The performance of organic and conventional cropping systems in an extreme climate year

D.W. Lotter, R. Seidel, and W. Liebhardt

Abstract. *The 1999 severe crop season drought in the northeastern US was followed by hurricane-driven torrential rains in September, offering a unique opportunity to observe how managed and natural systems respond to climate-related stress. The Rodale Institute Farming Systems Trial has been operating since 1981 and consists of three replicated cropping systems, one organic manure based (MNR), one organic legume based (LEG) and a conventional system (CNV). The MNR system consists of a 5-yr maize–soybean–wheat–clover/hay rotation, the LEG of a 3-year maize–soybean–wheat–green manure, and the CNV of a 5-yr maize–soybean rotation. Subsoil lysimeters allowed quantification of percolated water in each system. Average maize and soybean yields were similar in all three systems over the post-transition years (1985–1998). Five drought years occurred between 1984 and 1998 and in four of them the organic maize outyielded the CNV by significant margins. In 1999 all crop systems suffered severe yield depressions; however, there were substantial yield differences between systems. Organic maize yielded 38% and 137% relative to CNV in the LEG and MNR treatments, respectively, and 196% and 152% relative to CNV in the soybean plots. The primary mechanism of the higher yield of the MNR and LEG is proposed to be the higher water-holding capacity of the soils in those treatments, while the lower yield of the LEG maize was due to weed competition in that particular year and treatment. Soils in the organic plots captured more water and retained more of it in the crop root zone than in the CNV treatment. Water capture in the organic plots was approximately 100% higher than in CNV plots during September's torrential rains.*

Key words: organic agriculture, organic farming drought resistance, crop water, hydrology

Introduction

Long-term crop yield stability and the ability to buffer yields through climatic adversity are critical factors in agriculture's ability to support society in the future. Global climate change has brought about predictions of increased instability in climatic conditions, leading to increased incidence and severity of droughts, flooding and other extreme climatic events (Sombrock and Gommes, 1996; Weiss and Bradley, 2001). Organic crop systems in North America have been shown, on the average, to yield approximately 90% to 95% of conventional crop systems (Lotter, 2003). Where organic crop systems excel, however, is in water- and climate-stress situations. A number of studies have shown that under drought conditions, crops in organically managed systems produce higher yields than comparable crops managed conventionally (Dormaar et al., 1988; Stanhill, 1990). This advantage can result in organic crops outyielding conventional crops by 70–90% under severe drought conditions (Lockeretz et al., 1981; Petersen et al., 1999; Wynen, 1994). Others have shown that organically managed crop systems have lower long-term yield variability, i.e., higher cropping system stability (Henning, 1994; Peters, 1994; Smolik et al., 1995). Swift (1994) proposed that assessments of crop performance should include analysis of two components–-yield and stability of yield–from one climatic cycle to the next.

Several mechanisms may increase drought tolerance of organic cropping systems. The higher water-holding capacities found in organically managed soils (Liebig and Doran, 1999; Wells et al., 2000) may be the major one. Numerous studies have shown soil organic carbon (C) to be higher in organically managed systems (Clark et al., 1998; Drinkwater et al., 1995; Liebig and Doran, 1999; Petersen et al., 1999; Reganold, 1995; Reganold et al., 1993). Plant water uptake and ability to withstand drought are significantly improved by mycorrhizal associations (Syliva and Williams, 1992). Mycorrhizae have been shown to be more abundant in the roots of crops from organically managed systems relative to those of conventionally managed crops (Eason et al., 1999; Mader et

The authors are with The Rodale Institute, 611 Siegfriedale Rd., Kutztown, PA 19530. Corresponding author is D.W. Lotter (don.lotter@rodaleinst.org).

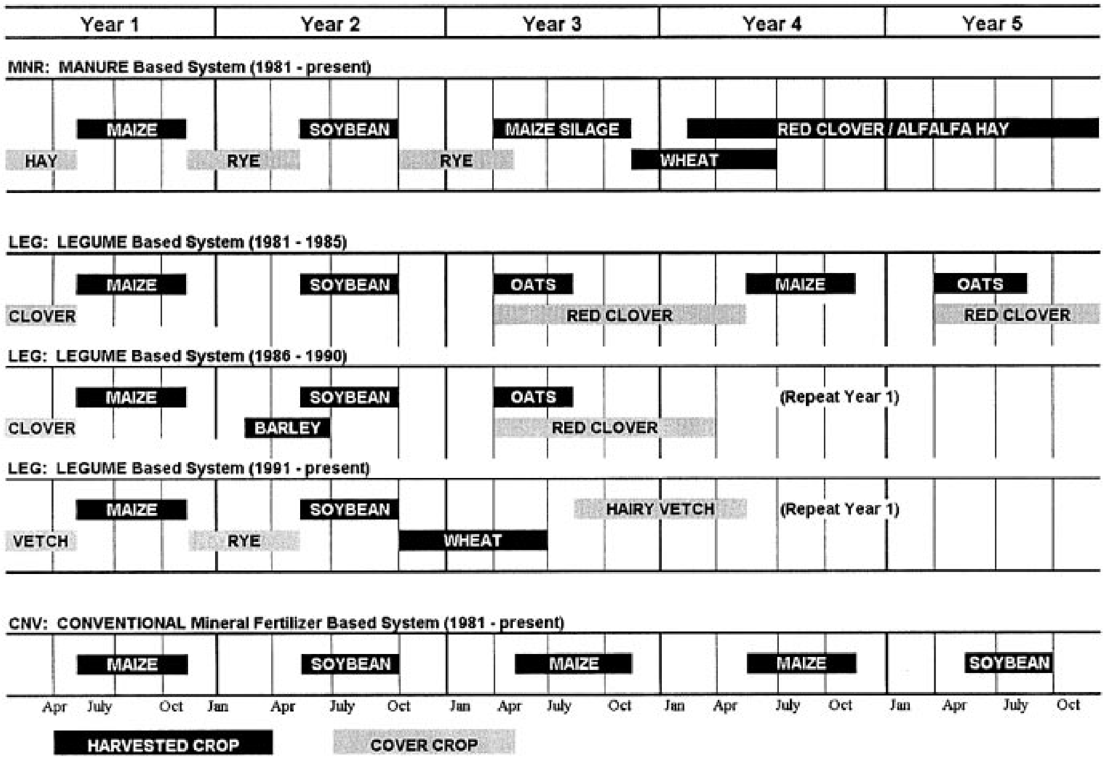

Figure 1. The Rodale Farming Systems Trial rotations. CNV, conventional management; LEG, legume-based organic; MNR, manure-based organic. In each system the nitrogen input is added before the maize crop: MNR, steer manures and red clover/alfalfa plow down; LEG, legume plow down (red clover or hairy vetch); CNV, mineral fertilizer. The rye cover crop was added as a catch crop to the MNR rotation in 1992 and to the LEG rotation in 1993.

al., 2000; Ryan et al., 1994). This suggests both a physico-chemical and biological basis for the increased drought tolerance of organic cropping systems.

The mitigation of runoff, erosion and crop losses as a result of rainfall excess, a serious agricultural constraint (Jaenicke, 1998; USDA, 1994), is also improved in organically managed systems. Organic management of soils leads to improved soil stability and resistance to water erosion compared to conventionally managed soils, due to higher soil C content and improved soil aggregation (Clark et al., 1998; Drinkwater et al., 1995; Liebig and Doran, 1999; Reganold, 1995; Reganold et al., 1993), permeability (Fleming et al., 1997; Gerhardt, 1997; Petersen et al., 1999; Reganold et al., 2001) and lower bulk density (Gerhardt, 1997; Liebig and Doran, 1999; Reganold et al., 1993), as well as higher resistance to wind erosion (Jaenicke, 1998). Comparisons of erosion rates in organic versus conventional systems, show significantly lower erosion in organically managed systems. Lockeretz et al. (1981) reported one-third less erosion from Midwest organic farms than from comparable conventionally managed farms. Fleming et al. (1997) showed that the K-factor (soil erodibility) of the revised universal soil loss equation was reduced in organically managed systems.

Organic cropping systems have been reported to outyield conventionally managed systems in situations of rainfall excess and climate extremes. In 1993, Japan's conventional rice crops were nearly wiped out by an unusually cold summer, while organically farmed rice yielded 60–80% of the annual average (Anon., 1994). In Central America over 1800 farms using organic and sustainable methods were the subject of a comparison study, using paired conventional neighbor farms, of the effects of Hurricane Mitch. Farms using organic and sustainable methods reported substantially lower economic losses, and 90% of the neighbors of the study farms indicated a desire to adopt their neighbors' methods after observing the environmental stress tolerance of the organic/sustainable farms (Holt-Gimenez, 2002).

Other studies have reported that under flooded conditions organically managed crops have outyielded conventionally managed crops, due to higher levels of water-stable aggregates in organic soils and associated reduced soil compaction after spring tillage (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).

The Rodale Farming Systems Trial was initiated in 1981 in order to compare the benefits and risks of three farming systems, two organic–manure based (MNR) and legume based (LEG)–and one conventional (CNV), on a long-term basis. Basic data on water capture, nutrient and pesticide leaching, yields, and crop and soil nutrient status have been collected. Crop system performance during years of

Table 1. Rodale Farming Systems Trial inputs for the 1999 crop season.

	N source	Cover crop seeding rate (kg ha^{-1})	Cover crop planting date	Incorporation date	Cover crop or fertilizer inputs (kg ha^{-1})	Cover crop or fertilizer % N	Total N input[1] (kg ha^{-1})	Main crop seeding rate (seeds ha^{-1})	Main crop planting date
Maize									
CNV[2]	Mineral	–	–	4/27/1999	112	30	34		
	fertilizer[3]			6/18/1999	373	30	112	64,000	4/27/1999
LEG	Hairy vetch	36	8/25/1998	4/30/1999	5425	5.18	281	64,000	5/12/1999
MNR	Hay[4]	11.2/5.6	3/3/1997	4/13/1999	1469	3.52	52		
	Steer manure	–		4/13/1999	5355	3.44	184	64,000	5/12/1999
Soybean									
CNV	–	–	–	–	–	–	–	432,000[5]	5/26/1999
LEG	–	157	11/9/1998	5/5/1999	1019	2.42	24.7	494,000	5/27/1999
MNR	–	157	11/9/1998	5/5/1999	1294	2.28	29.5	494,000	5/27/1999

[1] Total N inputs between the organic (MNR and LEG) and CNV differ substantially, given the low percentage availability of organic N.
[2] CNV, conventional management; LEG, legume-based organic; MNR, manure-based organic.
[3] Mineral fertilizer for CNV corn is applied as starter fertilizer at planting time and side dressed at 12 inches tall.
[4] Hay is a mix of red clover and alfalfa.
[5] Soybeans in the CNV system are planted in 18-cm rows, in MNR and LEG systems in 76-cm rows.

climatic stress is a particularly important area, given the evidence that climatic stress and variation is on the increase (Sombrock and Gommes, 1996). In this paper, by looking at crop and water dynamics during a climatic stress season within a multiple year experiment, we provide evidence that conversion to organic agriculture may provide increased long-term food production sustainability. The 1999 crop season in the northeast US was unique, with a prolonged crop season drought followed by heavy rainfall. These two stress factors, drought and torrential rains, serve to illustrate differences in the sustainability of the two crop systems.

Materials and Methods

Experimental site, treatment and design

The study was conducted on the 6.1 ha Farming Systems Trial (FST) at the Rodale Institute in Berks County, southeastern Pennsylvania. The soil is primarily Comly silt loam with 12% Berks shaly silt loam and a small area of Duffield silt loam. Annual precipitation is 1080 mm, with 50% occurring from May 1 to September 30. The annual average temperature is 12.4°C, summers are hot and humid, winters are relatively short and mild. The growing season is 180 days long, with 1600 growing degree days (based on 10°C).

Beginning in 1981, three farming systems were established: (1) manure-based organic (MNR); (2) legume-based organic (LEG); and (3) conventional (CNV) (Fig. 1). The purpose was initially to examine the process of converting from a conventionally managed cropping system to an organically managed system and to quantify the long-term changes in the sustainability and profitability of these systems.

The MNR system assumes a livestock component, and utilizes manure for fertilization. It consists of a 5-yr maize (*Zea mays* L.)–soybean (*Glycine max* L. Merr)–maize silage–winter wheat (*Triticum aestivum* L.)–hay [red clover (*Trifolium pratense* L.) and alfalfa (*Medicago sativa* L.)] rotation.

The LEG system does not include an animal component but produces cash grain crops every year, using a plow-down legume as a nutrient source in the 3-yr maize–-soybean–wheat rotation. Both the MNR and LEG systems rely on mechanical cultivation and heterogeneous crop mixes for their weed and pest control.

The CNV system is a cash grain system using mineral fertilizer and pesticides in its 5-yr maize–soybean rotation. Fertilizers and pesticides in the CNV system are applied according to recommendations by Pennsylvania State University. Maize and soybeans are common to the three systems. Seeding rates, biomass and N inputs, and planting dates for the three treatments are shown in Table 1.

The experimental design is a split-plot randomized complete block design with eight replications. Main plots are 18 × 91.5 m. To allow same crop comparisons in any year, each rotation main plot is split into three 6 × 91.5 m subplots and the main rotation was begun at three different crop entry points. Grass buffer strips (1.5 m wide) between the systems minimize cross movement of soil, fertilizers and pesticides.

Sampling methods

The parameters measured were cover crop and crop biomass, weed biomass, grain yields, percolated water volumes, soil water content and water infiltration rates.

Maize grain yields were assayed by mechanically harvesting the center four rows of each plot. Soybean and wheat yields were obtained by mechanically harvesting a 2.4 m swath in the center of each plot.

In four of the eight replications in each cropping system a 76 cm long by 76 cm diameter steel cylinder lysimeter was installed in the fall of 1990, to enable the collection of percolated water (Fig. 2). The top of each lysimeter was approximately 36 cm below the soil surface to allow field operations to be carried out in a normal fashion directly over the lysimeters. Approximately 20 holes were drilled in the center of the base plate, to allow for unrestricted flow of percolate from the cylinder into the flexible tube leading to the collection device, a 20-liter polyethylene carboy. Two more tubes were connected to the carboy: the air tube, which ran from the cap of the carboy to the soil surface, and a second tube, which ran from the base tubulation fitting of the carboy to the soil surface and served as the extraction tube for the percolate. The extraction tube was capped with a garden hose fitting; the air tube was capped with a two-way aluminum breather to allow airflow into the carboy during leachate extraction. The carboy was positioned below and offset to one side of the steel cylinder to enable gravitational flow of liquid to the collection device. Any percolate flowing from the cylinder into the carboy was collected via a marine utility pump connected to the extraction tube (Moyer et al., 1996). Water could not escape from the lysimeter system. Leachate samples were collected throughout the year. In 1999, the number of samplings was reduced due to the lack of precipitation during the summer.

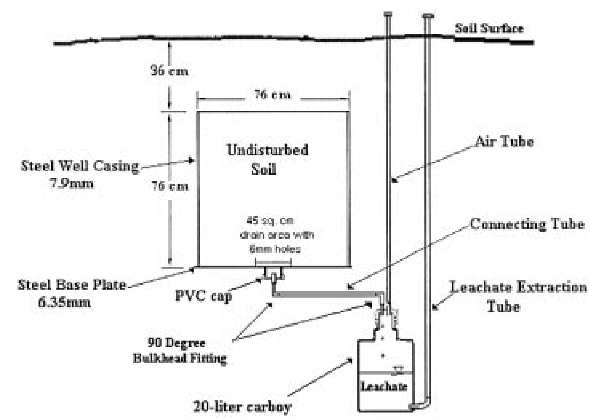

Figure 2. Lysimeter used to collect percolated water and leachate under plots in each treatment in the Rodale Farming Systems Trial.

Soil water content was determined gravimetrically on sieved soil (2 mm) from samplings taken in the LEG and CNV systems in June and October 1998 (in maize) and in May and October 1999 (in soybean).

Statistical analyses were performed with the General Linear Model Univariate procedure of SPSS software version 10.1.3 (SPSS, Inc., Chicago, IL).

Results and Discussion

Average yields of maize and soybeans from 1985 to 1998 were relatively equal between the three treatments, with a small but statistically significant underyield in the organic soybean treatments (Table 2). The 1986–1990 LEG soybeans were a relay crop and underyielded compared to full-season soybeans. When these years are not included in

Table 2. Average yields of organic maize and soybean in the Rodale Farming Systems Trial 1985–1998 compared to a conventionally managed system.[1]

Crop and management system[2]	N[3]	Yield (kg ha^{-1})	SD[4]	Relative to CNV
Maize				
MNR	63	7107 a	1448	105%
LEG	111	7001 ab	1452	103%
CNV	198	6757 b	1717	100%
Soybean				
MNR	64	2638 b	466	95%
LEG[5]	112	2332 c	838	84%
CNV	135	2770 a	379	100%

[1] Yields followed by a common lower-case letter are not statistically different ($P = 0.05$) according to Duncan's multiple range test.
[2] CNV, conventional management; LEG, legume-based organic; MNR, manure-based organic.
[3] Number of crop seasons × replications.
[4] Standard deviation.
[5] The 1986—1990 LEG soybeans were a relay crop and underyielded compared to full-season soybeans. When these years are not included in the mean, LEG soybean yields are not significantly different from those of CNV soybeans.

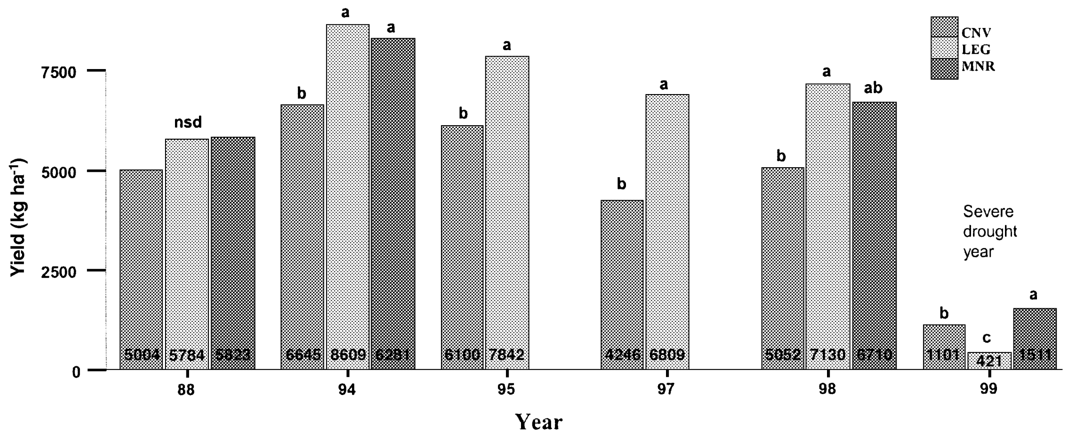

Figure 3. Maize yields in drought years (total April to August rainfall less than 350 mm). Different letters above bars in the same cluster denote statistical significance at the 0.05 level. Letters denoting significance are for one year only. CNV, conventional management; LEG, legume-based organic; MNR, manure-based organic.

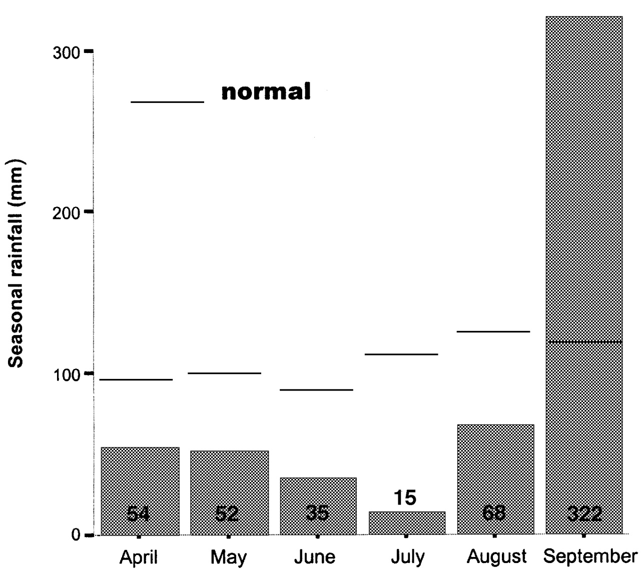

Figure 4. Crop season monthly rainfall at the Rodale Farming Systems Trial site, 1999.

the mean, LEG soybean yields are no different than the CNV soybeans. In four out of the five drought years (total April–August rainfall less than 350 mm) MNR and LEG maize outyielded CNV by a significant margin (Fig. 3). This gave us impetus to look at the 1999 severe drought year more closely.

Crop season rainfall for April, May, June, July and August 1999 at the FST (Fig. 4) were 55%, 66%, 17%, 29% and 40% of normal for those months, respectively. September 1999, with 268%, was a complete reversal of previous months as a result of Hurricane Floyd, and was the wettest September on record in the Northeast. September precipitation for weather stations across the 12 state region averaged 182 mm (7.16 in), which is nearly double (199%) the monthly normal. In Berks County over 200 mm of the month's 350 mm of rain fell in a 3-day period, with 91 mm in a 12-h period on September 16. Table 3 summarizes the crop system dynamics and performance for the three systems.

Drought and yield

Due to drought, maize and soybean yields were severely reduced in 1999 to less than 20% of the long-term average in maize and 60% in soybean. Relative to CNV, 1999 maize yields in the MNR and LEG treatments were 50% higher and 66% lower, respectively (Fig. 5). Soybean yields were 35% and 96% higher in the MNR and LEG, respectively, than in the CNV treatment.

Maize. Severely reduced yields in the LEG maize plots were largely due to weed pressure and to excessive cover crop biomass in that year, both of which consume limited soil water, the cover crop before maize planting and the weeds during the growing season. The primary weed species was foxtail (*Setaria* spp.) within the maize rows. The hairy vetch (*Vicia villosa* Roth) cover crop in the LEG maize, planted fall 1998, measured 5425 kg ha^{-1} (dry weight) when incorporated on April 30, 1999. This was nearly twice that needed for adequate N inputs of 150 kg N ha^{-1}. Conditions for growth of hairy vetch were ideal in fall and spring, and the vetch crop was the highest yielding ever in the FST. This coincided with the subsequent drought, and soil water depletion by the high level of cover crop biomass was likely partially responsible for the maize crop water stress later in the season. Additionally, dry conditions during early maize growth, as a result of soil water use by the abundant vetch crop, allowed foxtail, which can outgrow maize under these conditions, to outcompete maize and reduce its yield.

The residue of highly soluble N from the vetch as a result of the poor maize growth in 1999, which normally takes up the excess N, also gave rise to higher than normal leachable

Table 3. Relative performance of the three crop systems—manure-based (MNR), legume-based (LEG) and conventional (CNV)—during the 1999 season of drought followed by a major storm event.

System	Crop/soil situation	Relative performance	Late-season flood performance
Maize			
MNR	Low to moderate biomass of both spring cover crop and weed population, plus good water infiltration and soil water holding capacity gives optimum drought adaptiveness	Good	Good: good water capture, reduced runoff
LEG	High biomass spring cover crop and weeds overuse water and overcome benefits of good soil water-holding capacity and infiltration, causing crop failure	Very poor	Good: good water capture, reduced runoff
CNV	Poor soil water-holding capacity and infiltration limit ability of crop to adapt to drought despite negligible water use by weeds and no water use by a cover crop	Intermediate	Poor: poor water capture, high runoff
Soybean			
MNR	Low weed and spring cover crop biomass and good soil water infiltration and water-holding capacity give optimum drought adaptiveness	Good	Good: good water capture, reduced runoff
LEG	Low weed and spring cover crop biomass and good soil water-holding capacity and infiltration gives optimum drought adaptiveness	Good	Good: good water capture, reduced runoff
CNV	Poor soil water-holding capacity and infiltration limit ability of crop to adapt to drought despite negligible water use by weeds and no water use by a cover crop	Poor	Poor: poor water capture, high runoff

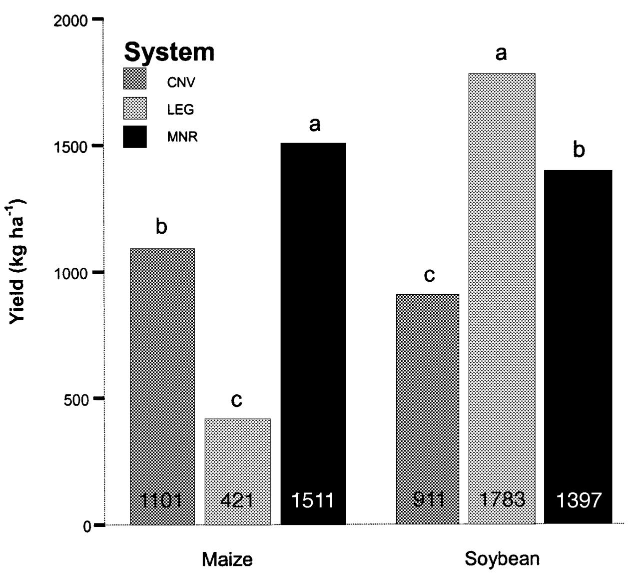

Figure 5. Maize and soybean grain yields in conventional (CNV), legume-based (LEG) and manure-based (MNR) plots, 1999. Different letters above bars in the same cluster denote statistical significance at the 0.05 level.

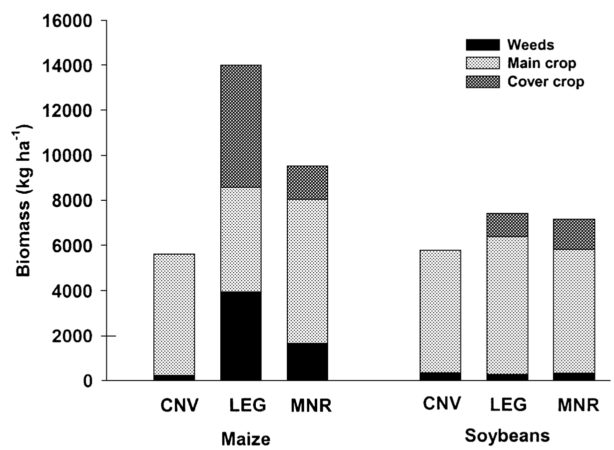

Figure 6. Total standing biomass (weeds, cover crop and main crop) in the three systems in two crops. CNV, conventional management; LEG, legume-based organic; MNR, manure-based organic.

nitrates during the 1999–2000 winter. Rye (*Secale cereale* L.) is planted in the fall after maize as a catch crop for excess N. However, the September torrential rains leached the excess nitrates before the rye was planted. The N budget will be the subject of another paper.

The MNR maize had a fall-planted red clover/alfalfa hay cover crop incorporated on April 13, measuring 1469 kg ha^{-1} (approximately 25% of the biomass of the LEG hairy vetch cover crop). Weeds were not a problem in the MNR treatment.

The total plant biomass for the main crop (at harvest), cover crop (at spring plowing) and weeds (late season) for maize and soybean are shown in Figure 6. Counting the maize crop, cover crop and weeds, the LEG system in 1999 supported nearly three times the plant biomass of the CNV system.

August weed biomass (the only weed sampling date) in the LEG maize plots was nearly equal to the maize biomass, and was over double that of MNR weed biomass and over 15 times higher than weeds in the CNV plots.

Maize biomass yields were much closer between systems in 1999 than maize grain yields, indicating that water stress in the LEG treatment occurred at the critical grain-filling stage in August.

Soybean. LEG soybean yields were significantly higher than MNR, and MNR in turn yielded significantly higher than CNV. In contrast to the LEG maize, the LEG soybean crop had fall-planted rye as a spring cover. The LEG soybean cover crop had only about one-fifth of the biomass (1019 kg ha^{-1}) as the LEG maize cover crop (Fig. 6, Table 1), and was comparable to the rye cover crop in the MNR soybean (1294 kg ha^{-1}).

Weed levels in the soybean plots were low in all three systems, at around 300 kg ha^{-1}, less than 10% of the weed biomass in the maize LEG treatment.

Water dynamics

Data collected over the past 10 years of the FST experiment show that the MNR and LEG treatments improve the soils' water-holding capacity, infiltration rate and water capture efficiency. LEG maize soils averaged a 13% higher water content than CNV soils at the same crop stage, and 7% higher than CNV soils in soybean plots (Fig. 7).

Water capture, as represented by percolated water harvested from the lysimeters, averaged 30% higher in the MNR and LEG plots than in the CNV plots in 1999 (Fig. 8), and in September, following high rainfall, the MNR system captured over two times as much water as the CNV plots, and the LEG only slightly less than two times the CNV (Fig. 9). In May, at the onset of drought, the CNV

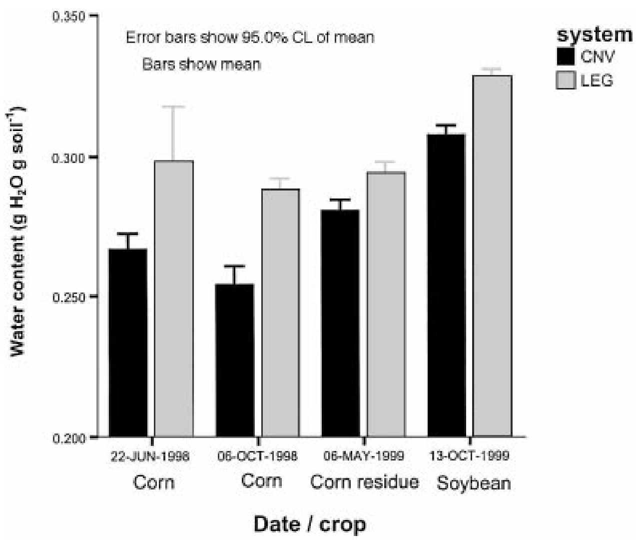

Figure 7. Water content of soils in organic and conventional cropping systems. MNR was not part of this analysis. CNV, conventional management; LEG, legume-based organic; Cl, confidence interval.

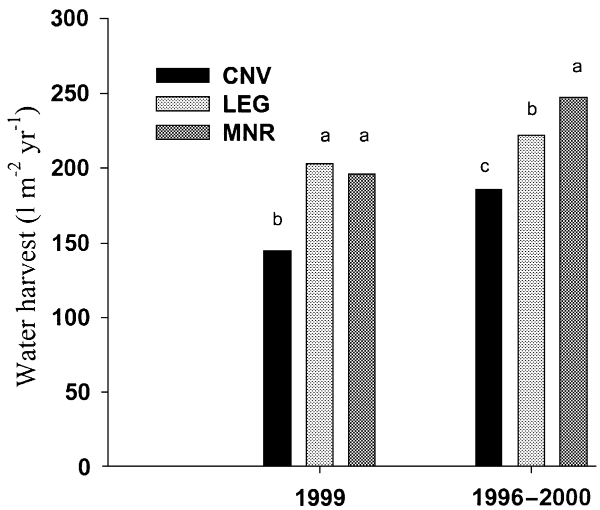

Figure 8. Percolated water harvested in 1999 and the average of 1996—2000 from the three crop systems in the Rodale Farming Systems Trial. Letters denoting significance are for one set of bars only. CNV, conventional management; LEG, legume-based organic; MNR, manure-based organic.

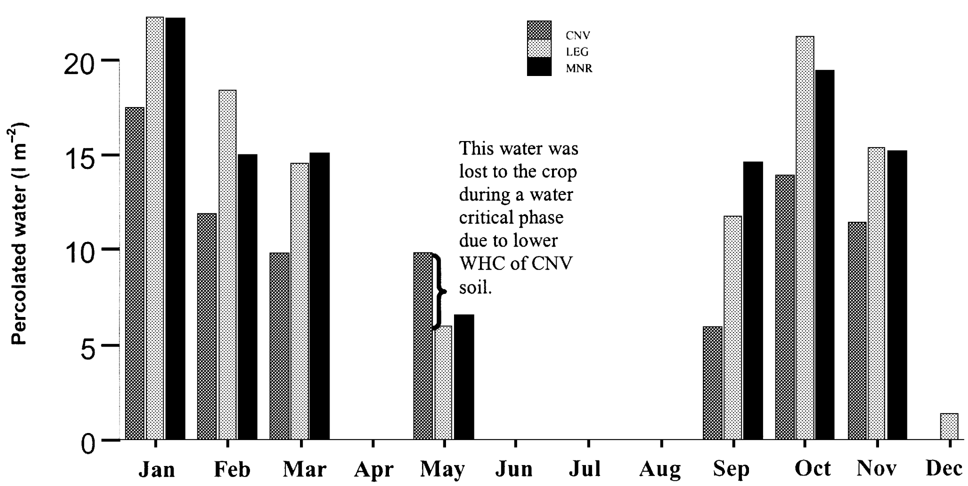

Figure 9. Monthly percolated water harvested from three cropping systems in 1999 in the Rodale Farming Systems Trial. CNV, conventional management; LEG, legume-based organic; MNR, manure-based organic; WHC, water holding capacity

plots, for the only time in 1999, had more percolated water than the other treatments, indicating that in the LEG and MNR plots more water was retained in the soil for crop use during a time when water was limiting. Over a 5-yr period, the LEG and MNR systems captured 16% and 25% more water than the CNV system, respectively (Fig. 8). The MNR plots captured significantly more water than the LEG system.

Conclusions

Evidence is presented that organic crop systems perform better than conventionally managed crop systems during climate extremes, in this case for both drought and excessive rainfall. In the 21-year Rodale Farming Systems Trial, in which two organic and a conventional crop rotation were compared, the organic crop systems performed significantly better in 4 out of 5 years of moderate drought. In the severe drought year of 1999, three out of the four crop comparisons (LEG soybean, MNR soybean and MNR maize) resulted in significantly better yields in the organic systems than the conventional. The LEG maize treatment yielded significantly less than the CNV due to weed pressure, demonstrating that skill in managing weeds is an important part of organic farming. Evidence indicates that the better water holding capacity of organically managed soils is a likely mechanism for better yields during water deficits. Water harvest, important for groundwater recharge, was significantly better in the organic systems in both the severe drought year and over a 5-yr period. Organic crop management techniques will be a valuable resource in an era of climatic variability, providing soil and crop characteristics that can better buffer environmental extremes.

References

Anon. 1994. Nature farming rice crop succeeds despite record cold summer: Story is front–page news in Japan. World Sustainable Agriculture Association Newsletter 3(12):1.

Clark, M.S., H. Ferris, K. Klonsky, W.T. Lanini, A.H.C. vanBruggen, and F.G. Zalom. 1998. Agronomic, economic, and environmental comparison of pest management in conventional and alternative tomato and corn systems in northern California. Agriculture Ecosystems and Environment 68(1–2):51–71.

Denison, R.F. 1996. Organic matters. The LTRAS century, 4 (March):Long Term Research on Agricultural Systems (LTRAS). College of Agricultural and Environmental Sciences, University of California Davis.

Dormaar, J.F., C.W. Lindwall, and G.C. Kozub. 1988. Effectiveness of manure and commercial fertilizer in restoring productivity of an artificially eroded dark brown chermozemic soil under dryland conditions. Canadian Journal of Soil Science 68:669–679.

Drinkwater, L.E., D.K. Letourneau, F. Workneh, A.H.C. Vanbruggen, and C. Shennan. 1995. Fundamental differences between conventional and organic tomato agroecosystems in California. Ecological Applications 5(4):1098–1112.

Eason, W.R., J. Scullion, and E.P. Scott. 1999. Soil parameters and plant responses associated with arbuscular mycorrhizas from contrasting grassland management regimes. Agriculture Ecosystems and Environment 73(3):245–255.

Fleming, K.L., W.L. Powers, A.L. Jones, and G.A. Helmers. 1997. Alternative production systems' effects on the K-factor of the revised universal soil loss equation. American Journal of Alternative Agriculture 12(2):55.

Gerhardt, R.A. 1997. A comparative analysis of the effects of organic and conventional farming systems on soil structure. Biol.ogical Agriculture and Horticulture 14(2):139–157.

Henning, J. 1994. Economics of organic farming in Canada. In N.H. Lampkin and S. Padel (eds.). The Economics of Organic Farming. CAB International, Wallingford, UK. p. 3–8.

Holt–Gimenez, E. 2002. Measuring farmers' agroecological resistance after Hurricane Mitch in Nicaragua: a case study in participatory, sustainable land management impact monitoring. Agriculture Ecosystems and Environment, in press.

Jaenicke, E.C. 1998. From the Ground Up: Exploring Soil Quality's Contribution to Environmental Health. Policy Studies Report No. 10. Henry A. Wallace Center for Agricultural and Environmental Policy,

Liebig, M.A., and J.W. Doran. 1999. Impact of organic production practices on soil quality indicators. Journal of Environmental Quality 28(5):1601–1609.

Lockeretz, W., G. Shearer, and D.H. Kohl. 1981. Organic farming in the Corn Belt. Science 211:540–546.

Lohr, L., and L. Salomonsson. 2000. Conversion subsidies for organic production: results from Sweden and lessons for the United States. Agricultural Economics 22(2):133–146.

Lotter, D.W. 2003. Organic agriculture. Journal of Sustainable Agriculture 21(4).

Mader, P., S. Edenhofer, T. Boller, A. Wiemken, and U. Niggli. 2000. Arbuscular mycorrhizae in a long-term field trial comparing low-input (organic, biological) and high-input (conventional) farming systems in a crop rotation. Biology and Fertility of Soils 31(2):150–156.

Moyer, J.W., L.S. Saporito, and R.R. Janke. 1996. Design, construction, and installation of an intact soil core lysimeter. Agronomy Journal 88:253–256.

Peters, S.E. 1994. Conversion to low-input farming systems in Pennsylvania, USA: an evaluation of the Rodale Farming Systems Trial and related economic studies. In N.H. Lampkin and S. Padel (eds.). The Economics of Organic Farming. CAB International, Wallingford, UK. p. 265–284.

Petersen, C., L. Drinkwater, and P. Wagoner. 1999. The Rodale Institute Farming Systems Trial: The first 15 years. The Rodale Institute, Kutztown, PA. Available at Web site www.rodalein-stitute.org (verified ??).

Pretty, J., and R. Hine. 2001. Reducing Food Poverty with Sustainable Agriculture: A Summary of New Evidence. SAFE Research Project, University of Essex, UK.

Reganold, J.P. 1995. Soil quality and profitability of biodynamic and conventional farming systems: A review. American Journal of Alternative Agriculture 10(1):36–46.

Reganold, J.P., A.S. Palmer, J.C. Lockhart, and A.N. Macgregor. 1993. Soil quality and financial performance of biodynamic and conventional farms in New Zealand. Science 260(5106):344–349.

Reganold, J.P., J.D. Glover, P.K. Andrews, and H.R. Hinman. 2001. Sustainability of three apple production systems. Nature 410(6831):926–930.

Ryan, M.H., G.A. Chilvers, and D.C. Dumaresq. 1994. Colonisation of wheat by VA-mycorrhizal fungi was found to be higher on a farm managed in an organic manner than on a conventional neighbour. Plant and Soil 160(1):33–40.

Smolik, J.D., T.L. Dobbs, and D.H. Rickerl. 1995. The relative sustainability of alternative, conventional and reduced-till farming system. American Journal of Alternative Agriculture 10(1):25.

Sombrock, W.G., and R. Gommes. 1996. The climate change–-agriculture conundrum. In F.A. Bazzaz and W.G. Sombrock (eds.). Global Climate Change and Agricultural Production. Food and Agriculture Organization of the United Nations, Rome, Italy. p. 1–14.

Stanhill, G. 1990. The comparative productivity of organic agriculture. Agriculture Ecosystems and Environment 30(1–2):1–26.

Swift, J.J. 1994. Maintaining the biological status of soil: A key to sustainable land management? In D.J. Greenland and I. Szabolcs (eds.). Soil Resilience and Sustainable Land Use. Proceedings of a symposium held in Budapest; 28 September to 2 October 1992, including the Second Workshop on the Ecological Foundations of Sustainable Agriculture (WEFSA II). CAB International, Wallingford, UK. p. 235–247.

Syliva, D.M., and S.E. Williams. 1992. Vesicular–arbuscular mycorrhizae and environmental stress. In G.J. Bethenfalvay and R.G. Linderman (eds.). Mycorrhizae in Sustainable Agriculture. Proceedings of a symposium, 31 October 1991. American Society of Agronomy, Crop Science Society of America, and Soil Science Society of America, Madison Wisconsin. p. 101–124.

USDA. 1994. Summary Report: 1992 National Resources Inventory. Soil Conservation Service, US Department of Agriculture, Washington, DC.

Weiss, H., and R.S. Bradley. 2001. What drives societal collapse? Science 291(5506):988.

Wells, A.T., K.Y. Chan, and P.S. Cornish. 2000. Comparison of conventional and alternative vegetable farming systems on the properties of a yellow earth in New South Wales. Agriculture Ecosystems and Environment 80(1–2):47–60.

Wynen, E. 1994. Economics of organic farming in Australia. In N.H. Lampkin and S. Padel (eds.). The Economics of Organic Farming. CAB International, Wallingford, UK. p. 185–199.

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