Comparisons of organic and conventional maize and tomato cropping systems from a long-term experiment in California

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Abstract

Yield differences and trends, organic matter accumulation, and the loss of nutrients to deeper soil horizons are discussed using data from organic and conventional maize/tomato cropping systems from the Long Term Research on Agricultural Systems Project (LTRAS) at the University of California, Davis. Compared to the conventional system, higher and increasing yields of tomatoes were observed in organic systems, but lower yields of maize. Fruit quality, measured as soluble solids, was not significantly different. Soil organic matter increased in the organic system, but remained stable in the conventional one. More irrigation water was used in the organic system than in the conventional one due to higher rates of infiltration, but less winter runoff occurred during the rainy season for the same reason. There was no measurable loss of inorganic N (NO_3, NH_4) in soil to 3 m depth in either the conventional or organic system after ten years of farming.

Introduction

Gradual changes in soil properties that affect long-term productivity may be hard to detect. The Long-Term Research on Agricultural Systems project (LTRAS) at the University of California at Davis was designed to detect and estimate changes in crop productivity trends due to the effects of differing irrigation and fertilization practices as well as environmental changes related to management. It includes an organic cropping systems comparison in which maize and tomatoes are grown in rotation and compared to conventionally produced crops. Many assume that organic farming systems are sustainable, but there are few data available about the performance of organic systems over time, either farms or experimental systems (Kaffka and Koepf, 1987; Kaffka, 1985; Mäder et al., 2002). The LTRAS experiment was inspired by results from other locations like Rothamsted in England, which has demonstrated that short-term trends can be poor predictors of long-term sustainability (Johnston, 1994).

The primary objective of the LTRAS project is to understand the relationships between sustainability and external inputs in locations with Mediterranean to semi-arid climates where irrigation is essential for crop production. The 10 cropping systems in the LTRAS experiment differ mainly in how much irrigation water, nutrients (particularly nitrogen) and carbon are added. One system follows organic farming guidelines and several are biologically-based, relying on nitrogen-fixing legume cover crops for fertility. Sustainability is determined from long-term trends in yield, profitability, efficiency in the use of limited resources (such as water or energy), and environmental impact, such as leaching of nitrate or pesticides. Trends in key soil properties, such as organic matter, pH, and salinity, changes in weeds, pests, and diseases are monitored to see whether any of these are good predictors for long-term sustainability. This report focuses on results from comparisons between organically (OCT) and conventionally (CCT) farmed maize/tomato systems after 11 years of differing management.

Methods

Following uniformity cropping with sudan grass (*Sorghum vulgare*) in 1992 and 1993, ten different cropping systems were established using 0.4 ha plots (Denison et al., 2004). Each cropping system is replicated three times and both phases of the two-year systems are present in each year. Systems differ in the amount of irrigation received (rain fed or irrigated) and in the amounts of N and organic matter applied to the soil either as winter legume cover crops, fertilizer, or composted manure. Crop yields and total biomass are measured and analyzed for total N and C. Record keeping and sample archiving includes yearly plant samples from all cropping systems, and time zero and subsequent soils samples collected every few years. In year 10, six soil cores to 3 m in depth were collected from each plot and analyzed in eight segments for N and pesticides to compare losses from the differing systems. Plots are large enough to allow for the use of commercial scale farm equipment, and records are kept for machinery and labor requirements. Daily weather data are collected at the site and irrigation amounts applied are measured using flow meters located at each irrigated plot. Systems rather than single inputs are compared, so a valid comparison requires that each system be managed as carefully as possible to achieve its potential yields. For example, both systems are irrigated as needed and amounts are recorded using water meters, but conventional and organic systems receive different amounts of N and C depending on what is judged best for each system. Conventional maize tomato systems receive 235 kg N ha^{-1} yr^{-1}, while OMT receive approximately 160 kg N ha^{-1} yr^{-1} as an annual winter legume cover crop and approximately 4.5 Mg ha^{-1} yr^{-1} (DW) composted poultry manure (250 kg N ha^{-1} yr^{-1}) on average. Planting dates also differ due to the use of winter legume cover crops in winter in the organic system, but not in the conventional one. The systems studied are simplified compared to actual farms, however, and are chosen to include representative crops rather than more complex, changeable crop rotations. California farmers rarely follow fixed crop rotations, but organic farmers especially tend to have more complex rotations than the one studied at LTRAS. Because plots are smaller than most actual farm fields (0.4 ha) and because of simplified crop rotations, comparisons at LTRAS may not allow for representative assessment of many secondary agro-ecological characteristics like insect and weed problems compared to actual farms.

Results and Discussion

After 10 years of management, soil organic matter levels differ significantly between the conventional (CMT) and organic (OMT) maize/tomato systems. OMT plots had 90 Mg C ha^{-1} added over the period from crop residues, legume cover crops, and composted manure, while CMT systems had 52 Mg ha^{-1}, entirely from crop residues. Soil organic matter levels increased in the OMT system, but remained stable in the CMT one (Kong et al., in press). In a carefully conducted assessment of the role of soil microorganisms and mineral N, Burger and Jackson (2003) reported that potentially mineralizable N (PMN) was approximately twice as abundant in the organic system (tomato phase) as in the conventional one throughout most of the season, and supported a much larger active soil microbial biomass community. This microbial community rapidly absorbed mineral N compounds present, especially NO_3–N. Increased infiltration of surface-applied irrigation water due to greater organic matter levels and the cumulative effects of cover crop growth on infiltration resulted in larger amounts of water being used for irrigation in the OMT system compared to the CMT (6,860 m^3 ha^{-1} compared to 13,350 m^3 ha^{-1} in 2003). Results are partly an artifact of the size of the plots, which limits the length of the irrigation run, and likely would be different (comparable) using sprinkler or drip irrigation systems. For the same reason, and due to cover crops in the winter period, surface water runoff volume during winter was less in the organic than in the conventional system (W. Horwath, personal comm.). Based on analyses to date, there have been no significant differences in the loss of inorganic N (NO_3, NH_4) between organic and conventional maize/tomato systems observed to date based on the analyses of soil core samples taken to 3 m in depth after the tenth year of cropping (Fig. 1). Both systems seem to be environmentally benign so far with respect to this system property.

Average grain yields on a dry weight basis for CMT maize were 11,990 kg ha^{-1} yr^{-1}, while for OMT they were 7,250 kg ha^{-1} yr^{-1}. The coefficient of variation (CV) for inter-annual yield variation was 14.1 % for CCT and 26% for OCT. Lower grain yields result in part from different planting dates used between the conventional and organic system. To allow vetch/pea winter legume cover crops to produce sufficient biomass and fix enough N, they must grow until early April. After incorporation, there must be a 30-day period for decomposition to avoid damage from the seed corn maggot (*Delia platura)*, which is associated with incorporation of fresh organic matter. This results in an unavoidable delay in planting of 40 days or more compared to conventional maize crops and is a structural yield disadvantage associated with organic production in this region, at least until an acceptable organic method of controlling this insect is developed. There are sufficient heat units to mature the later-planted maize crop, but starting the crop later in the summer season results in reduced yields because there is less seasonal light interception and correspondingly less photosynthesis. Conventional and organic system maize yields by year are reported in fig. 2A. Temple et al, (1994) reported similar maize yields among conventional, intermediate and organic systems when planted at similar dates.

Results for fruit yields of tomato, the more profitable crop, were opposite those for grain yields. CMT tomato yields (fresh weight of harvested fruit) were 56 Mg ha^{-1} yr^{-1} while OMT yields were 63.3 Mg ha^{-1} yr^{-1}. In this case inter-annual variation in yield was less in the OMT system: 18% compared to 30.4% in the conventional system. Yields are apparently stable for conventional maize but may be declining in the organic system.. No yield trends are apparent for tomatoes (fig. 2B). Tomato fruit quality was compared at harvest over the period. Soluble solids are a standard measure of quality, and are used as the basis for payment to farmers. There were no significant differences between the cropping systems in soluble solids (Fig. 3).

Conclusions

Comparisons of organic and conventional maize/tomato systems after 11 years of contrasting management indicate that soil quality, measured as total and protected organic C, can be improved using organic systems with winter legume cover crops and external inputs of composted manure in a Mediterranean climate zone. Increases in soil organic C do not appear to have reached a limit (Kong et al., in press). Improving soil quality, so defined, did not increase tomato yields, suggesting that there was no yield benefit from further increasing organic matter above moderate levels. In contrast, there appears to be an unavoidable yield loss associated with delayed planting of organic maize. Sustainability in agriculture is a composite quality in which different measures of system performance can be included. In some of the biophysical measures of system performance, such as nutrient retention and loss and tomato yield and quality, the organic system has performed as well or better than the conventional one, but in others like maize yield and irrigation water use efficiency, not as well.

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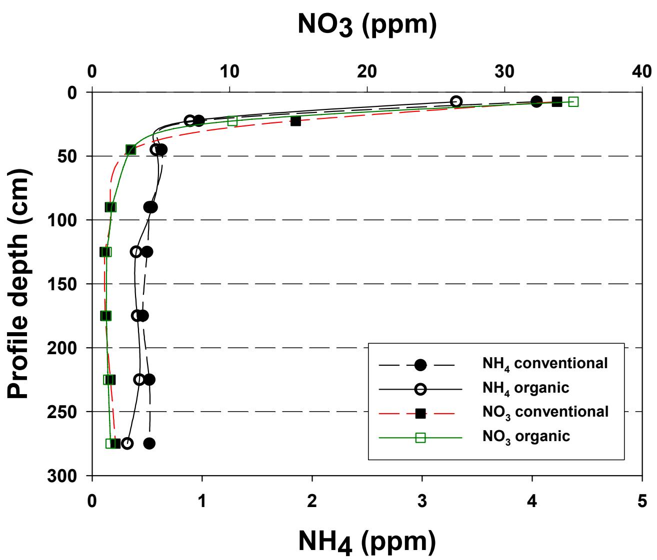

Fig. 1. NO_3 and NH_4 from CMT and OMT plots in fall 2003 collected from 0 to 300 cm deep in the soil profile. Values are the average of three soil cores.

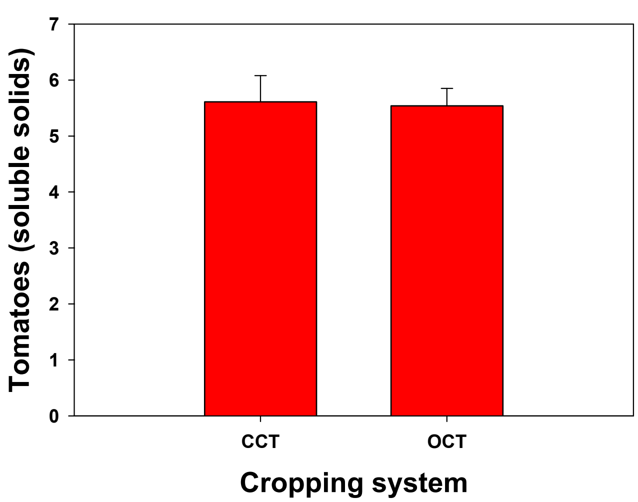

Fig. 3. Average soluble solids for the conventional (CCT) and organic (OCT) cropping systems (1994-2004)

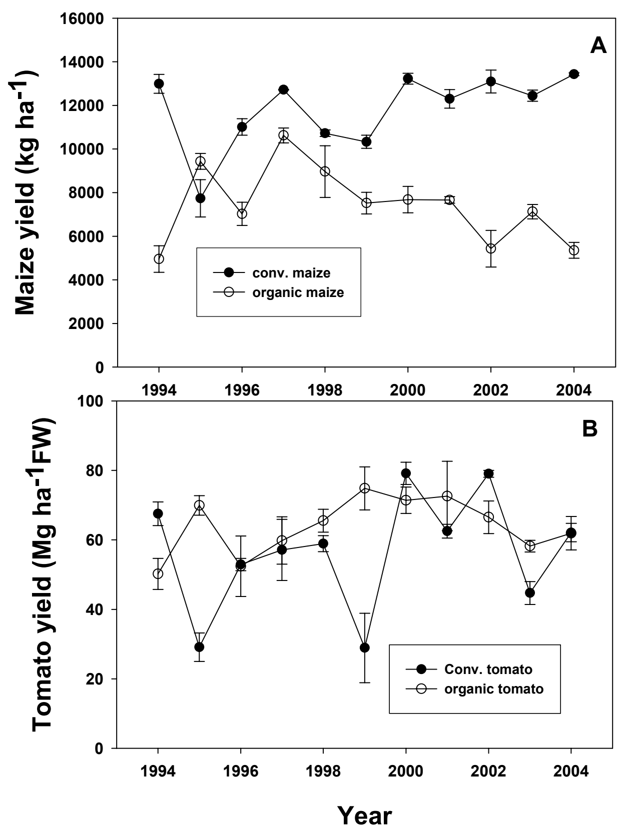

Fig. 2A,B. Maize and tomato yields (1994 to 2004) LTRAS