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SCIENCE DIRECT®

Science of the Total Environment 354 (2006) 43–59

Science of the Total Environment
An International Journal for Scientific Research into the Environment and its Relationship with Humankind

www.elsevier.com/locate/scitotenv

The use of town refuse ash in urban agriculture around Jos, Nigeria: health and environmental risks

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Received 29 September 2004; accepted 10 December 2004

Abstract

This paper reports on a study that examines the health and environmental risks of using town refuse ash in urban vegetable production in Jos, Nigeria, in terms of heavy metal accumulation in the food chain. Soil and crop samples, collected from five study farms, and samples of the river water used for irrigation, were analysed for seven heavy metals Fe, Mn, Zn, Cu, Ni, Cd and Pb. On the basis of the field data the paper discusses: (1) the potential soil deficiencies and toxicities; (2) the probable links between soil heavy metal levels and fertilisation practices; (3) the heavy metal concentrations in crop tissue in relation to crop growth and human health. The findings suggest that soil concentrations of the seven metals fall within 'typical' soil levels, and that there should not be any problems of either toxicities or deficiencies for crop growth. There was evidence of slight accumulation of Zn, Cu and Cd on some of the farms with a history of town refuse ash use. However, in all farms lettuce crops contained very large concentrations of Fe, and Pb concentrations that were 20 to 40 times higher than the WHO/FAO maximum recommended level in leafy vegetables for human consumption. The Cd content of carrot tissue was 10 times higher than the WHO/FAO recommended limit. The relatively small number of soil and crop samples precluded any formal attempt at correlating the concentrations of heavy metals found in the vegetable crops with the farm levels. Nevertheless, the data suggested that these were not linked. The paper goes on to consider various potential sources of the metals found in the crops, including irrigation water, town refuse ash and air-borne dust, and discusses additional health and environmental risks pertaining to the use of town refuse ash. Undoubtedly, the heavy Pb and Cd contamination of certain crops indicates the urgent need for future studies to ascertain the precise source of these metals, and although the practice of using town refuse ash does not appear to have resulted in large-scale contamination of soil in the farming area, there are a number of unsafe practices associated with it that call for the identification of strategies for the safe utilisation of urban waste in Jos.

Keywords: Town refuse ash; Heavy metals; Vegetable crops; Jos Plateau

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doi:10.1016/j.scitotenv.2004.12.025

1. Introduction

The production of food in the city has a long history, both in the developed (in the form of allotment gardens) and developing world. Since the early 1990s, in particular, there has been increasing recognition amongst the scientific and development community of the rising importance of food production in city areas, particularly in those parts of the world that have been characterised by economic collapse (Mbiba and Van Veenhuizen, 2001). Urban and peri-urban agriculture (UPA) can offer wide-ranging benefits. It can contribute substantial amounts to the proportion of food consumed in the city: Sweet (1999), for example, has estimated that 15–20% of the world's supply of vegetables and meat is produced in urban areas, and FAO (1999) estimates that 800 million urban dwellers are actively engaged in UPA, 200 million providing food for markets (FAO, 1999). UPA is practiced for a variety of reasons, for crisis management when markets are not working (e.g. in Cuba), as a strategy to overcome cash shortages or even for commercial purposes. As well as improving food security and nutrition, and creating employment for the jobless (Lynch etal., 2001), UPA can offer a range of environmental benefits, including improved waste recycling, and additional health benefits such as improved physical and psychological health due to increased physical activity (Lock and van Veenhuizen, 2001).

The reaction to UPA has been varied. In some cases UPA has faced strong opposition from city authorities, because of a range of negative health, environmental, economic and cultural aspects (Tinker, 1994), comprising contamination of crops with pathogens, chemical residues and heavy metals (Lock and van Veenhuizen, 2001), soil degradation (Quansah et al., 1997), surface and groundwater pollution with agro-chemicals (Lock and van Veenhuizen, 2001), conflicting land and water issues (Lynch et al., 2001) etc., and the perception that agriculture is not an appropriate activity for urban areas (Kalebbo, 1998). Kampala City Council (Uganda) was notorious for opposing UPA and practiced crop slashing to enforce prohibition. However, in 1994 it decided to liberalise the practice, and is now designating urban farming as 'official land use' (Kalebbo, 1998). Kampala has not been alone in acknowledging the importance of city food production, for UPA has been legalised in Accra (Ghana), Dar es Salaam (Tanzania) and many cities in South Africa. The problem is that the numerous health and environmental risks make it difficult for developing country city authorities to decide whether to legalise and include agriculture as an urban planning issue.

Although there are some who believe that UPA is damaging to the environment, others suggest that that it could instead be the answer to a number of important environmental problems (Binns and Lynch, 1998). One of these is the problem of waste disposal. Urban centres produce most of the world's waste and between a third and half of this goes uncollected (Sweet, 1999). It contributes to urban pollution and health risks, yet it has great potential because it can be exceedingly nutrient rich. By disposing of urban waste on city plots, farmers would obtain a cheap supply of nutrients while alleviating the waste disposal problem at the same time. There are many examples of waste utilisation in the developing world (for a comprehensive review see Allison et al., 1998), including the use of night soil (e.g. in Ghana—Owusu-Bennoah and Visker, 1994), composted waste (e.g. in Calcutta—Kundu, 1995), untreated and unsorted waste (e.g. in Senegal—Haramata, 1991), wood and household waste ash (e.g. in Nigeria—Hoffman et al., 2001) and wastewater (e.g. in Senegal, Burkina Faso and Mauretania—Gueye and Sy, 2001).

The Jos Plateau has been the location of vegetable gardening since the early 20th century because of the tin mining in the area that led to the development of a large expatriate community. The process of expansion of dry-season irrigated vegetable production began with Nigeria's petroleum boom in the 1970s, which was accompanied by an increased demand for vegetable produce by the growing urban and affluent population. This expansion was encouraged by the presence of a market but it was also enhanced by the Plateau's favourable temperate climate, its central position in relation to the rest of Nigeria, its relatively high degree of accessibility by road, rail and air, and the recession in the tin mining industry, which freed up a considerable labour force (Adepetu, 1985). Production was further stimulated with the implementation of the Structural Adjustment Programme in 1986, which with its stated aim of self-sufficiency, caused food importation to cease abruptly (Porter, 1992). Since the 1990s, expansion has continued, markedly so along the paved roads, but also wherever there is water available for irrigation. Today the Plateau is of considerable importance as a vegetable production area and it supplies markets all over Nigeria and beyond (Porter et al., 1991).

Around the town of Jos (which is one of the major production and marketing sites) farmers were reported to use farm waste ash (Phillips-Howard and Kidd, 1991) and town refuse ash (Alexander, 1986). The local farmers' strategy of combining inorganic fertilisers, manure and town refuse ash proved to be highly successful in reclaiming degraded land (affected by the tin mining that took place intensively in the 1940s and 50s), raising the soil's fertility levels to a point where agricultural production could be sustained (Alexander, 1996). Ash played a particularly important role in terms of raising the pH of the soil and providing a range of micronutrients, but increasing utilisation of town refuse ash led to concerns about the health and environmental risks (Alexander, 1996).

This paper reports on a field study that sought to shed some light on the health and environmental risks of using town refuse ash in urban vegetable production in Jos, focusing particularly on the accumulation of heavy metals in the food chain. The three main objectives of the study were:

(1) To assess any potential soil deficiencies or toxicities of select heavy metals;
(2) To identify whether there is any evidence of heavy metal accumulation in the soil or in the food chain;
(3) To highlight other potential health and environmental risks, suggesting areas for further research.

2. Materials and methods

2.1. Rationale

In order to build up a comprehensive picture of what might have been happening in terms of heavy metal accumulation, the following strategy was developed and followed:

(1) Five case study farms were selected and samples were collected from the cultivated and uncultivated soil and tested for plant-available (DPTA-extractable) heavy metals iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), nickel (Ni), cadmium (Cd) and lead (Pb).
(2) These seven heavy metals were chosen for different reasons. Cd, Ni and Pb can pose a health risk to humans via direct ingestion of the soil (this is especially the case for lead), or through plant uptake, and food chain contamination (Risser and Baker, 1990). Fe, Mn, Cu and Zn are of interest because they are essential plant micronutrients, but can also pose toxicity risks (Landon, 1984).
(3) Produce from the case study farms was harvested at the end of the farming season and tested for total (nitric acid extractable) Fe, Mn, Zn, Cu, Ni, Cd and Pb.
(4) The irrigation water source was tested for the above-mentioned seven heavy metals.
(5) Information was gathered on fertilisation practices on the five case study farms.
(6) The results were examined in combination with a study on the heavy metal contamination of ash samples collected from different locations in Jos reported in Pasquini and Alexander (2004).

This approach provides some preliminary data on the heavy metal status of soil and crops in the Jos area and can offer some insight into the likelihood of heavy metal accumulation taking place, acknowledging, however, that under field conditions it is very difficult to distinguish the source of one or more heavy metals that may be present in excessive concentrations in a particular vegetable crop. In a field situation there may be more than one contaminating source and not all can be easily taken into account. The environment is very dynamic compared to a laboratory situation, and therefore it is difficult, for example, to judge which chemical processes may be taking place that could influence the uptake of heavy metals into a crop. In the Jos situation town refuse ash is a probable candidate as a source of heavy metals, but in devising the methodological approach to establish this, several factors had to be considered. Firstly, the presence of heavy metals in ash does not necessarily mean that they accumulate in the soil in plant-available form. Secondly, there will be significant differences from farm to farm depending on application of ash from year to year, and the degree of contamination between batches. Thirdly, the presence of total quantities of heavy metals in the soil does not necessarily indicate uptake by the crops, as different metals are differently available (Stephens et al., 2001) and there are differences in uptake and tolerance between crop species and even varieties of the same species (Brooks, 1998; Webber, 1980a). Fourthly, there are methodological problems relating to the choice of suitable extracting agents for the different metals and their application to predicting plant availability (McLaughlin et al., 2000). Fifthly, there could be background levels in the soil due to the tin mining activities. Finally, other sources of heavy metals could be the irrigation water (as the Delimi River flows through the city before reaching the farming site under study) or atmospheric pollution.

2.2. Area description

The Jos Plateau consists mainly of open, undulating country above which rise stony hills and mountain ranges, and into which erosion has exposed belts of dissected terrain or cut valleys. The Plateau stands at about 1400 m in the south and declines gently in average altitude to 1100–1300 m in the north (Alford et al., 1979). It is characterised by three main rock types: the Basement Complex rocks (which include Older Granites and metamorphic rocks) that underlie more than half the Plateau; the Younger Granites and the Older and Newer Basalts (Phillips-Howard, 1988; Alford et al., 1979). The Post-Older Basalt Unconsolidated Deposits are particularly important as they form the parent material of many soils on the Jos Plateau. They are divided into the Rayfield, Bokkos and Bisichi Deposits and Ngell Alluvium (Alford et al., 1979). The study location is part of the Jos-Barakin Ladi area, an extensive area of undulating terrain, punctuated by scattered inselbergs and whalebacks, in the north and in the centre of the Plateau that is developed on Rayfield Deposits overlying Younger Granite or Basement Complex (Alford et al., 1979) (see the geology in Fig. 1). The soils characterising this area typically belong to soil associations developed on unconsolidated deposits (soils typical of the plains) but there are also cultivable valley land soils. These soils are traditionally known as *fadama* soils. True *fadama* soils may be gleyic Cambisols and they tend to be rich in organic matter, highly fertile, well-structured and quite permeable in the dry season, and hence they are potentially very productive. There may also be ferralic Cambisols (which are imperfectly drained, poorer in organic matter and inherently less fertile) and soils typical of the plains (Phillips-Howard, 1988). The study farms were located on soils overlying aplo-pegmatitic granite gneiss (Buchanan et al., 1971).

Vegetable production normally takes place during the dry season, which runs approximately from September through to April, and is characterised for the most part by the Harmattan wind and absence of precipitation. The onset and end of the season are obviously variable because they depend on the climatic conditions characterising a particular year. In 2000/2001, the farming season commenced in early September, with a few farmers taking advantage of the late rains. The majority of farmers commenced work in October. The rains returned on the 1st of April, but a month and a half passed before farmers started collecting their crop and abandoning their land for the wet season pause.

Farmers practice flood irrigation, by subdividing their plots of land into subplots and irrigation channels, which are built by raising the soil into ridges. Water from the Delimi River is pumped into the channels and flows under gravity, submerging each subplot in turn.

The season is long enough to allow two major rounds of harvesting, the first taking place in December or January. The farmers tend to intercrop, mixing slow growing species (such as cabbage or tomatoes) with quick maturing species (such as lettuce) in the same subplots. This is primarily for financial reasons, as the sale of a lettuce crop (after about 40 days) can yield the resources needed to tend the slower maturing crop. After the late December harvest farmers will plant new crops, and will often plant something different from the first half of the season. Farmers who wish to grow tomatoes will usually wait until November to sow the plants, and these will take till April to fruit. In order to maximise their use of space, some farmers will plant crops requiring little space, such as green-leaf, leeks, or onions, on the ridges of the subplots.

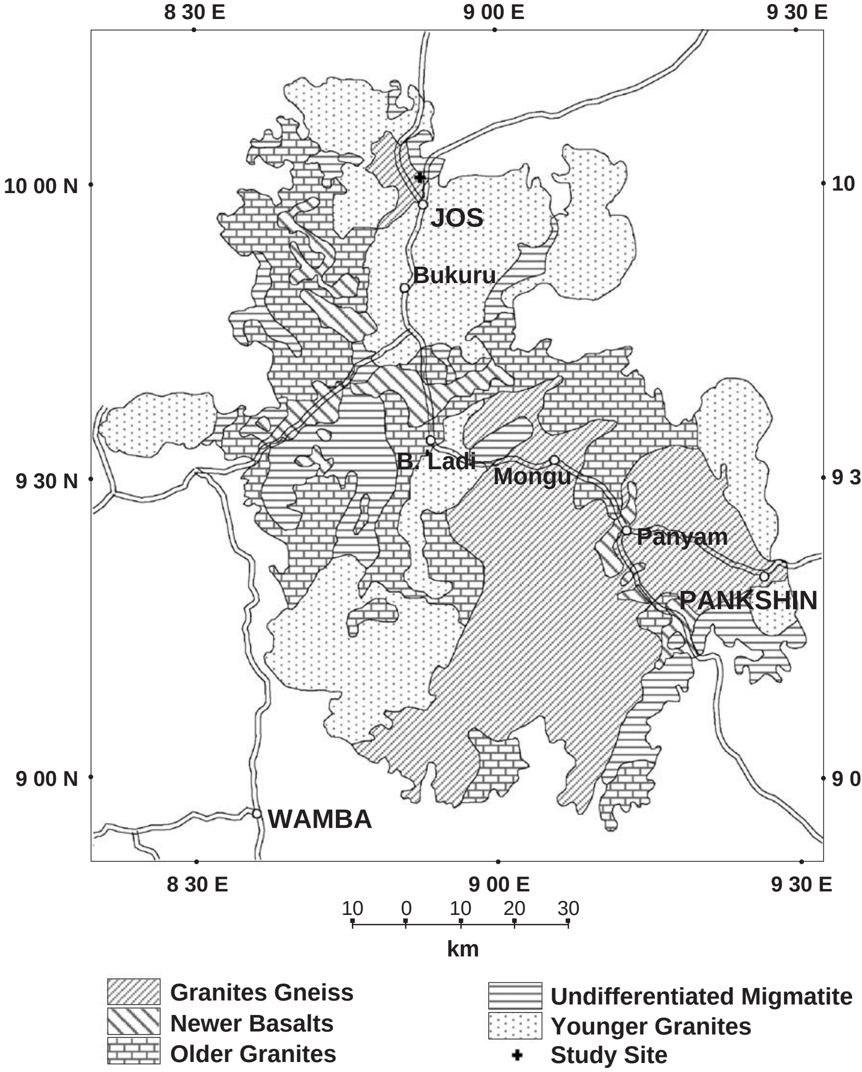

Fig. 1. The geology of the Jos Plateau.

The five case study farms were located along the Delimi River in the Delimi Langalanga farming location, to the north of Jos (Fig. 1). Although part of this area was used for tin mining, efforts were made to avoid selecting farms located on abandoned extraction areas, so as to avoid any confounding factor in the interpretation of the results, since the purpose of the study was to assess the risks of heavy metal accumulation from the use of town refuse ash. However, the possibility that small-scale smelting might have taken place on some of the farms cannot be entirely excluded. The farmers use the Delimi as a source of irrigation water. Four of the five farms were located on the left bank. The farms were chosen because: the plots had been under cultivation for at least 10 years; the particular plots selected were not subject to flooding during the rainy season; the farmers had differing fertilisation strategies, two of them with a history of intensive town refuse ash use; the farmers were going to plant the same crop, lettuce, at least in the first half of the season (because they try to guess which crops might sell favourably on the market, farmers usually cannot name which crop they will plant following the first cropping round, but in this case all farmers, except one who planted carrots, planted a second round of lettuce); the farmers appeared positively disposed towards collaborating with the study. The farms have been designated with the fictitious names of the owners: Audu and Hassan (adjacent farms sharing the same soil type), Shitu and Salem (also neighbouring farms on the same soil type) and Abdullahi (on the right bank, with a soil that was unlike the two types on the left bank).

2.3. Sample collection

The soil and crop sampling strategy was as follows:

1. Soil samples were collected at the end of the farming season (April–May), immediately after harvest.
2. Ten samples were collected from designated plots of land from each farm. This was considered adequate as the plots were very small, comprised between 0.02 ha and 0.1 ha (as a comparison, the EEC recommends that soil samples for fertiliser analysis should be made up by mixing 25 core samples taken from an area not exceeding 5 ha—Council Directive 86/278/EEC).
3. The sampling strategy was facilitated by the irrigation grid, as all subplots were assigned a number, each number was written on a piece of paper, and 10 numbers were drawn from the whole batch. These plots were then sampled.
4. Samples were collected with a soil augur to a depth of 30 cm (the maximum rooting zone for most vegetable crops—Landon, 1984).
5. Ten control samples were collected at different points from the grassy uncultivated verges of the study plots in each farm.
6. At the end of the farming season, 10 crop samples were taken from each study plot. These were all lettuce samples except in Salem's farm where carrots had been planted.
7. Two river water samples were collected at the end of the fieldwork season, when the Delimi River water was at its lowest level (so heavy metals were likely to be very concentrated) and treated with nitric acid as soon as possible upon arrival in the UK (since chemical resources were not available in Jos).

2.4. Laboratory analysis

Heavy metals in the soil samples were determined using diethylene-triamine-pentaacetic acid (DTPA) non-equilibrium extraction method. The solution is made up of a mixture of 0.005 M DTPA, 0.1 M triethanolamine (TEA) and 0.01 M $CaCl_2$, adjusted to pH 7.3. The choice of DTPA as an extractant was made after a careful consideration of the debate in the literature on the advantages and disadvantages of the different extracting agents (see Pasquini, 2002). It is beyond the scope of this paper to go into the details of the debate. It is sufficient to say that no single suitable extracting agent has been developed for all the heavy metals required in this study, however, DTPA was considered an acceptable extractant as it provides an indication of 'potentially' bioavailable metals and was designed to predict deficiencies for Fe, Mn, Zn and Cu in near neutral soils (and all farms in the study had near neutral soils except for Salem, which had a slightly acidic soil) (Connor, 1988). However, DTPA is not considered a suitable extractant for either Ni (Quevauviller et al., 1996) or Pb (Connor, 1988), and thus these results should only be considered a general indication of soil levels. After extraction with DTPA, the samples were analysed on the Varian SpectrAA 220FS Atomic Absorption Spectrophotometer for Fe, Mn, Zn, Cu, Ni, Cd and Pb.

Crop samples were digested with hydrogen peroxide to break down organic matter. The resulting digest was then tested for total (nitric acid extractable) Fe, Mn, Zn, Cu, Ni, Cd and Pb using microwave-assisted digestion (CEM's MARSX Microwave system) according to the Environmental Protection Agency's Method 3051 (CEM, 2000). The metals were determined on a PerkinElmer Elan 6100 DRC Plus ICP-Mass Spectrometer.

The two water samples taken directly from the Delimi River were simply filtered and tested to determine the concentration of the same seven heavy metals. This was a semi-quantitative analysis (with an error margin of ±20%) carried out by calibrating the PerkinElmer Elan 6100 DRC Plus ICP-Mass Spectrometer with a single solution.

Table 1
Mean heavy metal levels (DTPA-extractable) for cultivated and control soils for each of the five study farms (mg kg^{-1})

Variable tested		Au	Ha	Sa	Sh	Ab
Available Fe	Mean cult.	58.88	28.18	21.38	26.92	36.31
	Mean cont.	67.61	26.92	20.42	28.84	37.15
Available Mn	Mean cult.	43.52	40.04	23.00	36.44	48.04
	Mean cont.	45.10	61.50	34.41	46.50	53.34
Available Zn	Mean cult.	11.75	7.78	11.56	11.02	12.67
	Mean cont.	13.47	16.16	14.36	4.75	9.30
Available Cu	Mean cult.	3.63	3.63	1.38	2.69	3.80
	Mean cont.	3.63	3.31	1.20	1.09	2.63
Available Ni	Mean cult.	0.74	0.39	0.19	0.29	0.34
	Mean cont.	0.91	0.47	0.18	0.26	0.28
Available Cd	Mean cult.	0.11	0.07	0.08	0.10	0.19
	Mean cont.	0.30	0.10	0.09	0.05	0.06
Available Pb	Mean cult.	2.69	5.01	5.25	25.70	5.01
	Mean cont.	1.45	8.51	6.61	18.20	4.57

Source: adapted from Pasquini (2002). Back-transformed means (in original units) from Table C1 obtained by applying the inverse function used to transform the data. Key: Au=Audu; Ha=Hassan; Sa=Salem; Sh=Shitu; Ab=Abdullahi.

2.5. Statistical analysis

The purpose of the soil sampling strategy was to assess whether the differences between farms were the result of intrinsic soil characteristics or long-term cultivation effects or both. To do this, a 'two-way analysis of variance' was applied to the control and cultivated soils for every farm (Yates, 1973). In this context, the test could distinguish between farms on the basis of intrinsic soil chemical characteristics (the 'Farm' effect) by averaging across cultivated and control samples, and distinguish the effects of cultivation by identifying differences between cultivated and control averaging across farms (the 'Status' effect). Thus, the 'Status' effect reveals whether there are any overall differences between cultivated and control soils affecting all farms (e.g. an overall decline in available manganese in the cultivated soils in respect to the controls). Significant results where followed up with Tukey's Honestly Significant Difference (HSD) test (Sheskin, 1997). The two-way analysis of variance also looks for significance of a 'Farm*Status interaction' effect, which implies that differences between farms are not the same at the two levels of control and cultivated soils and/or differences between controls and cultivated are not significant across all farms. In the case of a significant interaction effect, to establish the nature of these differences, the procedure of conducting analysis of variance evaluating all levels of one factor across only one level of the other factor was employed (according to Sheskin, 1997, p. 503).

3. Results and discussion on the health and environmental risks in the Delimi farming area

3.1. Farm results

Table 1 shows the mean DTPA-extractable heavy metal levels for cultivated and control soils for each of the five study farms. The minimum and maximum values found across the five farms are contrasted to Berrow and Burridge's (1980) compilation of typical levels of heavy metals in soil, extracted with 0.05 M EDTA and 0.5 M acetic acid ('bioavailable' levels) in Table 2. The last column of Table 2 represents the

Table 2
Minimum–maximum range of heavy metals in the five Jos case study farms and typical values of heavy metals in soil extracted with 0.05 M EDTA and 0.5 M acetic acid and maximum permissible levels (total concentrations) according to the EEC (mg kg^{-1})

Element	Range in cultivated soil from Jos case study farms (DTPA extractable)[a]	Typical levels (EDTA extractable*)[b]	Typical levels (acetic acid extractable)[b]	EEC maximum allowable levels in agricultural soils pH 6–7[c]
Fe	21.38–58.88	100–3000	10–2000	–
Mn	23.00–48.04	5–100	5–100	–
Zn	7.78–12.67	<2–20	<2–30	150–300
Cu	1.38–3.80	<0.3–10	<0.05–3.0	50–140
Ni	0.19–0.74	0.1–5.0	0.2–5.0	30–75
Cd	0.08–0.19	<0.01–0.3	<0.01–0.3	1–3
Pb	2.69–5.25	<0.002–4.0	1.0–10.0	50–300

Source: adapted from [a]Pasquini and Alexander (2004); [b]Berrow and Burridge (1980); [c]Council Directive 86/278/EEC, Annex IA.

* Extractable levels by 0.05 M EDTA.

maximum allowable concentrations in agricultural soils according to the EEC, which serves to illustrate the divergence between regulatory maximum 'total' concentrations and typical 'bioavailable' levels. Making allowances for the fact that DTPA is reported to extract less than EDTA (Quevauviller et al., 1996) it appears that the soils in the farming area can be considered in the typical range for Fe (low end of the scale), Mn (mid-range), Zn (mid-range), Cu (low range), Ni (low range) and Cd (low to mid-range). Lead is in the typical range for all farms except Shitu, which has unusually high levels.

The results of the two-way analysis of variance are shown in Table 3. A significant 'Farm' effect indicated that there were overall differences in heavy metal status between the farms. A significant 'Status' effect indicated that were significant differences between control and cultivated soils, suggesting that cultivation practices were altering the heavy metal levels in the soil. A significant result for the main effects was followed up with Tukey's Honestly Significant Difference (HSD) test. These results are displayed in Table 4. However, in the case of a significant 'Farm*Status interaction' effect (Table 3) which suggested that either cultivation was not having the same effects across all farms, and/or differences between the farms were not the same at the control and cultivated levels, the procedure illustrated by Sheskin (1997, p. 503) was followed and the results are presented at the bottom of Table 4 in a single row. This was the case with available Zn, Cu and Cd.

Table 5 presents the mean values and standard deviations for total concentration of Fe, Mn, Zn, Cu, Ni, Cd and Pb in every crop batch tested. Four batches consisted of lettuce (batches labelled Abdullahi, Audu, Hassan, Shitu) and one batch of carrot (Salem's farm). All batches consisted of 10 replicates except for Salem where one sample was lost during preparation, and Audu where one sample was excluded from the analysis because it appeared to have been contaminated (probably by soil). These results can be contrasted with the typical ranges and critical concentrations of heavy metals in plants (mg kg^{-1}) according to Alloway (1990) (Table 6): in all cases except Fe where there was no information, the values from the case study farms fall within the normal range. A ratings scheme for foliar examination of micronutrients in crops according to Landon (1984) (Table 6) likewise suggests that levels of Mn, Zn and Cu are adequate for the lettuce crops. Fe values are far above the range given for adequate levels, however, it is unknown whether there is an excessive level. Salem's carrot values fall within the adequate range for Fe and Zn, but there is a suggestion of potential Mn and Cu deficiency. In terms of safe levels for human consumption, the crop Cd and Pb concentrations can be compared to the draft maximum permissible levels in vegetable crops destined for human consumption (mg kg^{-1}) proposed by the Codex Alimentarius Commission Alinorm 01/12 (FAO/WHO, 2001) in Table 7. In all cases Cd and Pb concentrations exceed the draft maximum permissible levels for human consumption.

The results for the two river water samples collected towards the end of the dry season, when the water level of the Delimi was extremely low, are presented in Table 8. The results can be compared to the phytotoxic threshold values in irrigation water for crop production. Fe, Mn, Zn and Cu are undoubtedly well above the threshold values, Ni concentrations are

Table 3
Results for seven heavy metal metals using two-way analysis of variance applied to control and cultivated soils of different farms

Variable tested	Farm effect		Status effect		Farm*Status interaction effect	
	F test	*p* value	*F* test	*p* value	*F* test	*p* value
Avail. Fe Log10(mg kg^{-1})	49.09 (4,90)	<0.001	0.34 (1,90)	N.S.	0.49 (4,90)	N.S.
Avail. Mn mg kg^{-1}	7.42 (4,90)	<0.001	11.22 (1,90)	0.001	1.28 (4,90)	N.S.
Avail. Zn Sqrt(mg kg^{-1})	4.39 (4,90)	0.003	0.24 (1,90)	N.S.	6.95 (3,90)	<0.001
Avail. Cu Log10(100*mg kg^{-1})	36.84 (4,90)	<0.001	19.03 (1,90)	<0.001	5.53 (4,90)	<0.001
Avail. Ni Log10(100*mg kg^{-1})	20.26 (4,90)	<0.001	0.00 (1,90)	N.S.	0.63 (4,90)	N.S.
Avail. Cd Log10(100*mg kg^{-1})	10.36 (4,90)	<0.001	0.80 (1,90)	N.S.	13.47 (4,90)	<0.001
Avail. Pb Log10(100*mg kg^{-1})	32.71 (4,90)	<0.001	0.15 (1,90)	N.S.	2.21 (4,90)	N.S.

Source: adapted from Pasquini (2002). Values in brackets in the *F* column are degrees of freedom.

Table 4
Outcome of multiple comparison tests carried out on terms that resulted significant in the two-way analysis of variance

Variable tested	Farm effect	Status effect	Farm*Status Interaction
Avail. Fe Log10(mg kg^{-1})	Mean order: Sa, Ha, Sh, Ab, Au Sa<Ha and Sh Sa, Ha, Sh<Ab Sa, Ha, Sh, Ab<Au	N.S.	N.S.
Avail. Mn mg kg^{-1}	Mean order: Sa, Sh, Au, Ab, Ha Sa<Ab, Au and Ha	Cult<Cont	N.S.
Avail. Ni Log10(100*mg kg^{-1})	Mean order: Sa, Sh, Ab, Ha, Au Sa<Ab and Ha Sa, Sh, Ab, Ha<Au	N.S.	N.S.
Avail. Pb Log10(100*mg kg^{-1})	Mean order: Au, Ab, Sa, Ha, Sh Au<Ab, Sa, Ha and Sh Ab, Sa, Ha<Sh	N.S.	N.S.
Avail. Zn Sqrt(mg kg^{-1})	Farm*Status interaction For Sh: Cont<Cult For Ha: Cult<Cont At Control mean order: Sh, Ab, Au, Sa, Ha, Sh<Au, Sa and Ha At Cultivated mean order: Ha, Sh, Ab, Sa, Au, N.S.		
Avail. Cu Log10(100*mg kg^{-1})	Farm*Status interaction For Sh: Cont<Cult For Ab: Cont<Cult At Control mean order: Sh, Sa, Ab, Ha, Au, Sh, Sa<Ab, Ha and Au At Cultivated mean order: Sa, Sh, Au, Ha, Ab, Sa<Sh, Au, Ha and Ab		
Avail. Cd Log10(100*mg kg^{-1})	Farm*Status interaction For Au: Cult<Cont For Ab: Cont<Cult For Ha: Cult<Cont For Sh: Cont<Cult At Control mean order: Sh, Ab, Sa, Ha, Au, Sh, Ab, Sa, Ha<Au At Cultivated mean order: Ha, Sa, Sh, Au, Ab, Ha, Sa, Sh, Au<Ab		

Source: adapted from Pasquini (2002). Outcome of Tukey's multiple comparison tests carried out for the main effect terms which tested significant using two-way analysis of variance (Table). No multiple comparisons were carried out if the outcome of the test was non-significant (this is marked by N.S. in the appropriate cell). Means are ordered from lowest to highest and (<) indicates which means are significantly lower. In the event of a significant 'Farm*Status Interaction', the results are presented exclusively in a single row.
Key: Au=Audu; Ha=Hassan; Sh=Shitu; Sa=Salem; Ab=Abdullahi.

Table 5
Mean values and standard deviations (in brackets) of different variables in six different crop batches (mg kg^{-1})

Variable	Au lettuce	Ha lettuce	Sh lettuce	Ab lettuce	Sa carrots
Tot. Fe	1585 (422)	1840 (1265)	2290 (537)	2417 (1092)	118 (30)
Tot. Mn	40.26 (6.58)	50.26 (21.57)	56.59 (13.29)	50.62 (11.93)	11.39 (4.20)
Tot. Zn	57.56 (8.21)	66.48 (23.65)	182.1 (123.9)	85.65 (11.65)	53.67 (17.55)
Tot. Cu	8.63 (0.90)	13.92 (5.44)	5.58 (0.80)	8.98 (1.09)	4.40 (0.98)
Tot. Ni	2.57 (0.41)	2.97 (1.82)	3.47 (0.91)	3.63 (1.58)	1.21 (0.83)
Tot. Cd	0.28 (0.07)	0.32 (0.06)	0.21 (0.03)	0.15 (0.03)	0.72 (0.30)
Tot. Pb	5.88 (1.44)	11.58 (2.88)	9.85 (3.86)	10.84 (3.90)	6.07 (2.64)

Source: adapted from Pasquini (2002). Key: Au=Audu; Ha=Hassan; Sh=Shitu; Ab=Abdullahi; Sa=Salem.

Table 6
Typical ranges and critical concentrations of heavy metals in plants (mg kg^{-1}) according to Alloway (1990) and a ratings scheme for foliar examination of micronutrients in crops according to Landon (1984)

Variable	Normal range[a]	Critical concentrations (1)[a]	Critical concentrations (2)[a]	Deficiency levels[b]	Adequate levels[b]	Excessive levels[b]
Fe	–	–	–	<50	50–250	?
Mn	20–1000	300–500	100–7000	<20	20–500	>500
Zn	1–400	100–400	100–900	<20	25–150	>400
Cu	5–20	20–100	5–64	<4	5–20	>20
Ni	0.02–5	10–100	8–220	–	–	–
Cd	0.1–2.4	5–30	4–200	–	–	–
Pb	0.2–20	30–300	–	–	–	–

Source: adapted from [a]Alloway (1990); [b]Landon (1984).
(1): Level above which toxicity effects are likely.
(2): Values likely to cause a 10% depression in yield.

about twice the threshold, whereas Cd and Pb are below.

3.2. Potential soil deficiencies or toxicities

The comparison between Tables 1 and 2 shows that for all farms the levels of heavy metals can be considered to be in the typical range for soils, with the exception of Shitu, which had strikingly high levels of Pb.

It is cautioned that potential toxicities or deficiencies cannot be established straightforwardly with soil data, as there are various complicating factors. Firstly, it should be noted that depending on the extracting agent used, different critical levels will be established, and that the most common soil testing methods do not relate well to field calibration studies (Landon, 1984). In this research, DTPA was chosen as the extracting agent and (as mentioned earlier in the paper) like with other extracting agents there are controversies surrounding the use of it. A second factor that confounds the interpretation of heavy metal concentrations in the soil is the soil environment itself. It is known that the availability of heavy metals to plants in soil is strongly dependent on the pH, and it is generally found that the toxicity of various metals is reduced at higher pH (Williams, 1980; Alloway, 1990), and the harmful effects are also alleviated by higher amounts of organic matter (Williams, 1980; Webber, 1980b). Furthermore, each element can be differently affected by a variety of factors. For example, deficiency conditions or contributory factors for Cu deficiency are low soil Cu, high soil P, high organic matter and N, high soil Zn and sandy texture (Landon, 1984, Table 7.26). Elements can interact with one another: for example, a study on Ni, Cu and Zn showed that generally the effects of the metals in combination tended to be additive (Davies, 1980), while other elements can be antagonistic (Prasad and Power, 1997). A third factor that will influence the dose–response curves for micronutrients (which will have both a lower and an upper critical concentration) or non-essential elements (which will only have the upper critical concentration) will be the sensitivity of each plant species. Plant species and their

Table 7
Draft levels (mg kg^{-1}) proposed by the Codex Alimentarius Commission Alinorm 01/12

Variable	Leafy vegetables[a]	Brassica[a]	Legume vegetables[a]	All other vegetables[a]
Cd	0.2	–	–	0.05
Pb	0.3	0.3	0.2	0.1

Source: adapted from [a]FAO/WHO, 2001.

Table 8
Semi-quantitative results on dissolved elements (mg l^{-1}) in Delimi river water and phytotoxic threshold values of selected trace elements for crop production

Variable	Delimi River water[a]	Phytotoxic threshold values[b]
Fe	331	5
Mn	29.7	0.2
Zn	29.3	2
Cu	2.5	0.2
Ni	0.43	0.2
Cd	n.d.	0.01
Pb	1.5	5

Source: adapted from [a]Pasquini (2002); [b]Pescod (1992), cited by Cornish (2002).

cultivars differ greatly in their sensitivity to both toxicities and deficiencies.

For all the reasons detailed above, the results on heavy metals in soil should be used as qualitative indicators of potential deficiencies and toxicities, and should be combined with data on crop tissue metal concentration. Nevertheless, in the light of the data and the near neutral status of the soils, a few general observations can be made. Soils in the study area are unlikely to be affected by either Fe or Mn deficiency or toxicity. In the case of Fe, toxicity is believed to be a rare problem (Landon, 1984), and there are probably no deficiency risks because the soil pH is below 7.0. Deficiencies tend to occur in fruit crops growing on calcareous soils (MAFF, 2000), while vegetables tend to be quite tolerant of low levels of Fe (Prasad and Power, 1997). Manganese deficiency commonly affects cereals, sugar beet and peas, and occurs in peaty, organic or sandy soils at high pH (MAFF, 2000). Manganese toxicity can instead occur in acid soils (Prasad and Power, 1997).

Zinc, Cu and Ni are well below the EDTA-extractable maximum allowable element concentrations in the UK, for non-calcareous soils (Alloway, 1990), and within Berrow and Burridge's (1980) 'typical' soil levels, so should not be present in toxic concentrations. Increasing research is strengthening the claim that Ni should be considered an essential plant nutrient (Prasad and Power, 1997), but it is not required in large quantities, so although Ni levels are very low in the study area, it should not pose a deficiency problem. It is not as simple to ascertain a potential Zn or Cu deficiency but both seem improbable. Possible deficiency levels for Zn extracted with DTPA are between 0.5 and 1.0 ppm, although plants vary in their requirements as well as their abilities to extract Zn from the soil. Furthermore, zinc deficiency is quite common in calcareous soils but is rare in acid soils (Landon, 1984). Copper deficiencies are uncommon in vegetables except in lettuce and onion, but occur mainly in cereals on sands and peats, reclaimed heathland and shallow soils over chalk (MAFF, 1980).

The evaluation for potential Cd and Pb toxicity is affected by various factors. For example, cadmium levels would appear to be quite low but even low levels can result in high yield depressions depending on the crop species: for example, solution cultures containing 0.2 μg Cd ml^{-1} are sufficient to cause a 50% yield depression in field beans, turnips and red beets, but 9.0 μg Cd ml^{-1} are required to obtain a similar depression in cabbage (Bingham and Page, 1975). In the case of Pb there is no satisfactory extractant procedure to predict plant uptake, primarily because little is known about the factors that control availability of heavy metals at the root/soil interface. There is, though, a general agreement that only a small proportion of total Pb in the soil is available for uptake by plants because of its low solubility and mobility (Alloway, 1990). A complication for both metals is that available guidelines for maximum permissible levels in soil are based on a strong acid digestion, not on extractable levels, and therefore nothing further will be said about potential Cd and Pb toxicities at this stage.

3.3. Heavy metal accumulation in the soil and links to fertilisation practices

The two-way analysis of variance was carried out to determine whether the levels were the outcome of intrinsic soil characteristics or the outcome of general or specific cultivation practices. The significant 'Farm' effect for available Fe, Mn, Ni and Pb (Table 3) suggested that the differences between certain farms were most likely the result of intrinsic soil characteristics. In particular, Tukey's HSD test confirmed that Shitu's Pb levels were significantly higher than those of the other four farms (Table 4). It is not possible to explain why Shitu's farm should have considerably higher Pb levels than the other farms. The absence of a significant 'Farm*Status interaction' effect excludes the possibility of cultivation practices being responsible, but possibly in the past a few large-scale contamination events took place that also affected the control soil.

The significant 'Status' effect for available Mn showed that across all farms there was a trend for the cultivated soils to be lower than their controls in available Mn levels. This could be attributable to crop uptake or linked to a decline in organic matter (which the five study farms were experiencing—Pasquini and Alexander, in preparation).

The significant 'Farm*Status interaction' effects are of interest because they can potentially be linked to farmers' individual fertilisation practices. There was a significant increase in Shitu and Abdullahi's cultivated soils in respect to the controls, in terms of available Cd and Cu. Additionally, Shitu had increased levels of available Zn. Both farmers claimed to be using large quantities of town refuse ash over the years, and it is possible that these heavy metal increases are linked to this input. In contrast, Salem explained that he never used town refuse ash on his particular plot of land, whereas Hassan and Audu had employed town refuse ash sporadically. Hassan's cultivated soil displayed a decline in available Cd and Zn, and Audu's soil displayed a decline in available Cd, and these could potentially be attributed to crop uptake.

3.4. Heavy metal concentrations in the vegetables: implications for crop growth and human consumption

The confirmation of whether there is heavy metal accumulation in the food chain can only be established by testing the levels in the crops themselves. It is not sufficient to do soil analyses alone.

The data presented in Section 3 (Table 5) can be examined in the light of research published in the literature. The determination of critical levels above, which symptoms of toxicity are likely to manifest themselves in a particular crop, is quite complicated. Pot experiments can be carried out to study the effects of a single element on a crop species, however, when a range of contaminants is applied to the crop (for example, as sewage sludge and, in this case, as urban waste ash), it becomes very difficult to disentangle which contaminant is actually responsible for yield suppression. Berrow and Burridge (1980), for example, applied different sludge types (uncontaminated sludge, Zn-rich sludge, Cu-rich sludge, etc.) to lettuce and red beet, over the course of 4 years, to examine heavy metal levels. In many cases, the applications caused crop failure so that they were not able to measure heavy metal contents. They concluded that lettuce and red beet tolerated Zn in the order of 200–300 mg kg^{-1} in dry tissue, but they were not able to determine critical levels for Cu and Ni because the Cu and Ni-rich sludges also contained high Zn levels, hence, crop stunting or failure could have been attributable to Zn.

Table 6 provides an indication of typical heavy metal ranges found in plants, the critical concentrations above which toxicity effects are likely and likely deficiency levels. These values, which are not targeted to specific crops, can be compared generally to the data presented in Table 5. Although they contained extremely high Fe levels (which may be linked to the large concentrations in the irrigation water, which in turn may reflect the underlying geology of the area), crops did not appear to be negatively affected by these. While lettuce levels of Mn and Cu seem adequate, carrot levels are below the deficiency threshold (even though they did not appear to be exhibiting any deficiency symptoms). A caution must be made that although leaf analysis of Mn is considered a useful diagnostic value, leaf Cu levels are not considered good indicators of Cu status (MAFF, 2000). Lettuce and carrot levels of Zn are adequate. Concentrations of Ni, Cd and Pb of all crops fall within the normal range for plants.

Cadmium, lead and nickel are of additional concern because of their toxicity to humans and animals. Cadmium is a particular problem, because it can cause problems to human health at plant tissue concentrations that are not directly phytotoxic (Peijnenburg et al., 2000). The draft levels for Cd and Pb in vegetables proposed in 2001 by the joint FAO/WHO Codex Alimentarius Commission are presented in Table 7. Contrasting the data from Tables 5–7 it is immediately clear that the lettuce batches differ in their mean Cd concentrations, some means falling below the limit for 'Leafy vegetables', and other surpassing it. Carrot, which can be grouped under the heading 'All other vegetables' has a mean concentration that is more than 10 times the limit set for this group. As for Pb there is no doubt that all crops present mean concentrations that are 20- to 40-fold in the case of lettuce, and 60-fold in the case of carrot, higher than the FAO/WHO maximum recommended level.

The small number of soil and crop samples precluded any formal attempt at correlating the concentrations of heavy metals found in the vegetable crops with the farm levels. Nevertheless, a couple of qualitative observations can be made. Firstly, the carrot concentrations of Cd are from two-fold to approximately five-fold larger than lettuce concentrations, and they do not appear to be reflected in soil levels. Indeed, Salem's farm Cd concentrations did not differ significantly from either Hassan, Shitu or

Audu (Table 4). This suggests that carrot may be accumulating Cd (contrary to the view held in the literature that leafy vegetables should have a higher concentration of Cd compared to root crops). Similarly, soil Pb concentrations are not reflected in the crop Pb concentrations: despite Shitu's strikingly high available soil Pb, his lettuce levels were in the same range as the lettuce from the other farms (it must be remembered, however, that it is reported in the literature that DTPA is not a suitable extracting agent for Pb—Connor, 1988).

In conclusion, the levels of Fe, Zn, Ni, Cd and Pb appear to fall within the normal range for plants for all crops. Carrots may indeed be deficient in Mn and Cu, but as the plants did not appear to be exhibiting deficiency symptoms further research into this is needed. The levels of Cd and Pb are of concern because of the implications for human health. Although the levels were within the typical range for plants, all crops had Pb levels that surpassed the FAO/WHO maximum recommended level, and carrots and certain lettuce batches had excessive amounts of Cd.

3.5. Sources of heavy metals

The soil data from the five case study farms has suggested that problems with Fe, Mn, Zn, Cu or Ni deficiency or toxicity in the Delimi Langalanga farming area are unlikely. This assessment is supported by the crop tissue concentrations, although there is a possibility that carrots may be deficient in Mn and Cu and this requires further studies. It is harder to judge soil Cd and Pb levels, although the available Pb levels for Shitu's farm were noticeably higher than those of the other farms. Crop Cd and Pb levels were comfortably within the normal range for plants, however, in terms of human consumption they posed a serious health risk.

The question remains of what the source of the various heavy metals is. The irrigation water contributes large amounts of Fe, Mn, Zn and Cu, considerably beyond the phytotoxic threshold values for crop production. Ni values were twice the threshold value, whereas Cd and Pb levels were well below the phytotoxic thresholds. Thus, irrigation water can potentially contribute large amounts of Fe, Mn, Zn and Cu (presumably deriving from processes of weathering, leaching and subsequent erosion of weathered products into the stream system), but not Ni, Cd or Pb.

Irrigation practices, however, do not differ greatly between farms, thus irrigation water cannot explain the apparent Zn, Cu and Cd enrichment in Shitu and Abdullahi's cultivated soil. Both farmers had a history of using town refuse ash, unlike Hassan and Audu who applied it sporadically and Salem who declared he never used it on that particular portion of land. Thus, it is reasonable to conclude that the application of town refuse ash is resulting in the slow accumulation of select heavy metals in the soil.

A study on the heavy metal composition of Jos town refuse ash shows that it a highly variable material. If average values are used in combination with farmers' current application rates, the annual applications do not exceed EU limit values for amounts of heavy metals that may be added to agricultural land (Pasquini and Alexander, 2004). However, the difference between the lowest and highest values recorded was highly variable: 1.4–35.4 g kg^{-1} for Fe, 110–21414 mg kg^{-1} for Mn, 42–3753 mg kg^{-1} for Zn, 27–662 mg kg^{-1} for Cu, 19–50 mg kg^{-1} for Ni, 6.1–12.2 mg kg^{-1} Cd and 26–6539 mg kg^{-1} for Pb (Pasquini and Alexander, 2004). Thus, contributions to agricultural land are likely to vary from year to year depending on the degree of contamination of a particular batch (which might also explain Shitu's unusual soil Pb contamination—possibly in the past he purchased large quantities of highly contaminated ash which he spread widely across his land), the actual availability of the heavy metals (which is unknown) and also on changing fertilisation practices. All farmers reported that the practice of using town refuse ash was declining, because the cost of obtaining this input had increased.

A final possible source of contamination is airborne dust. The Harmattan dust can bring large quantities of Ca, Mg and K (Møberg et al., 1991; Tiessen et al., 1991), and it is possible that it also carries other air-borne contaminants. Various studies have shown that anomalously large concentrations of heavy metals in plants can be caused by contamination with anthropogenic emissions and not soil composition (Alaimo et al., 2000), through foliar uptake (Greger et al., 1993). Therefore, the possibility that the concentrations of Pb and Cd found in the crops are caused by atmospheric pollution needs to be explored further.

3.6. Additional health and environmental risks

This study has provided an initial analysis of the health and environmental risks associated to the practice of using town refuse ash, in terms of heavy metal contamination. However, there are a number of other risks that need to be explored.

Some relate to the way in which ash is produced. Farmers produce the ash by open burning. A truck-load of refuse is brought to the farm and burnt in situ. Sorting takes place after burning is complete, as farmers find it less arduous and hazardous to remove non-degradable materials after the waste has been reduced to ash. Various studies have reviewed the environmental implications of incineration and ash disposal, for example the problem of the production of particulate and gaseous emissions containing heavy metals, polychlorinated dibenzodioxins (PCDDs), polychlorinated dibenzofurans (PCDFs), polycyclic aromatics (PCAs), polychlorinated biphenyls (PCBs), acids and other compounds. The ash itself will also contain all these substances, and this can eventually result in contamination of land and water (Lisk, 1988). Coal fly-ash changes the soil's chemical properties and has also been shown to affect microbial respiration, even though little is known about this (El-Mogazi et al., 1988). The production of ash in Jos is subject to the same risks and, additionally, the open burning of waste is even more dangerous as it will result in toxic emissions that are liberated directly into the atmosphere (with no attempt at detoxification), and because this takes place at ground level, it represents a possible health hazard to humans. This problem is not restricted to farmers but affects the general public. The waste collection system in Jos has virtually collapsed, and refuse collects in large heaps on the sides of the roads, especially in proximity of markets. Periodically, these heaps are set on fire to reduce the volume of waste, and during combustion the streets are filled for several days with heavy smoke.

Thus, there are studies needed on general atmospheric pollution levels, the contents of the emissions from the ash preparation, and the contents of the ash in terms of PCDDs, PCDFs, PCAs, PCBs, acids and other compounds. Furthermore, although a study on the total (nitric acid extractable) concentrations of heavy metals in ash is reported in Pasquini and Alexander (2004), research is needed on which forms they are present in and their plant-availability.

Although the practice of burning refuse prior to sorting will be partly responsible for the presence of heavy metals in the ash, and can cause contamination with other dangerous compounds, it is likely to reduce the hazards of handling raw waste in terms of pathogen contamination. If a sufficient temperature is reached during composting (60 to 70 °C), most pathogens are destroyed (Déportes et al., 1995), and thus it is probable that, in most instances, because the burning process reaches temperatures that are higher than the composting process (although lower than in modern incinerator plants), all pathogens should be destroyed. This needs to be ascertained through further studies.

Another issue for further research relates to the mode of application of the ash. Farmers apply ash in two ways: either at the beginning of the farming season directly to the soil, or when the crops are semi-grown, in which case part of the ash will fall on the soil, but most of it actually falls on the crops. This is deliberate and farmers explained (and it was indeed the case) that it changed the crop colour to a darker shade of green, and that ash was therefore good for the leaves (Pasquini and Alexander, 2005). It is speculated that the changing colour of the crops is the result of foliar uptake of nutrients through the leaves, however, as the foliar uptake of heavy metals from anthropogenic emissions has been documented (Alaimo et al., 2000), this raises the concern that crops may also absorb contaminants directly from the ash deposited on the leaves. If this is the case, even if soil contamination through ash application is slow and does not have a large impact on the crops, the direct application to the surface of the leaves could result in the build-up of heavy metals to dangerous levels.

4. Conclusions

This study sought to assess the health and environmental risks of using town refuse ash in urban and peri-urban vegetable production around Jos in Nigeria. Its primary focus was on the potential for heavy metal accumulation (Fe, Mn, Zn, Cu, Ni, Cd and Pb) in the soil and the food chain, and it has also discussed other health and environmental risks that need further research.

Caution should be applied when considering the outcomes of this study, since apart from Landon's (1984) compilation, the only available studies for comparison were based in temperate zones. Nevertheless, the findings of the study suggest that the soil concentrations of the seven heavy metals listed above fall within 'typical' soil levels, and that there should not be any problems of either toxicities or deficiencies for plant growth. Only one farm showed abnormally high Pb levels, but because the control soil also had very large concentrations, it was difficult to determine what the potential cause of the high levels might have been.

Two farms, however, were providing evidence of accumulation of select metals, Zn, Cu and Cd, which could be linked to the claim by the two farmers of having used large quantities of town refuse ash in the past. Of the remaining three farms, one farmer claimed he never used ash and the other two used it sporadically.

Crop samples were taken from each farm, and although none of the heavy metals was present in phytotoxic concentrations, Pb was present in concentrations that were 20 to 40 times higher in lettuce and 60 times higher in carrot, than the draft levels proposed by FAO/WHO (2001) for vegetables for human consumption. Carrot Cd levels likewise were 15 times higher than the FAO/WHO (2001) limit, whereas in the case of lettuce, contamination depended on which batch was being examined.

The limited number of samples and the restrictions tied to the type of extracting agent used did not allow correlation between crop levels and soil concentrations at this stage. However, the high levels of carrot Cd relative to the lettuce levels, which are not reflected by the soil levels, suggest that carrot may be selectively accumulating Cd. Further studies are required to establish the source of the Cd and Pb. The Delimi River water sample analysis showed that although the river had very high concentrations of Fe, Mn, Zn and Cu, Ni, Cd and Pb levels were low (however, since these conclusions are based on samples taken once at the end of the season, further studies to monitor water quality throughout the farming season need to be carried out). One potential source that requires investigation is atmospheric pollution, as crops may be accumulating high levels of Pb and Cd through foliar contamination.

Town refuse ash plays a very important role within local farmers' soil fertility management strategies, since it can raise the pH of the soil and contribute a range of micronutrients. To date, the practice of using town refuse ash does not appear to have resulted in the large-scale contamination of soil in the farming area. It is probable that the composition of the waste in the past was such that it contained mostly organic material. With increasing industrialisation and consumerism on the part of the town's population, though, the waste is liable to include sources of heavy metals. Indeed, ash samples collected from around the town showed that although mean contamination was low, there was high variability, with some samples being heavily polluted (Pasquini and Alexander, 2004). This potential risk, together with the evidence that crops contain large concentrations of Pb and Cd, and the unsafe practices associated with the preparation of town refuse ash, indicate that there is an urgent need to conduct further studies to ascertain the exact health and environmental risks, so as to identify a strategy for safe utilisation of urban waste in Jos.

Acknowledgements

This study was carried out under the auspices of a British Council-sponsored link between the Department of Geography, University of Durham, UK and the Department of Geography and Planning, University of Jos, Nigeria. The fieldwork was sponsored by: the Department of Geography, University of Durham; The British Council; the Tropical Agriculture Association; the Gilchrist Educational Trust; the Durham Geography Graduates Association; the Hatfield Trust and the Dudley Stamp Memorial Fund. Special thanks go to many people in Nigeria, particularly staff at the University of Jos, the farmers in the Delimi Langalanga community and the field assistant, Mr. Oluwashola Olaniyan. Thanks also to Mr. D. Wooff, Dr. I. Evans and Dr. N. Cox for their

statistical advice and to the laboratory staff at the Department of Geography.

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