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Soil micronutrient pools and their transfer to paddy-crops in semi-arid agro-ecosystems, Central India

Kriti Shukla, Anshumali*

Laboratory of Biogeochemistry, Department of Environmental Science and Engineering, Indian Institute of Technology, Indian School of Mines, Dhanbad, 826004, India

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ABSTRACT

Irrigation is a key component of crop productivity, environmental protection and sustainable agriculture. To understand this, paddy-crops and soil samples were collected from rainfed (RFS) and irrigated (IRS) soils of semi-arid agro-ecosystems, Central India. The objectives of the current study were to (1) determine total concentrations of Cu, Fe, Mn and Zn in paddy-soils and paddy-crops, (2) chemical fractionation of operationally defined pools of Cu, Fe, Mn and Zn content in paddy-soils. Total micronutrient concentrations followed the order as: Fe > Mn > Zn > Cu with higher values in RFS paddy-soils. High residual fraction indicated the existence of micronutrients within mineral lattice structure, which resulted in low to moderate mobility factor (MF) of Cu, Fe, and Zn in the paddy-soils. The high Mn concentrations in non-residual fractions resulted in MF more than 50%. The transfer factors of total micronutrients (TF_{TM}) showed high transfer of Zn and Mn to paddy-crops. The high TF_{EMF} (transfer factor of exchangeable micronutrient fractions) of Cu and Fe revealed significant accumulation in paddy-roots. Paddy-grains differed significantly ($P < 0.05$) in total micronutrient content with high values in IRS agro-ecosystems. The correlation and multiple linear regression analyses showed control of micronutrient fractions on availability, uptake, transfer and translocation in paddy-crops through root system.

1. Introduction

Copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn) are essential micronutrients, which serves as a co-factor for several enzymes involved in the metabolism of carbohydrates, lipids, proteins and nucleic acids (Barker and Pilbeam, 2015). Micronutrient deficiency is a major regional and global problem affecting more than two billion people (De-Regil et al., 2013; Bailey et al., 2015; FAO, 2015). Soil erosion, surface runoff, indiscriminate use of organic and inorganic agro-chemicals are causing deficiency or toxicity of micronutrients (Lal, 2001; Bronick and Lal, 2005; Wakeyo and Gardebroek, 2017), which results in loss of plant enzyme/protein functions, cell damage, oxidative stress, metabolic disturbances and subsequently affect crop productivity (Gill and Tuteja, 2010).

Rice is a staple food and source of energy for more than half of the world's population (Sharma et al., 2014). India ranks second worldwide in agronomy output (FAOSTAT, 2013), where rice accounts for more than 104 million tons of production (Soam et al., 2017). In India, several efforts have been made to fortify rice grains with micronutrients to meet dietary requirement of growing population, where > 190.7 million people are undernourished (Bhullar and Gruissem, 2013).

In agricultural soils, concentrations of Cu, Fe, Mn and Zn have reported in the range of 2-100 mg kg^{-1} (Lindsay, 1979), 20,000–550,000 mg kg^{-1} (Bodek, 1988), 450–4000 mg kg^{-1} (Noll, 2003) and 10–300 mg kg^{-1} (Barber, 1995), respectively. Micronutrient transfer from soil-to-plants is a major route of human exposure to agricultural soils (Liu et al., 2013). The optimum range of Cu, Fe, Mn and Zn in plants varies from 1–20 mg kg^{-1}, 50–150 mg kg^{-1}, 10–100 mg kg^{-1}, and 15–50 mg kg^{-1} dry weight, respectively, depending on the plant species, genotype, growth conditions, organ and tissue (Hänsch and Mendel, 2009). Micronutrient mobility depends on several factors including their inherently low total concentrations, operationally defined chemical fractions, pH, organic matter, soil-plant and soil-microbe interactions, and plant genotype (Rengel, 2015; Shukla et al., 2015; Agrawal et al., 2016).

Micronutrient availability in paddy-soils is considered as the most important factor influencing plant productivity (Zeng et al., 2011). Available fractions of micronutrients are found in the range of less than 20–70% in soils under rapid urbanization, industrialization and agricultural intensification (Zhong et al., 2011; Adamo et al., 2014; Hansda et al., 2017). For this reason, chemical speciation of soil micronutrients through single and sequential extraction have been extensively applied using a variety of extractants (Xiao et al., 2017). However, the relationship between chemical fractions of micronutrients and their plant

* Corresponding author.
E-mail addresses: kriti@ese.ism.ac.in (K. Shukla), malijnu@gmail.com, anshumali@iitism.ac.in (Anshumali).

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uptake is poorly characterized in paddy-soils. Soil-to-plant transfer factors (TFs) assess the efficiency of plants in absorbing micronutrients and quantify the existing differences between micronutrient mobility in soil and their uptake by plants (Rattan et al., 2005; Kachenko and Singh, 2006). But, a few studies are carried out to understand the impact of micronutrient fractions on the uptake, translocation and accumulation in the root, shoot and grains of the paddy-crops (Cao et al., 2014).

The agricultural soils of arid and semi-arid pediplains of central India have experienced several deformations and reactivation phases, resulting in mineral enrichment of the soil parent material (Bhattacharjee et al., 2008). High variations due to diversified geomorphologies, soil erosion, cropping pattern, mode of irrigation, mechanical farming and soil texture are reported in the rainfed and irrigated agro-ecosystems (Bajaj, 2010; Lal, 2016), which may influence the micronutrient availability to crops (Katyal and Sharma, 1991). None of the previous studies addressed the significance of soil micronutrient fractions to gain understandings of distribution, availability, retention and their translocation in different components of paddy-crop. To attain this, the objectives selected for the study were to (1) determine total concentrations of Cu, Fe, Mn and Zn in paddy-soils and paddy-crops, (2) chemical fractionation of operationally defined pools of Cu, Fe, Mn and Zn content in paddy-soils. The present study could find the justification for management of micronutrient deficiencies in rice grains traditionally cultivated in rainfed and irrigated agro-ecosystems of central India.

2. Materials and methods

2.1. Study area

The study was conducted in the semi-arid pediplains of Sidhi district, which lies on the north-eastern boundary of Madhya Pradesh, India, located above the Tropic of Cancer and extends between 22° 47.5′ to 24° 42.10′ N latitude and 81° 18.40′ to 82° 48.30′ E longitude with an average elevation of 311 m and a total land cover of 4720 km^2 (Fig. 1). The area lies over a transition between the Indo-Gangetic plain in the north and the Deccan plateau in the south. The area have a total population of 1.12 million with a density of 110/km^2 (Census of India, 2011).

The topography of the area is defined by the Vindhyan hills in the northern part, below and parallel to which runs the Son river valley; middle and the southeastern are Archaean and the remaining area is composed of Gondwana, Mahakoshal and Barakar formations. Deposition of Mahakoshal volcano-sedimentary lithounits and arenaceous-argillaceous-calcareous sediments of Semri-Vindhyan groups provided rich and varied geology (Kumar et al., 2016; Shukla et al., 2016a; Shukla et al., 2017). Several other lithounits including crystalline gneisses, ferruginous breccia, mylonitized hybrid rocks and phyllites, quartzite, banded iron formation and dolomite are commonly exposed (Banerjee et al., 2010; Mishra et al., 2017). Pediplains of the area are formed by the coalescence of thick, weathered mantle and fractured basaltic pediments with Mollisol, Alfisols, Entisols, Inceptisols and Vertisol with alluvial, red and black soil types.

The climate is sub-tropical with three distinct seasons (hot and dry summer, monsoon, and cool and dry winter); 1100 mm average annual rainfall; dry period of over 90 days (December to May); typicustic soil moisture regime and hyperthermic soil temperature regime. The agricultural land is approximately 37.5% out of which only 17% has assured irrigation (NRAA, National Rainfed Area Authority, 2012). Urea, diammonium phosphate and muriate of potash are the common fertilizers used as the sources of N, P and K, respectively. Paddy was fertilized with mineral fertilizers at 40 kg N and 25 kg P_2O_5 and 10 kg K_2O ha^{-1} in rainfed and 60 kg N and 40 kg P_2O_5 and 10 kg K_2O ha^{-1} in irrigated agro-ecosystems.

2.2. Sampling and preparation

A total of 30 geo-referenced sampling stations were selected to collect surface soil and paddy-crop samples during the maturity of the paddy-crops in October 2015. The latitude, longitude and elevation for each sampling point were recorded using a handheld Global Positioning System (Etrex 20, Garmin Ltd). Sampling stations were classified as, (i) rainfed agricultural sites (RFS, n = 15) and (ii) irrigated agricultural sites (IRS, n = 15). The samples were representative of agricultural soils with no direct source of pollution other than agricultural activities.

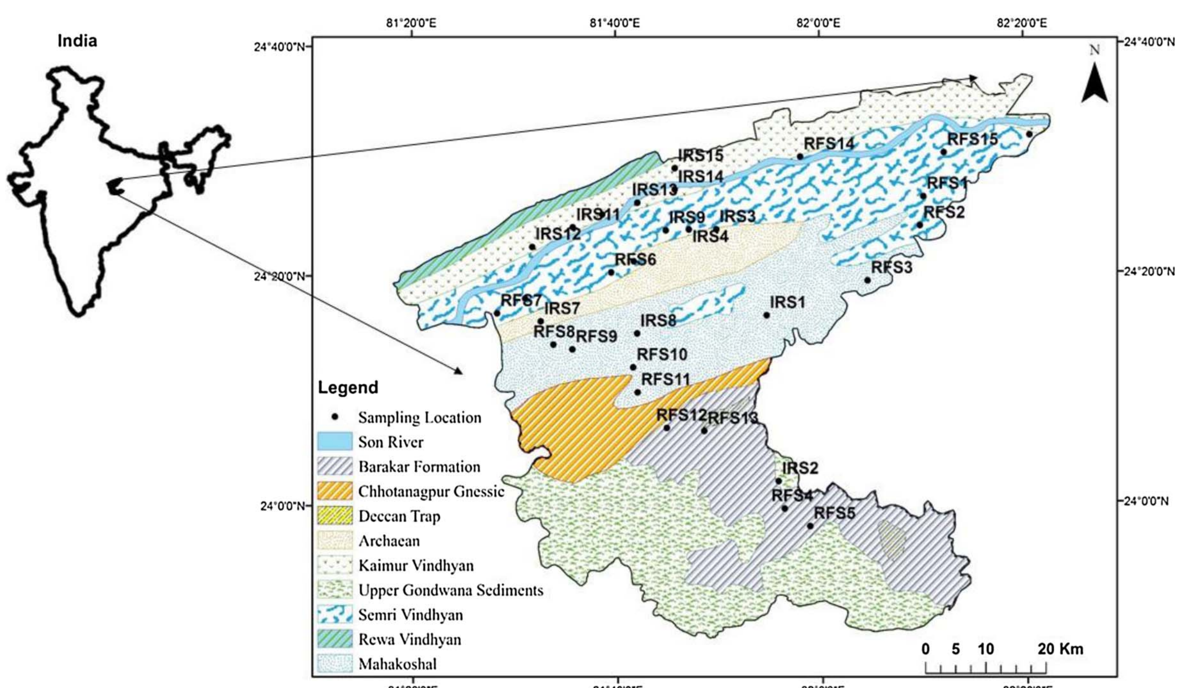

Fig. 1. Map of the study area showing geology and sampling locations as; Rainfed Site (RFS; n = 15) and Irrigated Site (IRS; n = 15).