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Sensitivity to information upscaling of agro-ecological assessments: Application to soil organic carbon management

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ABSTRACT

Upscaling of agro-ecological indicators applied in regional analyses is sensitive to scale issues of the input data. This study develops a methodology to quantify this sensitivity for an indicator of soil organic carbon (SOC) dynamics at the farming system level. A reference case consists of seven fully described farms in northern Italy. Both upscaling in complexity by substituting measured input with estimated input and upscaling in space by extending the methods to farms not included in the reference case are addressed. The indicator increased with 3–107% at four farms after substituting measured management input with that estimated by an expert, whereas it remained unchanged or decreased at the other three farms. Taking the modal value from a cluster of pedological input did not lead to additional uncertainty in most cases, and only slightly increased it in others. We evaluated spatial upscaling by including 733 farms divided in 18 clusters that were described with less information as compared to the reference farms. Within each cluster, we observed relevant variability of the indicator (coefficients of variation of 12–43%), as a consequence of the heterogeneity of farms comprised in each cluster. In each cluster we calculated the indicator for one virtual farm, defined by using modal values for basic farm inputs. In this case the indicator was highly correlated ($R^2 = 0.98$) with the average of the values obtained using measured basic farm inputs. We conclude that upscaling in complexity and space introduces uncertainty in the values of the indicator compared to the reference case. The extent of such differences depends on the variability of the systems under analysis and on indicator sensitivity.

1. Introduction

Agro-ecological assessments are frequently carried out with indicators (Viglizzo et al., 2006) and simulation models (Saffih-Hdadi and Mary, 2008). Indicators are particularly suitable for the evaluation of a large number of complex systems, as they require relatively few inputs that are easily obtained, and are computationally fast (Bockstaller et al., 1997).

Most assessments are deterministic and are carried out using single values of each input for every analysed system. All input, however, is affected by uncertainty that arises from (i) errors in input measurement, (ii) errors in input estimation, (iii) variability not taken into account such as within-field variability, (iv) differences between the scale at which the assessment is made and the scale at which inputs are available. Scale is defined here as the spatial resolution of the data. Large scale corresponds with a coarse resolution, covering a small area of land, whereas large scale corresponds with a high resolution and with a small area of land. When dealing with areas of different sizes and with information available at different scales, policy makers and decision makers need to either upscale their evaluations and simulations from small to large scale or downscale from large to small scale (Stein et al., 2001). Therefore uncertainty associated with scale is of great importance (Kros et al., 1993; Heuvelink, 1998; Post et al., 2008). Measured inputs are expensive but provide an accurate representation of the system studied, whereas estimated inputs are approximate and cheap. Assessments at a small scale commonly rely on measured input, whereas assessments at a large scale are mainly based on estimated inputs that cannot be measured.

The effects of input uncertainty on the uncertainty of an assessment are important to quantify, as for economic reasons frequently estimated inputs are used. Knowing the uncertainty will help decision and policy makers to better interpret the results of the assessments (Frank, 2008).

This study focuses on the dynamics of soil organic matter. Organic matter content influences water retention, nutrient cycling, biological activity and soil structure, thus contributing to the maintenance of soil fertility, i.e. the capability of a soil to sustain agricultural production (Singer and Munns, 1996). In addition, an increase of soil organic matter content decreases CO_2 concentration in the atmosphere, thus contributing to the reduction of the greenhouse effect (Freibauer et al., 2004). Nowadays, the dynamics of soil

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organic matter are under the action of contrasting driving forces. On the one hand, measures promoting carbon sequestration tend to favour practices that store carbon (C) in the soil (Lal, 2009). On the other hand, the development of second-generation biofuels – which can be produced using crop residues – will limit the amount of organic C that can be returned to soil (Wilhelm et al., 2004; Blanco-Canqui and Lal, 2009).

The objective of this research is to develop and test a methodology to quantify the uncertainty of upscaling agro-environmental assessments carried out with indicators. The methodology is applied to the evaluation of soil organic carbon (SOC) management in farming systems of northern Italy, characterised by a large variability of crop type and management, livestock density and agricultural practices (Bergamo et al., 2007; Bechini and Castoldi, 2006, 2009).

2. Materials and methods

2.1. Study area and data sets

The study area is the South Milan Agricultural Park (Parco Agricolo Sud Milano, PASM; 45°N, 9°E), a regional metropolitan agricultural Park near Milan (northern Italy; Fig. 1). It covers a flat area of approximately 470 km^2, of which 350 km^2 is agricultural (Bechini and Castoldi, 2006). The climate is sub-humid, with an average annual rainfall of about 950 mm. The distance from the sea is more than 100 km, and the nearest mountains are at about 50 km. As a consequence, the climate is relatively homogeneous across this area, and can be reasonably described with data from a single weather station. Annual reference evapotranspiration (ET_0) is on average 800 mm yr^{-1} with a peak in July (daily average of 5 mm d^{-1}). ET_0 exceeds rainfall from May to September. Summer crops are irrigated. The Park is located in an intensive Italian agricultural production area. The most important crops are maize (*Zea mays* L.), rice (*Oryza sativa* L.), permanent meadows, winter barley (*Hordeum* spp.), Italian ryegrass (*Lolium multiflorum* Lam.), winter wheat (*Triticum aestivum* L.), and soybean [*Glycine max* (L.) Merr.], with moderate to high yields.

During the period 1999–2003 (Bergamo et al., 2007; Bechini and Castoldi, 2006), a database on agricultural activities (called SITPAS) was developed. It contains detailed data from 733 PASM farms, obtained during single face-to-face interviews with each farmer. Data of interest for this work are related to cadastral parcels, crop rotations, and crop and livestock management. The spatial allocation of crops to cadastral parcels is described for each farm in the SITPAS.

For each of the 733 farms we carried out a cluster analysis on the percentage of farm area cultivated with the seven main crop

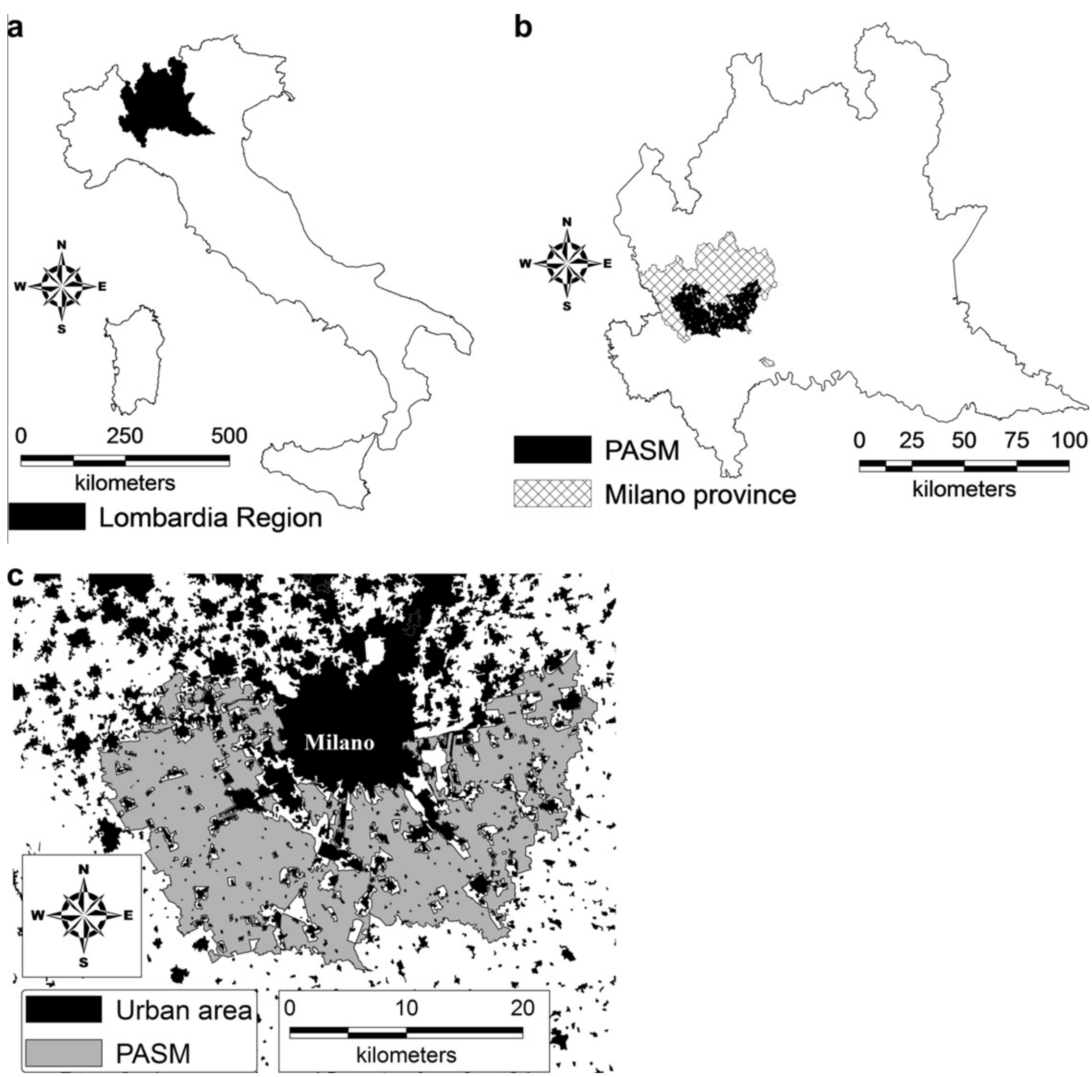

Fig. 1. Study area: (a) Italy, (b) Lombardia Region and Milan province, and (c) South Milan Agricultural Park (PASM).