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Heavy metals in the irrigation water, soils and vegetables in the Philippi horticultural area in the Western Cape Province of South Africa

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Abstract

The aims of this study were to investigate the extent of heavy metal contamination in the Philippi horticultural area in the Western Cape Province, South Africa. Concentrations of Cd, Cr, Cu, Mn, Ni, Pb and Zn were determined in the irrigation water, soils and vegetables in both winter and summer cropping seasons with an ICP-AES and tested against certified standards. Differences were found in heavy metal concentrations between the winter and summer cropping seasons in the irrigation water, soils and vegetables. Certain heavy metals exceeded the maximum permissible concentrations in the irrigation water, soils and vegetables produced in South Africa. These toxic concentrations were predominantly found in the summer cropping season for the soils and in the crops produced in winter. It is thus suggested that further studies are carried out in the Philippi horticultural area to determine the sources of the heavy metals to try and mitigate the inputs thereof and therefore reduce the amount of heavy metals entering the human food chain.

Introduction

Heavy metals are naturally occurring in the environment due to the natural weathering of bedrock. These naturally released heavy metals are usually contained in forms that are not readily available to plant roots (Tyler et al. 1989; Nellessen and Fletcher 1993; Prasad 2004). However, in recent years, this has changed due to the increase in anthropogenic activities which release more biologically available forms of heavy metals into the environment (Prasad 2004; Benavides et al. 2005; Islam et al. 2007; Arora et al. 2008). Agriculture is one of the most significant anthropogenic activities contributing to the release of bioavailable heavy metals into the environment (Martin et al. 2006). Mortvedt (1996) suggested that both organic (depending on the parent material) and inorganic/ chemical fertilizers are major sources of heavy metals, while Kabata-Pendias (2011) suggested that other agro-chemicals could also be significant sources of heavy metals to agricultural soils. Several researchers have subsequently shown that the continuous applications of both organic and inorganic/chemical fertilizers, as well as other agrochemicals such as pesticides, herbicides, fungicides, waste water and sewage sludge, allow for bioaccumulation of heavy metals and other chemical residues in agricultural soils (Reuss et al. 1976; Ayuso et al. 1996; Mortvedt 1996; Ihnat and Fernandes 1996; Harmon et al. 1998; Haroun et al. 2009; Worthington 2001; Goi et al. 2006; Cai et al. 2007; Arora et al.

Table 2 Heavy metal concentrations in the agricultural soil collected in both winter and summer cropping seasons from the Philippi horticultural area

	Heavy metal concentration (mg/kg)						
	Cd Mean±SE Range	Cr Mean±SE Range	Cu Mean±SE Range	Mn Mean±SE Range	Ni Mean±SE Range	Pb Mean±SE Range	Zn Mean±SE Range
Winter	0.74±0.18a	30.13±3.93a	14.53±2.02a[a]	96.74±12.29a	1.71±0.40a	19.24±2.91a[a]	72.71±8.49a[a]
	0.004–4.72[a]	2.04–107.70[a]	2.68–53.96	16.43–360.98	0–8.50	0.55–80.86	18.59–184.38
Summer	0.48±0.07a	37.52±4.10a	22.68±2.38b[a]	134.31±17.50b	3.12±0.44b	22.21±2.90a[a]	99.20±10.72b[a]
	0009–1.77	2.84–6.44	2.58–72.95	31.42–631.32	0–9.91	0–61.56	30.29–352.29
H	>0.05	>0.05	10.659	4.566	6.113	>0.05	4.566
P			0.001	0.033	0.013		0.033

Mean heavy metal concentrations with the same letters indicates no difference ($P \geq 0.05$) between the winter and summer concentrations

[a] Concentrations above the legal limit in South Africa

Although copper and zinc are considered essential micronutrients to plants for their roles as activators of many enzymes and cofactors for oxidative enzymes (Hopkins and Hüner 2004), excessive uptake of these metals could inhibit many metabolic functions which lead to growth retardation and injury to the plants which, in turn, leads to yield reductions (Van Assche et al. 1988; Stadtman and Oliver 1991; Somasekharaiah et al. 1992; Cakmak and Marshner 1993; Ebbs and Kochian 1997; Thomas et al. 1998; Prasad et al. 1999; Hegedus et al. 2001; Lewis et al. 2001; Romero-Puertas et al. 2004). Cadmium, chromium and lead on the other hand are well-known plant toxins. Despite the selectivity of plant roots to the uptake of mineral elements, these toxic elements are also taken up and incorporated into plant tissues (Hopkins and Hüner 2004; Prasad 2004). The uptake of cadmium, lead and chromium in excessive amounts by plants has adverse effects on both morphology as well as biochemical processes within plants (Baker 1972; Gruenhage and Jager 1985; Stiborova et al. 1987; Sharma and Dubey 2005).

Vegetables

The vegetable crops collected from the Philippi horticultural area were found to contain varying concentrations of the focus heavy metals (Table 3).

Table 3 Heavy metal concentrations in the vegetable crops collected in both winter and summer cropping seasons from the Philippi horticultural area

		Heavy metal concentration (mg/kg)						
		Cd Mean±SE Range	Cr Mean±SE Range	Cu Mean±SE Range	Mn Mean±SE Range	Ni Mean±SE Range	Pb Mean±SE Range	Zn Mean±SE Range
Cabbage	Winter	0.22±0.09b[a]	2.68±0.52b	5.55±0.57b	41.64±5.21b	0.34±0.25a	2.32±0.91a[a]	54.12±9.24a[a]
		0.01–0.55	1.32–4.75	3.93–7.83	26.20–58.38	0.02–1.60	0.06–5.12	28.90–82.02
	Summer	0±0a	1.02±0.11a	3.07±0.53a	24.50±2.44a	0.19±0.07a	0.07±0.03a	44.16±0.80a[a]
		0–0	0.84–1.29	1.62–4.08	20.12–31.46	0–0.31	0.05–0.10	43.17–45.75
	H	*6.968*	*6.545*	*5.500*	*4.545*	*>0.05*	*>0.05*	*>0.05*
	P	*0.008*	*0.011*	*0.019*	*0.033*			
Cauliflower	Winter	0.38±0.06b[a]	1.41±0.26a	5.77±1.53a	30.25±3.46a	0.22±0.09a	0.77±0.34b[a]	63.71±5.94a[a]
		0.18–0.57	0.48–2.36	3.45–13.23	24.43–46.97	0.02–0.56	0.05–2.20	50.62–89.10
	Summer	0.001±0.001a	0.80±0.21a	7.05±2.13a	27.23±1.92a	0.10±0.07a	0.01±0.01a	64.42±3.96a[a]
		0–0.004	0.31–1.51	4.66–15.56	20.87–32.39	0–0.33	0–0.05	54.75–78.43
	H	*7.857*	*>0.05*	*>0.05*	*>0.05*	*>0.05*	*6.844*	*>0.05*
	P	*0.005*					*0.009*	
Carrots	Winter	0.23±0.08b[a]	2.46±0.40a	4.22±0.29a	8.50±0.52a	0.46±0.18a	3.79±0.93b[a]	30.55±4.31a
		0.01–0.73	0.88–5.40	2.91–5.55	6.12–11.08	0.03–2.01	0.03–9.96	18.43–57.20[a]
	Summer	0.06±0.02a	4.48±1.34a	7.30±0.66b	15.96±4.64a	1.66±0.50b	0.14±0.04a	35.67±3.51a
		0.02–0.13	0.85–14.50	4.70–9.79	6.56–55.69	0.15–5.16	0.02–0.35	22.43–53.26[a]
	H	*4.624*	*>0.05*	*11.763*	*>0.05*	*6.96*	*10.227*	*>0.05*
	P	*0.032*		*0.001*		*0.008*	*0.001*	
Lettuce	Winter	0.51±0.16b[a]	4.21±1.57a	9.90±1.74a	40.18±10.96a	3.39±1.39a	4.14±1.50a[a]	73.52±10.59a[a]
		0.05–0.85	1.28–8.88	5.73–16.14	16.28–79.85	0.03–6.98	0.05–9.40	39.66–100.40
	Summer	0.06±0.02a	3.71±0.59a	9.24±1.55a	28.57±2.07a	1.66±0.44a	0.09±0.04a	57.25±6.23a[a]
		0.002–0.17	1.84–5.06	4.18–14.84	23.26–35.47	0.29–2.62	0.05–0.27	32.22–71.50
	H	*5.633*	*>0.05*	*>0.05*	*>0.05*	*>0.05*	*>0.05*	*>0.05*
	P	*0.018*						

Mean heavy metal concentrations with the same letters indicates no difference ($P \geq 0.05$) between the winter and summer concentrations

[a] Comparisons were made within crop species and concentrations above the legal limit in South Africa

In certain of these vegetable crops, significant differences were found in heavy metal concentrations between the winter and summer cropping seasons. However, where these differences were observed, heavy metal concentrations were generally higher in the vegetables harvested in the winter cropping season, with the exception of copper and nickel concentrations in carrots which were higher in the summer cropping season (Table 3).

According to South African Legislation and regulations made under the Foodstuffs, Cosmetics and Disinfectant Act, Act number 54 of 1972, fresh produce containing the metals cadmium, copper, lead, tin and zinc in amounts greater than what is stipulated in the act will be deemed harmful or damaging to human health (Government Gazette 1994). In the current study, cadmium, lead and zinc concentrations in each of the vegetable crops exceeded these limits of 0.1, 0.3–0.5 and 40 mg/kg, respectively (Government Gazette 1994). These harmful concentrations of cadmium and lead were only observed during the winter cropping season while zinc concentrations exceeded the legal limits in both winter and summer cropping seasons (Table 3).

This result is of serious concern. Prolonged exposure to these toxic heavy metals through the consumption of vegetables could lead to the disruption of several biochemical processes within the human body (Anhwange et al. 2013). Although zinc is an essential nutrient to humans necessary for the functioning of a large number of metalloenzymes, excess uptake of zinc can alter cholesterol metabolism, weaken blood vessels, induce vomiting and diarrhoea, as well as damage the kidneys (DuPuy and Mermel 1995; Hallberg et al. 1993). Cadmium and lead on the other hand have no beneficial effects on human health. Cadmium has been classified by the International Agency for Research on Cancer (IARC) as a human carcinogen that can be implicated in various cancers (Järup 2003), while high levels of lead have been found to affect an array of human physiological systems, including renal function, neurological functions and immunological functions (Gidlow 2004).

From these results, it is clear that the irrigation water, soils, as well as the fresh produce produced in the Philippi horticultural area contains varying concentrations of certain heavy metals. Due to the integral role that the Philippi horticultural area plays in the acquisition of mineral nutrients to the communities surrounding the Philippi horticultural area, which are also suffering from food insecurity (Battersby-Lennard and Haysom 2012), it is suggested that further studies are conducted in the Philippi horticultural area in order to determine the major agronomic sources of heavy metals to the irrigation water and soils in the area. Further work is also needed not only to try and mitigate the inputs of these heavy metals but also to remove already existing metals from the irrigation water and soils to mitigate the uptake of these metals by the crops grown in the Philippi horticultural area. This in turn would result in a reduction in heavy metals entering the human food chain in this area.

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