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Six-year transition from conventional to organic farming: effects on crop production and soil quality

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Abstract

Organic farming has become increasingly important in recent decades as the consumer has grown its focus on the food and environmental benefits of the technique. However, when compared to conventional farming systems, organic farm system are known to yield less.

Presented in this paper are the results from two organic cropping systems following six years of organic management. Fertilisation management differentiated the two systems; one was fertilised with green manure and commercial organic fertilisers, while the other was fertilised with dairy manure. A conventional cropping system, managed with mineral fertiliser as typical in the southern Piemonte region (Italy), served as the "bussiness as usual" crop management. The first hypothesis tested related to crop yield variation during the initial phase of organic management; we expected a sharp reduction in the early phase, then minor reductions later on. The second hypothesis tested related to soil fertility variation; we expected enhanced soil fertility under organic management.

Overall, the organic system produced less, relative to the conventional system in interaction with year effect. Yield reduction seemed related to the lower soil nutrient availability of organic fertilisers that provided nutrients consequent to mineralisation. Therefore, summer crops are well-suited to manure-fertilised organic farms as mineralisation happens at higher temperatures, as opposed to winter wheat, which is largely reduced in such systems. Commercial organic fertilisers can, however, limit this effect through their high nutrient availability in the winter and early spring

Also shown was that soil quality, defined as a general decrease in soil organic carbon (SOC) over time in the three analysed arable systems, can be mitigated by manure additions. Green manuring can maintain SOC and increase total N in soil, only if introduced for a sufficient number of years during crop rotation. Finally, soil fertility and Potential Mineralisable N in the different systems demonstrated that organic systems managed with commercial organic nitrogen fertilisers and green manure do not improve soil quality, compared to systems managed with mineral fertilisers.

Keywords: organic farming, crop production, manure fertilisation, commercial organic fertiliser, soil quality.

1. Introduction

The increased importance of organic farming in recent decades has come from a heightened consumer awareness of its associated food and environmental quality benefits. Worldwide land under organic farming in 2011 encompassed more than 37.2 million hectares (Willer and Yiussefi, 2011). Organic farming in Italy has also expanded due, in part, to financial support from the European Union through the Rural Development Programme, such that in 2010, its number of organic operators totaled 47,663. Nearly 4% of these farmers were located in the Piemonte region (MiPAAF, 2011). Here, the most important organic crops are grassland and ley managed by livestock farms; they cover 42.6% of the utilized agricultural area (UAA) under organic farming. Other diffuse crops are cereals (31.6% of UAA), such as rice and maize (Corsi, 2008).

Organic farming improves the environmental quality of the agricultural system (Gomiero et al., 2011; Gaudino et al., 2014) and the organoleptic quality of its products (Crecente-Campo et al., 2012; Gopinath et al., 2008; Warman and Havard, 1997), with no decrease in sanitary quality and yield (Biffi et al., 2004, Edwards, 2009). However, when compared to conventional farming systems, yield reductions are frequent (Seufert et al., 2012), ranging between 20 and 40% for arable crops and 0 to 30% for forage crops (Seufert et al., 2012, Stockdale et al., 2001). Farmyard manure is able to mitigate such reduced crop yields. Indeed, many long-term field trials have demonstrated average crop yield reductions of 20% on livestock-based organic systems relative to conventional systems. On stockless farms, decreases have been 33 to 45% (Kirchmann and Ryan, 2004).

During system transition from conventional to organic, yield reductions are made more evident (Cong Tu et al., 2006; Gopinath et al., 2008; Gopinath et al., 2009; Liebhardt et al., 1989). Conversion of an agricultural system to an organic one requires time for soil biological activity to adapt to its new situation. Moreover, as Monaco et al. (2009) demonstrated, previous organic fertiliser additions affect Nitrogen (N) mineralisation more than do fresh additions. Hence, multiple years are required for the soil to mineralise past organic fertiliser and manure additions for the crop to be provided with appropriate N availability. This causes transition times to vary and generally lengthen if the system was previously fertilised with mineral fertilisers alone (Clark et al., 1998; Drinkwater et al., 1995).

Reduced soil N availability is often regarded as the main factor responsible for very low organic system productivity (Berry et al., 2002; Clark et al., 1998; Clark et al., 1999). The capacity of the system to supply the crop with N is affected by the pattern and timing of N mineralisation and its synchronisation to crop N demand (Berry et al., 2002). Fertiliser, ammendement, and fertilisation strategy choices, when appropriate, can synchronise crop need to nutrient availability and minimise environmental pollution (Poudel et al., 2002).

The C/N ratio of a fertiliser is a good indicator of its organic matter mineralisation and a useful measure when making an appropriate fertiliser choice (Monaco et al., 2008). Slurry and poultry manures possess C/N ratios of less than 15:1 (Berry et al., 2002). Therefore, these sources are quickly mineralised in soil, increasing nutrient availability and sustaining yield production at levels similar to mineral fertilisers (Olesen et al., 2009; Sistani et al., 2008). Farmyard manures also have C/N ratios close to or less than 15:1, making them crop production promoters as well (Grignani et al., 2007). On the contrary, when the supply of organic matter comes from straw residues or grass catch/cover crops containing higher C/N ratios, N immobilisation is typically increased and rarely accompanied by increased crop yields (Baggs et al., 2000; Olesen et al., 2009).

Organic management also has an important effect on soil quality. From a long-term, whole cultivation system perspective, organic management is expected to increase soil organic matter content (SOM) (Schjønning et al., 2002; Stockdale et al., 2001). Nonetheless, there are instances in which increased soil organic matter fails to occur, even in long-term trials (Gosling and Shepherd, 2005). Instances in which increased SOM is highly correlated to C balance (Clark et al., 1998; Drinkwater et al., 1995; Mazzoncini et al., 2010; Stockdale et al., 2002) can, in turn, be affected by lower crop yields and crop residue inputs (Gosling and Shepherd, 2005). In addition, factors independent of management practices, such as soil type and climate, can severely limit the capacity of soil to stock more SOM (Flieβbach et al., 2007).

Organic fertilisation is known to improve soil chemical properties and to increase its microbial biomass activity (Drinkwater et al., 1995; Fließbach et al., 2007; Marinari et al., 2006; Mazzoncini et al., 2010; Poudel et al., 2002; Schjønning et al., 2002; Werner, 1997). In short time frames, soil biologic activity measurements can accurately evaluate the enhanced ecologic and agronomic soil fertility that comes from organic cropping systems. Potentially mineralisable N (PMN) and microbial respiration are considered two sensitive indicators of the changes that soil undergoes with different farming systems (Marinari et al., 2006).

The availability of phosphorous (P) and potassium (K) to plants is another indicator that can be used; they depend on the P and K budget. In general, organic farm systems have higher P and K inputs than do stockless systems due to their greater use of animal manure (Clark et al., 1998; Eltun et al., 2002; Gosling and Shepherd, 2005; Borda et al., 2011). For example, when poultry manure or sewage sludge with N:P ratios between 0.4 and 1.1 (Sistani et al., 2008) or at 0.6 (Criquet and Braud, 2008) is applied, surface soil horizon available P increases (Shepherd and Withers, 1999). Similarly, animal manure applications (characteristically low N:K ratios) increase soil exchangeable K (Clark et al., 1998; Drinkwater et al., 1995; Sistani et al., 2008). However, while this increase is larger than in conventional systems, it has not always been measured when the balance indicates greater outputs than inputs (Kirchmann and Ryan, 2004)

This paper studies the effect of transition from conventional to organic farming on crop yield and soil fertility during a six year-period. Transition is mainly driven by changes in fertilisation and weeds managements. The first tested hypothesis is related to the crop yield variation during the initial phase of organic management; we expected a sharp reduction in the early phase, then minor later on. The second tested hypothesis is related to soil fertility variation; we expected enhanced soil fertility in organic management. Both hypotheses would be more evident under manure fertilisation. We present the results obtained in two organic cropping systems, one fertilised with green manure and commercial organic fertilisers, while the other fertilised with dairy manure. A third, mineral-fertilised conventional cropping system was included to represent the “business as usual” technique of previous, widespread cropping management in the Piemonte region (Italy) south plain.

2. Materials and methods

2.1 Experimental site and climate

The experiment was carried out in a 1.2 ha experimental field during the 2001-2006 period in NW Italy (Piemonte region). The site was located at 44° 34’N and 7° 41’E. Field soil was classified as Aquic Haplustept, coarse-loamy over loamy-skeletal, mixed, nonacid, mesic (Soil Survey Staff, 2010). Prior to start of the experiment, the field was managed with barley monoculture in a conventional system. Only mineral fertilisers were used. The ploughed soil layer (0-35 cm) had the following properties: 10.5 g kg^{-1} soil organic carbon, 1.07 g kg^{-1} total nitrogen, 9.9 C/N ratio, 33 mg kg^{-1} Olsen P and 39 mg kg^{-1} exchangeable K.

The area, characterised as a continental climate, received most of its rainfall during the spring (April and May) and autumn (September and October). Table 1 reports the main climatic parameters of the 2001-2006 period. Average annual total rainfall was 702 mm. Mean annual temperature during the same period was 12.9°C, with average minimum and maximum temperatures of 7.8 °C and 18.1 °C, respectively. Heavy rains measured during the last two months of 2003 were more than double that measured as average over the six-year period.

Table 1: Climatic parameters of the 2001-2006 period.

	2001		2002		2003		2004		2005		2006		Mean	
	*(°C)	**(mm)	*(°C)	**(mm)	*(°C)	**(mm)	*(°C)	**(mm)	*(°C)	**(mm)	*(°C)	**(mm)	*(°C)	**(mm)
January	1.8	22.8	-0.6	9.2	2.2	18.6	1.3	64.6	2.4	3.0	1.3	75.2	1.4	32.2
February	5.4	24.6	4.8	176.0	2.3	0.4	3.5	91.8	2.8	2.4	3.3	52.2	3.7	57.9
March	8.8	44.6	9.4	49.2	9.3	8.8	7.5	14.6	8.8	34.0	7.3	8.6	8.5	26.6
April	11.4	16.8	11.7	63.2	12.7	72.0	12.3	141.0	12.7	123.2	13.7	15.8	12.4	72.0
May	17.9	169.2	15.7	114.8	19.4	17.6	16.5	70.2	19.3	67.4	17.9	30.0	17.8	78.2
June	20.2	9.2	21.3	102.6	24.9	45.0	22.1	15.6	22.6	13.8	21.8	25.6	22.2	35.3
July	22.7	45.4	21.3	104.2	25.2	11.0	23.2	8.6	23.8	35.0	25.7	57.0	23.6	43.5
August	23.4	35.6	20.7	209.8	26.0	14.4	22.9	15.4	22.3	77.4	21.6	25.2	22.8	63.0
September	15.5	43.4	16.6	210.8	18.6	73.6	20.0	7.6	19.6	117.8	20.5	232.6	18.5	114.3
October	15.3	48.0	12.1	85.2	11.0	60.6	14.7	24.8	13.3	93.0	15.5	32.4	13.6	57.3
November	5.6	43.8	7.7	160.2	7.5	137.4	8.1	38.4	6.8	20.6	8.8	6.6	7.4	67.8
December	-0.3	0.6	4.6	76.0	3.9	144.6	4.0	46.0	1.5	18.2	4.1	37.6	3.0	53.8

*C°: Average monthly temperature
**(mm): Monthly total rainfall

2.2 Experimental design

Three cropping systems were compared in a split plot design, in which system represented the main factor and crops the second factor. Due to the expected different behaviors of spring and autumn crops, the dataset was divided by crop and then the statistical analysis was handled as a randomized complete block design repeated for each crop. Each treatment, described below, comprised three plots (300 m^2 each) in which three crops (wheat, maize, and soybean or pea legume) were hosted simultaneously and replicated in four blocks.

- OrM represented an organic livestock farm cropping system in which nutrients were supplied from farmyard manure;
- OrF represented an organic stockless farm cropping system in which fertilisation management used green manuring and commercial organic fertilisers authorized for organic farming by European regulations;
- Conv represented a low-input, conventional farm cropping system; its fertilisation needs were met with conventional mineral fertilisers.

Both OrM and OrF relied on organic agriculture techniques set by Council Regulation (EEC) No 2092/91 at the time of the experiment, and Council Regulation (EC) No 834/2007 (EC, 2007) and Commission Regulation (EC) No 889/2008 (EC, 2008) in place currently. The conventional management utilised integrated agriculture techniques (IAT) defined by the regional Rural Development Program (Council Regulation No 1257/1999 at the time of the experiment and by the current Council Regulation No 1698/2005).

2.3 Agricultural management

The three-year rotation included a winter cereal (wheat, *Triticum aestivum* L.), either a legume of soybean (*Glycine max* L. during 2001 to 2003) or field pea (*Pisum sativum* L. during 2004 to 2006), and a summer cereal (maize, *Zea mays* L.). Soybean was replaced by field pea to improve weed management. OrF was planted with green manure (*Vicia villosa* L. at a density of 230 kg seeds ha^{-1})

in October before maize and soybean during 2001 to 2003, but before maize only during 2004 to 2006 because field pea planting was too early for sufficient catch crop development. Soybean and maize were planted in the second decade of May, field pea was planted in the second decade of March, and winter wheat was seeded between late October and early November, except in 2004 when abundant rainfall in late 2003 severely damaged its autumn emergence and a new crop was established in the spring (March 18th). Sowing densities were 7.5 seeds m^{-2} and 35 seeds m^{-2} for maize and soybean, respectively and 200 kg seeds ha^{-1} and 250 kg seeds ha^{-1} for winter wheat and pea, respectively.

Seedbeds were prepared using a rotovator. The soil was regularly ploughed 35 cm deep in autumn for winter wheat and winter vetch and in spring for maize and legumes. Following local practice, maize, soybean, and pea crop residues were incorporated into the soil and winter wheat straw was collected.

Weeds were controlled by false seeding and tine harrowing + ridging in OrM; only tine harrowing + ridging was used in OrF. It was not possible to apply false seeding in OrF because of a late harvest of green manure. Herbicides were regularly used in the Conv system.

Irrigations supplied 40-50 mm of water 0-4 times annually on maize per climate conditions.

2.4 Fertilisation management

Fertilisation management in both OrM and OrF conformed to the European regulation limit of 170 kg N ha^{-1} year^{-1}, which refers to the farm average of the full three-year crop rotation. Fertilisation is specific to crop need and averaged to be within the total value, such that the total average may differ little from the limit due to post-distribution analysis of N content of the different fertilisers. P and K amounts were constrained by N/P and N/K ratios of the organic fertilisers. In OrM, manure was spread before seeding at an average rate of 61.5 t^{-1} ha^{-1} year^{-1} in maize and 34.5 t^{-1} ha^{-1} year^{-1} in winter wheat. In OrF system, a mixture of composted organic fertilisers (poultry manure, manure, feather meal, and oleaginous residues) was applied to winter wheat before seeding (2.4 t^{-1} ha^{-1} year^{-}

^{1}). Poultry manure alone was supplied to maize before seeding and at sidedressing (3.1 t^{-1} ha^{-1} year^{-1} per application), as well as at sidedressing for winter wheat (1.5 t^{-1} ha^{-1} year^{-1}). No N was supplied to legumes, but they did receive a distribution of potassium sulphate containing magnesium salt prior to seeding (433.5 kg^{-1} ha^{-1} year^{-1}). Vetch green manure was seeded in autumn before summer crops (maize and soybean) during the first three-year rotation and prior to maize only during the second three-year rotation. The crop was chopped and immediately ploughed into the soil in early May.

N, P, and K supply in Conv respected local regulations and standards for integrated agriculture techniques (IAT) according to the specific crop: 200 kg N ha^{-1}for maize, 140 kg N ha^{-1} for winter wheat, and no N supply for legumes. Only mineral fertilisers were applied in Conv. Ammonium nitrate (241.5 kg^{-1} ha^{-1} year^{-1}) and urea (125 kg^{-1} ha^{-1} year^{-1}) were spread during winter wheat topdressing; urea (200 kg^{-1} ha^{-1} year^{-1}) alone was spread during maize topdressing. Potassium chloride was supplied before seeding in winter wheat, maize, and legumes (248, 250, and 241.5 kg^{-1} ha^{-1} year^{-1}, respectively). Amounts were based on crop demand and soil enrichment needs. No P was spread in Conv because IAT precludes P fertilisation in soil richer than 20 mg kg^{-1} of Olsen P.

All organic fertilisers were sampled for nutrient concentration analysis during fertiliser spreading (Table 2). Each sample was analysed for dry matter, C, total N, total P, and total K. Dry matter was measured after drying samples for 24 h at 70°C; C and total N content was were determined using a CHN elemental analyser (Flash EA 1112, Thermoquest, according to MIPAF method, 2000). Ammonium N was quantified through steam distillation: total P and K contents were determined after mineralisation in a muffle furnace at 450°C for 5 h with spectroscopy under continuous-flow conditions (Evolution II, Alliance) for P and with atomic-absorption spectroscopy (GBC 900) for K. Organic fertilisers showed very high variability in composition as expected for these matrices. The fraction of ammonium N on total N was between 12% and 16%, with higher values in Poultry manure. Composted organic fertiliser showed a lower presence of P and K compared to N content, while the highest proportional contents were in Poultry manure for P and Farmyard manure for K.

Table 2: Chemical characteristics of the organic fertilisers. Values in brackets indicate SD.

Fertiliser	Number	Dry matter g kg^{-1} fresh matter	Organic C g kg^{-1} dry matter	Total N g kg^{-1} fresh matter	C/N	NH_4-N g kg^{-1} of fresh matter	Total P g kg^{-1} of fresh matter	Total K g kg^{-1} of fresh matter
Farmyard manure	12	237 (40.1)	244 (134.3)	5.5 (0.8)	10.6 (5.8)	0.7 (0.5)	1.4 (0.3)	6.0 (2.1)
Composted organic fertilizer	6	915 (40.2)	355 (112.4)	65.7 (27.3)	7.5 (7.7)	7.6 (10.4)	10.4 (11.3)	8.6 (3.1)
Poltry manure	5	860 (37.5)	310 (61.4)	31.1 (13.2)	9.7 (3.3)	5.0 (3.5)	13.6 (5.7)	25.5 (7.8)

Tab 3: Fertilisation management from 2001 to 2003 (1^{st} 3-year period) and from 2003 to 2006 (2^{nd} 3-year period). Values are expressed in kg ha^{-1} y^{-1}.

System	Timing	Winter wheat	Maize	Soybean/Pea
OrM	**Before seeding**	**Manure**: 1^{st} N: 193, P: 63, K: 265 2^{nd} N: 208, P: 45, K: 198	**Manure**: 1^{st} N: 347, P: 101, K: 362 2^{nd} N: 313, P: 57, K: 298	
OrF	**Before seeding**	**Composted Organic fertiliser** 1^{st} N: 123, P: 9, K: 25 2^{nd} N: 168, P: 38, K: 20	**Green manure**: 1^{st} N: 220 2^{nd} N: 149 **Poultry-manure:** 1^{st} N: 75, P: 51, K: 78 2^{nd} N: 100, P: 39, K: 76	**Green manure**: 1^{st} N:190. **Potassium sulfate:** 1^{st} K: 117 2^{nd} K: 100
	Sidedressing	**Poultry- manure:** 1^{st} N: 34, P: 26, K: 35 2^{st} N: 91, P: 32, K: 39	**Poultry- manure:** 1^{st} N: 44, P: 28, K: 47 2^{nd}N: 100, P: 39, K: 76	
Conv	**Before seeding**	**Potassium chloride:** 1^{st} K: 123 2^{nd} K: 127	**Potassium chloride:** 1^{st} and 2^{nd} K: 125 **Urea:** 1^{st} N: 73 2^{nd} N: 96	**Potassium chloride:** 1^{st} K: 125 2^{nd} K: 116
	Sidedressing 1	**Ammonium nitrate:** 1^{st} N: 65 2^{nd} N: 61		
	Sidedressing 2	**Urea:** 1^{st} N: 85 2^{nd} N: 46	**Urea:** 1^{st} N: 108 2^{nd} N: 92	

Note. OrM: organic livestock farm cropping system; OrF: organic stockless farm cropping system; Conv: conventional farm cropping system

Table 3 lists the nutrients applied through fertilisation during the two three-year rotations. The average N applied in Conv during the second three-year rotation is less than that applied during the first, which derived from a reduced N supply to wheat during 2004 (spring sowed due to adverse 2003 autumn weather). Consequently, only ammonium nitrate was applied during topdressing.

OrF had the highest average N input values of 229 (first rotation) and 203 kg ha^{-1} $year^{-1}$ (second three-year rotation). These results are the sum of fertilisation input and vetch green manure fixed-N. Vetch green manure fixed-N was quantified according to the ^{15}N isotope dilution method (Rennie, 1984) described in the "Data analysis" section.

During the first three-year rotation, legume green manuring supplied an average of 137 kg N ha^{-1} $year^{-1}$, as opposed to 50 kg N ha^{-1} $year^{-1}$ when green manuring was limited to maize in the second three-year rotation.

P and K supply depended on the amounts of organic fertilisers applied based on their N content, which meant both organic systems received high P quantities. On the other hand, Conv system received no P fertilisation due to its high available P level in soil. OrM system had the highest supply of K because of the large K content common in farmyard manure. Both of the organic systems exhibited highly variable nutrient supplies during both rotation periods, likely resulting from variability in the nutrient concentrations of commercial organic fertilisers and from differing quantities of biomass incorporated in green manure.

2.5 Crop sampling and analysis

Samples were collected to determine yield, quality, and nutrient uptake of grain and aboveground biomasses. Maize was manually collected from areas of 18 m^2 from each plot, while winter wheat and legumes were collected by using a plot combine harvester from areas of 9 m^2 within each plot. Each crop grain and straw yield were weighted independently. Aboveground vetch biomass was collected from 3 m^2 areas within each plot. Plant samples were dried at 60 °C for 72 hours to determine dry matter (DM).

We determined grain and plant total N with a CHN elemental analyser (Flash EA 1112, Thermoquest, MIPAF method, 2000). Total P content was quantified after mineralisation in a muffle furnace at 450°C for 5 h with spectroscopy under continuous-flow conditions (Evolution II, Alliance), as was total K content after mineralisation with atomic-absorption spectroscopy (GBC 900). Soil surface budgets were then calculated from fertiliser input information.

Surface weed coverage was constantly monitored to evaluate its influence on crop yields. Surface weed coverage was quantified on three 0.5 m^2 areas in each plot during April, May, and June for winter wheat and during May, June, and July for maize. Reported values represent the average of the three measurements.

2.6 Soil sampling and analysis

The soil was sampled at the start of the experiment (in 2000) and after each three-year rotation cycle (2003 and 2006). The samples were collected in October before autumn fertilisation. Three 0-35 cm soil cores were sampled from each plot, air dried, and then sieved through 2-mm mesh screen. From these samples, organic C, total N, exchangeable K, and Olsen P were all measured. Organic C and total N were determined using a CHN elemental analyser (Flash EA 1112, Thermoquest); exchangeable K ($BaCl_2$ extraction followed by AAS determination) and Olsen P (Olsen et al., 1954) were determined according to the MIPAF method (2000).

PMN was also analysed through anaerobic incubation (modified Keeney, 1982) after each three-year rotation to estimate the availability of organic N to the soil. Samples were taken from the same 0-35 cm horizon.

2.7 Data analysis

Crop N balance surplus (CBS) was calculated according to Bassanino et al. (2007) as follows:

$$CBS = Fc + Fo + Ad + Bfx - (Y*b) \qquad (1)$$

where F*c* is the mineral fertiliser N; F*o* is manure or other organic fertiliser N; A*d* is wet and dry atmospheric deposition N (26 kg N ha^{-1}, Bassanino et al., 2011); B*fx* is the biological N fixation by legumes; Y is crop yield (grain or crop residues collected from the field); and b is the respective N content of all harvests.

B*fx* was quantified as:

$$Bfx\ (\mathrm{kg\ N\ ha^{-1}}) = Ndfa * ((Y * b) + (Yr * br)) \quad (2)$$

where Ndfa is the ratio of N derived from the atmosphere, Yr is the below ground biomass yield, and br is N content of root.

Ndfa refers to the aboveground soybean and vetch biomasses determined during 2002 and 2003 using the ^{15}N isotope dilution method (Rennie, 1984) on 2 m^2 microplots. Sorghum and sunflower were selected as non-fixing comparative species for soybean Ndfa estimation, and Italian ryegrass was chosen for vetch. Ndfa values for soybean showed large statistically significant differences between systems (P(F) = 0.033) in 2003, where OrF (53.0%) and Conv (69.1%) had higher values of Ndfa than did OrM (11.4%). In vetch, the average Ndfa value calculated in OrF corresponded to 92.4%.

N fixation of pea was estimated as equal to 79 % (Rennie and Dubetz, 1986).

Ndfa for roots was assumed to be the same as that of aboveground biomass. The N content of root legumes biomass was quantified according to Mahieu et al. (2009).

CBS was also calculated for P and K without accounting for Ad, which was assumed to be negligible.

Results on yield, aboveground biomass, and nutrient concentration of grain and straw for each crop were analysed through ANOVA that accounted for system, block, and year effects, in addition to system x year interactions.

Variations in soil chemical properties and PMN were analysed through ANOVA separately for each sampling and for the full six-year period.

As CBS values served mainly to justify soil changes, they were calculated for each replication and averaged over the two three-year rotations and over the six-year period. Values were analysed through one-way ANOVA.

Homogeneity of variance was tested through the Levene test, and residuals were tested for normality via the Kolmogorov-Smirnov test. When system averages were significantly different, they were separated by the Bonferroni multiple comparison test. When system x year interaction resulted significant, average values per system in each year were separated thorough the Bonferroni multiple comparison test.

Statistical correlations between straw winter wheat P concentration and soil Olsen P, as well as between straw winter wheat K concentration and soil exchangeable K, were studied using Pearson's correlation. The P analysis was separated between years to eliminate inter-year variability that cannot be explained by this correlation; the K analysis was separated between systems.

All statistical analyses were conducted using SPSS 17.0 software.

3. Results

3.1 Crop yields

Crop yields for the different crops are reported in Table 4. It shows that system, year, and system x year effects were always highly significant. System yields differed each year, and highlighted very strong year interaction with meteorological variability, competitive weed differences, and plant disease development.

Table 4: Grain yield and above-ground biomass (Mg DM ha^{-1}). Legumes refer to soybean (2001 - 2003) and pea (2004 - 2006). Different letters denote different System means (P < 0.05). Different letters in System×Year interaction denote different means of grain or ABG (P < 0.05) between systems in each year. Averages were separated through Bonferroni post hoc test.

		System	2001	2002	2003	2004	2005	2006	mean	Effect	P(F)
Wheat	Grain	Conv	4.6 a	5.5 a	5.2 a	5.3 a	6.5	6.7 a	5.6 a	System	0.000
		OrM	3.4 b	5.0 a	3.6 b	4.0 b	6.6	5.6 b	4.7 b	Year	0.000
		OrF	3.9 ab	3.5 b	4.9 a	3.6 b	6.7	7.0 a	4.9 b	Syst. x Year	0.000
	ABG*	Conv	8.4 a	10.5 a	9.5 a	8.6 a	12.8	13.6 a	10.6 a	System	0.000
		OrM	6.6 b	9.6 ab	6.7 b	6.5 b	12.4	10.7 b	8.8 b	Year	0.000
		OrF	7.1 ab	6.7 b	9.1 a	5.9 b	12.6	15.2 a	9.4 b	Syst. x Year	0.000
Maize	Grain	Conv	13.1 a	11.2 a	8.9 a	12.4 a	12.5	9.5	11.2 a	System	0.000
		OrM	10.0 b	10.2 a	5.8 b	10.3 a	10.9	9.2	9.4 b	Year	0.000
		OrF	11.1 ab	7.1 b	9.0 a	7.2 b	11.3	8.8	9.1 b	Syst. x Year	0.000
	ABG*	Conv	24.1 a	21.2 a	15.6 ab	23.5 a	24.2	19.4	21.3 a	System	0.000
		OrM	19.6 b	19.2 a	12.1 b	21.1 a	22.5	19.6	19.0 b	Year	0.000
		OrF	21.4 ab	12.9 b	17.2 a	14.7 b	21.2	18.4	17.6 c	Syst. x Year	0.000
Legumes	Grain	Conv	2.6 a	2.8 a	3.7 a	3.4 b	5.3	3.6	3.6 a	System	0.000
		OrM	2.0 ab	2.4 ab	4.3 a	4.7 a	4.8	3.6	3.6 a	Year	0.000
		OrF	1.7 b	1.9 b	1.5 b	1.6 c	4.9	3.6	2.5 b	Syst. x Year	0.000
	ABG*	Conv	7.0 a	4.8	7.5 a	5.6 b	9.2	7.1	6.9 a	System	0.000
		OrM	4.9 b	4.5	8.4 a	8.0 a	8.8	7.2	7.0 a	Year	0.000
		OrF	4.3 b	4.1	3.3 b	2.5 c	8.9	8.0	5.2 b	Syst. x Year	0.000

* Above Ground Biomass
Note: Block effect P(F) = 0.000 in Wheat grain and ABG; 0.040 in Maize grain; n.s. in Maize ABG, Legumes grain and ABG
OrM: organic livestock farm cropping system; OrF: organic stockless farm cropping system; Conv: conventional farm cropping system

In general, weed infestation is not correlated to crop yield (Figures 1 and 2), however in single year weeds coverage was usually higher in organic systems, mainly in OrF system.

OrM management—where less grain and aboveground biomass were produced than in Conv in four years out of six—limited wheat yields most. Wheat performed somewhat better in OrF where it produced less than Conv in two of the six years. On the contrary, maize and legume yields did worse under OrF management. Maize grain yields were reduced, on average, 16% in OrM and 19% in OrF, and aboveground biomass reductions averaged 11% in OrM and 17% in OrF. Lower production in OrM maize in 2003 was justified by severe *Sesamia Agriotes* damage. In the case of legumes, the conventional system never produced more than OrM.

Figure 1 Relation between weed coverage and crop yield during the different years in winter wheat.
Pearson's correlation coefficient: -0.345, not significant.

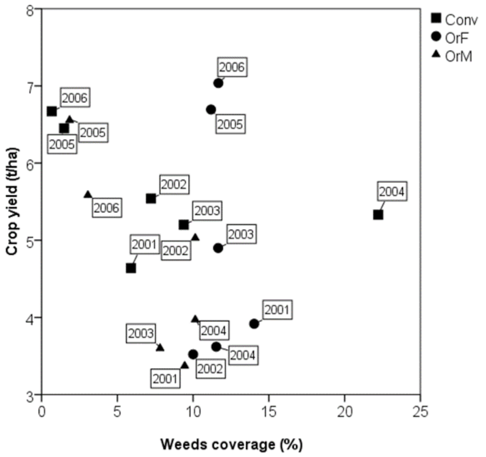


Figure 2: Relation between weed coverage and crop yield during the different years in maize.
Pearson's correlation coefficient: -0.246, not significant.

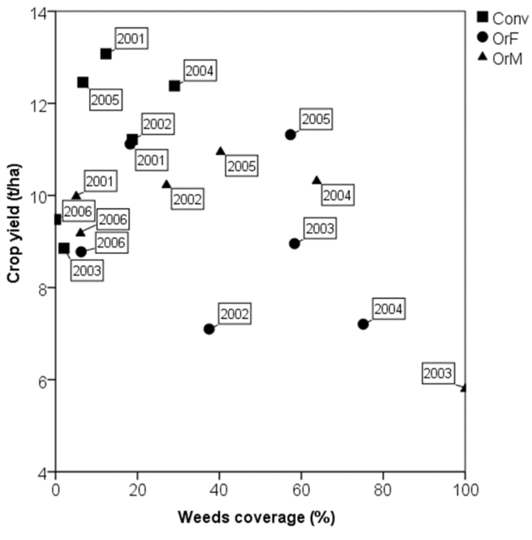


Table 5: N concentration in grain and straw of the different crops (g N kg^{-1} DM). Legumes refer to soybean (2001 - 2003) and pea (2004 - 2006). Different letters denote different System means ($P < 0.05$). Different letters in System×Year interaction denote different means of Grain or Straw ($P < 0.05$) between systems in each year. Averages were separated through Bonferroni post hoc test.

		System	2001	2002	2003	2004	2005	2006	mean	Effect	P(F)
Wheat	Grain	Conv	21.3	28.3 a	25.7 a	30.0 a	26.7	23.1	25.8 a	System	0.002
		OrM	22.2	26.5 a	21.0 b	26.8 b	24.6	23.2	24.1 b	Year	0.000
		OrF	22.4	22.8 b	21.7 b	30.0 a	26.0	24.1	24.5 b	Syst. x Year	0.001
	Straw	Conv	3.1 b	6.2	5.8	9.0 a	7.7	5.9	6.3 a	System	0.003
		OrM	4.4 ab	5.3	4.4	6.6 b	6.2	5.0	5.3 b	Year	0.000
		OrF	5.1 a	4.7	4.8	9.3 a	6.8	6.8	6.3 a	Syst. x Year	0.008
Maize	Grain	Conv	14.6	13.8	12.7	13.1	16.9	17.0	14.7 ab	System	0.036
		OrM	14.0	13.9	16.9	14.7	16.3	16.7	15.4 a	Year	0.000
		OrF	12.7	14.1	14.1	12.3	16.5	16.4	14.4 b	Syst. x Year	n.s.
	Straw	Conv	7.3	8.6	10.2	10.1	9.1	9.7	9.2	System	n.s.
		OrM	6.8	9.5	10.8	11.0	10.3	9.5	9.7	Year	0.000
		OrF	7.2	8.7	9.8	12.2	10.0	10.5	9.7	Syst. x Year	n.s.
Legumes	Grain	Conv	67.5	70.5	68.3 a	37.5 b	36.4	38.5	53.1 a	System	0.015
		OrM	65.9	67.0	63.9 b	34.3 b	38.2	38.4	51.3 b	Year	0.000
		OrF	65.6	67.8	67.0 ab	43.4 a	37.3	38.5	53.3 a	Syst. x Year	0.007
	Straw	Conv	21.2 a	10.4	7.6	7.9 b	16.0	8.8	12.0 ab	System	0.048
		OrM	13.6 b	10.0	8.0	8.9 ab	18.3	9.9	11.4 b	Year	0.000
		OrF	16.0 b	10.8	10.8	12.5 a	18.2	11.5	13.3 a	Syst. x Year	0.012

Note: Block effect P(F) = 0.046 in Wheat straw N concentration; n.s. in all other cases
OrM: organic livestock farm cropping system; OrF: organic stockless farm cropping system; Conv: conventional farm cropping system

Table 6: P concentration in grain and straw of the different crops (g P kg-1 DM). Legumes refer to soybean (2001- 2003) and pea (2004 – 2006). Different letters denote different System means ($P < 0.05$). Different letters in System×Year interaction denote different means of Grain or Straw ($P < 0.05$) between systems in each year. Averages were separated through Bonferroni post hoc test.

		System	2001	2002	2003	2004	2005	2006	mean	Effect	P(F)
Wheat	Grain	Conv	2.7	3.8	2.4	3.4	3.6	4.1	3.4	System	n.s.
		OrM	2.7	3.9	2.4	3.0	3.4	4.6	3.4	Year	0.000
		OrF	2.7	3.8	2.4	3.6	4.0	4.2	3.4	Syst. x Year	n.s.
	Straw	Conv	0.8 b	1.2 c	0.8 b	1.0 c	1.1 c	1.0 b	1.0 c	System	0.000
		OrM	1.3 a	2.0 a	1.5 a	1.6 b	1.9 a	1.7 a	1.7 a	Year	0.000
		OrF	0.9 b	1.7 b	1.2 a	1.9 a	1.5 b	1.2 b	1.4 b	Syst. x Year	0.001
Maize	Grain	Conv	2.7	3.3	1.4	2.2	3.2	3.9	2.8 a	System	0.044
		OrM	2.5	2.5	1.8	2.0	2.6	4.6	2.7 ab	Year	0.000
		OrF	1.8	2.8	1.5	2.0	2.3	4.1	2.4 b	Syst. x Year	n.s.
	Straw	Conv	0.9	1.0 b	1.1	0.9 b	1.3	1.3	1.1 b	System	0.004
		OrM	0.9	1.8 a	1.5	1.2 b	1.1	1.6	1.4 a	Year	0.000
		OrF	0.8	1.0 b	1.2	1.9 a	1.4	1.5	1.3 a	Syst. x Year	0.000
Legumes	Grain	Conv	7.1	7.2	6.7	3.6	3.9 a	4.3 b	5.5	System	n.s.
		OrM	6.9	7.5	6.9	3.2	2.8 b	5.5 a	5.5	Year	0.000
		OrF	6.7	7.7	7.0	3.3	3.7 a	5.2 a	5.6	Syst. x Year	0.000
	Straw	Conv	2.3 a	1.3 b	1.1 b	0.6 b	1.5	0.8 b	1.3 b	System	0.000
		OrM	1.7 b	1.8 ab	1.5 ab	0.9 ab	1.8	1.3 a	1.5 a	Year	0.000
		OrF	2.1 ab	1.9 a	1.8 a	1.3 a	1.7	1.3 ab	1.7 a	Syst. x Year	0.014

Note: Block effect P(F) = n.s. in all cases
OrM: organic livestock farm cropping system; OrF: organic stockless farm cropping system; Conv: conventional farm cropping system

3.2 Nutrient concentrations in tissues

The values reported in Table 5 show nitrogen concentrations for both wheat and maize grain highest under Conv management. In the case of wheat grain, both organic systems were lower than Conv two years out of six. In maize grain, OrM N concentration was as high as Conv, but lower under OrF. Legume grain concentrations were lowest under OrM management. Averaged wheat straw N concentrations indicated that both OrF and Conv were higher than OrM, while maize and legume straw N concentrations revealed no differences across managements. The P content analysis between systems (Table 6) differed only in maize grain in which Conv and OrM had higher values. When statistical differences arose in straw, the lowest P concentration was usually measured in Conv due to its lack of fertilisation from the start of the experiment. In the analysis of K content (Table 7), grain and straw displayed system, year, and system x year effects for both wheat and legumes. Interaction was not significant in maize. Overall, most of the data ranked the K content of the treatments as OrM, OrF, and Conv (higher to lower). Legume grains demonstrated a different result; OrF was highest due to its low production and OrM was lowest due to its high production.

Table 7: K concentration in grain and straw of the different crops (g K kg-1 DM). Legumes refer to soybean (2001 – 2003) and pea (2004 – 2006). Different letters denote different System means (P < 0.05). Different letters in System×Year interaction denote different means of Grain or Straw (P < 0.05) between systems in each year. Averages were separated through Bonferroni post hoc test.

		System	2001	2002	2003	2004	2005	2006	mean	Effect	P(F)
Wheat	Grain	Conv	5.2	4.9	5.1	5.3	4.9 b	4.3	5.0 b	System	0.004
		OrM	5.5	4.7	5.2	5.4	5.5 a	4.6	5.1 a	Year	0.000
		OrF	5.5	4.7	5.3	5.4	4.9 b	4.3	5.0 ab	Syst. x Year	0.036
	Straw	Conv	9.7	17.9 a	16.5	23.2 a	17.6 b	17.6	17.1 a	System	0.020
		OrM	10.5	16.5 a	14.3	16.4 c	21.3 a	15.7	15.8 b	Year	0.000
		OrF	9.8	12.6 b	16.6	19.3 b	21.0 a	18.5	16.3 ab	Syst. x Year	0.000
Maize	Grain	Conv	4.2	4.9	3.8	4.0	4.0	4.3	4.2 b	System	0.002
		OrM	4.1	4.8	4.6	4.3	4.2	5.0	4.5 a	Year	0.000
		OrF	4.0	4.8	3.9	4.1	3.9	4.6	4.2 b	Syst. x Year	n.s.
	Straw	Conv	9.6	12.3	14.2	11.6	9.2	10.4	11.2 b	System	0.000
		OrM	14.2	12.9	18.4	13.2	11.5	12.7	13.8 a	Year	0.000
		OrF	10.1	11.3	13.4	8.5	8.7	9.5	10.2 b	Syst. x Year	n.s.
Legumes	Grain	Conv	17.9	17.8	20.9 ab	11.7 a	10.6	10.2 b	14.9 b	System	0.001
		OrM	18.4	18.9	20.6 b	10.5 b	11.6	12.0 a	15.3 ab	Year	0.000
		OrF	18.5	18.7	21.9 a	12.4 a	10.9	11.6 a	15.7 a	Syst. x Year	0.003
	Straw	Conv	13.0	10.1	10.9 b	9.0 b	13.7 b	24.4 b	13.5 b	System	0.000
		OrM	12.6	12.2	16.4 a	15.2 a	22.3 a	34.2 a	18.8 a	Year	0.000
		OrF	13.0	14.4	16.8 a	16.1 a	15.0 b	26.5 b	17.0 a	Syst. x Year	0.007

Note: Block effect P(F) = 0.008 in wheat straw K concentration; n.s. in all other cases
OrM: organic livestock farm cropping system; OrF: organic stockless farm cropping system; Conv: conventional farm cropping system

Table 8: Average Crop balance surplus (CBS) for each period (kg ha^{-1} year^{-1}). Different letters denote different means (P < 0.05) between systems in each period. Averages were separated through Bonferroni post hoc test.

	System	2001-2003	2004-2006	2001-2006
N	Conv	19 c	-1 c	9 c
	OrM	75 b	98 b	86 b
	OrF	169 a	124 a	146 a
System P(F)		0.000	0.000	0.000
P	Conv	-23 b	-27 c	-25 b
	OrM	35 a	9 b	22 a
	OrF	28 a	25 a	27 a
System P(F)		0.000	0.000	0.000
K	Conv	61 b	47 b	54 b
	OrM	156 a	94 a	125 a
	OrF	47 b	41 b	44 b
System P(F)		0.000	0.000	0.000

Note. OrM: organic livestock farm cropping system; OrF: organic stockless farm cropping system; Conv: conventional farm cropping system

3.3 N, P, and K crop balance surpluses (CBS)

In general, the organic systems had larger surpluses than did the conventional system, with minor exceptions. The N CBSs displayed in Table 8 indicate that throughout the full cropping cycle, larger surpluses resulted in the organic systems than in Conv. Organic systems had N surpluses during the entire experimental period (2001-2006), averaging 87 kg ha^{-1} year^{-1} for OrM and 153 kg ha^{-1} year^{-1} for OrF. The higher N surplus in OrF derives from the presence of green manuring that through N fixation provides additional N quota to the system. The main surpluses were associated with maize, which received the highest N fertilisation (Table 3) among the crops. Reduced N input (Table 3) and increased productivity of winter wheat (Table 4) achieved in the second three-year period resulted in a null N CBS for Conv. The P surplus measured in the organic systems followed the expectation associated with their P fertilisation management. Conv lacked P supply throughout the experiment, which implied its soil P depletion was about 25 kg ha^{-1}year^{-1}. Finally, K CBS showed a surplus in all systems. It was noted above all in OrM, while OrF and Conv were quite similar.

Table 9: Variation in soil property mean values measured October 2000, 2003 and 2006 at 0-35 cm. Different letters denote different means (P < 0.05) between systems in each period. Averages were separated through Bonferroni post hoc test.

	System	2000-2003	2003-2006	2000-2006
Org C kg ha^{-1}	Conv	-7851 b	-8406	-16256 b
	OrM	-1910 a	-5583	-7493 a
	OrF	-2045 a	-10693	-12739 ab
P(F)	System	0.024	n.s.	0.044
	Rotation	n.s.	n.s.	n.s.
N tot kg ha^{-1}	Conv	348 b	-955 ab	-607
	OrM	389 b	-561 a	-172
	OrF	1226 a	-1682 b	-456
P(F)	System	0.015	0.028	n.s.
	Rotation	n.s.	n.s.	n.s.
Olsen P kg ha^{-1}	Conv	-29 b	-23 b	-52 b
	OrM	3 a	4 a	7 a
	OrF	-18 b	-16 ab	-34 b
P(F)	System	0.001	0.011	0.000
	Rotation	n.s.	0.001	0.000
Exch. K kg ha^{-1}	Conv	206 a	46	252
	OrM	70 b	171	241
	OrF	118 ab	29	146
P(F)	System	0.030	n.s.	n.s.
	Rotation	n.s.	n.s.	n.s.

Note: Block effect P(F) = 0.002 in Olsen P, 2000-2003; 0.042 in Exch. K, 2000-2003; n.s. in all other cases
OrM: organic livestock farm cropping system; OrF: organic stockless farm cropping system; Conv: conventional farm cropping system

Table 10: C:N ratio and Potential Mineralisable Nitrogen (PMN) at sampling depth of 0-35 cm measured in October during the experimental period. Different letters denote different means ($P < 0.05$) between systems in each measured year. Averages were separated through Bonferroni post hoc test.

	System	2000	2003	2006
C:N	Conv	9.7	8.8	8.5 b
	OrM	10	9.2	9.1 a
	OrF	10	8.1	9 a
P(F)		n.s.	n.s.	0.001
PMN mg kg^{-1}	Conv		24.8 b	32.7 b
	OrM		39.1 a	48.8 a
	OrF		25.8 b	33.8 b
P(F)			0.000	0.000

Note: OrM: organic livestock farm cropping system; OrF: organic stockless farm cropping system; Conv: conventional farm cropping system

3.4 Chemical properties of soil

Soil organic carbon (SOC) content decreased in all the systems during the six-year period (Tab. 9). The loss was significantly higher in Conv than in both organic systems during the first three-year period and over the total period. OrM system protected SOC more than OrF did.

In the first three-year period, total N increased in all treatments; OrF varied most over the period due to a large N CBS. During the subsequent three-year period, all treatments had reduced total N, but the reduction was less in OrM, and more in OrF system. Therefore, the total variation over the six-year period showed no significant differences among the systems. Olsen P trend variations were similar in both periods. OrM increased soil P content, while reductions were detected in OrF and in Conv. Exchangeable K increased in all systems according to their respective K budgets. Measurements showed significant differences only after the first period with higher values in Conv.

Table 10 lists the soil organic matter characteristics in terms of C/N and PMN for all the systems. System effect separated the treatments for C/N only after six years of rotation when Conv resulted lower than both organic systems. PMN differences between systems were evident after both three and six years of rotation. Results showed higher N availability in OrM compared to OrF and Conv.

4. Discussion

4.1 Crop yield

Organic system crop yields were lower than in the conventional system. The reduction, averaged from the six-year period, was 17% in OrM for both winter wheat and maize; no reduction was recorded in legumes. In OrF, the reductions (same period) were quantified as 12%, 19%, and 29% in winter wheat, maize, and legumes, respectively. However, annual differences were evident and driven mainly by system x year effect. The observed reductions were attributed to fertilisation management (Cong Tu et al., 2006), mineralisation activity (Berry et al., 2002, Stockdale et al., 2002), weed control, and meteorological trends.

No clear trend in crop yields was evident over time. Transition period production variation appeared absent. Instead, it was dominated by annual effect, which contrasted with Gopinath et al., (2008) who reported that organic winter wheat yield losses were limited to the first two years of the conversion period. Other authors have proposed yield losses continue for longer periods (Eltun et al., 2002; Kirchmann and Ryan, 2004).

The larger winter wheat yield reduction in OrM relative to Conv, probably resulted from low-temperature-induced low mineralisation causing limited nutrient availability during autumn, winter, and early spring. The lower straw wheat N concentrations in OrM confirmed this phenomenon with lower values compared to those of OrF and Conv. OrF demonstrated a better capacity to support winter wheat yields *versus* OrM because commercial organic fertilisers mineralise quickly due to their lower C/N ratios and higher available N fractions. In fact Poultry manure fertiliser showed the higher ratio of readily available N, as confirmed also by Shepherd and Withers (1999).

In contrast to wheat, maize grows when a more active N mineralisation is expected; for this reason, fertilisation management influenced grain yields less than in winter wheat. Berry et al. (2002) has noted that maize takes advantage of N mineralisation and crop update synchronisation. Excluding 2003 (insect damage data not shown), OrM average maize yields over the entire period were only

9% less than those in Conv. Maize straw N concentration exhibited no differences among the systems. This result substantiated that active soil mineralisation adequately supplies maize for growth. Both organic fertilisation managements were able to support maize N uptake. OrF yielded less than Conv due to low weed control.

N concentrations in legume tissues confirmed increased availability of N, especially in the manured system during spring and summer for the same reason we recorded a lower Ndfa in OrM and a higher Ndfa value in Conv and OrF (data not shown). In fact, legume N-fixation increases with depletion of soil available N provoked by intercropping or weed uptake, leaching, immobilisation, and others (Corre-Hellou and Crozat, 2005; Hauggaard-Nielsen et al., 2009).

Mineralisation activity also controls soil available P (Stockdale et al., 2002). Analysis of P content in straw demonstrated that maize and legumes in Conv (system characterised by no P supply) are often similar to the content in OrM and OrF from the P made available by soil mineralisation. On the contrary, P content in winter wheat straw in Conv was always lower than in the organic systems. This highlighted the lower flux of P that came from mineralisation activity limited by low temperatures. The high P concentrations observed in OrF legume straw was borne out by the lower yield in this system as compared to the other systems.

As expected, K tissue content in OrM was higher than in the other systems due to its higher K CBS.

4.2 N, P, and K Crop Balance Surplus (CBS)

Our results showed that N CBSs were higher in organic systems than in Conv. Clark et al. (1998) found similar results in N surplus measures, as much as 36% more in an organic system fertilised with organic external inputs than in conventional. In Conv, where integrated agriculture techniques are applied, N CBSs were rather low and during the second three-year period even slightly negative, underlining the low long-term sustainability of this system.

It is expected that in organic systems legumes cause N fixation and consequently lead to increased N CBS (Berry et al., 2002; Corre-Hellou and Crozat, 2005; Stopes et al., 1996). Indeed, this was the case for the OrF system that relied on biological fixation for 46% of its N inputs, as opposed to 5% in OrM characterised by a minor share of legumes and lower Nfda.

P CBSs in the two organic systems were positive, but lower than those reported by Bassanino et al. (2011) in the same region as the field experiment (39 kg P ha^{-1} year^{-1}) and on conventional livestock farms characterised by higher organic inputs.

Finally, K CBS was quite high in OrM because of its use of external farmyard manure with a narrow N:K ratio (Gopinath et al., 2008; Sheperd and Withers, 1999). K CBS was largely positive in the other two treatments as well due to low input levels and the absence of ley and other crops with large uptakes (Berry et al. 2002).

4.3 Chemical properties of soil

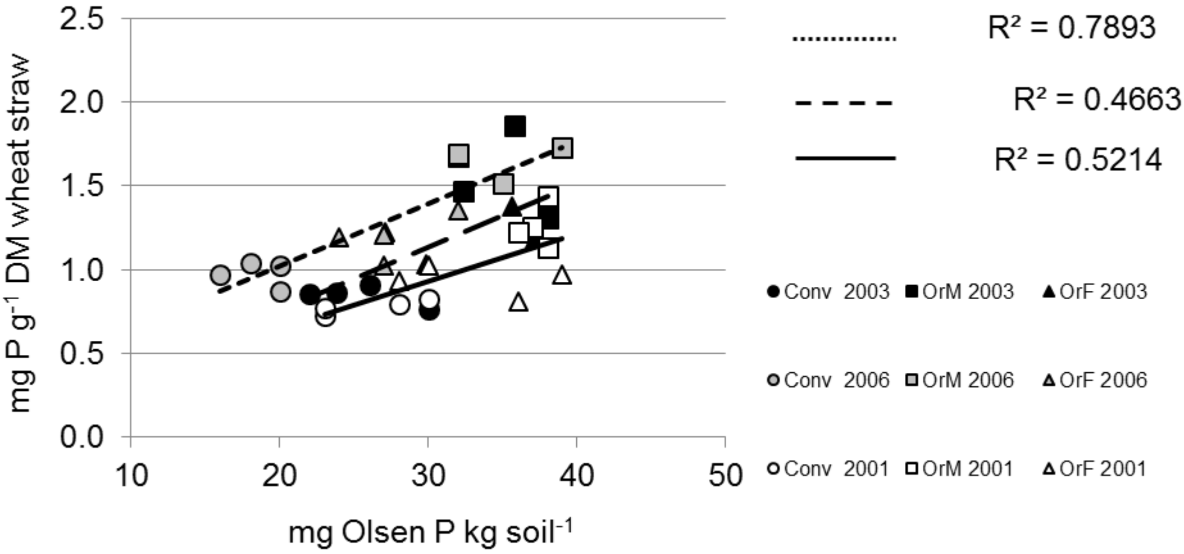
C and N content decreased across all treatments. Despite the start of conversion from conventional to organic management in 2001, SOC did not increase as others have reported (Gopinath et al., 2008; Mazzoncini et al. 2010; Stockdale et al., 2001). However, others have reported neither a decline in SOC content in organic treatments (Tiessen et al., 1982), nor an absence of differences between organic and conventional managements during transition (Clark et al, 1998; Marinari et al., 2006) or after even longer periods (Gosling and Shepherd, 2005). In this experiment, OrM was able to limit SOC depletion to less than 8000 kg C ha^{-1} over the course of six years, a much smaller quantity than was measured in the Conv system. It must be emphasised that it is not the organic system *per se* that helped to reduce organic matter losses, but the fact that manure fertilisation is part of the organic system (Flieβbach et al., 2007). The important role of manure fertilisation to maintain SOC content, or to limit SOC depletion, has been largely documented in other works carried out in similar environments (Bertora et al., 2009; Grignani et al., 2007). Low C/N organic inputs applied as commercial organic fertilisers in OrF systems are not efficient in stocking SOM.

Soil total nitrogen trended lower over the six-year period without treatment differences. The near zero (only 9 kg ha^{-1} year^{-1}) Conv N imbalance might indicate that 101 kg ha^{-1} year^{-1} could represent the average, entire period Conv soil N reduction in the 0-35 cm layer of a system in which input and crop uptake are balanced. This soil N reduction could be related to N losses. Of note is that important soil N reductions occur in systems characterised by fertilisation N similar to crop N uptake. Furthermore, both in OrM and OrF, where CBS is largely positive, soil N is also reduced (28 kg ha^{-1} $year^{-1}$ and 76 kg ha^{-1} $year^{-1}$, respectively). This result suggests that while both organic fertilisation managements failed to reduce N losses, the organic managements, performed better than commercial organic fertilisers, which impart a greater impact on the environment from N losses. The ability of farmyard manure to limit soil N reduction—or even to increase soil N—depends on the fertilisation amount as has already been demonstrated by others in the same environment (Grignani et al., 2007; Bertora et al., 2009). Moreover, the lower capability of commercial organic fertilisers to reduce N losses is usually attributed to lower C/N ratios that are prone to increase the rate of mineralisation and potential N losses (Berry et al., 2002).

Green manuring in OrF during two years of the first three-year rotation expanded its capacity to increase total N of the soil relative to OrM or Conv, as PMN analysis revealed that the added N was less mineralised than that present in OrM. The reduction of N supply through green manuring during the second three-year period reduced the capacity to stock soil organic N, hence the N content in OrF at the end of the study period was equal to that of the other two treatments, but less available than OrM.

P CBS values alone cannot explain the variation of Olsen P in the soil (Sistani et al., 2008), as the form used to supply P determined different results. Under Conv management, reduced Olsen P is consistent with the lack of fertilisation. Farmyard manure efficiently maintained P availability in the soil. In OrF the reduction of available soil P relative to positive budgets indicates chemical immobilisation in P forms not available to the crop (Halvorson and Black, 1985) or potential losses from leaching (Borda et al., 2011, Cherry et al., 2008).

Figure 3: Correlation between winter wheat straw P content and Olsen P in the soil. Pearson correlation has been split by year (* significant at $p < 0.05$; ** significant at $p < 0.01$; *** significant at $p < 0.001$).



The different availability of soil P is also demonstrated by the strong correlation (Figure 3) of P concentration in winter wheat straw and Olsen P. In fact, winter wheat straw seemed to be a good indicator of Olsen P and demonstrated the reduction of soil available P in OrF and Conv.

Finally, positive values of K CBS provoked positive exchangeable K variation. Total variation of exchangeable K over the six-year period, however, was not proportional to K CBS values, which probably resulted from the complex role played by organic fertiliser containing K not fully available to the plant.

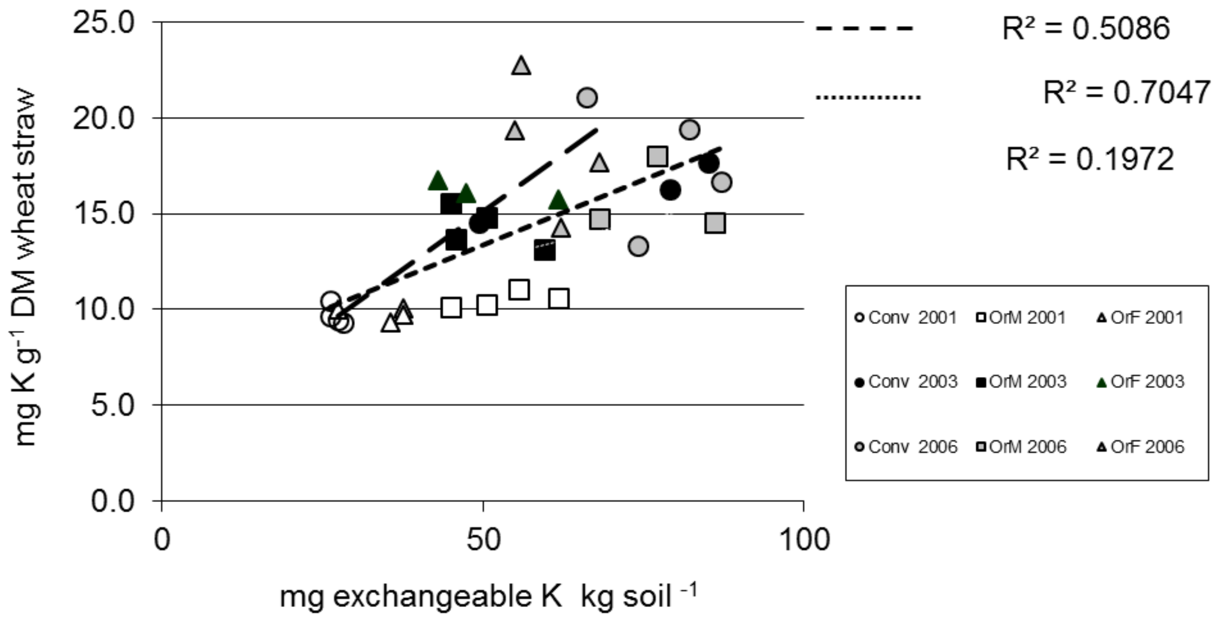


Figure 4: Correlation between winter wheat straw K content and exchangeable K in soil. Pearson correlation has been split by treatment (* significant at $p < 0.05$; *** significant at $p < 0.001$).

The correlation between soil exchangeable K and winter wheat straw K concentration (Figure 4) revealed that the latter is a good indicator of soil K status, but its significance decreased from Conv to OrF to OrM due to their progressive increase of K derived from organic fertilisers.

5. Conclusion

Organic systems produced less, in general, than did the comparative conventional system; however, the reduction was in interaction with year. The expected trend, related to the conversion period, was not evident in this experiment. Instead, yield reduction seemed related to lower soil nutrient availability derived from organic fertilisers that provided nutrients mainly as a consequence of mineralisation activity. This result implies that organic farming based on manure fertilisation is more suitable for summer crops that take advantage of mineralisation and higher summer temperatures. Winter wheat, on the contrary, suffers larger reductions in manured organic system due to slow mineralisation. However, the use of commercial organic fertilisers contains this reduction due to their higher nutrient availability and makes them better suited for winter crops.

All arable systems analysed in this work were characterised by decreased soil organic carbon over time. However, manure contained soil organic carbon and soil total N depletion better. Green manuring maintained SOC and increased total N in the soil if applied often during the intercropping periods of crop rotation. Nonetheless, this effect is unstable across years if the frequency of green manuring intercropping falls to less than two out of three years.

Soil fertility indicators (soil organic matter, total N variation, P and K availability) and Potential mineralisable N demonstrated that organic systems managed with commercial organic nitrogen fertilisers and green manure perform similarly to those managed with mineral fertilisers.

Finally, P and K concentrations in winter wheat straw seem to be good indicators of P and K soil availability.

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