Fractionation and distribution of zinc in soils of biologically and conventionally managed farming systems, Western Australia

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Abstract

Understanding the distribution of zinc (Zn) fractions in soils is important for effective and efficient management of the fertilizer resources given world-wide limitations of crop production and food quality by insufficient Zn. Soils were collected from the farmers' field with the history of biological (combination of organic and conventional farming practices) and conventional management systems in Dalwallinu and Merredin, Western Australia. A sequential extraction procedure was used to fractionate water-soluble (WS), exchangeable (EX), specifically adsorbed (SA), acid-soluble (AS), manganese (Mn)-oxide-occluded (Mn-OX), organic matter occluded (OM), amorphous iron (Fe)-oxide-bound (AFe-OX), crystalline Fe-oxide-bound (CFe-OX), and residual (RES) Zn forms. There was a similar trend of distribution of Zn fractions in both farming systems from the two locations. More than 80 % of the total Zn content occurred in the relatively inactive and mineral-bound residual form (RES), whereas only a small fraction occurred in WS, EX, OM, AFe-OX, and CFe-OX fractions. Among all the fractions, water soluble and exchangeable (which are important for plant use) were higher in biological than conventional soils at both locations. Management systems, particularly biological practices, enhanced plant-available and total Zn pools in soils.

Key Words

Zinc, fractionation, biological and conventional farming systems.

Introduction

Availability of zinc (Zn) for plants is reported to be associated with the distribution of this nutrient among soil fractions. Therefore, understanding of the distribution of Zn among various fractions of soils will help to characterise chemistry of Zn in soils and possibly its availability for plant uptake. However, distribution of Zn among various chemical forms may vary significantly in response to changing soil properties (Adhikari and Rattan 2007). Sequential fractionation quantifies the element distribution between fractions of different binding strengths, as defined by properties of selected extractants. Viets (1962) defined five distinct pools for micronutrients. These are i) water soluble, ii) exchangeable, iii) adsorbed, complexed and chelated species, iv) associated with secondary minerals and insoluble metal oxides, and v) associated with primary minerals. Other scheme of Zn fractionation yielding various other distributions into measurable pools have been proposed by Shuman (1979), Iyengar *et al.* (1981), Nielsen *et al.* (1986), Elliot *et al.* (1990), and Rauret *et al.* (1999).

Zinc deficiency in soils suggests that both native and applied Zn react with the inorganic and organic phases in the soils, which influences plant-availability of Zn. Viets (1962) reported that the distribution of Zn among active and non-active soil constituents, and soil solution, is also fundamental to an understanding of the soil chemistry of Zn. Metals in the soil solution existed in different fractions (Luo and Luo 2002), with potentially different bioavailability and environmental mobility of various chemical forms. Management systems alter the Zn pools in soils; e.g. Dvorak *et al.* (2003) reported that the application of sludge together with inorganic Zn fertilization increased Zn mobility. Similarly, Qian *et al.* (2003) also revealed that addition of animal manure increased the labile pool of Zn in soils. Biological farming systems (BF) defined as the combination of organic and conventional farming systems, which aims at achieving optimum yield without compromising soil health. On the other hand, conventional farming system (CF) aims at achieving highest possible yield through the use of chemical fertilizers and other external inputs. In the study presented here we characterized the soil-Zn fractions under different farming systems in Western Australia. The aims of the research were: to assess the distribution of Zn fractions in different soils of biological and conventional management systems, and to determine the relative importance of various soil-Zn fractions in different soils.

Material and methods

Soils: Surface layer (0-10 cm) soils with the history of biological farming (BF) and conventional farming (CF) systems from Dalwallinu (Lat. 30° 14'166" S and Long. 116 °32'377" E) and Merredin (Lat. 31° 44'530" S and Long. 118° 18' 879" E), Western Australia were collected. Soils were mixed thoroughly and sieved through a 2-mm sieve. Subsamples were taken and ground into fine powder for analysis.

Table 1. Soil properties of biologically (BF) and conventionally managed (CF) soils.

Soil properties	Merredin		Dalwallinu	
	BF	CF	BF	CF
Organic carbon g/kg	8.7	8.0	9.5	9.0
NO_3 N (mg/kg)	12	14	9.5	13
pH $CaCl_2$	5.5	5.4	5.1	4.9
pH H_2O	6.1	6.1	6.2	5.7
NH_4 N (mg/kg)	4	5	2	2
Phosphorous (mg/kg)	31	30	21	18.2
Potassium (mg/kg)	181**	349	60*	42.5
DTPA extractable Zn mg/kg	0.71**	0.32	0.58**	0.36
Total Zn (mg/kg)	14.2*	12.43	12.33*	10.33

Note: * and ** denote significant differences at the 0.05 and 0.01 probability levels, respectively, between the two farming systems for each location separately.

Sequential fractionation methods

The sequential fraction procedure (except the residual fractions) to study the distribution of Zn fractions in different soils was used as described by Adhikari and Rattan (2007) and Iwasaki and Yoshikawa (1993) (as a modified form of the fractionation scheme reported by Miller *et al.* 1986). Soil sample mass used was 1.5 g; after each fractionation step, samples were washed with 20 mL of milliQ water.

For the respective fractions, the following extractants and procedures were used. Water soluble (WS): soil samples were shaken with 25 mL H_2O for 16 h. Exchangeable (EX): 25 mL 0.5 M calcium nitrate [Ca(NO)3)2]-solution and shaking for 16 h. Specifically absorbed [lead (Pb)-displaceable fraction] (SA): shaking in 25 mL of 0.05 M lead nitrate [$Pb(NO_3)_2$] and 0.5 M ammonium acetate at pH 6.0 for 2 h. Acid-soluble fraction (AS): 25 mL of 2.5% (v/v) acetic acid and shaking for 2 h. Manganese-oxide-bound fraction(Mn-Ox): samples were shaken in 50 mL of 0.1 M hydroxylamine hydrochloride solution at pH 2.0 for 30 min. Organic-matter-bound fraction (OM): 50 mL of 0.1 M potassium pyrophosphate solution at pH 10.0 and shaking for 2 h. Amorphous iron-oxide-occluded fraction (AFe-Ox): samples were treated with 50 mL of 0.1 M oxalic acid solution and 0.175 M ammonium oxalate [$(NH_4)_2C_2O_4$] solution at pH 3.25 for 4 h in the dark. Crystalline iron-oxide-occluded fraction (CFe-Ox): samples were kept in 50 mL of 0.1 M oxalic acid, 0.175 M $(NH_4)_2C_2O_4$ and 0.1 M ascorbic acid in a boiling water bath for 30 min.

Residual fraction (RES): This fraction was estimated by subtracting the sum of all Zn fractions measured as described above from total Zn (see below) as per Rico *et al.* (2009).

Total zinc (T Zn): A well-mixed sample of about 0.5 g soil was digested in 12 mL Aqua regia as mentioned by Cheng and Ma (2001). After extraction, all aforementioned samples were centrifuged and Zn was determined using an Atomic Absorption Spectrophotometer (AAS) (Perkin Elmer 400) at The University of Western Australia, Perth, Australia.

Statistics: Data were statistically analyzed using Statistical Analysis Systems (SAS 9.1 Institute Inc., Cary, NC, USA) was used for linear correlation analysis and data analysis tool pack of MS excel used for T test.

Results and discussion

Total Zn in soils indicates the potential capacity of soils to supply Zn for crop production given the capacity of crop to exploit it. However, total Zn in soil doesn't indicate Zn availability to plants. Soil Zn fractions is influenced by different factors for e.g. Adhikari and Rattan (2007) reported that soil pH and organic matter level markedly alter the distribution of Zn among the plant available pools. Table 2 shows distribution of different fractions of Zn in soils from biological and conventional management systems from two locations (Merredin and Dalwallinu). There were significant differences in total Zn content in biological and conventional soils at both locations. Distribution pattern of Zn fractions and total Zn was found similar in both locations (table 2) except Mn-OX in both location and CFe-OX fraction in Merredin where CF having higher than BF.

Table 2. Distribution of zinc fractions (mg/kg) in two different farming systems at Merredin and Dalwallinu locations in Western Australia.

Zinc fractions	Merredin		Dalwallinu	
	BF	CF	BF	CF
Water soluble (WS)	0.20	0.17	0.10	0.10
Exchangeable (EX)	0.15	0.14	0.27*	0.21
Specifically absorbed (SA)	0.23*	0.18	0.05	0.03
Acid soluble (AS)	0.31*	0.12	0.12*	0.11
Manganese (Mn)-oxide-occluded (Mn-OX)	0.76*	0.86	0.20	0.26
Organic matter occluded (OM)	0.58*	0.35	0.78*	0.60
Amorphous iron (Fe)-oxide-bound (AFe-OX)	0.60*	0.28	0.36*	0.20
Crystalline Fe-oxide-bound (CFe-OX)	0.21*	0.34	0.28*	0.17
Residual (RES)	11	9.9	11*	8.3
Total Zn	14*	12	12*	10

Note: * denotes significance at the 0.05 probability level between the two farming systems for each location separately. CF= conventional farming systems and BF= biological farming systems.

For plant production point of view WS, and EX Zn are important which is higher in BF in both sites. However, only Ex Zn fraction was significant in Dalwallinu BF. DTPA-extractable Zn was significantly higher in biologically managed soils than in conventionally managed soils (Table 1), which is important indicator to measure the plant available Zn in soil (Cheng and Ma 2001). Here, in both sites, biological farming systems revealed increased Zn concentration than conventional farming systems, where mainly adding of organic matter contributed to that increased concentration of different Zn fractions (Table 2). Iwasaki and Yoshikawa (1993) reported that management systems particularly intensive fertilizers use had great role in accumulating Zn in soils for plant use.

Conclusion

Biologically managed soils have higher Zn content compared to conventionally managed soils. Adding the organic matter into soil and maintaining better soils health is important for better crop production as well as environmental benefits, particularly in the areas of intensive cropping systems with higher external input use. Available Zn is influenced by the management practices. Biological farming systems should be promoted to achieve better soils conditions and for sustainable agricultural development.

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References:

Adhikari T, Rattan RK (2007) Distribution of zinc fractions in some major soils of India and the impact on nutrition of rice. *Communications in Soil Science and Plant Analysis* **38**, 2779-2798,

Cheng M, Ma LQ (2001) Comparison of three aqua -regia digestion methods for twenty florida soils. *Soil Sci. Soc. Am. J.* **65**, 491-499.

Dvorak P, Tlustos P, Szakova P, Cerny J, Balik J (2003) Distribution of soil fractions of Zn and its uptake by potatoes, maize, wheat and barely after soil amendment by sludge and inorganic Zn salt. *Plant and Soil Environment* **49**, 203-212.

Elliot HA, Dempsey BA, Maille PJ (1990) Content and fractionation of heavy metals in water treatment sludges. *J. Environ. Qual*. **19**, 330-334.

Iwasaki K, Yoshikawa G (1993) Fractionation of zinc in greenhouse soils. *Soil. Sci. and Plant Nutr.* **39**(3), 507-515.

Iyengar SS, Martens DC, Miller WP (1981) Distribution and plant availability of soil zinc. *Journal of Soil Science Society of America* **45**, 735-739.

Luo Y, Luo YM (2002) Cu and Zn in an acid soil amended with alkaline biosolids. *Pedosphere* 12, 165-170.

Miller WP, Martens DC, Zeolazincy LW (1986) Effect of sequence in extraction of trace metals from soils. *Journal of Soil Science Society of America* **50**, 598-601.

Nielsen D, Hoyt PB, McKenzie AF (1986) Distribution of soil zinc fractions in British Columbia orchard soils. *Canadian Journal of Soil Science* **66**, 445-454.

Qian P, Schoenau JJ, Wu T, Mooleki SP (2003) Copper and Zn amounts and distribution in soil as influenced by application of animal manure in east-central Saskatchewan. *Canadian Journal of Soil Science* **83**, 197-202.

Rauret G, Lopez-Sanchez JF, Sahuquillo A, Rubio R, Davidson C, Ure A, Quevauviller Ph (1999) Improvement of the BCR three step sequential extraction procedure prior to the certification of new sediment and soil reference materials. *J. Environ. Monit*. **1**, 57-61.

Rico MI, Alvarez J.M, Lopez-Valdivia LM, Novillo J, Obrador A (2009) Manganese and zinc in acidic agricultural soils from central Spain: Distribution and phytoavailability prediction with chemical extraction tests. *Soil Science* **174**, 94-104.

Shuman LM (1979) Zinc, manganese and copper in soil fractions. *Soil Science* **127**, 10-17.

Viets FG (1962) Chemistry and availability of micronutrients in soils. *Journal of Agriculture and Food Commodity* **10**, 174-178.

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