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Effects of organic farming practices and salinity on yield and greenhouse gas emissions from a common bean crop

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ABSTRACT

A field experiment was conducted at Agrinio, West Greece, to compare the impacts of organic *vs.* conventional farming practices on yield, N nutrition and greenhouse gas emissions in common bean (*Phaseolus vulgaris* cv. 'contender'). In both farming systems, irrigation water containing 0.5 or 10 mM NaCl was used. The conventionally treated plots were fertilized with an inorganic fertilizer, whereas the organically treated plots received organic compost. Conventional farming resulted in significantly higher fresh weight of green bean pods than organic farming (5.50 kg m^{-2} *vs.* 3.67 kg m^{-2}, respectively). However, the cropping system had no impact on dry pod biomass, because the dry matter content of the organically produced bean pods was higher than that of pods originating from conventional farming (9.88% *vs.* 7.20%, respectively). The presence of 10 mM NaCl in the irrigation water restricted significantly the total plant biomass and fresh pod yield (−22.8%), without any interaction with the farming system. The decrease in fresh pod yield by organic farming was due to a shortage in soil mineral N (NO_3^- and NH_4^+) at the early growth stage, which reduced the tissue N levels. Organic farming increased significantly the number or root nodules at the stage of early pod filling in comparison with conventional farming. However, at both systems the total soil N increased appreciably at this developmental stage, although no N was supplied to the crop, thereby pointing to intensive symbiotic N_2-fixation by bean. Organic farming resulted in significantly lower N_2O emissions than conventional farming in terms of the overall Global Warming Potential of the treatments (363 kg ha^{-1} *vs.* 455 kg ha^{-1}, respectively). However, the N_2O emission intensities did not differ significantly between organic and conventional systems, highlighting the importance of maximizing yield within organic systems in order to reduce their environmental impact.

1. Introduction

Organic farming systems rely on ecologically sound practices, such as biological pest control, composting, enhancement of soil fertility through biological processes, and crop rotation, while excluding the use of synthetic chemicals in crop production. However, in organic agriculture, the supplied N is organically bound and thus the N availability to plants depends on mineralization rates of soil organic matter, which is hardly predictable under field conditions. As a result, timely supply of sufficient plant-available N can be a problem in organic agriculture and this may result in lower yields (Seufert et al., 2012). Legume crops are capable of providing N to the soil through symbiosis with N_2-fixing rhizobacteria. Nevertheless, also in legume crops the timely delivery of plant available N forms may pose a problem, since at the initial cropping stages the proliferation of N_2-fixing rhizobacteria results in immobilization rather than in release of plant available inorganic N forms (Oberson et al., 2013).

Another question related to the cultivation of legumes is their impact on emissions of carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4) from the soil, which are considered the major greenhouse gases (GHG) contributing to global climate change (Forster et al., 2007). Although CO_2 is the main anthropogenic greenhouse gas, the agricultural sector is dominated by N_2O and CH_4 emissions (Schulze et al., 2009). In addition to its role as a greenhouse gas, N_2O is considered the most important ozone-depleting substance in the 21st century (Ravishankara et al., 2009). Animal and crop production may account for as much as 70% of annual global anthropogenic N_2O emissions and about 33% of global CH_4 emissions (Mosier et al., 1998; Mosier, 2001).

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Furthermore, nearly 25% of CO_2 emissions arising from anthropogenic activities at global level are attributed to agriculture (Cole et al., 1997). As a total, agricultural activities contribute 10–12% of total GHG emissions worldwide (Smith et al., 2007).

The management of cropping systems provides a powerful tool for the mitigation of GHG emissions in agriculture (Zhong et al., 2009; Rees et al., 2012; Sainju et al., 2012). Indeed, the reduced amounts of N fertilizers supplied to crops in organic agriculture by comparison with conventional cropping could be responsible for the lower N_2O emissions observed under organic management (Flessa et al., 2002; Burger et al., 2005; Petersen et al., 2006; Phillips, 2007). On the other hand, organic fertilizers used in organic cropping systems are associated with increased rates of organic matter decomposition, which may enhance N_2O and CO_2 emissions in comparison with conventional cropping systems. With respect to CH_4 emissions, soils used for plant production are minor sources of CH_4 only after application of manure or other organic materials (Johnson et al., 2007; Dendooven et al., 2012).

Symbiotic nitrogen fixation by *Rhizobium* in roots of legume crops is an environmentally friendly source of plant available nitrogen in the soil and can appreciably reduce the input of agrochemicals and energy in agriculture. Therefore, the inclusion of legumes in crop rotations is highly beneficial in maintaining soil fertility, especially in organic agriculture. In most Mediterranean countries, common bean (*Phaseolus vulgaris*) is a profitable legume crop that might be included in crop rotations, especially by farmers producing organic vegetables. The impact of some management practices on CO_2 and N_2O emission by common bean grown conventionally in greenhouses has been investigated by Fernández-Luqueño et al. (2009). However, the effects of the farming system (organic or conventional) on the emissions of GHG in field-grown common bean crops have not yet been investigated.

When assessing environmental impacts of agricultural production, the amounts of GHG emissions on an area and intensity (emissions per unit of yield) are both important metrics. Thus, when considering the impact of a farming practice on GHG emission, it is important to assess its impact on yield as well (Pandeya et al., 2012). To our knowledge, the impact of the farming system (organic *vs*. conventional crop management) on both GHG emission and green pod yield in common bean crops grown under Mediterranean climatic conditions has not been previously investigated.

A major problem in Mediterranean countries is the salinity of the irrigation water which is frequently higher than the threshold levels for maximal production. Common bean is highly sensitive to salinity (Scholberg and Locascio, 1999). Bean is a typical Na excluder (Bayuelo-Jiménez et al., 2003), but its efficiency to restrict the translocation of Na to the photosynthetically active leaves declines rapidly as the external NaCl salinity increases (Savvas et al., 2007), while its Cl^- exclusion efficiency is low (Seemann and Critchley, 1985). As a result, salinity drastically affects photosynthesis, water relations, and carbon metabolism, while disturbing nutritional balance in bean plants (Bayuelo-Jiménez et al., 2003). Salinity impairs the establishment of *Rhizobium*–legume symbiosis in common bean although this effect depends also on the specific combination of the rhizobial strain and the host cultivar (Faghire et al., 2011). Furthermore, salinity seems to affect the activity of N fixing microorganisms, which are especially important in organic systems (Manchanda and Garg, 2008). Thus, there is a need to determine the impact of the farming system on GHG emissions in green bean crops, alongside measurements of yield and symbiotic N_2-fixation, and their interaction with salinity. This study involved a detailed comparison of organic and conventional farming practices in a bean crop supplied with either good-quality or saline irrigation water. The specific aim of the study was to test whether and how plant biomass, fresh pod yield, nitrogen nutrition and GHG emissions are influenced by organic farming practices and their interactions with irrigation water salinity.

2. Materials and methods

2.1. Site description and experimental design

In spring and summer 2011, a two-factorial experiment was conducted in a field near Agrinio in West Greece (38°35′15.41″N, 21°25′38.47″E) using common bean (*P. vulgaris* cv. 'Contender') as experimental plant. The total annual precipitation in the experimental site was 850 mm while the mean monthly temperature was 17 °C during the experimental year. The courses of the average monthly air temperature and the cumulative monthly precipitation during the experimental year are shown in Fig. 1.

The soil in the experimental site was classified as a clay loam, with an organic matter content of 2.05%, total N 0.082%, P 175 ppm, K 632 ppm, soil pH 7.4 (1:1 water extract) and EC of 0.63 mS cm^{-1}. The experimental field had been certified for organic cropping since 2003. Site preparation was based on local tillage practices involving mouldboard ploughing to a depth of 20–25 cm followed by two rotary-harrowings. The preceding crop was vetch (*Vicia sativa* L. cv. Alexander). Vetch was sown in all experimental plots in November 2010 and the biomass produced was incorporated as a green manure by the first week of March. Organic or conventional farming systems were established as main plots with four randomly allocated plots per system. Each plot was divided into two subplots irrigated either with good-quality or with salt-enriched water containing either 0.5 or 10 mM NaCl, respectively. Thus the experiment, which was a split-plot design, included a total of 16 experimental units.

Seeds were sown at a depth of 3 cm. Plant spacing between and within rows of common bean was 50 cm, giving a density of 80,000 plants ha^{-1}. Each subplot corresponded to a net cultivated area of 60 m^2. Beans were sown on 30 April 2011 and the crop was harvested on 30 July 2011. Management of the organic farming plots was based on the principle that organic cropping systems should minimize the use of external inputs, including N fertilizers, avoiding the use of synthetic fertilizers (Scialabba and Hattam, 2002). A cropping system is correctly evaluated by altering the whole system rather than individual parameters and looking at the combined effect of this change. Accordingly, fertilization practices differing in both the level and the form of the fertilizers were applied in the organic and conventional plots. Thus, in the conventionally treated plots, a synthetic inorganic fertilizer was applied as base dressing before sowing at a rate of 120 kg ha^{-1} N, 160 kg ha^{-1} P_2O_5, and 160 kg ha^{-1} K_2O, following standard recommendations for conventional field-grown bean crops. In the organically managed plots, an organic fertilizer produced by compressing composted crop residues was applied before sowing, which provided an equivalent of 25 kg ha^{-1} N, 175 kg ha^{-1} P_2O_5, and 250 kg ha^{-1} K_2O, following common practices of local organic growers. Synthetic pesticides were not used either in the conventionally or in the organically managed plots. The plants were irrigated through a drip irrigation system equipped with one dripper per plant.

2.2. Sampling and analysis methods

Soil samples were collected in all plots 30, 60 and 85 days after sowing from a depth of 0 to 30 cm using a metal sampling auger. After their collection, the soil samples were thoroughly mixed and sieved through a 2 mm sieve to obtain representative subsamples and exclude large particles (stones and plant material). Subsequently, a subsample was used to determine soil nitrogen