU. Most of the conversions to OA have been carried out in regions of lower value agricultural land.

Approximately 80% (by weight) of OPs sold in the U.S. go to wholesale channels, 13% direct to consumer, 7% direct to retail. Twenty percent of OFs have products that reach export markets (Walz 1999). Two major direct-to-consumer OP market channels are farmer's markets and Community Supported Agriculture (CSA) programs. Farmer's markets have grown 25-fold since the sixties to 2,500 currently in the U.S. CSAs are based on a partnership between farmers and local consumers where all agree to share the costs and products of the farm (Hinrichs 2000), although many CSAs are now essentially subscriptions for a periodic produce box. In 1997 there were an estimated 1000 CSAs serving 100,000 households in the U.S. (Hederson 1998).

Average purchase point price premiums for fresh OPs in the U.S. average approximately 60% (Berlau 1999; Lohr and Salomonsson 2000), and can reach 175% (Thompson and Kidwell 1998) to 230% (Glaser *et al.* 1998), and 294% (Vandeman 1998) for processed foods. Premiums in the EU are lower, averaging 10%-50% (Lohr 1998) owing to subsidies for OA and resultant increased production (Padel and Lampkin 1994b). At the farm gate, premiums averaged over 100% for processing tomatoes from 1990-96 (Greene 2000), and other major fruits and vegetables 1992-96(Greene 2001), and from 1989-1999 41% for dry beans, 29% for corn, and 28% for safflower (Klonsky 2000b). Other sources report premiums exceeding 50% for grain and soybeans from 1993-1999 (Greene 2001). Corn premiums, the most volatile, ranged from 7% to 125% (Klonsky 2000b). Clothing from organically grown cotton in 1996 had a 34% price premium (Greene 2001).

An OP price premium of 30% is reported to be a threshold past which mainstream buyers switch back to CPs (Hamm 1997), while another report cites 10% as the threshold (Fost 1992). The common perception that organic produce is cosmetically inferior to conventional produce (Payson *et al.* 1994) has not been born out in studies (Conklin and Thompson 1993; Consumer-Union 1999), and when OPs are cosmetically inferior it may not significantly diminish consumer choice of OPs (Thompson and Kidwell 1998).

The nature of demand for organic products.

A Louis Harris poll undertaken shortly after the 1989 "Alar in apples" report by the Natural Resources Defense Council and its subsequent media publicity reported that 84% of Americans "expressed a preference for organic food (Harris 1990). Increased demand following the Alar publicity caused prices to rise sharply for several years (Jolly and Norris 1991), but since then attitudes appear to have softened. Significant regular OP purchases are made in 10% of U.S. households, ranging from 4.8% of households with extended families to 18% of households made up of childless couples. The major factors accounting for this variation (plus its effect, + or -) were income (+), education (+), household size (-), and presence of children (-) (Spence 1999). Other surveys report similar numbers and emphasize occasional OP buyers, who average about 1/3 of consumers (Hartman-Group 1997; EMS 1998). Of consumers who chose not to buy organic, 28% said OPs were too expensive or a higher price; 19% saw no difference; 8% were not aware of OPs; and 6% said the quality was not as good (Packer 1998). Surveys in the EU have reported similar consumer patterns (Hamm 1997; Lohr 1998). Consumer demand for OPs in the UK has recently doubled that of other EU countries with 2/3 of consumers buying OPs (Soil-Association 2001).

Demand for OPs has been shown to be driven by two main concerns: belief that OPs are more healthful and tasty, and as an additional but secondary reason, belief that OA is more environmentally friendly than CA (Goldman and Clancy 1991; Hamm 1997; Hartman-Group 1997). At least one study adds "tastiness" to health and environmental friendliness as consumer reasons for buying OPs (Ott *et al.* 1991). Consumer concerns about pesticide residues in foods are part of the healthfulness component in OP demand. A 1997 poll showed that 69% of U.S. consumers are "extremely or very concerned" about pesticide residues in foods (HealthFocus 1997).

Fear of transgene (genetically modified) foods has been a factor in pushing up OP sales in the U.S. (NBJ 1999) and in Europe (Reuters 1999). The rapid rise of the U.S. organic dairy industry can be ascribed almost solely to consumer aversion to milk from cows given bovine growth hormone (rBGH) (Depuis 2000), a transgene product. In Europe, demand for OPs has been substantially boosted by mistrust of the food production system as a result of bovine somatotropic encephalopathy (Mad Cow Disease) fears (Tate 1994; Hamm 1997).

Yields and profitability.

Yields.

Several reviews of comparison studies of OA and CA crop yields and economic performance have been done. A 1990 literature review of 205 OF/CF crop comparisons, predominantly from North America and northern Europe, found that on the average, OF crops yielded 10% less than CF crops (Stanhill 1990). Padel and Lampkin (1994b) reviewed comparative studies of yields and economic performance of OFs vs. CFs. In the UK, organic yields averaged 11% lower, and in Canada 6% lower. In the U.S., according to Padel and Lampkin, crop yield differentials are highly variable, from 60% lower in California rice to 50% higher in Midwest oats, with the majority of comparisons reporting slightly to moderately lower yields for OA. This situation may be changing, as a recent survey (Liebhardt 2001) showed that in four different crops (corn, soybeans, wheat, and tomatoes) in different parts of the U.S., OA yields averaged 5% lower than CA. In areas of Europe where crop production is intensive, Germany, Denmark, and the Netherlands, OA yields averaged 30%-40% lower than conventional. In a survey of 17 Japanese prefectures (542 data sets), the average OF rice yield was 13% below its prefectural average with a range of 2-21%. As in the EU, the highest yield differences were in the high-yielding prefectures (Neera *et al.* 1999).

Discussions of yield comparisons need to take into consideration the quality of the target crop. The review of OF/CF comparison studies by Woese et al. (1997) concluded that one of the clear differences between OPs and CPs is higher percentage dry matter in fresh organic produce, which would compensate for lower total yields of non-seed OPs. A typical example is a 12 year OA/CA comparative study of relative yield and composition of vegetables, which found 24% lower yield but 28% higher dry matter in OPs (Lampkin 1990). Comparative animal feeding studies have reported that OP-fed animals needed approximately 25% less food than CP-fed animals (McCarrison 1926; Staiger 1988).

Milk yields on organic dairy farms are typically 10% lower per cow, while stocking rates are 20-30% lower, resulting in per hectare milk yields 30%-40% below conventional (Lampkin and Padel 1994a). A more recent study in Canada showed equivalent milk yields between OA and CA dairy systems (Ogini *et al.* 1999).

A number of studies have shown that under drought conditions crops in OA systems produce significantly higher yields than comparable CA crops (Dormaar 1988; Stanhill 1990), often outyielding conventional crops by 70-90%[4] (Figure 1) (Lockeretz *et al.* 1981; Wynen 1994; Petersen *et al.* 1999). Others have shown that OA crop systems have less long-term yield variability (Henning 1994; Peters 1994; Smolik *et al.* 1995). It has been proposed that assessments of crop performance should have two components – non-declining crop trends, and stability of yield from cycle to cycle (Swift 1994).

The mechanisms of increased drought resistance of organic crop systems may be several. Plant water uptake and ability to withstand drought stress has been shown in numerous studies to be significantly improved by mycorrhizal associations (Syliva and Williams 1992), which are more abundant in the roots of OA crops relative to CF crops (reviewed above). Higher water holding capacities found in OF soils may also play a role (Table 3). Clark et al.'s (1999) California comparison field trial, in which OA crops were limited by mid-season N while the paired conventional crop was limited by water, may be illustrative of this drought performance difference.

OA systems have been reported to outyield CA systems in years of inclement weather and flooding. In 1993, Japan's conventional rice crops were reported to be nearly wiped out by an unusually cold summer while naturally farmed rice yielded 60-80 percent of the annual average (Anon. 1994). In Central America over 1,800 farms using organic and sustainable methods were the subject of a comparison study of the effects of Hurricane Mitch, along with paired conventional neighbors. Organically and sustainably managed farms using organic and sustainable methods were reported overwhelmingly to have lower economic losses, and it was reported that 90% of the neighbors of the study farms indicated a desire to adopt their neighbors' methods (Holt-Gimenez 2000). Other studies have reported that under flooded conditions OA crops have outyielded CA crops due to better composition of water stable aggregates in OA soils and associated reduced soil compaction after spring tillage operations (Denison 1996). A survey of 208 projects in developing tropical countries in which contemporary organic practices were introduced showed average yield increases of 5-10% in irrigated crops and 50-100% in rainfed crops (Pretty and Hine 2001).

Figure 1. Corn grain yields from 26 matched pairs of organically and conventionally managed fields. The solid line is the best fit of data points, the dashed line represents equal yields from each matched pair. From (Lockeretz *et al.* 1981)

The so-called "organic transition effect," in which a yield decline in the first 1-4 years of transition to OA occurs, followed by a yield increase when soils have developed adequate biological activity (Liebhardt *et al.* 1989; Peters 1994; Neera *et al.* 1999) has not been borne out in some reviews of yield comparison studies (Stanhill 1990; Padel and Lampkin 1994a) and at least one replicated field trial (Denison 2000); however, others provide ample evidence for the effect (Dabbert 1994).

The underyield of OA crops relative to CA may or may not be a harbinger of the future. On one hand, as cropping systems intensify worldwide, it would seem that the yield gap would widen. However, most OA/CA yield comparisons have been made under optimal conditions, and extrapolations of future crop yields must take into account the high likelihood that climate disruptions will increase the incidence of droughts and flooding (Sombrock

[4] One is tempted to imagine the media publicity that would follow the unveiling of a universally insertable transgene for crop drought resistance of similar magnitude to that shown by organic crop systems in drought resistance

and Gommes 1996; Weiss and Bradley 2001), in which case, based on evidence presented earlier, OA systems are likely to out-yield CA systems. Additionally, research investment into OA systems has amounted to a tiny fraction of that invested in CA systems, and OA systems are considered by some experts to be immature relative to well-funded CA systems (Lampkin 1994; Pretty 1995; Clarke 2001). Development of OA systems has been similar in many ways to contemporary peasant agricultural systems in lesser-developed countries – a hodgepodge of small research programs, farmer experimentation, and modified traditional practices. Going head-to-head in yield comparisons may be unfair until research and extension investment into OA catches up and allows OA systems to reach a mature stage comparable to CA systems.

The common claim that large-scale conversion to OA would result in drastic reductions in world food supplies or large increases in conversion of undisturbed land to agriculture (Avery 1995; Trewavas 2001) have not been borne out in modeling studies. Conversion studies show that domestic food consumption would not suffer, exports would vary depending on crop, and the structure of farming would change (Woodward 1998). Widespread conversion to OA would likely result in increases in OA crop yields over current averages as a result of increased investment in research and extension (Lampkin 1994). Australian and German studies found that post-conversion food supply could be maintained if crop hectarage ratios were adjusted, and that the main outcome would be a loss of farmer income. The Australian study concluded that widespread adoption of OA would involve only a minor loss of farmer income (Wynen 1996), while the German study by Braun (Braun 1994) concluded this income loss would be 24%. Neither study used organic price premiums.

A German study concluded that if per capita dietary calories from meat were reduced to 21% from the current 39%, all German cropland could be converted to OA without an increase in imports or expansion of agricultural land (Figure 2). According to the report such a conversion will be possible in 2017, as surveys indicate that 40% of German youth plan to maintain low or no-meat diets (Seemueller 2000). The threshold for this conversion may come sooner, as abandonment of meat-consumption is accelerating Europe as a result of BSE (Morabia *et al.* 1999).

Figure 2. Reduction of meat consumption to 21% from 39% of total calories would allow total conversion to OA in Germany with no need for additional agricultural land. Italy averages 25%. From (Seemueller 2000)

Economic performance.

Numerous studies have shown that the common OA combination of lower input costs and favorable price premiums can offset reduced yields and make OFs equally and often more profitable than CFs (Reganold *et al.* 1993; Holland *et al.* 1994; Padel and Lampkin 1994a; Smolik *et al.* 1995; Cormack 1996; Stonehouse 1996; Hanson *et al.* 1997; Petersen *et al.* 1999; Reganold *et al.* 2001). Studies that did not include organic price premiums have given mixed results on profitability. In the U.S. Midwest, Welsh (1999) reviewed OF/CF profitability comparison studies, and concluded that the advantage of one system over the other depended on the region, and that within-system variation (variation in the environment) had a greater effect on profits than between-system variation (OA vs. CA). CFs do better in the wetter Corn Belt, while OFs do better in the drier areas because of the better drought

research.

tolerance of OA crops (Welsh 1998). However, other long-term cropping studies in the Midwest found OF systems to be economically superior without price premiums (Hanson *et al.* 1997; Sahs *et al.* 1998).

Input costs of comparable OFs and CFs, reviewed in Padel and Lampkin (1994b), are generally lower in OA; input costs on the average are 50-60% lower for cereals and legumes, 10-20% lower for potatoes and horticultural crops, and for dairy operations 20-25% lower than comparable CA systems. Studies from Europe and Canada show labor costs in OA average 40-50% higher, and that worker wages are generally higher. Gross margins, the difference between farm output and variable costs, are generally similar or, where there are favorable price premiums, higher in OA. Labor costs increase with the number of products grown. In these cases price premiums are needed to compensate for reduced output and increased labor costs. There appears to be a trade-off between crop diversification for ecological and economic stability, and concentration on just a few crops to reduce input costs.

Certification standards and trade

By the 1970's protocols for certification of OPs and OFs were under development by private organizations in the U.S. and Europe. By the 1980's certifying bodies numbered in the hundreds worldwide, and many national and regional governments had developed organic certification guidelines. These worldwide standards all a contain a common core of rules (Tate 1994). A breakthrough for OA came in the early 1990's when the EU mandated policies for subsidization of OA by shifting the Common Agricultural Policy (CAP) priorities from agricultural price supports to the reduction of the environmental impacts of agriculture via "extensification" (read: reduced capital input intensity), and by instituting the agri-environmental Regulation 2078/92 (EEC 1999). This has been a major factor in the rapid growth of OA there (Hamm 1996). In 1992 the EU implemented organic standards with Regulation 2092/91 for the production, processing, and trade[5] of OPs.

Internationally, three bodies are central to global OP standards: the International Federation of Organic Agriculture Movements (IFOAM), Codex Alimentarius, and the International Organization for Standardization (ISO)[6]. IFOAM is a private, non-profit, Europe-based organization with 770 member organizations from 105 countries. IFOAM's Basic Standards for organic production, processing, and distribution have been used extensively since the 1970s for development of certification programs by bodies such as the EU, FAO, and various national organic programs. In 1992 the IFOAM Accreditation Programme was developed for accreditation of national, regional, and private certification bodies in the categories of crop production, processing, livestock, wild products, input manufacturing, retailing, and certification transference (IFOAM 2000b). The IFOAM-affiliated International Organic Accreditation Services (IOAS), under the ISO61 framework for accreditation, accredits organic certification bodies for compliance with IFOAM Basic Standards, as well as for compliance with EU Regulation 2092/91 (IOAS 1999).

Codex Alimentarius, part of the FAO/WHO Food Standards Program, sets international food standards. Guidelines for the production, processing, labeling and marketing of OPs were approved by the Codex Committee on Food Labelling in 1999 (FAO 1999). Codex is not a regulatory body; its guidelines can be used by countries

[5] www.prolink.de/~hps

[6] Respectively: www.ifoam.org, www.codexalimentarius.net, www.iso.ch

wishing to establish or enforce organic standards. Trade disputes regarding organic standards can be settled by the World Trade Organization in reference to the Codex standards (Schmid and Lovisolo 1998).

ISO65, an international standards protocol administered by the International Organization for Standardization, sets requirements for bodies operating product certification systems. Bodies such as the EU require ISO65 compliance by certifiers of OP producers that export to the EU. The new USDA Organic Rule requires ISO 65 compliance for certifying bodies (USDA 2000c).

U.S. Standards.

Development of national standards by the USDA has been driven by the need to provide a unified standards system and to take advantage of OP export potential, which has been limited by lack of agreements on certification standards. In 1997 there were over 40 organic certification organizations in the U.S., including a dozen state programs.

The USDA National Organic Program (NOP)[7] organic standards Final Rule (USDA 2000c), a legally enforceable federal regulation, was announced in December 2000 after a contentious, decade-long process which served to more clearly define the meaning of "organic". A division of the USDA Agricultural Marketing Service, the NOP was mandated by the National Food Protection Act of 1990. Using the recommendations of the advisory National Organic Standards Board (NOSB), made up of volunteer representatives from the OA community, the NOP establishes 1) national standards for production and marketing of OPs; 2) a list of synthetic substances approved for use in OA (the National List of Allowed Materials); 3) an organic certification program; and 4) OP import guidelines. The allowance of synthetic food additives in OPs was a controversial, landmark decision which paved the way for the scaling-up of the production of processed OPs to industrial levels for mainstream marketing (Pollan 2001). The decision was opposed by many within the NOSB and the OA community, who felt it eroded OA core values (Gussow 1997),

In 1997 the USDA published an Issue Paper for the proposed national organic standards in the *Federal Register* as part of the required comment period, and in the ensuing year received over 300,000 responses, the most in the history of the USDA comment protocol (Haapala 2001). Three issues stood out as unacceptable to respondents: 1) use of transgenic crops in OA, 2) irradiation of OPs, and 3) use of sewage sludge in crop systems. All of these were subsequently dropped from the second draft of the proposed Rule.

The USDA Organic Rule is closely modeled after existing organic certification protocols. The producer of an organic crop must manage soil fertility by the use of rotations, cover crops, and the application of plant and animal materials or low-solubility natural minerals. These practices must maintain or improve soil organic matter content, manage deficient or excess plant nutrients, and control erosion to the extent that these functions are applicable to the operation. The producer must use preventive practices to manage crop pests, weeds, and diseases, including but not limited to crop rotation, soil and crop nutrient management, sanitation measures, and cultural practices that enhance crop health. Raw animal manure must either be composted or, in the case of food crops, must be in soil 120 days before harvest.

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[7] www.ams.usda.gov/nop

Organic certification of farms generally consists of an annual visit by a representative of the certifying agency, which must now be accredited by the USDA NOP. Production operations and accounts are inspected. Certification services are paid for by the producer and generally consist of either a flat fee or a percentage of receipts of inspected acreage. Producers with less than \$5,000 yr^{-1} in OP sales are exempt from certification under the new Rule. A transition period of 3 years during conversion from conventional to organic production is required, during which time products may be marketed as “transitional organic” but cannot receive organic price premiums.

Companies wishing to market new substances for use in OA must first petition the NOSB, which has contracted the non-profit Organic Materials Review Board[8] to review materials petitions. The NOSB may then put it on the National List of Allowed Substances.

Organic livestock must have access to the outdoors, shade, shelter, exercise areas, fresh air, and direct sunlight suitable to the species, its stage of production, the climate, and the environment. To be certified, organic livestock cannot be given antibiotics or hormones, must be fed 100% organically grown feeds, and ruminants must have access to open pasture. As with EU Reg. 2092/91, maximum stocking density is not specified.

Processed OPs have four levels of labeling: 100%, 95-99%, 70-95%, and <70% organic ingredients, with additional specifications for each category.

An implementation period of 18 months for the USDA Rule means that bodies wishing to be certified as organic have until October 2002 to comply.

Mushrooms, greenhouse operations, honey (bees), and fish are under review by the NOSB for organic certification standards (Brickey 2001). The NOSB has formed an Aquatic Animal Task Force to develop certification protocols for the origin of aquatic products, the source and content of aquaculture diets, the environmental impact of the production system, and the potential contact between aquatic animals and prohibited substances (USDA 2000c). Organic standards for handling, processing, and labeling of fiber products are under development (OTA 2001). The first certified organic restaurant in the U.S. opened in 1999 (Anon. 1999b), although restaurants and retailers that sell OPs are exempt from mandatory certification under the USDA Rule. Large-scale organic turfgrass projects have been initiated (O.U. 2000).

Organic accreditation plans for flowers, fabrics, and body care products are under discussion at IFOAM (IFOAM 1997). When implemented these would likely be discussed by the NOSB for possible USDA NOP accreditation.

Many of the major organic industry players report that the USDA NOP Final Rule standards are "high" (Bowen 2001) and that they are "a good working definition of organic production and are true to the organic philosophy and approach" (CCOF 2000; Haapala 2001). One item has generated protests from existing certification organizations (Bowen 2001; IFOAM 2001b) - the “floor and ceiling” ruling for OP labeling. The organic certification label of an existing private certifier can only signify compliance with USDA NOP and cannot refer to higher or different standards that use the term “organic”. This ruling departs from protocols in the EU and other countries where third parties can certify with their own organic standards as well as for the national standards. However, under the USDA Rule, certification for other standards that do not refer to “organic”, (i.e. “Biodynamic”), is acceptable (Haapala 2001).

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[8] www.omri.org

A portion of the OA community has objected to the idea of government oversight of OA via the NOP as well as what they believe to be the watering-down of the core values of OA (Duesing 1995; Allen and Kovach 2000; Goodman 2000; Vos 2000). Others have alleged violations of the Organic Foods Production Act in the USDA Final Rule (Kindberg 2001).

Organic certification equivalence between the U.S., potentially the world's largest OP exporter, and the EU, the world's largest importer of OPs (Segger 1997), may take up to five years to negotiate (Jones 1999). Until then U.S. exporters must obtain a separate authorization for each OP shipment. Substantial barriers to U.S. OP exports to interested EU resellers exist, the most common of which are inconsistently applied trade regulations and arbitrary technicalities imposed by EU nations (Fuchshofen 2000). U.S. exporters of OPs to the EU must comply with a number of criteria beyond most U.S. organic standards such as guaranteeing that manures used in crop production are not from "factory farms", providing detailed information that the operation is "self-sustaining", and prohibition of the use of Chilean nitrates (QAI 2001). Six countries - Argentina, Australia, Czech Republic, Israel, Hungary, and Switzerland - have organic programs based on EU Regulation 2092/91 and have achieved the coveted EU Article 11 status which streamlines the process of exporting to that lucrative market. Japan's new organic regulations are reported to be trade-unfriendly as well (Fuchshofen 2000). In order to export OPs to the U.S., the exporter must be certified by a USDA NOP accredited body, whether U.S. or foreign.

Institutional and media support for OA.

The OFRF survey of U.S. organic farmers showed that they perceived themselves as making substantial progress with little support from public agencies and government institutions and that they considered the main barrier to OA to be uncooperative or uninformed extension personnel (Walz 1999). The lack of information and extension support for OA may in a large part be accounted for by negative attitudes toward OA that have been common in government and the scientific establishment. A quote from Nixon administration Secretary of Agriculture Earl Butz represents the prevailing attitudes of many farmers and scientists in the 1970's and into the 1980's "When you hear the word organic, think starvation." (Lipson 1997). As an undergraduate majoring in agriculture at a land grant university in the 1970's, the author heard virtually the same statement from agriculture faculty. These attitudes have prevailed despite the publication of several studies (discussed above) since the 1970's that showed that neither hunger nor serious food shortages would result from a system-wide conversion to OA in North America.

Conservative or negative attitudes toward organic and sustainable agriculture (SA) within the scientific and academic community have been reported as a significant barrier to research and extension work (Larson and Duram 2000), and scientists engaging in OA research have related that they incurred substantial personal and professional costs as a result (Lipson 1997). In an early-1990s survey of 584 agricultural research principal investigators, responses to nine agricultural terms were rated quantitatively. The term "organic farming" finished as second most negative, only slightly more favorable than "government regulation" (Harp and Sachs 1992). As a result of these attitudes, research and teaching on the science of agroecology, the foundational science behind OA[9], has stagnated at

[9] See (Altieri 1995) for an introduction to agroecology.

land grant institutions (Lacy 1993)[10]. SA researchers have had to form alternative extension systems in order to effectively disseminate their research (Larson and Duram 2000). In a study of funds allocated to OA research by the USDA in 1995, the Organic Farming Research Foundation found that, out of 30,000 projects, 34, less than 0.1%, were focused on OA and another 267 projects were compatible with but not focused on OA (Lipson 1997). Infrastructural support for OA research mirrors funding - the proportion of land dedicated to research on OA in the U.S. in 2000 comprised 245 ha or 0.07% of land grant university agricultural research area (Tooby 2001). Despite these conclusions, which are mostly from the 1970's through the 1990's, it is the experience of the author as well as one of the reviewers of this paper that there has been significant moderation of the negative attitudes toward OA that were prevalent in land-grant universities and other institutions.

By the late 1970s most research on OA had come under the term sustainable agriculture (SA). SA is distinguished from OA primarily by the legal and voluntary written standards that are part of OA, and in current usage OA is a subset of SA.

Government support for OA may be improving. At the federal level, two provisions relating to OA were included in the Agricultural Risk Protection Act of 2000 (Zygmont 2000), adding OA to the list of "good farming practices" necessary for crop insurance. The second provision authorizes cost share assistance for transition to OA. An Organic Transition Program with funds for research has been initiated at USDA (USDA 2000a).

The Horticultural and Tropical Products Division of the USDA Foreign Agricultural Service[11] (FAS) has been designated to handle information and promotional programs regarding international trade in U.S. organic commodities (USDA 2000d). Under the USDA-FAS Unified Export Strategy program, the non-profit Organic Trade Association[12] has been funded to represent U.S. international trade in organic products. As with other commodity groups, the USDA shares the costs of overseas marketing and promotions of U.S. OPs.

Media and organics.

Media reports on organics have mirrored organic industry growth - the appearance of the subject "organic food" in 70 major newspapers has grown steadily from 0 in 1988 to over 300 in 1998 (Demeritt 1999). However, references to organic in the media are far from all positive, and the organic industry has come under occasional withering and unfair attacks, the most damaging and egregious being the recent politically motivated allegations of contamination of OPs by deadly microbes. In 1997 unpasteurized apple juice contaminated with *E. coli 0157:H7,* believed to have come from manure used as fertilizer, was implicated in the death of an infant and hospitalization of several others. Despite the fact that the juice was neither labeled nor implied as organic, and that organic certification rules have guidelines to prevent contamination of food by manures, a 1998 press release (Avery 1998) by Dennis Avery of the agrochemical industry supported (Keeler 2000) Hudson Institute, using the apple juice incident, stated: "According to recent data compiled by the U.S. Centers for Disease Control (CDC), people who eat organic and 'natural' foods are eight times as likely as the rest of the population to be attacked by a deadly new

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10 The UC Davis agroecology program (a section of the Graduate Group in Ecology) is virtually unfunded, despite the fact that UCD has the unique combination of having the top programs in the U.S. in both agriculture (ISI 1998) and ecology (Brett *et al.* 1999).

11 www.fas.usda.gov/htp

12 www.ota.org

strain of *E. coli* bacteria.”. This theme, plus what later proved to be false statements about pesticide residue analyses in OPs vs. CPs (Bell 2000), was featured in a prime-time television news magazine story, run at least twice, that negatively portrayed organic foods and farming (ABC 2000). The story was rebutted after researchers from the CDC, whose *E. coli* data were used for the Hudson report, stated that there was no basis for Avery’s statements (Burros 1999; Rutenberg and Barringer 2000). However, the disinformation persists - the U.S. representative to the U.N. Food and Agriculture Organization, George McGovern, was quoted in 2001 as saying "in some of these organic foods ... fertilizer residue makes them unsafe to eat" (Dolinsky 2001).

Agroecological characteristics of organic agriculture.

Organic carbon is the central element of organic crop production systems, and the soil ecological community it feeds modulates nutrient retention and release, soil structure, and even resistance to many diseases and insects and even weeds. Fundamental differences in the biological, chemical, and physical characteristics of soils have been found between OA and CA systems (Bossio and Scow 1998; Clark *et al.* 1999).

Conversion to OA production systems requires substantial structural changes from CA. Simply reducing or eliminating synthetic inputs in otherwise conventionally-managed systems does not represent OA, as complex interactions and feedback between soil, crops, non-crop organisms, and inputs must be managed in order to optimize production. Crop rotations and cover crops are the agroecological management factor that overwhelmingly recurs as a critical component in surveys of organic farmers and reviews of OA system research. In most OA systems cover crops are the source of the vast bulk of organic carbon inputs needed for the desired soil microbial community and adequate nutrient pool. Often carefully designed, timed, and intensively managed, rotations are also commonly an integral part of weed, pest, and disease management strategies in OA systems.

Some researchers have seen a trend in OA toward replacement of agroecological practices such as rotations, vegetation design, and management intensive techniques with a set of energy and capital intensive organic "technology packages" and input substitutions, especially in agriculturally intensive areas of California, and see this as a deterioration of OA standards and core values (Rosset and Altieri 1997; Guthman 2001). While Guthman found this trend on newly converted California OFs, respondents to a 1997 survey of U.S. organic farmers (Walz 1999) survey showed that, for the most part, organic farmers in the U.S. are not converting in large numbers to the use of input substitutions (Table 4).

Organic farmers named weed management their top priority in research needs in the OFRF survey of U.S. organic farmers (Walz 1999) followed by the “relationship between fertility management and crop health and pest/disease resistance”, and “relationship of organic growing practices to nutritional value of product” (Table 1). Also figuring prominently was “whole farm planning / ecosystem integration.”

The development of increasingly sophisticated agroecological techniques in OA can be illustrated by the suite of inputs now commonly used in organic apple production. Twenty-five years ago it was common to hear from experts that it is impossible to produce popular (non-disease resistant) varieties of apples organically. Today most of these apple varieties are produced organically. Strategies in one orchard may involve combinations of: carefully designed cover crop mixtures and mowing/disking schedules for fertility and pest management; careful monitoring and accounting of temperature, humidity, and insect counts in pheromone attractant traps; carefully timed pheromone release for codling moth (*Cydia pomonella*) mating disruption; granulosis virus applications for additional codling moth control - carefully timed to target first instar larvae; applications of *Bacillus thuringensis* (a bacterial pesticide) for leafroller (various genera); applications of elemental fungicides for scab (*Venturia inequalis*) control scheduled via a biometeorological computer model; winter sprays of oils and minerals for various pests; foliar applications of fish emulsion, seaweed extracts, and/or compost tea solutions for crop nutrition and disease management; careful elimination of end-of-season "mummy" fruits; and enhancement of nearby predator habitat to enhance control of pests. This sophisticated approach to agricultural management, known to some as "integrated crop management", has been called "the other precision agriculture" in reference to CA's technology intensive "precision agriculture" (Padgitt *et al.* 2001).

Table 4 Management practices used by cross-section of U.S. organic farmers (all crop types), ranked by frequency of use (Walz 1999)

Weed management.

Weeds are clearly the biggest problem in OA crop systems according to the OFRF survey. Weeds can be the most important factor in yield loss in some OA systems (Petersen *et al.* 1999) and in others less important than N limitations (Clark *et al.* 1999). Weeds are a particularly onerous problem during the transition from CA to OA (Petersen *et al.* 1999; Walz 1999).

According to the OFRF survey, the weed management techniques most commonly used in OA production are mechanical cultivation, hand or hand implement, crop rotations, and cover crops (Table 4). Other methods not listed in Table 4a are water management, pre-germination of weeds, planting to moisture, buried drip irrigation, and strategies for long-term reduction of the weed seed bank (Gaskell *et al.* 2000). Improved cultivation implements – knives, reversed-disc hillers, rolling cultivators, spring tines, brush hoes, guide wheels and sleds are improving weed control (Smith *et al.* 2000). Other weed management strategies with potential for OA are microbial biocontrol agents (Kennedy and Kremer 1996), night tillage (Gallagher and Cardina 1998), organic compliant herbicides such as corn gluten (McDade and Christians 2000), and cultivator-mounted computer guidance systems for distinguishing crop from weed (Smith *et al.* 2000).

Traditional visual assessments of weed problems in OA may need empirical verification, as organic crop systems have been shown to tolerate higher weed densities without yield loss than conventional systems (Clark *et al.* 1999; Petersen *et al.* 1999; Belde *et al.* 2000). Higher weed populations in OA systems have been correlated with higher plant biodiversity and may include rare or ecologically important species (Altieri 1994; Albrecht and Mattheis 1998). Soils with higher organic matter content, nearly always the case in OA relative to CA, have been shown to have higher populations of beneficial rhizobacteria that inhibit weed seed germination (Kremer 1999). A frequent problem in OA systems is weed seeds in uncomposted manures, which can add substantially to weed problems (Teasdale 1998; Petersen *et al.* 1999). "Critical weed-free period" methodologies, in which the timing of weed control is optimized based on crop sensitivity to weed pressure, have been developed for organic crops (Welsh *et al.* 1999).

Some organic farmers in the Midwest have successfully developed conservation tillage (CT) methods, which reduce tillage and soil disturbance (Kuepper 2000). CT strategies have heretofore been heavily dependent on herbicides. In California, CT has for the most part not been successfully adapted to organic crop systems because of inability to control competition by cover crops with the crop planted into it (Gaskell *et al.* 2000), and because of difficulty controlling weeds (Brown 1998). Organic CT methods are under development there (Brown 1998; Mitchell *et al.* 1999; Gaskell *et al.* 2000).

Pest management.

In the OFRF survey, pest management was seventh on the list of research priorities that organic farmers ranked (Table 4b), indicating that pest management, contrary to popular belief (Avery 1998; Trewavas 2001), is generally not a major problem in OA systems. Comparative OA/CA field research corroborates this (Clark *et al.* 1998; Letourneau and Goldstein 2001). Crop rotations, beneficial arthropod and vertebrate habitat, and *Bacillus thurigensis* are the most frequently used arthropod pest management strategies according to the OFRF survey (Table 4b). Aggressive pest scouting and early detection, not covered in the OFRF survey, are also important (Fernandez-Cornejo *et al.* 1998; Fouche 2000) as well as mass trapping of pests (Olkowski 2000). Substantial resources for biological control of invertebrate pests exist and are under continuous development (Weeden *et al.*).

Comparative OA/CA research on tomato showed similar levels of pest damage in the two systems, while OA tomatoes had greater species richness of all functional groups - herbivores, predators, and parasitoids. Fallow management and surrounding habitat were found to be more important than insecticide use in influencing arthropod community structure (Letourneau and Goldstein 2001).

Regulated pest management districts and government-imposed pest eradication programs may compromise organic certification status. Alternative pest management programs have been developed in order to exempt OFs from pesticide application requirements (Ellen 1998). Quarantine methods for export commodities that are organically acceptable and that replace chemical fumigation are being developed (Neven and Mitcham 1996).

OA has long used “total system” approaches to pest management now being called for in CA (Lewis *et al.* 1997). High agroecosystem biodiversity, a core element of OA, is considered to be an important pest management factor in unsprayed agroecosystems (Altieri 1994; Brown 1999). Parasitization of agricultural pests is higher and damage to crop by the pest significantly lower in agricultural systems with a higher number of non-crop plant species (Thies and Tscharntke 1999). Natural enemy insectary plants can be cultivated to increase predation and parasitism (Luna *et al.* 1999; Fouche 2000).

Organic farmers have long maintained that synthetic fertilizers and pesticides increase crop susceptibility to pests[13] (Rodale 1945; Albrecht and Walters 1975; Yepsen 1976). Research substantiates some of these claims.

[13] As part of a group of students studying organic and sustainable agriculture at UCD in the 1970s, l attended talks by organic farmers. They often related that their crops were naturally "resistant to insects and disease" compared to conventionally grown crops, and that a moderate level of insects, even pests, is good to have in a crop, and that the use of pesticides and synthetic fertilizers increases crop susceptibility to pests. These ideas were the subject of either dismissal or ridicule by agricultural science faculty. Now, 25 years later research on plant systemic acquired resistance is verifying virtually all of these observations. I would like to dedicate this paper to those early organic farmers, and the consumers who supported them, who pioneered the OA movement at a time when it was more difficult to farm organically.

Organic crops have been shown to be more tolerant of, as well as resistant to, insect attack. Tolerance of OA crops to pests has been shown (Andow and Hidaka 1998; Lotter *et al.* 1999), characterized in comparative research by reduced damage to OA plants per number of pests. Resistance, characterized by a reduction in insect attack, has been conferred by growing plants in OA soils in the greenhouse and comparing insect growth and reproduction (Kajimura 1995; Phelan *et al.* 1996; Phelan 1999). Insects had significantly lower survival and reproduction rates on plants grown in OA soils than on plants in CA soil, and in one case (Phelan *et al.* 1996) egg laying was 18-fold higher on CA plants than on identical OA plants.

OA rice is reported to have thicker cell walls (Hirai and Kimura 1979) and lower levels of free amino acids than CA rice (Kajimura 1995; Wang-GY 1998). Plant susceptibility to insect herbivory has been shown in numerous studies to be associated with high plant N levels (Phelan *et al.* 1996; Phelan 1999) related to high inputs of soluble N fertilizers. Free amino acids, associated with high N applications, have been reported to increase pest attack (Hedin *et al.* 1993).

A synergistic effect of synthetic N fertilizer and a pesticide on exacerbating pest problems in plants has been reported. Godfrey et al. (2000) reported aphid populations on field-grown cotton increased 3-4-fold from low to high N fertilization rates. Treatment with a pyrethroid pesticide caused aphid populations to flare 3-4-fold again in the high N plots compared to the unsprayed high N treatment. Generation times for aphids at high N were less than 1/3 of those of low N plants.

Disease management.

Organic farmers ranked disease management 8th on the list of research priorities (Table 4b), indicating that along with arthropod pest management, disease is not a top priority problem in most OA crop systems. Crop rotations, resistant crop varieties, compost or compost tea applications, and companion planting were the most commonly cited disease management strategies listed by farmers in the OFRF survey (Table 4c).

Soil-borne root diseases have been shown to be less severe in OA soils than CA soils (Workneh and Van Bruggen 1994; Lotter *et al.* 1999; Wang *et al.* 2000) and have been shown in numerous studies to be reduced by additions of organic matter of optimal C/N ratio (ca. 12:1) via fostering of antagonistic and beneficial microbes (Papavizas and Adams 1969; Campbell 1989; Mandelbaum and Hadar 1990; Hu *et al.* 1997; Hoitink and Boehm 1999). OA soils have consistently been shown in numerous studies to have significantly higher microbial biomass C and N (Table 3). Numerous studies have shown that root-colonizing vesicular-arbuscular mycorrhizal (VAM) fungi protect plants against pathogenic root-infecting fungi (Azcon-Aguilar and Barea 1992) and that OA crops have significantly higher VAM colonization than CA crops (Ryan *et al.* 1994; Eason *et al.* 1999; Mader *et al.* 2000).

Herbicides used in conventional crop systems may be related to reduced disease resistance. Increased soil-borne root disease caused by glyphosate (Roundup®), one of the most commonly used herbicides in CA, has been shown. This occurs via glyphosate inhibition of systemic resistance of the crop it is meant to benefit (Liu *et al.* 1997; Descalzo *et al.* 1998). Pesticide effects on the natural resistance of plants has been insufficiently researched.

Composts (Zhang *et al.* 1996) and aqueous solutions of compost (compost tea) (Cronin *et al.* 1996; Zhang *et al.* 1998) have been shown to induce plant systemic resistance, in which defense compounds are produced that inhibit pathogen and insect attack. In the former experiment, composts applied to soil induced resistance to a fungal disease in the foliage of the plant as well as root resistance to the soil-borne disease *Pythium*.

At least one study has shown that OA crop systems can be a major inoculum source of diseases for neighboring CA crops, in this case, late blight of potato (Zwankhuizen *et al.* 1998).

Microbial disease control products may hold potential for future use in OA; these are reviewed in Weeden (2001).

Soil management, biology, and crop nutrition.

Cover crops, legumes, compost, and animal by-products are the most common fertility management strategies used by organic farmers (Table 4d). Numerous comparison studies, summarized in Table 3, have shown OA soils to have generally higher measures of soil quality than CA soils: higher water holding capacity, microbial biomass, organic matter (carbon), total N, permeability, aggregate stability and pH; and significantly lower nitrates and electrical conductivity. Analysis of soil data from 30 paired organic and conventional farms showed that organic matter, aggregate stability, humic acid, infrared absorbance, and pH most effectively discriminated the two systems (Armstrong *et al.* 2000).

Some of the changes in soil biological and chemical properties upon conversion to OA can take several years, such as increases in total soil organic matter content and microbial community structure (Clark *et al.* 1999), while other biological properties can change almost immediately, as with aggregate microbial biomass and activity (Gunapala *et al.* 1998).

OA fertility techniques in the first years after conversion commonly fail to meet mid-season peak N-uptake demands of crops (Power and Doran 1984; Clark *et al.* 1999; Pang and Letey 2000). Transition yield declines are often the result of microbial immobilization of N when high C/N ratio organic amendments are used (Fauci and Dick 1994). In a California long-term comparison study, crops in OA plots were limited by mid-season N while the paired conventional crop was limited by water (Clark *et al.* 1999). Pang and Letey (2000) used soil simulation models of manure applications to demonstrate that meeting peak N demands of crops that have high N-uptake rates, such as corn, may be difficult without producing a buildup of post-crop soil N, which can leach into waterways. It took at least two years after conversion to OA for the organic sources of N to meet corn peak demands. Wheat, with much lower peak N demand than corn, was adequately served in the first year by N releases from the manure application. Using OM decay series data to determine amounts of N released in subsequent years after each application of manure, Pang and Letey estimated that varying the amounts of annual manure applications can optimize N availability at crop peak use and minimize post peak excess N. Their simulations also showed that maximum yields of corn could be achieved with applications of small amounts of soluble N at the crop peak use period. Organic producers who wish to maximize yields in such crops could do so by applying organically acceptable high soluble N fertilizers of such as guano. However, this “input substitution” practice risks producing high plant N levels and may compromise the traditional product quality and resistance to pest attack that are hallmarks of OA.

In OA systems with post-season cover crops (catch crops) N leaching has not been found to be a problem (Clark *et al.* 1999). Nitrate leaching can be reduced by 65-70% with catch crops (Wyland *et al.* 1996). N-mineralization models for cover crop mixtures and incorporation schedules have been developed to optimize mid-season N and minimize leaching in OA systems (Granstedt and Baeckstrom 2000).

Contrary to reports reviewed above, adequate release of available N for plants via biological cycling of organic matter can occur in the first season of conversion to OA (Gunapala *et al.* 1998; Denison 2000). In a California field trial, minimal differences in microbial activity and ability to decompose organic matter were found between established organic plots and plots in the first months of conversion to organic. However, it was reported that in the post-amendment CA plots, twice the nitrates were released as OA plots, a situation that could lead to nitrate leaching in the CA and transitional systems. Soils in the first season of conversion to OA tend to have different microbial communities than long term OA soils - fungi were reported as dominant in the long term OA plots while bacteria dominated in the converted CA plots.

Methodologies for comparing and evaluating OA and CA systems.

Numerous methodologies have been developed for analyzing the environmental costs, sustainability, and productivity of OA vs. CA systems, and a number have been used for OA/CA comparisons (vanderWerf *et al.* 1997; Clark *et al.* 1998; Glover *et al.* 2000; Stolze *et al.* 2000; Tellarini and Caporali 2000; Edwards-Jones and Howells 2001; Haas *et al.* 2001; Hansen *et al.* 2001). Wiren-Lehr (2001) and Hayo and Petit review methodologies for assessing sustainability in agriculture.

Assessment methodologies can be based on theoretical agroecosystem dynamics (Xu and Mage 2001), measurable agroecological indicators (Bockstaller *et al.* 1997), on-farm biodiversity (Paoletti 1999b), pesticides (Kovach *et al.* 1992; Levitan *et al.* 1995; Wijnands 1997), soil quality (Doran and Jones 1996; Werner and Brown 1998; Doran and Zeiss 2000; Glover *et al.* 2000), life cycle assessment using standardized protocols (Haas *et al.* 2001), input/output methodologies (Tellarini and Caporali 2000), or economic indicators (Freyenberger *et al.* 2001). Guthman (2001) developed an "agroecological rating system" for comparing OA systems, in which farms are rated predominantly on their level of use of outside inputs vs. farm-intrinsic strategies. Faeth (1993) developed an economic analysis of farms that takes into account costs external to the market system, such as erosion and water pollution. Utilization of this approach may help transfer some of OA's internalized costs of environmental impact reduction from a small number of farmers and OP consumers to its beneficiaries, society at-large (Clark *et al.* 1998).

The most important agricultural system evaluation approach currently being used, predominantly in the EU, is the environmental indicator methodology, in which the system's most significant information is broken down into categories, simplified, quantified, and reported in a scorecard format. An agricultural system model using a "Driving Force – State – Response" (DSR) protocol is used in combination with environmental indicators. Various "Driving Forces" cause the "State" of the environment to change, which in turn causes "Responses" from consumers, farmers, the economy, and the government (Stolze *et al.* 2000). Stolze et al. (2000) use the DSR model in their study of the environmental impacts of organic farming in Europe. The performance rating of organic farming in each of a list of environmental areas using this method is shown in Table 5.

Broad-scope methodologies for assessment of agriculture's impacts have been developed (Andreoli and Tellarini 2000; Antrop 2000; Bosshard 2000) and implemented (Kuiper 2000; MacNaeidhe and Culleton 2000;

Rossi and Nota 2000; Stobbelaar *et al.* 2000), many driven by EU policy directives that mandate the development of broad-scope approaches (Stobbelaar and van Mansvelt 2000). Methodologies for assessment of the ethical treatment of livestock have been developed as part of the broadening of OF environmental accounting (Halberg 1996; Vaarst 2000).

Safety and quality of organic vs. conventional foods.

The healthfulness of foods has safety and quality components (FAO 2000). OP related safety issues are pesticide and other residues, pathogens, and toxic or unapproved intrinsic (genetic) factors. Quality attributes related to organic foods have been defined as: nutritional, organoleptic (taste, smell, appearance, texture), and functional (FAO 2000). Process attributes have been added to quality by some: authenticity (i.e. GMO vs. non-GMO), biology (manner of culture), and ethics (environmental and animal welfare) (Woodward and Meier-Ploeger 1998).

Safety of OPs.

Analyses of pesticide residues (PRs) in produce in the U.S. and Europe have shown OPs have significantly lower PRs than CPs (Woese *et al.* 1997; FAO 2000; Benbrook and Baker 2001). Recent USDA PR data for a wide range of U.S. fruits and vegetables, analyzed and reported by Benbrook and Baker (2001), detected PRs in 30% of CPs and 7% of OPs. When found, the PR levels in CPs averaged 2.5 higher than OPs. CPs were 7-10 times more likely to contain multiple PRs. Most PRs found in OPs are the result of spray drift from neighboring crop operations and from residues in soils remaining from pre-conversion farming. However, according to the authors of the study, a significant portion of the cases in which OPs contained PRs are likely to have been caused by fraudulent use of pesticides. Cases in which certified organic farmers have illegally applied pesticides to crops have been rare (Bowen 2000). However, changes in OA demographics, with more farmers entering OA for primarily economic reasons (Guthman 2001), may increase the likelihood of illegal use of pesticides.

Nitrates are a significant contaminant of foods, generally associated with intensive use of N fertilizers. Several dozen studies have compared nitrate contents of OP vs. CP produce and found significantly higher nitrates in CPs in nearly all cases (Woese *et al.* 1997; FAO 2000; Muramoto 2000).

Highly publicized allegations that OPs are likely to harbor dangerous human pathogens have been made (Avery 1998) and subsequently rebutted[14] (Burros 1999; Anon. 1999a; Rutenberg 2000). Under OA protocols, fresh manure cannot be applied to soil less than 120 days before harvest of a food crop whose product can come into contact with the manure (USDA 2000c). The pathogen of most concern, *E. coli* 0157, is eliminated from manure in 35 to 56 days at ambient temperatures (Pell 1997; Jones 1999).

Subtherapeutic use of antibiotics for enhancing weight gain in conventional livestock production is likely to pose a much greater public health risk than manure use in OA. This practice has been shown to select for antibiotic-resistant bacteria and to be the cause of antibiotic-resistant bacterial infections in humans (Witte 1998; Falkow and Kennedy 2001). Use of antibiotics is not allowed in OA except to save an animal's life (USDA 2000c).

Many OA organizations worldwide have taken a zero-tolerance policy on transgenic (GMO) compounds in OPs (IFOAM 1998). Contamination of foods by unwanted or unapproved transgenic compounds can occur by post harvest mixing, pollen drift from neighboring transgenic crops, impure seed supply, and inter-farm transport by field

[14] Details discussed in Part 1.

equipment (Howell-Martens 2001). The most intractable of these is pollen drift, which may make transgenic zero-tolerance impossible in some crops in some areas. All non-transgenic corn in the corn-growing areas of the Midwest in 2000 tested positive for transgenic elements, and there are documented cases of organic corn there testing positive for transgenic compounds as a result of pollen drift from neighboring transgenic crops (Riddle 1998; Howell-Martens 2001), as well as from impure seed (Howell-Martens 2001). Transgenic compounds approved only for animal feed have been detected in human foods (Kaufman 2001). The USDA Organic Rule allows for the presence of unintentional transgenic constituents in OPs, however, the major OP trade partners, EU and Japan, test for transgenes in imported food, and will likely reject OPs that test positive for transgenic compounds (Anon. 2001; Haapala 2001)[15]. This issue poses an extremely serious problem for OA (Howell-Martens 2001).

Quality of OPs.

Comparative studies of healthfulness of OPs vs. CPs have had limitations that do not allow claims of the superior healthfulness of OPs to be clearly substantiated (Anon. 1997; Clancy 1997). A substantial percentage of studies suffer from flawed experimental design (FAO 2000). The remainder are limited by the narrow scope of parameters analyzed, i.e. traditional physico-chemical analyses of vitamins, minerals, and protein, and have left virtually unstudied important areas such as functional compounds in foods, also known as nutraceuticals (Borchers *et al.* 2000; FAO 2000). Functional compounds can be important health factors in the diet and have lacked adequate research (Rhodes and Price 1997; Borchers *et al.* 2000; Lazarus and Schmitz 2000). Many of these functional compounds, such as polyphenols, are produced in the plant as defense compounds against insects and disease, and their levels in the plant can be affected by the growing system (Lazarus and Schmitz 2000).

Comparative analysis of traditional nutrients (vitamins, minerals, protein) show no clear differences between OPs and CPs (Woese *et al.* 1997), although crude meta-analysis of the research literature gives the edge to OPs in this area (Worthington 1999). Reviews of OP/CP comparison studies that included assessments of animal health have shown sufficient trends toward better reproductive health in OP fed animals (Woese *et al.* 1997; Worthington 1999) to "raise a yellow flag" and point to a clear need for further research in this area using animal bioassays. These studies highlight the point that traditional physico-chemical analyses do not sufficiently assess the total human health effects of foods (Kienzl-Plochberger and Velimirov 1996; Clancy 1997).

Clear OP/CP differences are seen in higher dry matter content of foliar OPs, and in animal feeding tests that show a significant animal preference for OPs (Woese *et al.* 1997). A number of comparative studies have found higher total-N concentrations and lower protein quality in CPs, expressed as essential amino acid index and net protein utilization level (Schuphan 1974; Pettersson 1977; Eppendorfer *et al.* 1979; Syltie *et al.* 1982; Roinila and Granstedt 1996; Granstedt and Kjellenberg 1997). Differences in N-content and quality can be ecologically important, as high nitrogen and free amino acids have been shown to increase susceptibility to pests (see pest management section).

[15] The EU transgene zero-tolerance policy may be changing. Discussion of 0.3-0.5% transgene thresholds is underway as of this writing (Brough 2001).

Quality after storage has been reported to be better in OPs relative to CPs after comparative tests. (Pettersson 1977; El-Saidy 1982; Knorr 1983; Linder 1985; Deffune 1996; Piamonte-Peqa 1996; Granstedt and Kjellenberg 1997; Raupp 1997; Benge *et al.* 2000; Reganold *et al.* 2001).

Reviews of OP/CP sensory analysis studies have reported results that do not clearly substantiate claims of superior OP tastiness (Woese *et al.* 1997), although a cursory review shows that while most tests are either inconclusive or inadequately designed, when there is a difference tasters more often favor OPs than CPs. Organic farmers often grow produce varieties that are tastier than those commonly grown in CA, and this may justifiably add weight to the popular belief that OPs are tastier.

The case of wine, an industry whose participants have an exceptional level of sensory awareness, is representative of many OP/CP sensory comparisons. The growing system of ninety-one German organic and conventional white wines was not distinguishable to a taste panel for 14 sensory attributes. As with many OP/CP fruit and vegetable taste comparisons, vineyard location and variety had much more of an influence on sensory attributes than growing system. However gas chromatography could discriminate OP vs. CP in 75% of the wines (Dupin *et al.* 2000). OA researchers have long claimed as well as demonstrated that differences between OPs and CPs can be measured using physical tests - chromatography, copper chloride crystallization, and photon emission tests (Finesilver *et al.* 1989; Granstedt and Kjellenberg 1997; Woese *et al.* 1997).

Information about whether the food is organic or conventional has been shown to be significant in the taster's perception of sensory quality. Conventional tomatoes that were given a high quality score in blind tests were later judged to have only moderate quality (demotion) when the same tasters were told they were conventional. OP tomatoes that were ranked poor quality in blind tests were later judged to have moderate to high quality (promotion) when the tasters were told they were organic. Tomato cultivar influenced sensory differences more than growing system (Haglund *et al.* 1997). Similar sensory promotion of OP rice was made by Japanese tasters when given production information (Asano *et al.* 1998).

Meat quality and animal health.

Research on 26 organic dairy herds around Sweden showed the incidence of disease and clinical mastitis to be lower and cows with a high somatic cell count fewer in organic herds than in comparable conventional herds (Hamilton 2000). Swedish government meat and carcass inspection data on the total number of pathological findings in slaughtered livestock showed significantly lower pathologies in organic pigs (n = 3483) but no difference between organic and conventional cattle (n = 4949) and sheep (n = 4997). Organically raised beef had higher meat quality and lower fat (Hansson *et al.* 2000). These animal health results cannot be used to draw conclusions about feed quality, as living conditions between the systems are substantially different and affect animal health.

Environmental costs of organic vs. conventional agriculture.

The environmental costs of conventional agriculture are substantial, and the evidence for significant environmental amelioration via conversion to OA is overwhelming. A review of over 300 published reports by Stolze et al. (2000), summarized in Table 5, reports that out of 18 environmental impact indicator areas (floral diversity, faunal diversity, etc.), organic farming systems perform significantly better in 12 and perform worse in none. Reviewed below are CA's major environmental costs: pesticide and nutrient pollution of aquatic and marine systems, water and wind erosion; and reduced biodiversity, plus reviews of OA/CA comparison studies in each of these areas.

Table 5. Environmental indicator assessment of organic farming systems relative to conventional farming. From review by Stolze et al. (2000) of 300+ publications.

There is also a high pre-consumer human health cost to CA, particularly in the use of pesticides (Conway and Pretty 1991). It is estimated that 25 million agricultural workers in developing countries are poisoned each year by pesticides (Jeyaratnam 1990).

Pesticides.

Approximately 375,000 metric tons of pesticides are applied each year in U.S. agriculture; 62% herbicidal, 22% insecticidal, and 9% fungicidal. Pesticides enter the non-target environment primarily through atmospheric volatilization and aerial drift, runoff to surface water bodies in dissolved and particulate form, and leaching into groundwater (NRS 1993).

The U.S. National Water Quality Assessment Program (NAWQA) reported that more than 95% of streams and nearly 50% of shallow wells were found to contain agricultural pesticides, mostly below EPA thresholds for health (USGS 1999). However, EPA thresholds were set for single chemicals and do not account for synergistic effects of mixtures, nor are there threshold data for transformation products (Gilliom *et al.* 1999). Nearly all of the NAWQA stream samples and half of the well samples that were found with pesticides contained two or more pesticides (USGS 1999). Aquatic and marine communities are especially vulnerable to agricultural chemicals (Havens and Steinman 1995). While there are no U.S. EPA thresholds for herbicide effects on aquatic-life, Canadian thresholds were exceeded in 17 of 40 agriculture-associated streams tested (USGS 1999). None of the pesticides found in the NAWQA study are used in OA.

Pesticides also affect terrestrial biotic communities. One literature review cites more than 50 reports documenting adverse effects of pesticide use in the U.S. on avian, mammalian, and amphibian wildlife populations (Robinson 1991).

Pesticides considered to be hazardous to human and ecosystem health are few in OA, contrary to press releases by opponents of OA (Avery 2001). Use of pesticides is minimal - fewer than 10% of OFs use botanical insecticides on a regular basis, 12% use sulfur, and 7% use copper-based compounds (Walz 1999). OA is not immune to the inadvertent use of dangerous pesticides, and dependence on natural origins is not a guarantee of safety. Rotenone, a botanical insecticide commonly used in households, has been linked to Parkinson's Disease in rats and poses a risk to humans. Pyrethrum, a botanical pesticide, has recently been listed by the EPA as a likely carcinogen. However, a survey of organic vegetable growers showed that only 5.3% use rotenone and 1.7% use pyrethrum (Fernandez-Cornejo *et al.* 1998).

Agricultural nutrients.

Unlike the pesticides tested for by the NAWQA program, agricultural nutrients that can become pollutants of aquatic systems are part of both OA and CA, although the “leakiness” of the two systems is substantially different.

Two major scientific bodies[16] recently named nitrogen pollution as one of the Earth's "preeminent problems", and that there is insufficient public awareness of it (Moffat 1998). Agriculture is the primary anthropogenic source of N leakage to the environment (Socolow 1999). It is estimated that, on the average, only 50% of synthetic N fertilizer applied to crops is used by the plants (Matson *et al.* 1997), and some intensive systems can lose up to 275 kg N ha^{-1} via soil leaching (Ellis and Wang 1997). In the U.S. Midwest the ratio of N-inputs in fertilizer to N-outputs in corn rose from 74% in 1964 to 200% in the 1980's (Frink *et al.* 1999). Since 1965, a doubling of agricultural food production was associated with a 6.9-fold increase in N fertilization, a 3.5-fold increase in phosphorus (P) fertilization, and only a 1.1-fold increase in agricultural land area. According to one researcher, the necessary doubling of agricultural production in the next decades may triple the annual leakage rates of N and P to the environment if CA methods are used (Tilman 1999).

Sediment/siltation and nutrient (N and P) pollution from agriculture are the most frequent sources of adverse impacts to rivers, lakes, estuaries, and wetlands, the most serious being eutrophication (EPA 1995). Additional consequences of agroecosystem N-leakage are loss of biodiversity of both aquatic communities (Carpenter *et al.* 1998) and terrestrial plant (Wedin and Tilman 1996) and insect (Haddad *et al.* 2000) communities, especially losses of N efficient plants and the food chains they support. Additionally, leaching of cations from soils, and increased concentrations of the potent greenhouse gas NO_2 and other N oxides are consequences of N loading (Vitousek *et al.* 1997; Moffat 1998). Runoff high in nutrients is particularly damaging to estuarine systems because of low dilution. In Chesapeake Bay, loss of native sea grasses, subsequent reductions in juvenile fish and shellfish populations, and a 96 percent reduction in oyster populations from levels 100 years ago are linked with agriculture-caused eutrophication (Johnson *et al.* 1985). The 13,000 km^2 hypoxic zone in the Gulf of Mexico is caused primarily by the eutrophication from runoff of N and P from agriculture in the Mississippi watershed (Socolow 1999). The NAWQA study found concentrations of nitrates exceeding the US EPA drinking-water standard of 10 mg L^{-1} in 15% of samples beneath agricultural land.

The National Research Council reports that water quality is directly linked to soil quality, and that attempts to address non-point-source water pollutants will be effective only if agricultural soil quality is also improved (National-Research-Council 1993).

Amelioration by OA.

Numerous OA/CA comparative studies have been done on soil nutrient and water dynamics (Table 3) and (Stolze *et al.* 2000), and virtually all show significantly lower leachable nitrates in OA than comparable CA systems, often several-fold. In the studies listed in Table 3, leachable nitrates in CA ranged from 1.5 to 20-fold greater than OA. Soils under OA management have been shown to be more efficient at storing N than CA managed soils (reviewed below) (Clark *et al.* 1998; Drinkwater *et al.* 1998). In a review of nitrate leaching in European livestock operations, 4 out of 5 studies showed lower leaching from the organic farms (Hansen *et al.* 2001). Nitrate leakage is not lower in OA in every sector - a Danish study showed that while OA dairy cow systems lost less N than CA dairies, OA pig farms had higher N-loss than CA pig farms. It was recommended that dairies be managed

[16] The Ecological Society of America and the internationally constituted Scientific Committee on Problems of the Environment

organically and pig operations conventionally (Dalgaard *et al.* 1998). Stolze et al. (2000) note that OA systems can be vulnerable to nitrate leaching by improper management in two main areas: manure for compost and poorly timed disking under of cover crops, particularly legume/grass mixtures.

Phosphorus loss from OA is lower than comparable CA systems in all studies found. P is lost mainly through erosion, although runoff and leaching can also be significant, especially where P accumulates in soils, such as in livestock operations (Sharpley 1999). Organic dairy farms in the NE U.S. had 68% less net P accumulation per ha and 60% less per kg milk than comparable conventional farms (CFs) (Anderson and Magdoff 2000). Eutrophication potential by P loss from German CA livestock operations was reported to be 4-fold higher than comparison OA operations (Haas *et al.* 2001). Comparison studies in Denmark have shown significantly greater nutrient losses on CFs than comparison OFs (Hansen *et al.* 2001).

Erosion.

Agriculturally generated water erosion (USDA 1994) and wind erosion (Jaenicke 1998) are considered to be serious problems related to agriculture. Numerous studies show OA soils to have significantly better measures of soil stability and resistance to water erosion than CA soils – higher organic matter content and permeability, and lower bulk density (Table 3), as well as better measures of resistance to wind erosion (Jaenicke 1998). Comparisons of erosion in OA/CA systems, both empirical and modeling studies, have found significantly lower erosion in OA. Lockeretz (1981) reported 1/3 less erosion from Midwest OFs than comparable CFs. Studies in Germany concluded that region-wide conversion to OA would reduce water-borne soil erosion by 39 to 50% (Zerger and Bossel 1997) and wind-borne soil erosion by 41% (Piorr 1996). Empirical comparative OA/CA erosion studies show similar reductions in OA systems (Siegrist *et al.* 1998). The K-factor (soil erodibility) of the Revised Universal Soil Loss Equation has been shown to be significantly reduced in OA systems (Fleming *et al.* 1997).

In a USDA comparative trial, cover crop-based OA plots had 25% lower erosion than the CA no-tillage system, while the manure-based no-cover-crop OA system had substantially higher erosion than either of the above systems. The no-till system had a pesticide hazard several orders of magnitude higher than either of the OA plots (Teasdale 1998).

Energy use and greenhouse warming potential.

Comparative studies of energy use show lower per unit-of-yield fossil fuel energy use in OA (Stolze *et al.* 2000) relative to comparable CA systems. Two OA/CA comparison studies in the Midwest showed 60-70% lower energy use on OFs, one analyzing whole farms with comparable output (Smolik *et al.* 1995), the other comparing energy use per dollar of production (Lockeretz *et al.* 1981). Energy use in California organic cotton was reported 10-27% lower than CA cotton (Helmuth). OA apple production was found to be significantly more energy efficient than CA in a replicated trial (Reganold *et al.* 2001). A Danish government study estimated that upon 100% conversion to OA a 9-51% reduction in total energy use would result, depending on the level of import of feeds and the amount of animal production (Hansen *et al.* 2001). Energy use per unit of milk is significantly lower on Danish (Refsgaard *et al.* 1998) and German (Haas *et al.* 2001) OA dairy farms than on comparable CA systems.

OA crop systems in the Midwest U.S. were reported in a 10-year study (Robertson *et al.* 2000) to have about 1/3 of the net greenhouse warming potential (GWP) of comparable CA crop systems, but 3-fold higher GWP than CA no-till systems, which included embedded energy. There was no difference in nitrous oxide emissions and methane oxidation between the three systems. Average soil carbon (C) accumulation was 0, 8, and 30 g m^{-2} yr^{-1} respectively in CA, OA and CA no-till plots. It has been estimated that application of OA practices in the major corn/soybean growing region in the U.S. would increase soil C sequestration by 1.3 - 3 10^{13} g yr^{-1}, equal to 1-2% of the estimated annual C released into the atmosphere from U.S. fossil fuel combustion (Drinkwater *et al.* 1999).

In Germany, the production of a kg of CA wheat generates 163% more greenhouse gases (CO2 equivalents) than a kg of OA wheat (Taylor *et al.* 1999), this difference shown in other studies to be due to N fertilizer inputs in CA (Stolze *et al.* 2000). Stolze et al. (2000) in their review of European systems, saw trends toward lower CO_2 emissions in OA but were not able to conclude that overall, CO_2 emissions are lower per unit of product in OA than CA. CA's 30% higher yields in agriculturally intensive areas of Europe may account for this (see yields section). In the German dairy study above (Haas *et al.* 2001), OA energy use per unit milk was less than half of the CF and less than one-third per unit land; however, because of slightly higher methane emissions per unit of OA milk, and the high GWP of methane, the GWP of the two operations was equivalent.

On-farm biodiversity.

On-farm biodiversity is generally higher on OFs than comparable CFs systems in all categories (MacNaeidhe and Culleton 2000; Stolze *et al.* 2000; The_Soil_Association 2000) - non-crop plant species (Albrecht and Walters 1975; Moreby *et al.* 1994; Stopes *et al.* 1995; Hald 1999; Rydberg and Milberg 2000; van Elsen 2000; Hansen *et al.* 2001), soil biota (Jaffee *et al.* 1998; Paoletti 1999a; Stolze *et al.* 2000), invertebrate species (Paoletti 1999b; Stolze *et al.* 2000; Letourneau and Goldstein 2001), and non-pest butterflies (Feber *et al.* 1997; The_Soil_Association 2000). Non-pest bird abundance is higher on OFs (Hald 1999; Stolze *et al.* 2000; The_Soil_Association 2000), in some cases 10-fold (vanMansvelt *et al.* 1998), and bird habitat area higher (Stolze *et al.* 2000), sometimes 5-40-fold higher on OFs than comparable CFs (vanMansvelt *et al.* 1998). Studies show higher bird species richness on OFs than comparison CFs (McLaughlin and Mineau 1995; Christensen and Mather 1997). Species richness of carabid beetles, important ground-dwelling predators, was reported to be significantly higher on OFs in 7 out of 9 OA/CA comparison studies; and carabid abundance also tended to be higher (Clark 1999). Earthworm abundance and species richness is higher on OFs (Stolze *et al.* 2000) and can be drastically reduced in pesticide intensive CA systems such as orchards relative to OA systems (Paoletti 1999a). Crop diversity is generally higher on OFs (Duram 1997; McCann *et al.* 1997; vanMansvelt *et al.* 1998; Stolze *et al.* 2000), and crop rotations and intercropping, central components of OA systems, have shown to increase biodiversity (McLaughlin and Mineau 1995). Europeans give importance to landscape and aesthetic diversity of farms and often couple these parameters with measures of biodiversity. Some studies there show OFs to have greater landscape diversity than comparable CFs (vanMansvelt *et al.* 1998; Hendriks *et al.* 2000; Kuiper 2000), although Stolze et al. (2000) in their review find trends in this direction but not sufficient to give OFs a clear mandate on the issue.

Genetic pollution, the migration of transgenes unregistered for such transfer, to wild plant populations and crops, may be considered an environmental impact of CA. Gene transfer to the wild has occurred via use of herbicide resistant transgenic canola varieties that readily cross-pollinate with wild cruciferous species, initiating fears of the ramifications of transgenes in the wild (Lefol *et al.* 1996; Riddle 1998). Altieri (2000) reviews the ecological risks of transgenic crops in agroecosystems.

It is clear that the environmental costs of OA are substantially lower than CA in virtually every category. Nevertheless, there are weak points in OA that need attention in order to further reduce environmental impacts: disking under of grass or legume cover crops at the wrong time of year leading to N losses; overuse of tillage with associated loss of nutrient stability and soil and epigeal biodiversity; over-reliance on off-farm or out-of-region animal feeds; and nutrient leakiness in some animal operations such as that reported on Danish pig operations. It has been reported that some U.S. farmers are avoiding the 3 yr transition period for converting from CA to OA by bringing set-aside land, often marginal for agriculture and environmentally sensitive, into OA production (Guthman 2001). As OPs move into mainstream marketing channels, analysis of post-production processing and distribution systems would likely turn up environmental costs of packaging, transport, and marketing that are increasingly indistinguishable from CPs. Given that approximately 90% of fossil energy used in food systems is post-production (Dahlberg 2000), the latter area is important to energy analyses.

Conclusion.

High growth rates of OP sales and the entry of mainstream business interests, government, and consumers into OA is spurring calls from within OA for improved protocols to support social values, local production, the family farm, and overseas OA workers (Browne *et al.* 2000; DeLind 2000; Anon. 2001b). The recent focus on the expansion of the organic industry and on global trade in OPs has been questioned as compromising the core values of OA and its ability to foster sustainability and social equity (Duesing 1995; Le Noallec 1999; DeLind 2000; Klonsky 2000a; Norberg-Hodge 2000). Some in the organic community maintain that consumption of local and regional products and an intimate link between producers and consumers is a core value of OA, and they oppose global marketing of OPs (cited in Klonsky 2000). Issues such as food distribution, income distribution and concentration, labor conditions, decision-making power, and research priorities are increasingly a focus (Allen 1996; Hermann 1997). These issues are likely to be stress points for the OA community as OA expands.

Efforts to develop protocols for transparency and accountability of production methods over global trade networks and to increase the “social embeddedness” of food production and trade are being made by and in close association with OA. OA bodies are increasingly collaborating with global trade organizations, known as “Fair Trade” or “ethical trade” networks, whose objective is to improve the lot of small farmers and laborers in lesser developed countries by increasing their percentage take of the final price of the export products they produce (Browne *et al.* 2000; Blowfield 2001). OA certification bodies and Fair Trade representatives have made plans to develop combined inspection protocols (Sams 1997; IFOAM 2000a) and enhance alliances between Fair Trade and organic consumer groups (Cummins 2001). Fair Trade products globally are estimated at less than 5% of the size of the total OP market (Raunolds 2000).

Policy changes are needed in order to give OA its due support and level the agricultural playing field in North America. The high costs of conversion to OA, a system that confers substantial benefits to the public in the form of reduced environmental costs, need to be transferred from the farmer and OP consumer to the public. The case has been made for environmental protection-related subsidies for conversion to OA (Bateman 1994; Lampkin 1994), in particular for the U.S. (Lohr and Salomonsson 2000), and alternatively for "green payments" and agricultural pollution taxes (Foltz *et al.* 1995).

Proprietary approaches to improving agricultural systems have garnered enormous investments from not only the private sector, which stands to profit from them, but the public sector as well. The prevailing market orientation to society appears to have blinded policy makers to the fact that non-proprietary approaches to the improvement of agricultural production systems, such as agroecological techniques, will be equally or more effective in providing solutions. The problem is that investments into research on non-proprietary solutions are much less likely to give a high rate of return to private investors, the current model for providing solutions, since successful solutions can be used by the public and do not confer advantage to the investor. The fact that OA has become competitive with CA in so many different situations, in spite of its relatively depauperate research and extension infrastructure, is a testament to its potential and its worthiness as a candidate for equal public funding as CA receives. Nevertheless, agricultural biotechnology-related research, despite its huge backing by the private sector, received the "lion's share" of USDA research money in 2000 (Kaiser 2000). Land grant university agricultural research programs are increasingly "partnering" with biotechnology companies (Brown 2000; Lacy 2000) and devoting their resources to proprietary technologies.

A truly dynamic approach to the improvement of food production systems would be to allocate equal funding to research on non-proprietary approaches to agriculture (i.e. organic methods) as proprietary approaches (i.e. biotechnology) receive from their private sources, and then allow these two approaches to be packaged and "marketed" to farmers and consumers. History shows us that such hybrid approaches to humanity's challenges are nearly always more successful than those limited to predominantly one approach. The task before us of feeding the planet's growing population while at the same time conserving the environment is too immense a challenge to risk over-dependence on a limited approach, albeit exciting and sophisticated, such as commercial biotechnology.

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Figure 1. Corn grain yields from 26 matched pairs of organically (OA) and conventionally (CA) managed fields showing higher yield by OA systems relative to CA during droughts (lower left of graph). The solid line is the best fit of data points, the dashed line represents equal yields from each matched pair of farms. From (Lockeretz *et al.* 1981)

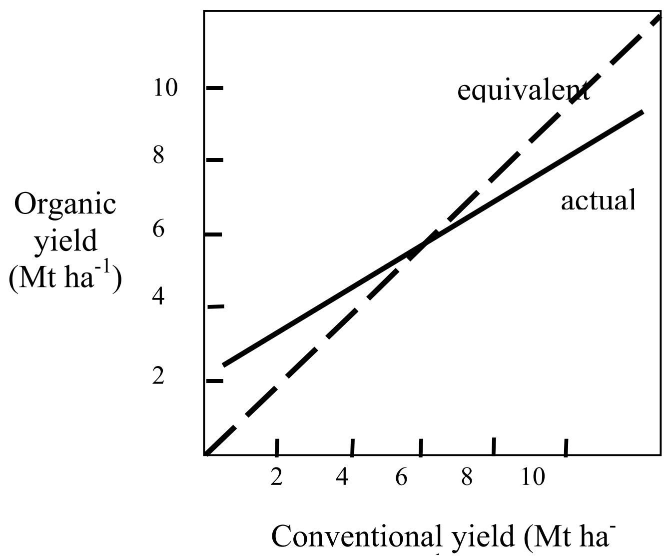

Figure 2. Amount of agricultural land needed for organic vs. conventional agriculture in Germany as a function of the population's average percentage of dietary calories from meat. A reduction in meat consumption from 39% to 23% of total calories would allow 100% conversion to OA with no need for additional agricultural land or increased imports. From (Seemueller 2000)

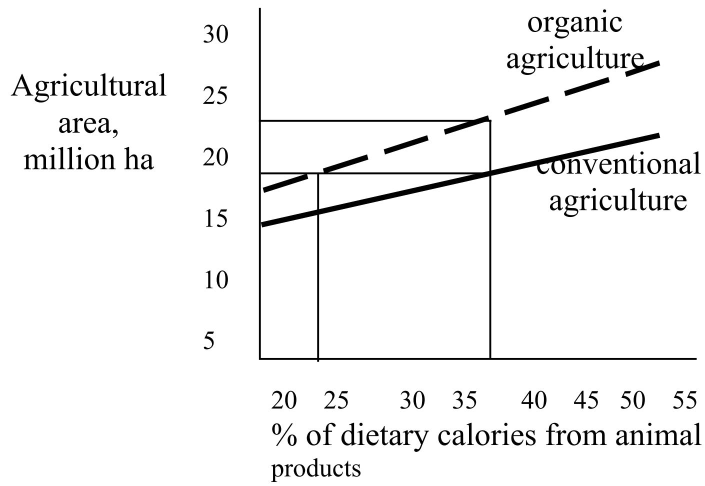

Table 1: Nationally surveyed organic farmers rankings of constraints to production and research needs. (Walz 1999)

a. Constraints to production.	b. Research needs
1. Cost of organically allowable inputs	1. Weed management
2. Uncooperative or uninformed extension agents	2. Relationship between soil fertility and crop health, pest & disease resistance
3. Distance or transport of organically allowable inputs	3. Relationship between growing practices and health-giving properties of foods grown
4. Sourcing or finding organically allowable inputs	4. Soil biology
5. Achieving desired yields	5. Crop rotations for fertility and pest management
6. Information on organic practices unavailable or hard to find	6. Cover crops and green manures
7. Effectiveness of organically allowable inputs and methods	7. Management of arthropod and nematode pests
8. Personal lack of knowledge about organic practices	8. Plant disease management
9. Social pressure from other farmers or community to farm conventionally	9. Habitat management for pest control
10. Pressure from lenders to farm conventionally	10. Food safety issues (e.g. *E. coli, Salmonella)*

Table 2. OP commodity type values, growth rates, and share of OP market for 1998 and projections for 2003. Source: (Datamonitor 1999).

OP Commodity group	**OP market value (in $1,000)**			**Share of organic market (%)**	
	1998	**2003**	**1998-2003 Avg. Annual Growth**	**1998**	**2003**
Produce	3,486	5,210	8.4%	64.5	39.6
Frozen Foods	400	2,101	39.3%	7.4	15.9
Dairy	424	2,015	36.6%	7.9	15.3
Bakery & Cereals	201	970	36.9%	3.7	7.4
Ready Meals	145	758	39.2%	2.7	5.8
Chilled Foods	274	635	18.3%	5.1	4.8
Meat & Meat Products	168	617	29.8%	3.1	4.7
Baby Foods	84	417	37.7%	1.6	3.2
Other	112	219	14.4%	2.1	1.7
Soft Drinks	60	153	20.4%	1.1	1.2
Beer & Wine	46	77	10.9%	0.9	0.6
Overall	**5,401**	**13,172**	**19.5%**	**100**	**100**

Table 5. Environmental indicator assessment of organic farming systems relative to conventional farming. From review by Stolze et al. (2000) of 300+ publications. Legend: Organic farming performs: ++ much better, + better, 0 the same, - worse, -- much worse. |__X__| indicates a subjective confidence interval of the final assessment marked by "X".

Indicators	Organic performance relative to conventional (++ + 0 - --)
Ecosystem	**|________X_________|**
Floral diversity	|__________X___|
Faunal diversity	|__________X___|
Habitat diversity	|______ __X__|
Landscape	|_____ ___X__|
Soil	**|________X_____________|**
Soil organic matter	|___X________|
Biological activity	|__X__|
Structure	| _X__|
Erosion	|__________X__________________|
Ground and Surface Water	**|__X__|**
Nitrate leaching	|__X_____________________|
Pesticides	|__X__|
Climate and Air	**|___ ___X__|**
CO2	|__X__|
N2O	|________ __X__|
CH4	|_______ ___X__|
NH3	|__X__|
Pesticides	|__X__|
Farm input and output	**|___X________|**
Nutrient use	|__X__|
Water use	| _X__|
Energy use	|__X________|

Table 3. Soil quality parameters measured in comparative studies of organic vs. conventional agricultural systems. "+" = organic significantly (_ = or < 0.05) higher than conventional; "-" = organic significantly lower than conventional; "ns" = no significant difference. Parameters not evaluated in the studies are left blank.

Study	pH	EC	BD	WHC	MB	PM	C	TN	NO(L)	P	K	Perm	CEC	AggSt	Overall quality
Liebig and Doran 1999			-	+	+	+	+	+							
Clark et al. 1998	+	-			+	+	+			+	+				
Fleming et al 1997					+							+			
Drinkwater et al. 1995	+	-				+	+	+	-						
Reganold et al. 1993[1]	+		-			+	+	+		+	ns		+		
Reganold et al. 1995[1]	+	-					+	ns		+	ns				
Reganold et al. 2001												+		ns	+
Korsaeth and Eltun 2000									-						
Lord et al. 1995									-						
Petersen. 1999							+		-			+			
Goldstein et al. 1998									-						
Kristensen et al. 1995									-						
Siegrist et al. 1998														+	
Gerhardt et al. 1997			-				+					+		+	
Smolik et al. 1995									-						
Wells et al. 2000	+	ns		+			ns			+	+			+	
Haas et al. 2001									-						
Mader et al. 2002	+				+			-	-	-	-			+	

EC = electrical conductivity; BD = bulk density; WHC = water holding capacity; MB = microbial biomass; PMN = potentially mineralizable N; C = % soil carbon; TN = total soil N; NO3 = leachable nitrates; P = phosphorus; K = potassium; Perm = permeability (also porosity); CEC = cation exchange capacity; AggSt = soil aggregate stability;

[1]Biodynamic system.

* _ = 0.1 level of significance

Table 4 a-d. Management practices used by cross-section of U.S. organic farmers (all crop types), ranked by frequency of use (Walz 1999).

a. Weeds	b. Insects	c. Disease	d. Soil fertility
Mechanical tillage	Crop rotations	Crop rotations	Cover crops
Weeding by hand or hand tool	Habitat for beneficial insects	Resistant crop varieties	Compost
Crop rotations	Habitat for beneficial vertebrates	Compost or compost tea solutions	Gypsum or lime
Cover crops	*Bacillus thuringensis*	Companion planting	Animal by-products (fish, bone, blood)
Mulches	Releases of beneficial arthropods	Sulfur / sulfur-based materials	Mineral amendments
Planting date adjustment	Dormant or summer oils	Copper-based materials	Uncomposted manure
Smother crops	Insecticidal soaps	Solarization	Compost tea
Row width adjustment	Botanical insecticides		
Flaming or burning	Trap crops		
Grazing	Pheromones / mating disruption		
Ridge tillage	Release of viral pathogen		
Solarization			