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Research paper

# Crop yield and energy use in organic and conventional farming: A case study in north-east Italy

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ABSTRACT

The role played by organic farming as an alternative system to conventional farming is widely questioned, since conflicting results on crop yields sometimes greatly affect system efficiency. As a result, prolonged monitoring studies on organic (OF) and conventional farming (CF) systems are still required, especially in real-life farm conditions, in which the entire production process is quantified. In this context, this study reports crop yields (winter wheat, maize, soybean) and energy efficiency, over a 13-year monitoring period, on a farm in north-east Italy in which two sectors are farmed following OF and CF practices. Results showed that organic yields were always lower than conventional ones, averaging 69%, although their range varied greatly over the years (from 45% to 90%) and depended on crop type. Several management constraints had effects on the lower yields, especially reduced available nutrients and cropping season, but also the timings and types of tillage operations. By contrast, OF practices usually had positive effects on the environment, due to reduced energy input mainly fertilisation (−33.4% MJ $ha^{-1}$ $y^{-1}$) and the generally higher productivity of invested energy ($E_{Out}$ $E_{In}^{-1}$ = 4.53 in OF and 4.28 in CF); energy use differences per product unit were mainly equal. Other factors, such as local climate and soil variability, may have influenced system performance, but as the two experimental sites were located at a distance of 3.5 km from each other, the data reported here are still valuable, in that they represent the results of 13 years of monitoring, during which farm management played a major role. This case study, although conducted in two separate sites, did not highlight the best overall solution at farm level, it does indicate that the agricultural systems applied would be better suited for different situations and targets (e.g., productive, energetic, ecologic).



## 1. Introduction

Organic farming (OF) systems covered 43.7 million hectares worldwide in 2014, covering about 1% of total agricultural land in 172 countries (Willer and Schaack, 2016). Although representing a very limited surface area, OF shares are significant in some countries, particularly in Oceania (4.1%) and especially in the European Union (5.7%), where 10.3 million hectares (+150% since 2000) occupy about 27% of the world's organic land. In addition, organic retail sales in the EU were assessed at 23.9 billion euros (2014), second only to the US as the largest single market for organic products (Willer and Schaack, 2016). The global growth perspective of OF is debated (Murthy et al., 2014) since it must be placed within the current challenges of feeding a growing population (Godfray et al., 2010) and maximising system efficiency (Foley et al., 2011). On one hand, several studies have reported reduced yields in organic (average reductions 20–25%) vs. conventional farming (CF) systems (e.g., Connor, 2008; Seufert et al., 2012); on the other, environmental impacts are often reduced per unit area, but not necessarily per product unit (Meier et al., 2015). Lower yields are in fact seldom compensated by reduced inputs, thus involving a decrease in system efficiency. For instance, Pang and Letey (2000) evaluated the nitrogen (N) dynamics in wheat and maize grown following OF management and found a mismatch between N uptake and N mineralisation curves. As a result, OF system efficiency was lower than that of CF, due to the poor timing between N availability (i.e., slow mineralisation) and N crop requirements, with potential effects on groundwater quality, especially in systems with high doses of organic amendments (Borin et al., 1997a; Morari et al., 2012). By contrast, the continual net extraction of nutrients from the soil under the OF system may lead to long-term soil depletion, particularly when organic inputs are poor (Tuomisto et al., 2012).

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In this context, it has been argued that applying well-designed crop rotations including both legumes and manure may be considered a realistic alternative to CF systems (Mader et al., 2002), although current high-yielding crops usually have sudden N demands which may be difficult to satisfy with organic fertilisers (Dawson et al., 2008). This was also reported by De Ponti et al. (2012), whose meta-analysis emphasised that the yield gap between OF and CF tended to increase as conventional yields increase, although the relationship was not strong; the above authors did not find any difference in crop yields when comparing short-term and long-term experiments. Other concerns relate to pests, diseases and in particular weed control (Stockdale et al., 2001) in OF systems, in which the use of agrochemicals is prohibited, although for others (Benaragama et al., 2016) increased weed-crop competition is still questioned. However, in carefully controlled conditions, OF has the potential to achieve the yields obtained in CF with reduced energy consumption (Pimentel et al., 2005), with positive implications in terms of both food supply and reduced environmental impact.

Italy, with 1.3 million hectares, is the second country in Europe for total organic agricultural area, after Spain (1.6 million ha) and followed by France and Germany (1.1 million ha each), being 6.1% of the national used agricultural area (UAA). The adoption, or maintenance, of organic farming has long been supported by a variety of measures, in particular through Axis 2 of the Rural Development Programme (RDP) under the CAP policy (improving the environment and countryside). In the latest RDP (2014–2020), organic farming was established as a separate measure. Organic farmers will also automatically qualify for the "Greening obligation" which accounts for 30% of direct payments (European Commission, 2015). However, the environmental benefit related to policy-driven EU funding is widely questioned, since it is affected by site-specific heterogeneity at regional level as a result of the variability of agro-climatic and farm management. Most farms are conducted according to OF or, alternatively, CF practices, since the concurrent adoption of both systems must follow strict rules (e.g., maintaining organic and conventional fields separate) to avoid contamination between organic and conventional products (fertilisers, seeds, etc.). Therefore, research on the direct comparison of mixed farms following both organic and conservation practices in stabilised systems is still a key aspect in addressing EU agri-environmental guidelines. In this context, we analysed the performances of organic and conventional systems in two sectors belonging to the same farm, located in north-east Italy, in terms of crop yields and energy efficiency, over in a monitoring period lasting 13 years.

## 2. Materials and methods

### 2.1. Study area

Crop management information and yield data were collected at the "L. Toniolo" experimental farm of the University of Padova (Italy), composed of two sectors in which crops, with the same technical supervision, have been managed according to organic farming practices since 2003, in Pozzoveggiani (ca. 12.5 ha), near Padova (45°20′42″N, 11°54′39″E; 7 m a.s.l.) and according to conventional practices in Legnaro (ca. 42.0 ha), also near Padova (45°21′00″N, 11°57′02″E; 7 m a.s.l.). The two areas are situated about 3.5 km apart on the same alluvial plain (Fig. 1), which is a flat area with similar geomorphology, land cover and therefore landscape characteristics. Both sites, 6 m above sea level, have a shallow water table fluctuating from about 0.5–1.5 m in late winter-early spring to 1–2 m in summer. The local climate is sub-humid, with a mean annual temperature of 13.5 °C. Annual rainfall (P) is about 850 mm, distributed uniformly throughout the year; evapotranspiration ($ET_0$), calculated with the Hargreaves formula, locally calibrated (Berti et al., 2014), averages 995 mm $y^{-1}$ (Fig. 2). $ET_0$ exceeds rainfall from April to September, especially during the summer (June to August) when the difference between $ET_0$ (up to 5.1 mm $d^{-1}$) and P is on average 260 mm. The soil is a loamy Fluvi-Calcaric Cambisol (CMcf) (IUSS Working Group WRB, 2014), characterised by low natural fertility due to little organic matter in soil contents (about 15 g $kg^{-1}$) and low cation exchange capacity; however, it contains excessive amounts of calcium carbonates ($CaCO_3$) (Regione Veneto, 2005). The main physical and chemical soil parameters of the organic and conventional fields are listed in Table 1 and refer to a field survey conducted for a total of 240 sampling points during 2007.

**Table 1**
Main physical and chemical parameters of topsoil in two farming systems. Data from a 2007 field survey. Standard errors in brackets.

| Soil parameters[a] | OF | | CF | |
|---|---|---|---|---|
| Sand, 2000-50 μm (%) | 41.56 | (4.98) | 49.97 | (5.51) |
| Silt, 50-2 μm (%) | 41.85 | (4.45) | 36.28 | (4.90) |
| Clay, <2 μm (%) | 16.59 | (1.39) | 13.75 | (1.82) |
| pH | 7.70 | (0.08) | 7.50 | (0.09) |
| EC, 1:2.5 (mS $cm^{-1}$) | 0.22 | (0.02) | 0.19 | (0.02) |
| Organic carbon (g $kg^{-1}$) | 9.10 | (0.58) | 7.10 | (0.58) |
| Total Kjeldahl nitrogen (g $kg^{-1}$) | 1.07 | (0.06) | 0.87 | (0.06) |
| Available phosphorus (mg $kg^{-1}$) | 20.77 | (4.93) | 19.20 | (4.44) |

[a] 0–20 cm soil layer.

**Table 2**
Varieties of crops studied in OF and OC systems.

| Crop System | Crop | Varieties (number of times used, days of crop cycle) |
|---|---|---|
| OF | Wheat | Bolero (2, medium-late cycle), Bologna (10, medium-late cycle). |
| | Maize | PR36B08 (4, 112 days), DKC 6040 (2, 128 days), Nk Famoso (1, 127 days), Biancoperla, (1, 120 days), Korimbos (3, 125 days), Ronaldoinio (1, 85 days). |
| | Soybean | PR92M22 Pioneer (2, maturity group 1), Regir (4, maturity group 1), Aires (5, maturity group 0+), Pedro (1, maturity group 1-). |
| CF | Wheat | Africa (2, medium cycle), Solehio (2, medium cycle), Aubusson (2, medium-late cycle), Guadalupe (2, medium cycle), Vaiolet (2, medium cycle), Blasco (2, medium-early cycle) |
| | Maize | PR32P26 (4, 130 days), Costanza (3, 130 days), PR31N27 (2, 132 days), P1758 (1, 132 days), PR34N43 (1, 128 days), Golden H. (1, 132 days). |
| | Soybean | Dekabig (6, maturity group 1+), Hilario (1, maturity group 1), Regir (1, maturity group 1), Demetra (3, maturity group 1+). |

### 2.2. Management of organic and conventional farming systems

The farm area managed according to organic farming (OF) standards at Pozzoveggiani follows a strict three-year rotation with maize (*Zea mays* L.), wheat (*Triticum aestivum* L.) and soybean (*Glycine max* (L.) Merr). Table 2 lists the crop varieties. Agronomic field operations generally include mouldboard ploughing to a depth of 30 cm, followed by seedbed preparation with a disc harrow. Since organic farming does not allow the use of chemical pesticides, before sowing mechanical weed control of spring crops (maize and soybean) is carried out with the stale seedbed technique (1–3, according to climatic conditions over the years), whereas weed control is generally accomplished with a smoothing harrow and hoeing operations throughout the crop season (Fig. 3). Maize and soybean residues are incorporated during ploughing; wheat straw is used as livestock bedding and then returned to the field