Geoderma Regional 7 (2016) 120–131

Contents lists available at ScienceDirect

Geoderma Regional

journal homepage: www.elsevier.com/locate/geodrs

Amounts and associations of heavy metals in paddy soils of the Khorat Basin, Thailand

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ARTICLE INFO

Article history:
Received 2 November 2015
Received in revised form 5 February 2016
Accepted 8 February 2016
Available online 12 February 2016

Keywords:
Element
Heavy metals
Paddy soils
Spatial distribution
Khorat Basin

ABSTRACT

This study determined the amounts and speciation of heavy metals (HM) in paddy soils at100 sites in the Khorat Basin, Thailand to provide a guide to reducing HM concentrations in rice. The soils were analyzed for HM in crystalline iron oxides (DCB, dithionite citrate bicarbonate extract), amorphous iron-manganese oxides (oxalate soluble) and total element concentrations (AR). The soils have median HM concentrations in both topsoil and subsoil that are mostly lower than the thresholds for concern listed in Thailand's Soil Quality Standard for Habitat and Agriculture but with a few high values of concern. Soils derived from alluvium and wash deposits from sandstone have low concentrations of HM compared to soils on basalt. Manganese, Co and Pb in soils on all parent materials are mostly in the oxalate soluble fraction which is considered to be labile. Much the Fe and V are associated with the crystalline iron oxide fraction.

All metals showed similar spatial distributions with relatively lower concentrations of all elements except Si and Zr in the eastern part of the Basin due to the prevalence of sandy soils. Commonly, concentrations of HM in these paddy soils increase with depth reflecting the increase in clay content as the HM are mostly incorporated into or adsorbed onto clay minerals and Fe/Mn oxides.

1. Introduction

Asian countries, including China, Peninsular Malaysia, Vietnam, India, Philippines, Indonesia, Bangladesh and Pakistan have investigated the contamination of agricultural soils and crops by heavy metals due to their potential effects on human health and the long-term sustainability of food production in contaminated areas (Herawati et al., 2000; Luo and Teng, 2006; Brus et al., 2009).

Paddy soils are an important resource for rice production in tropical countries, so heavy metal (HM) contamination of these soils would have adverse consequences on production and marketing of rice. Jasmine rice (*Oryza zativa* L.) is widely cultivated in Northeast Thailand, where about 6 million hectares in Northeast Thailand produced 12 million tons of rice in 2011 which accounted for 52% of Thailand's total rice production (Phaithong and Pagdee, 2013). There is some concern that rice from this region may be contaminated with HM by anthropogenic activities, especially by industry and the use of phosphate and micronutrient fertilizers that contain As, Cd and Pb (Chen et al., 2008; Romić, 2012).

Pollution with HM is a potential problem in marketing rice for export, as customers impose severe conditions on the permitted levels of HM in rice (Wong et al., 2002). The Khorat Basin is the leading jasmine rice production area in Northeast Thailand, but little attention has been paid to the amounts and forms of HM in these paddy soils in relation to the HM concentrations in rice. This research determined the speciation and spatial distribution of HM in soils to provide a basis for improved management of paddy soils in Northeast Thailand, under tropical savanna climate.

The bioavailability of HM contaminants in soils depends to some extent on the speciation or chemical forms of HM. Speciation may be assessed by extraction techniques which provide knowledge of the affinity of HM with soil components and thus their likely bioavailability (Norvell, 1984; Katana et al., 2013). Heavy metals may be retained by soil components by exchange onto clay minerals, oxides or organic matter or may precipitate or co-precipitate as sulfides, carbonates and Fe/Mn oxides or hydroxides (Aydinalp and Katkat, 2004). Methods for evaluating the bioavailability of HM in soils include single extraction and sequential extraction procedures (Meers et al., 2007). Dithionite citrate bicarbonate solution is believed to extract organically bound, amorphous Fe, Mn oxide sand some crystalline Al, Fe, Mn oxides (Blume and Schwertmann, 1969; McKeague et al., 1971; Evans and Wilson, 1985). Acid ammonium oxalate dissolves metals associated with organic matter and amorphous Mn, Fe oxides. The total concentration of elements in soil as extracted by strong acid (aqua regia) is commonly measured but is now recognized as a poor indicator of the

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http://dx.doi.org/10.1016/j.geodrs.2016.02.002

potential toxicity of HM (Ivezić et al., 2013). However the total concentration of HM is still used in legislation in many countries to determine the maximum permissible concentrations of elements in soils (US EPA, 2002; PCD, 2004; CCME, 2007). Generally, monitoring of total HM concentrations in paddy soils is used to evaluate the potential risk of paddy soils being contaminated with toxic HM, particularly — Cd, As, and Pb (Hang et al., 2009; Karatas et al., 2007). A number of reports have been published on concentrations of toxic metals including Cd and Pb in rice and paddy soils in Japan, China, and Indonesia (Suzuki and Iwao, 1982; Fazeli et al., 1998; Herawati et al., 2000). However, few studies exist for Thailand, and little information is available on toxic HM contamination of paddy fields and consequent risk assessment, though rice is the most important staple food for Thai people.

The main objectives of the present study were (1) to investigate the extractability of HM using acid and sequential dissolution methods, (2) to relate amounts of HM dissolved to other soil properties, (3) to determine if soil series have distinctive HM contents and (4) to explore the spatial distribution of the various forms of HM and other elements in soils of the Basin.

2. Materials and methods

2.1. Soil sampling and analysis

This study was carried out in the Khorat Basin. The geographic coordinates of the Basin are 14° 15′ to 16° 51′ north latitude, and 101° 14′ to 105° 45′ east longitude which represents an area of 115,000 km^2. Diverse sedimentary rocks occur in the Basin together with a small area of basaltic intrusions (Fig. 1). The soils were variously derived

Table 1
Soil series, classification and parent materials for paddy soils in the Khorat Basin.

Parent material	Classification	Soil series
Recent alluvium	Aeric (Plinthic) Endoaquepts	Chum saeng (Cs)
	Ustic Endoaquerts	Si Songkhram (Ss)
	Vertic (Aeric) Endoaquepts.	Ratchaburi (Rb)
	Ustic Endoaquerts	Phimai (Pm)
Alluvium	Typic (Aquic) Paleustults	Lom Kao (Lk)
	Aeric Plinthic Paleaquults	Nakhon Phanom (Nn)
	Aeric Plinthic Paleaquults.	Phen (Pn)
	Aeric (Plinthic) Endoaqualfs	Tha Tum (Tt)
	Typic Natraqualfs	Kula Ronghai (Ki)
	Typic Paleustults	Satuk (Suk)
Wash deposits from sandstone	Aquic Grossarenic Haplustalfs	Ubon (Ub)
	(Oxyaquic) Kandiustults	Korat (Kt)
	Aeric Kandiaquults	Roi Et (Re)
	(Aeric) Plinthic Paleaquults	Renu (Rn)
Residuum and colluvium from basalt	Ustic Epiaquerts.	Burirum (Br)
	Typic Rhodustalfs.	Surin (Su)

Taxonomic names (Soil Survey Staff, 2006).

from recent alluvium, alluvium over residuum, wash deposits from sandstone, wash over residuum derived from clastic rocks, residuum derived from clastic sedimentary rocks and residuum and colluvium from basalt (Table 1 and Fig. 2).

The sampling strategy was to provide samples (sites) for each of the soil series from sites that are widely dispersed through the Basin. One hundred sites (sixteen soil series) under paddy cultivation were sampled at three depths (Ap, Ap-60 and 60–100 cm) (Fig. 2). Most soils occur on terrace and plain locations and have experienced leaching of Si and basic cations in the tropical climate with high rainfall,

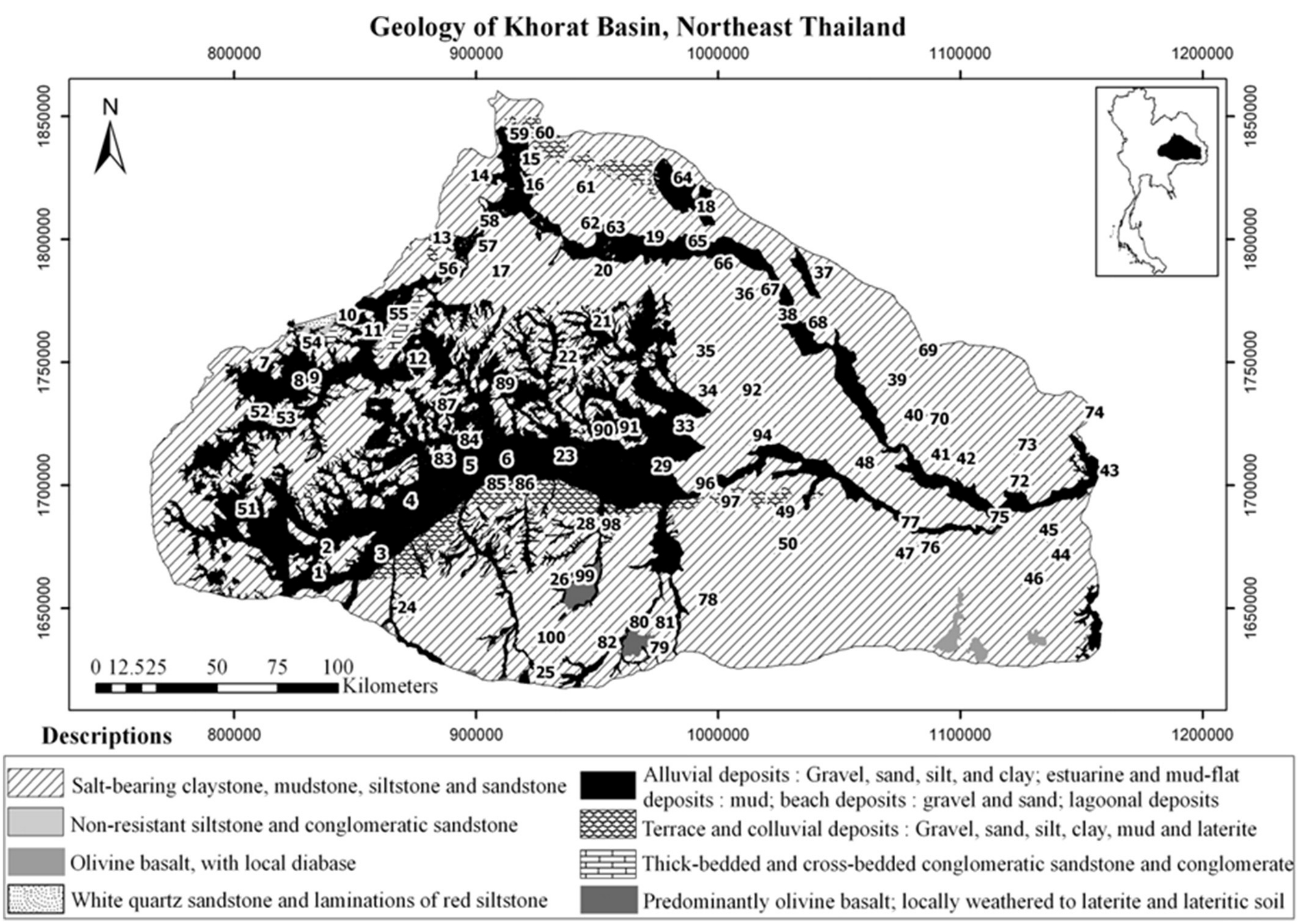

Fig. 1. Geology map and sampling sites for paddy soils in the Khorat Basin, northeast Thailand (Geological Survey Division Staff, 1985).