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Soil property, CO_2 emission and aridity index as agroecological indicators to assess the mineralization of cover crop green manure in a Mediterranean environment

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ABSTRACT

In this study soil chemical and biochemical properties, cover crop biomass production and quality, and climatic factors (AI) have been taken into account in order to identify sensitive agroecological indicators suitable for an early assessment of green manuring outcomes, measured in terms of soil CO_2 emission and soil mineralization dynamics in a short term experiment in a Mediterranean environment. The field experiment was conducted over two cropping rotations during 2004–2005 in central Italy. A winter cover crop/sweet pepper sequence with the cover crop used as green manure was adopted. The cover crop treatments were common vetch (CV), rye grass (RG), and fallow soil as the control (Control). Soil enzyme activities (acid phosphatase. protease and β-glucosidase), CO_2 emission, and inorganic nitrogen concentrations were monitored from cover crop green manure incorporation to pepper harvesting in order to evaluate soil mineralization dynamics. The climatic conditions were summarized by the monthly aridity index (AI) calculated as the precipitation/temperature ratio. A group of mineralization indexes, calculated using values of available nitrogen and enzyme activities, was used to describe the soil process during crop cycle after green manure. The mineralization process dynamic results as a combined effect of climatic conditions and soil organic matter quality produced by different cover crop green manures. The common vetch green manuring was effective in lowering the soil C/N with respect to the control soil (5.7 vs. 8.3 and 8.5 vs. 12.1 in 2004 and 2005, respectively), promoting CO_2 emission (8.95 vs. 5.19 and 6.75 vs. 4.28 Mg CO_2-C ha^{-1} in 2004 and 2005, respectively), enzyme activity, nitrogen release, and crop aboveground biomass (8.59 vs. 7.05 Mg ha^{-1} dry matter). Among the selected agroecological indicators, the relationships between enzyme activities and the monthly aridity index may suggest a new approach for agronomists and soil scientists to understand the combined effect of temperature and precipitation on soil mineralization dynamic. The high aridity index at the time of green manuring may have caused a priming effect of SOM and promoted soil mineralization during the vegetable crop growing season in a Mediterranean environment. Finally, no evidence was found between soil CO_2 emission and the aridity index; soil respiration was mainly affected by cover crop biomass and the soil C/N ratio.

1. Introduction

The use of green manure cover crops followed by the main crop is considered an important agronomic technique in Mediterranean cropping systems to improve soil quality and crop production. Several benefits of cover crop green manure are known: (1) reducing the dependence on mineral fertilizers (Yadav et al., 2000); (2) maintaining organic matter in the soil to provide nutrients for plant growth (Yadav et al., 2000); and (3) increasing the size and activity of soil microbial communities (Kautz et al., 2004; Manici et al., 2004; Tejada et al., 2008). Generally, in vegetable cropping systems, the species used as green manure have a low C/N ratio to ensure rapid biomass decomposition and avoid the microbial immobilization of N that would decrease available N in the soil for the subsequent cash crop (Ranells and Wagger, 1997; Wagger et al., 1998; Wyland et al., 1995).

Although the rate of biomass decomposition depends on its composition, crop residues and cover crop biomass incorporated into the soil enhance both growth and activity of soil microorganisms (Elfstrand et al., 2007; Lagomarsino et al., 2008). Particularly, the direct incorporation into the soil of fresh legume cover crops enhances microbial biomass and soil enzyme activities more than

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other forms of organic matter, e.g. compost (Elfstrand et al., 2007). Enzymes produced to catalyze decomposition and nutrient mineralization processes allow microbes to access energy and nutrients present in complex substrates (Allison and Vitousek, 2005; Asmar et al., 1994; Sinsabaugh et al., 1993). Moreover, a priming effect on humus mineralization was discovered after legume green manure 85 years ago (Löhnis, 1926). The acceleration or retardation of soil organic matter (SOM) turnover is also of wide interest in the recent literature (Kuzyakov, 2010). However, primary productivity and nutrient cycling are directly related to the amount and seasonal distribution of precipitation and temperature. In particular, in semiarid ecosystems, the rates of these processes are primarily controlled by scarce, erratic, and discontinuous precipitation inputs (Mazzarino et al., 1998; Noy Meir, 1973). Several studies have reported seasonal fluctuation of soil mineralization processes (e.g. microbial respiration and enzyme activities) resulting from variation of climatic conditions (Kabba and Aulakh, 2004; Manzoni and Porporato, 2009). However, to date few data are available to assess the short-term effects of climatic factors fluctuation, such as precipitation and temperature, on cover crop green manure mineralization. Conversely, precipitation and air temperature as the De Martonne aridity index (AI) are frequently used for rational classification of climate to identify susceptibility to drought conditions. The AI can also be used for weather-crop production model building (Oury, 1965) or to assess climate change effects on annual runoff (Arora, 2002). As far as soil CO_2 emission is concerned, a relationship between soil temperature or moisture and mineralization has been reported in previous studies (Amos et al., 2005; Bajracharya et al., 2000; Mancinelli et al., 2010; Parkin and Kaspar, 2003). In cropping system experiments, the effects of various factors related to soil, climate, and cropping systems can be analyzed using indicators based on operational models. Such indicators are still lacking in several areas, notably to assess the impact of specific agricultural techniques applied mainly in sustainable agriculture (Bocktaller et al., 2008). In this study soil chemical and biochemical properties, cover crop biomass production and quality, and climatic factors (AI) have been taken into account in order to identify sensitive agroecological indicators suitable for an early assessment of green manuring outcomes, measured in terms of soil CO_2 emission and soil mineralization dynamics in a short term experiment in a Mediterranean environment.

2. Materials and methods

2.1. Site and soil characteristics

The experiment was carried out in Central Italy (Viterbo) in the years 2003/2004 and 2004/2005 at the Experimental Farm of the University of Tuscia (Viterbo) located approximately 80 km North of Rome (42°25′N, 12°04′E; 295 m a.s.l.).

The climate of the area is typical of the Mediterranean environment, characterized by cool, moist winters and warm, dry summers. The long-term mean annual amount of precipitation is 730 mm of which 180 mm occurs from June through September. The long-term mean annual average temperature is 13 °C. The highest mean monthly temperatures occur from July through August when maximum values are 30 °C and minimum values are 16 °C.

As the experimental area is located in a Mediterranean environment, the temporary situations of below-average precipitation and of above-average temperature can occur, resulting in drought stress that is particularly harmful during the crop vegetation period. The combined effect of temperature and precipitation can provide information on the drought level at a given site (Vogt and Somma, 2000). In this study, we applied the monthly aridity index (AI) to further understand such temporary variations during growing season of a vegetable crop in a soil amended with green manure. According to De Martonne (1926), AI in a monthly basis was calculated as:

$$AI = \frac{P_i}{T_i + 10}$$

where AI = aridity index; P_i = monthly precipitation amount; T_i = monthly mean air temperature. Subsequently, the aridity index has been related to enzyme activities, soil inorganic nitrogen concentrations, and CO_2 flux in order to verify the relationship between climatic factors and soil respiration.

The soil of the experimental field was of volcanic origin classified as a *Typic Xerofluvent*. Physicochemical characterization and subsequent classification analyses were carried out using the official methods of analysis (MiPAF, 2000). The particle size distribution analysis indicated that the textural class of the surface horizon (0–20 cm depth) fell within the sandy-loam USDA classification, with 57% sand, 35% silt, 8% clay. The soil had 0.97% and 0.12% of total organic C and N content, respectively (C/N ratio 8.3), a field capacity of 25% and wilting point of 18%, a $pH_{(H_2O)}$ of 7.2, a cation exchange capacity of 37.7 cmol kg^{-1}, and an electrical conductivity of 525 $\mu S\ cm^{-1}$.

Before starting the trials (autumn), chemical and physical analysis were carried out in twelve soil samples collected from the experimental area (four soil samples in each of the three block) in order to verify the field homogeneity. Soil properties did not differ within the three blocks. In both years of experimentation, the previous crop was the barley (*Hordeum vulgare* L.) grown for two consecutive years.

2.2. Experimental field and treatments

The experimental field was arranged in a randomized block design with three replications, where three soil managements with common vetch (CV) and ryegrass (RG) as green manure, and a fallow soil as the control (Control) were compared in plots 6 × 6 m. A cover crop/sweet pepper sequence, with the cover crop used as green manure, was adopted.

Cover crops were sown in October and green manured in May just before transplanting the vegetable crop (sweet yellow pepper) which was grown from June through October.

The cover crops species tested in this experiment were the Italian ryegrass (*Lolium multiflorum* Lam. var Elunaria) and common vetch (*Vicia sativa* Roth. var Topaze), which were planted on October 3rd in the first year and on October 20th in the second year of the experimentation. Before planting the cover crops, the soil was plowed to a 20 cm depth and fertilized with 90 kg P_2O_5 ha^{-1} as triple superphosphate. The cover crops were broadcasted at rates of 50 kg ha^{-1} for the ryegrass seed and 90 kg ha^{-1} for the common vetch seed. The cover crops were grown undisturbed during the winter and spring until they were incorporated in the soil by a plow at 20 cm depth on May 30th in the first year and on May 28th in the second year of experimentation.

The fallow soil plots (Control) were kept bare during the growing cycle of cover crops by mechanical weeding using a disc harrow after weed emergency. The soil was plowed at the same depth and time of cover crop incorporation.

After cover crop green manuring and soil tillage of the Control, a sweet yellow pepper crop (*Capsicum annum* L. cv F1 CLEOR) was transplanted on June 5th in the first year and on June 3rd in the second year of experimentation. Pepper plants were arranged in single rows with 33 cm between plants within each row and 120 cm between rows, giving a plant density of 25,252 plants ha^{-1}. During the pepper-cropping period, chemical fertilizers were not applied and four treatments with a copper product against *Phytophthora infestans* were performed.