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The Uptake of Heavy Metals by Paddy Plants (*Oryza sativa)* in Kota Marudu, Sabah, Malaysia

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Abstract: The objective of this study was to determine and compare the content of heavy metals in various parts of the paddy plant, namely the grains, husks, leaves, stems and roots compared to the levels in the soil around the root zone. The study was conducted in several rice fields near Marudu, Sabah, Malaysia. The heavy metals studied were cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), manganese (Mn), lead (Pb) and zinc (Zn). The heavy metals present in paddy plants and soils were detected using the atomic absorption spectrophotometer (AAS) model Perkin Elmer 1100B. Other parameters studied were the soil grain sizes, percentage organic carbon and soil pH. The results showed that Fe was the most predominant metal ion in the rice grains and roots, while Mn was the most predominant metal in the rice husks, leaves and shoots. The highest mean percentage recorded for the soils of Kota Marudu were as follows: organic carbon (8.02%), grain size (85.92%) and soil pH (5.91). Mn occurred in the highest concentration in the non-litogenic fraction of the soil in all the areas studied. However, the concentrations of heavy metals in the rice grains were still below the maximum levels as stipulated by the Malaysian Food Act (1983) and Food Regulations (1985).

Key words: Heavy metals · Paddy plants (*Oryza sativa)*

INTRODUCTION

Heavy metal pollution is mainly the result of human activities such as agriculture, mining, construction and industrial processes [1, 2]. According to Kabata-Pendias and Pendias [3] and Whitney [4] improper waste disposal activities and overuse of pesticides were among the most significant sources of heavy metal pollution in the environment. Heavy metals in the environment are a health hazard due to their persistence, bioaccumulation and toxicity to plants, animals and human beings [5].

According to McLaughlin *et al*. [6], Cu, As and Pb were available in the agricultural soils in Australia and New Zealand as a result of prolonged heavy use of various types of pesticides. High concentrations of heavy metals in the soil would increase the potential uptake of these metals by plants. Since rice is the staple food for most of the world including Malaysia, it is important to determine the content and distribution of heavy metals in paddy plants (especially the grains) as well as paddy soils.

The objective of the study was to determine the concentrations of heavy metals in the paddy plant parts and the root zone soil in the paddy area of Kota Marudu, Sabah, Malaysia.

MATERIALS AND METHODS

Sampling Area: The study area was located in Kota Marudu, Sabah, which is known to be one of the major paddy planting areas in Sabah, with approximately 8,610 hectares under paddy cultivation.

Soil Collection and Analysis: In the study, five locations were selected randomly for the sampling activities. Five clumps of paddy plants were chosen as replicated samples from each location. The whole paddy plant was uprooted together with the soil around the root zone area to a depth of between 0-30 cm. In the laboratory, the paddy plants were washed under running water, patted dry with a clean paper towel and then cut into various parts, i.e. leaves, stems, roots and grains. The samples were oven-dried at 70°C to constant weight, followed by

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acid-digestion according to the AOAC [7] method using HNO_3 and $HClO_4$ (25:10 ml). The clear digested liquid was filtered through a 0.45 µm acid-resistant filter paper and the metal content in the filtrate was determined using the atomic absorption spectrophotometer (AAS) model Perkin Elmer 1100B (Germany).

Heavy Metals Study: Soil samples were oven-dried at 70°C to constant weight and then pulverized using a mortar and pestle. Ten grams of the powdered soil sample was used to extract heavy metals using ammonium acetate at pH7, following the method of Badri [8]. The content of the metals Pb, Cd, Cu, Cr, Zn, Mn and Fe were determined using the atomic absorption spectrometer (AAS) model Perkin Elmer 1100B. Other parameters studied included the determination of soil pH [9], percentage organic carbon [10] and soil particle size of <63 µm [8].

RESULTS AND DISCUSSION

Heavy Metals Study: The mean concentrations of heavy metals in the paddy plant parts (Table 1) showed that all the studied metals were present except for Pb, which was only detected in the paddy roots. Most of the metals accumulated in the roots except for Mn, which was at its highest level in the paddy leaves, whilst Cd was more evenly distributed throughout the whole plant. Likewise, Cu also accumulated at its highest concentration in the roots of the paddy plant. In general, the metal by the roots uptake was highest for Fe in the roots followed by Mn in the leaves (Table 1).

Most metals that were found abundantly in the paddy plants were nutrients like Fe, Mn, Zn and Cu that are required for various enzyme activities and play important roles in photosynthesis and growth of the plant [11, 12]. Pb was not detected in the various plant parts but occurred in low concentrations in the roots of the paddy plant. Other studies have shown that Pb and other metals could be derived from the basic rocks in agricultural areas as well as from pesticides and fertilizers [13].

Cd was evenly distributed at low concentrations in the various parts of the paddy plant. Jarvis *et al*. [14] reported that Cd was easily taken up by plants and transported to different organs although it had no beneficial effects to plants and animals. Pesticides and fertilizers are known to be the main sources of heavy metal pollution in agricultural areas [3]. In the Kota Marudu area the fertilizer used was mainly rock phosphate, which is known to contribute appreciable amounts of Cd to agricultural soils especially paddy areas [15] as well as areas cultivated with oat, ryegrass, carrot and spinach [16].

Results of soil analyses showed that Mn was present in the available form at the highest level in the soil, followed by Zn and Cd (Table 2). Although Cu, Fe and Pb were absent in the easily leachable and ion exchangeable soil fractions, they were however, detected in appreciable amounts in the various parts of the paddy plant. These metals were probably derived from the basic rock materials [13]. Soil grain size could also affect the availability of metals in the soil, whereby the size and structure of the

Table 1: Concentration of heavy metals (mg/kg) in paddy plant parts collected from Kota Marudu, Sabah

Paddy parts/ metals	Cd	Cr	Cu	Fe	Mn	Pb	Zn
Rice	0.180 ± 0.028^a	1.342 ± 0.241^b	0.312 ± 0.411^b	2.886 ± 8.867^{bc}	1.529 ± 0.484^c	ND	0.685 ± 0.416^c
Sekam	0.183 ± 0.022^a	0.727 ± 0.183^d	0.189 ± 0.326^b	0.273 ± 0.398^c	2.343 ± 1.161^c	ND	0.519 ± 0.194^c
Leaf	0.203 ± 0.023^a	1.020 ± 0.088^c	1.243 ± 1.566^b	5.228 ± 4.635^b	13.744 ± 3.963^a	ND	1.214 ± 0.556^b
Stem	0.239 ± 0.386^a	0.711 ± 0.239^d	1.529 ± 4.648^b	4.781 ± 2.25^b	7.109 ± 3.792^b	ND	0.676 ± 0.416^c
Root	0.190 ± 0.028^a	1.861 ± 0.458^a	9.252 ± 11.28^a	43.993 ± 2.047^a	7.772 ± 2.451^b	1.565 ± 4.686^a	2.306 ± 0.932^a

Note: Means within the same row followed by the same letter are not significantly different to each other at p> 0.05, ND = not detected

Table 2: Concentration of heavy metals (mg/kg) in soil samples collected from the Kota Marudu paddy area in Sabah

Metals/ soils	Cd	Cr	Cu	Fe	Mn	Pb	Zn
Paddy soils (n=25)	0.776 ± 0.139^a	2.075 ± 0.482^a	ND	ND	46.350 ± 24.135^a	ND	21.094 ± 11.248^a

Note: Means within the same row followed by the same letter are not significantly different to each other at p> 0.05, ND = not detected

Table 3: Mean values of soil pH, percentage organic carbon and grain size <63µm of soil samples collected from the Kota Marudu paddy area in Sabah

Paddy area	Soil pH	Percentage grain size <63µm	Percentage organic carbon
Kota Marudu (n =25)	5.91 ± 0.316^a	85.92 ± 9.340^a	6.72 ± 1.455^b

Note: Means within the same row followed by the same letter are not significantly different to each other at p>0.05

soil particles determine the surface area that influences the chemical and physical characteristics of the mineral [3]. Loredo *et al*. [17] showed that the Hg and As content in the soil increased with a decrease in soil particle size. In this study, the soil particle size was quite small, thus facilitating the binding of heavy metals to the soil particles.

Soil pH and organic matter content are also very important factors controlling mobility and concentration of elements in the soils. The mean soil pH was low at 5.91 (Table 3), indicating that most of the metals were not in the available form and those that occurred in the easily leachable and ion exchange fraction were probably derived from various pesticides and fertilizers applied to the soil. Errickson [18] noted that most heavy metals occurred in the available form only at low soil pH, thus underlining the important role of soil pH in the availability of metals in the soil.

The soil carbon organic content was also quite low (Table 3), which indicated that metals were less likely to be bound to organic matter to form metal-chelate complexes. Thus, the metals occurred mostly in the available form and were readily taken up and accumulated in the paddy plants.

CONCLUSION

Most of the heavy metals studied were found to accumulate mainly in the roots of the paddy plant, while other parts including the grains contained low levels that are below the allowable limits stipulated under the Malaysian Food Act 1983[19] and Food Regulations 1985 [19]. The heavy metals in the soil studied were mainly derived from the basic rocks found in the study area and the availability of toxic metals to the paddy plants were found to be quite low.

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