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Assessment of total soil and plant elements in rice-based production systems in NE Italy

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ABSTRACT

Macro- and micronutrients concentrations and PTEs contents in soils and plants (rice) from the rice district in the Venetian territory (NE Italy) have been determined by Inductive Coupled Plasma Optical Emission Spectrometry (ICP-OES), with the following aims:

- to determine the background levels of macro- and microelements in the study area;
- to assess possible contamination of soils and plants;
- to calculate the Translocation Factor (TF) of metals from soil to plant, and the possible hazard for human health.

Four rice plots with different rotation systems were investigated from seedling time to harvesting; sampling of soils (0–30 cm) and plants was carried out 4 times during growing season (three replicates). Rice plants were separated into the roots, stems, leaves and grains, and then oven-dried. Chemical and physical analyses were carried out at the Soil Science Lab of the University of Bologna and Venice, respectively. The results obtained point to a land with high soil contamination by Li and Tl. The total concentrations of most studied metals (Al, As, Be, Cd, Co, Cr, Cu, Fe, Ni, Pb, Sb, Sn, Sr, V, Zn) in the soil samples fell in the natural geochemical background concentration levels, even though the concentration levels of some of them (e.g. Sn) overcame the Italian threshold limits for green areas (DM 152/2006). Most elements are likely associated with the geochemistry of the parent material. Antimony and Ti contents in soils are positively correlated with soil pH, while As, Be, Fe, Li, Sb, Ti, Tl and Zn are negatively correlated with organic matter content. With the exception of strontium, soil metals are always correlated between variable couples. Heavy metals in plants vary according to the sampling season, texture and moisture, and soil pH. Most non-essential trace elements are accumulated in rice roots and, only in cases of essential micronutrients, in leaves. Therefore, rice can be assumed as an excluder plant (i.e. metal in the roots < metal in soil) for Li, Sn, Tl. The results of multiple linear regression analysis showed that soil extractable P and total Ca played an important role in predicting annual grain yield of rice. The average translocation of metals from the soil to the root was found to be >1, irrespective of the essential/not essential function; conversely, only essential elements (Cu, Fe, Mn, Zn) are translocated rather easily from the roots to leaves (TF $\leq$ 1) via xylem, and very little are translocated to grains (TF $\ll$ 1). Rice plants were able to accumulate non essential metals in their tissues especially in the roots, but not in the edible part, and this could be useful for the restoration of contaminated sites with a very limited hazard for human population consuming rice crops.

1. Introduction

Environmental contamination involving potentially toxic elements (such as heavy metals) has attracted a great deal of attention in recent years, driven especially by concerns for human health (Morgan, 2013; Wahsha et al., 2014). Heavy metal contamination of soils became a severe issue in agricultural production around the world in the past few decades. Many sources, of both natural and anthropic origin, can contribute to this contamination (Fanrong et al., 2011; Kuo et al., 2006; Ramadan and Al-Ashkar, 2007). Possible "natural" accumulation may be related to heavy metal-bearing rocks (e.g. As in sedimentary rocks: Bhattacharya et al., 2002; Sr in carbonate sediments: Kabata-Pendias and Mukhrjee, 2007; Ni and Cr in serpentine soils: Gonnelli and Renella, 2013). Anthropic

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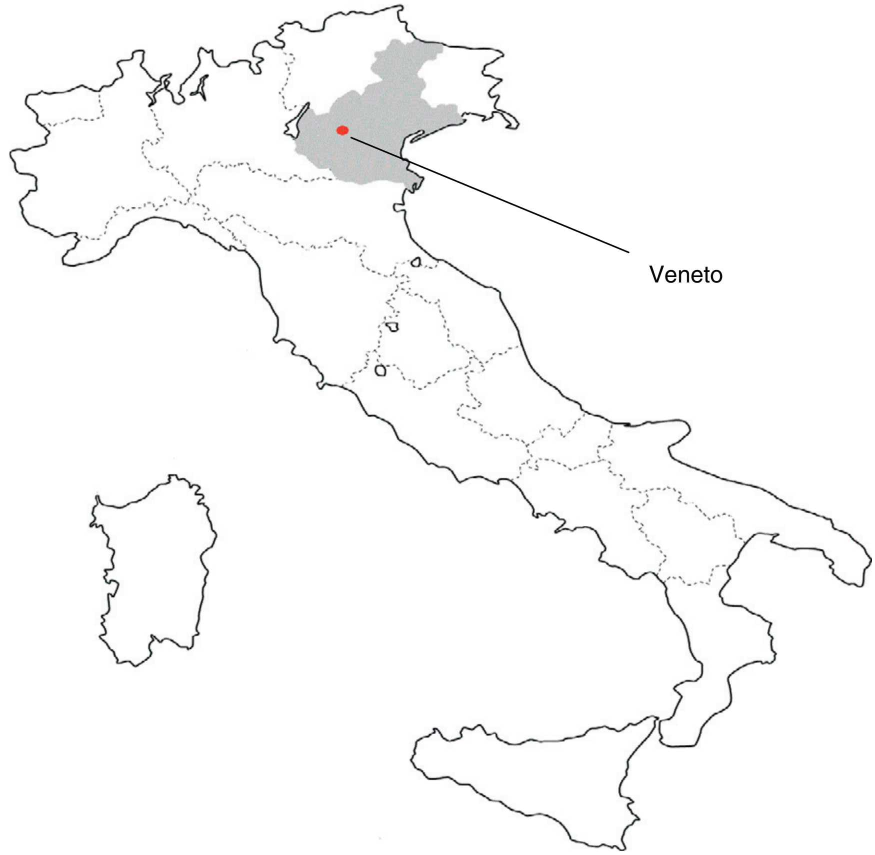

Fig. 1. Location of the study area.

activities such as agriculture, mining or industry make large use of metals and metal-enriched materials (e.g. Cd in plastic stabilizers and metallurgy, Cr in textiles, magnetic tapes, varnish and leather factories, Ni in batteries: Adriano, 2001; Bini et al., 2008; Siegal, 2002), and can be non-point sources of metals, including chemical fertilizers and pesticides, farm manure, sewage sludge, and wastewater irrigation.

Recognition of the sources responsible for soil contamination is an important issue, since high loads of heavy metals applied to soils, or stored in soils, may determine soil quality degradation, surface and groundwater pollution, and accumulation in plants, phytotoxicity and successive translocation to the food chain (Bini, 2008; Wahsha et al., 2012b). High concentration of toxic elements in soils would increase the potential uptake of these metals in the edible parts of vegetative tissues that may result in a direct pathway into the human food chain (Fanrong et al, 2011; Tariq and Rashid, 2013). Hence, in order to produce safe crops, it is essential to assess possible accumulation of harmful elements in agricultural land that could be helpful for proper application of pesticides, herbicides, organic and inorganic fertilizers, avoiding any human health concern.

Plants display a different ability to absorb and translocate metals from soil to the aerial parts. Baker and Walker (1990) classified plants into three groups according to their ability to accumulate/exclude metals into their tissues: *Accumulators* are plants that can concentrate metals in their above-ground tissues to levels that exceed those in the soil; *Indicators*, are plants that concentrate metals in their above-ground tissues and the metal levels in the tissues of these plants commonly reflect those of the soil; *Excluders* are plants which effectively limit the amount of metal translocation from roots to shoots, (i.e. they maintain relatively low levels of metal in their shoots).

Rice is a widely diffused food crop in the world; it is consumed by more than three billion of the world's population (FAO, 2004). It is one of the most economically important cereal crops in Italy, which is the largest rice producer in the European Union (EU): approximately 2/3 of the European rice is produced in Italy. Rice cultivation in Italy is highly specialized and represents 70–80% of the rice farming surface, although in the last years soybean and maize have been successfully and increasingly grown as annual rotation crops in rice fields (Chisci, 2009; Russo and Callegarin, 1997). Rice cultivation is carried out on paddy soils that are managed in a special way; these soils are kept submerged seasonally, so that during the period of submergence, the soil undergoes reductive conditions. Various metals such as iron, manganese, silica, and phosphate become more soluble, disperse to the soil surface and move by diffusion and mass flow to the roots and subsoil. Zheng and Zhang (2011) stated that in paddy soils, the metal speciation probably undergoes changes among various moisture regimes; these include: (1) moist, oxidative conditions at a certain field capacity in land preparation step; (2) waterlogged conditions at seedling; (3) a short period of saturation (the establishment of temporary low oxygen conditions) during growing season, followed by draining and drying the surface soil at harvest (oxidizing conditions). These conditions and oxygen leakage by rice roots lead to the development of certain features (e.g. depletion pedofeatures), (Bullock et al., 1985), mostly occurring in rice fields, which are related to element redox-status variation, and hence affect their mobility and bioavailability.

Therefore, our attention was focused towards the determination of element levels in paddy soils under different rotation systems, and their bioavailability to plants in relation to possible harmful effects on human health.

The objectives of this research were to:

- Determine the background levels of macro- and microelements in the study area;
- Assess possible contamination of soils and plants;
- Calculate the Translocation Factor (TF) of metals from soil to plant, and the possible hazard for human health.