Dynamic Soil, Dynamic Plant ©2009 Global Science Books

Trace Element Enrichment in Austrian Soils from Fertilization, and Regional Effects

Manfred Sager[*]

Austrian Agency for Health and Food Safety, Competence Centre of Elements, Spargelfeldstrasse 191, A - 1220 Vienna, Austria

Correspondence: * **manfred.sager@ages.at**

ABSTRACT

In all kinds of fertilizers sold on the Austrian market, 22 main and trace elements were determined in quasi total digests by ICP multi-element spectrometry, and total N by combustion. Accessory elements were expressed in terms of a fertilization rate of 100 kg N resp. 100 kg P/ha. The country was parted in regions due to geological and climate criteria. The rate of use of different kinds of fertilizers varied between the regions. Whereas there were no regional differences in composition of mineral fertilizers, some were found for commercial organic fertilizers, manures and garden moulds, which could be traced mainly to land use. Regional geology just explained differences in Al, Ba and Be in composts, population density effected Na and Pb, and Cu and Zn in manures reflected the amount of commercial animal feedstuff used. When fertilized with the same equivalents of P or N, composts supplied higher loads of accessory elements than mineral fertilizers, except for Cd-As-Be-V. For budgeting, atmospheric deposition as well as average concentrations and crop yields of wheat and potatoes were taken into account. If an organic farmer takes organics from the local market at the same N- or P-rate per area, accumulations in the soil growing wheat or potatoes are more probable, unless these excesses can be used for other special crops. It will be necessary to budget not only N, P and C, but also trace elements.

Keywords: atmospheric deposition, composts, manures, mineral fertilizers, trace element budgeting

Abbreviations: DAP, di-ammonium phosphates; **NPK**, mineral fertilizer containing N, P and K as main components; **PK**, mineral fertilizer containing P and K as main components

INTRODUCTION

Soils have various functions. They are the most important substrate to grow crops for human nutrition, for domestic animals, or maybe for the supply of energy in the future. In addition, they have important functions of filtering and storage of groundwater. For urban civilizations, they give space for recreation areas like parks, playgrounds, hiking trails, etc. Threats to arable soils arise from urbanization, contamination, salinization, compaction and erosion.

Fertilization means the input of plant nutrient compounds to the soil in order to increase crop yield. In addition, all fertilizing procedures should sustain favourable humic contents and soil pH. Application of fertilizers in inappropriate amounts and element proportions may influence the quality of crops as well as the environment. Indicators for sustainable ecological conditions are the nitrogen budget, the phosphorus budget, the humics budget, biodiversity, energy input, soil compaction, soil erosion, and the emission of gases (Danneberg *et al*. 1999; Kehres 2007).

In many cases, nitrogen is the limiting main nutrient. It is much slower available from plants, dungs and crop residues, than from mineral fertilizers and manures (Peszt *et al.* 1997).

Which kinds of fertilizers are available?

In Austria, “Guidelines of Adequate Fertilization” (Danneberg *et al*. 1999) have been issued to recommend ecologically and economically feasible amounts of nutrient loads. The term “fertilizer” covers a wide range of mixtures of inorganic salts as well as organic compounds and wastes. Apart from main constituents N-P-K-S, their composition is highly variable among fertilizer types. This includes microelements necessary for plant growth (e.g. Zn, Mo, Co, B), unwanted and largely toxic elements (e.g. Cd, Pb), and elements of low physiological activity (e.g. Li).

For all over Austria, the annual input of nutrient elements per hectare arable area has been estimated for 1995 as 51 kg N + 34 kg P_2O_5 + 77 kg K_2O from organic fertilizers produced on site, and 47 kg N + 22 kg P_2O_5 + 25 kg K_2O from mineral fertilizers (Dachler and Kernmayer 1997). Until Austria joined the European Union, Austria had a closed market for fertilizers; after this, budgeting would be biased by unknown imports and exports. Of course there are variations between different regions, crops and soil types. P_2O_5 and K_2O input peaked in the sixties, and N- input peaked in the eighties, but since then there has been a slight and steady decrease.

Within this context, all samples containing organic carbon have been termed as organic fertilizers, others as mineral fertilizers. Organo-mineral fertilizers contain at least 25% organic substance in their dry mass. They may be mixed from wood residues, crude phosphates, K-salts, K-Mg-salts, limestone, magnesia, gypsum or other ground rocks of natural origin; no industrial by-products are permitted. Garden moulds are mixtures from compost and other components (except peat and synthetics) as a substrate for growing green plants, with a minimum of 15% organic substance. Composts should contain at least 15% of organic substances within their dry mass (Dachler and Kernmayer 1997).

Whereas mineral fertilizers are industrial or mining products, wastes from domestic animals and from plant production are recycled to the soil as organic fertilizers.

Contrary to fertilizers, soil aids do not contain significant amounts of plant-available nutrients, but they improve soil respiration and the soil water regime.

Received: 6 February, 2009. Accepted: 26 June, 2009.

Original Research Paper

Mineral fertilizers

Apatite $Ca_{10}(PO_4)_6F_2$ is by far the most important mineral source for phosphates. The Ca^{2+} can be easily substituted by Cd^{2+}, which is just marginally smaller (ionic radius 0.10 nm). Sr^{2+} (0.11 nm), Eu^{2+} (0.11 nm), Pb^{2+} (0.12 nm), and Ba^{2+} (0.135 nm) are also possible substituents for calcium. Phosphate can be substituted by arsenate and vanadate, and very important for biological apatites, 3 phosphates by 4 carbonates. The position of fluoride can be also occupied by hydroxide or chloride (McConnell 1973; Sery *et al.* 1995; Van Cauwenbergh 1997). Substitution leads to various minerals of apatite structure at the atomic level. The average contents of Cd, Cr, Hg, V, and U in sedimentary phosphate rocks are significantly higher than those in igneous phosphate rocks. Fertilizers from carbonatites have higher contents of rare earth elements, Sr, Ba, and Th, whereas fertilizers from phosphorites have higher contents of Cd, As, and U (Otero *et al.* 2005). These accessory elements, or impurities, cannot be removed from the bulk by physical methods (e.g. flotation), but only via complete dissolution and recrystallisation. Phosphates are usually mined open air at a large scale at dry locations, and recrystallisation on site is too expensive.

Nitrogenous components, however, get synthesized largely via the gas phase, with ammonia as the first step, thus they are usually very clean.

Contrary to soils, mineral fertilizers are largely soluble, because they should be available to the crops within one season of growth.

Fertilization with ammonium sulfate, di-ammonium phosphate, or urea may shift the soil pH towards more acidity, whereas hyperphosphate and ammonium nitrate lime tend to increase soil pH. In Austria, 58% of nitrogen load came from ammonium nitrate lime, 36% from various NPK mixtures, 4% from urea, and only 2% from diammonium phosphate. The P- load came mainly from NPK mixtures (54%), 21% from PK fertilizers, and 16% from super phosphate, triple phosphate and diammonium phosphates (Dachler and Kernmayer 1997).

Organic fertilizers and the carbon cycle

Organic fertilizers are defined to contain at least 50% of organic substance (as ignition loss 550°C), and more than 1% of either N (total), P_2O_5 (total), or K_2O (water soluble). Organo- mineral fertilizers contain at least 10% of organic substance (as ignition loss 550°C), and also more than 1% of either N (total), P_2O_5 (total), or K_2O (water soluble) (BGBl II 27.2.2004, Nr.100). In this compilation, special kinds of organic fertilizers, like manures, and composts, have been treated separately. Others may be mixtures from various sources.

Undoubtedly, a certain amount of organic amendment is necessary to ensure proper microbial activities and an organic carbon pool to favour the activity of the soil fauna (e.g. earthworms), which prevents too much compaction and erosion. Recycling of nutrients is also beneficial to protect surface waters from eutrophication, and to maintain nitrate in potable waters at low levels.

There are efforts to recyle biological waste from households, gardens and parks as organic fertilizers via fermentation which is termed composting. This is advantageous to sustain humics, utilize plant nutrient N and P, and substitute peat (Kehres 2008). Compost addition should supply N, P, K, and Mg and thus substitute mineral fertilizer, store carbon in the soil diminish erosion and nitrate leaching, and improve water storage capacity. It seems to be the most efficient measure for recultivation of deteriorated soils. Accessory elements, however, may be widely variable, and inputs of additional elements should be regularly and thoroughly controlled, which is one of the goals of this article.

Peat is usually mined from ecologically intact wetlands and largely imported from Eastern Europe. About 80% of peat is used for growing vegetables and flowers, or parks and roadside areas. In order to preserve ecologically valuable wetlands, it should be substituted by composts and soil aids.

Humics is a general term for dead organic residual substances in soils, which serve as nutrient basis for all soil organisms which rely on organic compounds (bacteria, fungi and higher trophic levels). Sugar beet and turnips decrease humics equivalent to 1300 kg carbon/ha annually, potatoes 1000 kg carbon, maize 800 kg, and cereals 400 kg (Kehres 2007). Humics is a major constituent of organic fertilizers.

In Germany, currently about 6.1 million tons of biological waste are composted, and in addition, 1.9 million tons are fermented each year. On the average, more than half of the compost is directly applied to arable soils, about 11% to hobby gardens, 12% for recultivation, and 13.5% are used as the organic component in the production of organo-mineral fertilizers (Kehres 2008). In Austria, the annual production of organic and organo-mineral fertilizers has been estimated to be 35000 tons (Dachler and Kernmayer 1997).

In terms of thermal utilization, 1 kg yields more than 11 MJ as caloric respective electric energy. In biogas facilities, biogas is extracted for heating and/or electricity production, and the so-called fermentation residue can be taken as organic fertilizer as well (EdDe *Dokumentation* Nr.11, 2007).

Combustion and composting of green plant wastes save about the same CO_2-emissions. If the green plant wastes contain much water and many fine mineral particulates, composting is favourable over combustion. If energy-crops are permanently used for combustion, and supplied by mineral fertilizers, this will result in a reduction of soil humics and decrease soil fertility on a long term (Kehres 2008).

Organic farming and bio-waste

In organic farming, nutrient supply is given via manures, dungs and composts, as well as organo- and organo-mineral fertilizers. These are largely produced locally. Domestic animals excrement up to 10% of their body weight per day. Of course, atmospheric deposition also varies from region to region, as well as crops, domestic animals and soil composition. In organic farming, there is no addition of nutrient elements from easily soluble and thus readily available mineral fertilizers, and no addition of synthetic pesticides and fungicides (Danneberg *et al.* 1999).

Residues from biogas production are usually put to arable soils as fertilizers without further treatment. Further processings to improve spreading on the field, and to increase plant nutrient, are discussed (Kehres 2008).

Nitrogen from manures is almost as rapid available as nitrogen from mineral fertilizers, whereas nitrogen from dungs and crop residues, however, acts much slower (Peszt *et al.* 1997). Addition of manure to soils is limited, however, in order to avoid penetration of nitrogenous compounds to the groundwater, and to avoid changes of soil characteristics. In Maryland (US), intense fertilization with poultry litter of high levels of Cu, Zn, As, and P led to respective inputs much higher than the extraction of wheat and corn crops grown on site, resulting in a significant increase in 1 M-HNO_3 extractable metals. Soil pH was shifted from pH 4 to more than pH 6, when compared with adjacent wood soils. In this region, intense poultry production yielded approximately 400 000 tons of litter per year, which was generally applied to fields in close proximity to the production houses (Codling *et al.* 2008).

Addition of manures has some liming effect on acid soils, where high levels of available aluminum become problematic. For the animal manures and sewage sludge, soil pH was highest after one week and declined thereafter, whereas pH steadily increased for soybean residues. Exchangeable and monomeric Al significantly decreased (Naramabuye and Haynes 2007).

Trace elements

Numerous investigations about nitrogen, carbon, phosphorus, sulfur, and potassium cycles have been made in order to optimize the supply of main nutrients N and/or P. Some trace metals levels have been of concern also, because their toxicity effects have been widely known, like Pb and Cd. Other elements which may be beneficial for plant growth, but also toxic at higher levels, are even added to fertilizers, like Co, Mo and B. Usually, their level in fertilizers is controlled by authorities, if their contents has been put on the label. Some other elements are accessory in phosphorites and apatites (McConnell 1973), e.g. beryllium, vanadium or uranium, which have hardly been treated so far among agriculturalists.

The addition of Cu and Zn to commercial animal feeds is known to raise their levels in the respective manures (Sager 2006).

Trace element deficiencies may harm crop yields of fruits, vegetables, and cereals. They cannot be concluded from the soil type, but from soil genesis. Lack of Mn harmed oats in Germany and the Netherlands ("Dörrfleckenkrankheit"). Too low Zn and Cu prevented wheat and oats to develop their shoots, but rye was tolerant. Lack of boron caused cracks in apples. In fruit farming, various combinations of B-Cu-Fe-Mn-Zn have been successfully applied, and B+Mo have been given to vegetables, like Cucurbitae (pumpkin, cucumber, melon) and Cruciferae (cabbage, rape, radish, mustard) (Donald ad Prescott 1975).

In the Netherlands, metals in soils even in rural areas have accumulated for decades, due to fertilizer and manure application, as well as atmospheric deposition. Though inputs are steadily decreasing, the removal with crops is still less than the total input. Model calculations revealed that leaching of arable soil has got an important source of surface water contamination. In the Netherlands, the surface runoff and the leaching of soils contributes 48% of Ni, 38% of Pb, 36% of Zn, 26% of Cu, and 22% of Cd to the total input into surface waters (Bonten *et al.* 2008).

Contaminations from atmospheric deposition

Whereas the farmer can influence the loads to his field via the fertilization pathway, additional inputs occur from atmospheric deposition. Therefore, it is worth while to compare total deposition data with median loads put to the fields together with 100 kg N or 100 kg P per hectare, and obtained from various types of fertilizers. Main pathways of output are the crops, groundwater leaching, and soil erosion. From this, possible enrichments or depletion can be concluded in the long term.

Till the early 1990s, coal combustion was the main source of arsenic emissions in Europe, but within 1990 to 2004, arsenic emissions have declined at about 53% (Harmens *et al.* 2008).

For Cd, waste incineration was the major anthropogenic emission source in 1990, but until 2005, the manufacturing industries and construction, as well as the public electricity and heat production sector became the main sources. In most European countries, Cd deposition declined to half since then (Harmens *et al.* 2008).

The main sources of Cr pollution are iron and steel mills. Between 1990 and 2004, Cr emissions decreased by 37%, but Cr contents in mosses used as bioindicators, hardly changed (Harmens *et al.* 2008).

Within the last decade, Cu emissions have been fairly constant. Its main sources are metal smelters, fossil fuel combustion, and brake wears (Harmens *et al.* 2008).

About 70% of Ni emissions come from petroleum refining, public electricity and heat production sectors, and from manufacturing industries. Central Europe is a region of rather low Ni emissions, and slight decreases of total depositions are noticeable (Harmens *et al.* 2008).

Road transportation as the main source of lead emissions is dwindling away, and the main lead sources are manufacturing industries and construction (Harmens *et al.* 2008).

In Vorarlberg, the most western country of Austria, the annual atmospheric deposition of lead decreased from 300 g/ha in 1990 to 20 g/ha in 2006 (Scherer *et al.* 2008). Similarly, in the Marchfeld northeast of Vienna, lead immision decreased from 86 to 16.5 g/ha between 1985 and 1997 (author, unpublished data).

The main source of antropogenic vanadium emissions is still the combustion of fuel oils, but emissions follow a clearly decreasing trend in Europe (Harmens *et al.* 2008).

In Europe, about 42% of Zn emissions come from the road transportation sector, followed by metal production at 21%. As an essential micronutrient, Zn in mosses has the most homogenous distribution among various regions (Harmens *et al.* 2008).

Besides sampling total atmospheric deposition in beakers (Bergerhoff-technique), lichens (Bieber and Uhl 2005) and mosses (Zechmeister 1997) were sampled throughout the country, particularly in remote areas, and calibrated versus Bergerhoff-data. The Austrian Environmental Agency measures concentrations per cubic metre air or per liter rain (data not given here).

Scope of current work

Quite often, a surely too simple question is put forward: what is better, mineral fertilization or organic amendments?

When we look at current fertilization practice, fertilizer dosage is not simply done just by fertilizer weight, but with respect to the input of a certain N or P load per area. Thus, the load of all accessory elements has to be considered per nutrient rather, in order to achieve a realistic classification of wanted or unwanted enrichments or deficiencies.

The dataset compiled within this context should help to estimate threats of contamination and salinization from fertilizer application, and the selection of suitable fertilizer types.

Regional differences in animal farming result in different animal waste (from cattle, pigs, chicken, none) and mineral fertilizer substitution, which may result in regionally different loads of accessory elements. Though Austria is a rather small country, it covers a lot of geological and pedological zones within Central Europe. Therefore it was an interesting task to look for differences in the (inorganic) composition and sales rates between samples taken from different regions, in particular for organic fertilizers, composts, manures and biogas residues.

MATERIAL AND METHODS

ICP multi- element spectroscopy permits to determine a lot of elements in the sample digest simultaneously, provided suitable dilutions have been done to meet the optimum calibration ranges and to minimize matrix effects. Samples were measured in 1+24, 1+4, and undiluted for the entire element spectrum. In case of high P, high Ca or high K samples, 1+49 or 1+99 dilutions were also necessary (for analytical lines and approximate detection limits see Sager 2005). The number of available analytes is limited by volatilizations, incomplete dissolution, and interactions with the usual glass vessels, as well as insufficient detection limits and blanks.

For samples low in organic carbon, 5 g were extracted with 3 M hydrochloric acid at a boiling water bath, filtered, the residue dry ashed in a muffle furnace at 560° in covered beakers, extracted with 3M hydrochloric acid again, filtered and made up to a combined total of 250 ml. For samples high in organic carbon, 10 g were dry ashed at first, dissolved in 3M hydrochloric acid at a boiling water bath, and treated as above. Manures were weighed wet into beakers, dried over 2 nights and treated as high organic carbon samples. Water contents were determined in aliquots at 110°C. All data were finally corrected to yield concentrations per dry mass.

For environmental screening presented within this context, the detection limits of the ICP-OES were regarded as sufficient. Uranium, tin and antimony would be accessible by additional measurements on the ICP-MS. Due to homogenization problems, dry ashing is still preferred, particularly for composts, manures and organic fertilizers.

Quality control was done by participation in the MARSEP ring test program of Wageningen Agricultural University (The Netherlands), 4 times 4 samples a year, as well as an in-house prepared NPK control sample running with each batch.

Within **Tables 2-18**, data for mean crust occurrence have been taken from Bowen 1979. Unless soil data were available from Austria, mean soil data were taken from Ure and Berrow 1982.

For calculations of annual extraction by crops, median concentration data (Houba, Uittenbogaard 1994) were multiplied with an average output of 4.5 tons of grains + 3.6 tons of straw per hectare. The yield of potatoes was estimated to be 30 tons fresh weight, equivalent to 6 g dry weight. Maize was assumed to yield 8 tons per hectare. Regional variations of wheat and potatoes grown on uncontaminated soils due to soil type and variety have been investigated in detail recently (Spiegel and Sager 2008), and range till a factor 2.

Assignment to regions

The sample data sets were grouped according to the postcode of the sampling location, which go along the main railway lines, but roughly represent the province and the region. Just small corrections had to be made for the exact assignment.

Austria covers almost all types of all central European landscapes resp. geological formations. In the Alps there are areas of limestone, schist, and of igneous rocks. The pre-alpine region is a lowland on tertiary sediments of intense agricultural use between the alps and the Bohemian massive, covering a wide range of soil types. In the Bohemian massive (Waldviertel and Mühlviertel) you meet largely acid brown soils upon igneous rocks (granite, gneiss,). In the Pannonian area (Marchfeld, Wiener Becken, Northern Burgenland), a lot of chernozems have developed in a flat area (120-200 m above sea level) in a rather dry climate (450-550 mm). The Weinviertel is a small part of the pre-Carpathian lowlands, of tertiary origin and partially covered with loess. Because the main part of the pre-Carpathian lowlands is in Moravia (Czech Republic), the local term Weinviertel was kept. Southeast of the alpine areas, there is a hilly area mainly on tertiary sediments, cropped with maize, fruits, woods and the like (Styria and Southern Burgenland).

RESULTS

General

Organic fertilizers, manures, dungs and composts are presumably of a more local origin. For the manures, the kind of animal which has been the source, is of more pronounced effect than the region; this will be treated within a further evaluation. Most regions, however, specialize for certain crops or domestic animals, and thus regional differences appear as well.

For manures and composts, data are not given for those regions, of which the number of samples was below 10 (including outliers), because this was regarded to be not representative.

In terms of concentration ranges, commercial organics, manures and composts are overlapping, but the medians (= the most expectable values) differ more than 2-fold for Cd, Cu, Mg, Mn, and V.

The expectable loads for 100 kg N had a strong regional tendency, with minima in the alpine and southeast areas, and maxima in the Weinviertel and the Pannonian areas. Only Mg was an exception, yielding maximum load with N fertilization in the Bohemian massive.

Organic fertilizers of any kind available in the alpine areas, had their minimum in most of the elements investigated: Al, Be, Cd, Co, Cu, Li, Fe, Mg, Mn, Mo, Na, Ni, Zn. Minimum input for 100 kg N is expectable for As, Ba, Cr, Pb, Sr, and V in the Southeast. Maximum loads for 100 kg N from organic fertilizers of any kind were found in the Weinviertel for Al, As, Be, Cd, Co, Cr, Fe, Ni, Pb, Sr, and V, and in the Pannonian region for Ba, Cu, Li, Mn, Mo, Na, and Zn.

From the number of samples, a certain frequency of use can be concluded, which is clearly different among the regions. The alpine regions are a top region for organic fertilizers. Among the mineral products, NPKs were strongly preferred in the mountains, but the overall fertilizing rate was the lowest. To the contrary, in the Weinviertel there was minimum use of organic fertilizers, but tops for triple phosphates, and PKs. Basic slag potash was sold only in this region, but its use was stopped in about 2005.

Di-ammonium phosphates have been largely sold in the pre-alpine and southeastern areas. Limes were preferably used in the Bohemian massive, where there are a lot of acid soils, but not in the Pannonian and the Weinviertel.

Because most frequency distributions are asymmetric, tables 1-18 contain the medians, with respect to dry mass. In order to discard possible outliers, 5-95% of the data ranges has been given; outliers do not change the medians.

Nutrient contents

Whereas it is conventional to give the nitrogen contents as the atom-percent, phosphorus is often tabulated as P_2O_5 in Austria, but it seems to be reasonable to give atom-percent P also for comparisons at an international level.

Though the ranges of nutrient contents are overlapping, the most expectable values (medians) differ. Composts are poorer in nitrogen, and also the N/P proportion. The N/P proportion does not show regional trends, however.

In organic farming, the load of organic fertilizers is selected largely due to the nitrogen contents. But the level

Table 1 Regional variations in nutrient contents referring to dry mass.

	% N	Range	% P	Range
Commercial organics				
Pannonian	5.29	2.42 - 14.9	1.73	0.15 - 3.87
Weinviertel	6.25	3.84 - 12.6	2.08	1.16 - 3.95
Northern pre-alpine region	6.65	1.20 - 13.3	1.90	0.20 - 4.37
Southeast	6.74	4.05 - 12.3	1.80	0.40 - 4.53
Alpine regions	6.87	2.80 - 13.4	1.75	0.34 - 4.86
Bohemian massive	7.12	4.50 - 13.2	2.39	0.42 - 4.68
Manures and dungs				
Bohemian massive	5.72	2.16 - 8.42	0.94	0.29 - 1.62
Alpine regions	6.24	5.55 - 14.55	1.42	1.05 - 2.09
Northern pre-alpine region	8.15	4.09 - 19.2	1.69	0.77 - 4.19
Pannonian	8.32	2.00 - 22.2	1.56	0.58 - 3.69
Composts				
Northern pre-alpine region	0.87	0.57 - 4.19	0.413	0.15 - 1.04
Bohemian massive	1.30	0.73 - 2.40	0.628	0.20 - 1.55
Weinviertel	2.09	1.48 - 3.07	0.93	0.34 - 1.51

available in the region, may differ. E.g., in the Bohemian massive, you may expect more nitrogen from commercial organics than from manures, whereas it is reverse in the Pannonian region. In **Table 1** the regions are grouped due to expectable nitrogen contents.

Aluminum

Total Al is a main component of the earth crust, its mean crust concentration being 8.2%, and its mean soil concentration 6.7%. Total Al in rocks was found about Gaussian distributed with a mean of 8.1% in the Bohemian Massive, and 9.2% in the Central Alpine Zone. Total Al levels are lower in the limestone and molasse areas (Thalmann *et al.* 1989). In the Austrian soil inventory program, however, Al was not investigated.

Because silicates and refractory oxides remain largely insoluble, the data obtained by the analytical method applied do not reflect total contents, but largely the amounts bound to soil humics and hydroxides. Plant-available Al (at about 200 mg/kg) significantly limits plant growth in acid soils, causing P-deficiency or Ca-deficiency symptoms (Sager 1986), but as complexes of Al^{3+} with humics are second strongest after Cu^{2+}, the soil organics counteract any action of Al.

Concentrations of Al in composts roughly reflected the geological element distribution, but commercial organics, manures and dung did not. Whereas concentration ranges of

Table 2 Regional data for aluminium, sorted for g/kg (acid extractable) Al.

Al: Mean crust = 82 g/kg
Mean soil = 67 g/kg

Type	g/kg	Range	kg for 100 kg N	Range	kg for 100 kg P	Range
Commercial organics						
Southeast	0.405	0.010 - 15.4	0.62	0.043 - 12.5	2.22	0.18 - 72.9
Pannonian	0.476	0.040 - 12.7	1.10	0.037 - 12.0	2.77	0.53 - 150
Alpine regions	0.487	0.043 - 6.82	0.47	0.066 - 10.1	2.25	0.28 - 70.5
Bohemian massive	0.495	0.14 - 0.79	0.64	0.19 - 12.8	2.62	0.51 - 58.0
Northern pre-alpine region	0.602	0.004 - 12.0	0.86	0.024 - 81.0	2.96	0.066 - 414
Weinviertel	0.978	0.027 - 7.52	2.63	0.202 - 14.0	4.14	0.73 - 36.3
Manures and dungs						
Bohemian massive	1.44	0.23 - 13.6	2.39	0.69 - 6.64	12.9	3.04 - 81.9
Northern pre-alpine region	1.99	0.41 - 10.4	1.74	0.40 - 16.7	13.4	3.26 - 64.6
Alpine regions	2.22	0.67 - 4.86	2.88	0.84 - 8.21	15.2	3.21 - 45.1
Pannonian	2.39	0.33 - 6.04	2.70	0.46 - 8.50	12.5	1.40 - 67.7
Composts						
Northern pre-alpine region	10.4	7.37 - 15.3	82.8	9.7 - 149	188	104 - 769
Weinviertel	15.2	9.86 - 25.7	52.1	23.5 - 88.4	148	84 - 366
Bohemian massive	17.2	15.7 - 17.8	78.3	38.2 - 176	275	110 - 1047
Ammonium nitrate limes	0.096	0.063 - 0.355	0.035	0.02 - 0.06		
N-P-K fertilizers	0.66	0.002 - 2.90	0.43	<0.02 - 2.12	1.44	<0.02 - 14.1
P-K fertilizers	0.71	0.16 - 2.23			1.16	0.70 - 2.66
N-P-K + sulfate	0.72	0.02 - 1.89	0.49	0.02 - 1.51	1.68	0.09 - 8.59
Di-ammonium phosphates	3.39	1.14 - 5.25	1.84	0.59 - 2.82	1.63	0.67 - 2.70

Table 3 Data for arsenic, sorted for the input equivalent to nitrogen.

As: Mean crust = 1.5 mg/kg	Crop uptake:	Atmospheric deposition:
Soil medians (Austria) 4-15 mg/kg	wheat 0.27 + 0.62 g	Marchfeld 1985: 6.0 g/ha.a
Mean soil = 11.3 mg/kg	maize 2.2 g	East of Austria 1997/98: 2.1 g/ha.a

	mg/kg	Range	g for 100 kg N	Range	g for 100 kg P	Range
Commercial organics						
Southeast	0.68	< 0.5 - 7.7	0.91	< 0.8 - 5.8	5.4	< 2 - 31
Alpine regions	0.66	< 0.5 - 4.7	0.92	< 0.8 - 9.7	4.3	< 2 - 111
Northern pre-alpine region	0.75	< 0.5 - 8.3	0.97	< 0.8 - 73	3.8	< 2 - 297
Bohemian massive	1.00	< 0.5 - 4.1	1.53	< 0.8 - 5.7	4.5	< 2 - 22
Pannonian	1.02	< 0.5 - 2.2	1.82	< 0.8 - 4.3	6.6	< 2 - 45
Weinviertel	3.12	< 0.5 - 5.0	3.8	2.2 - 6.5	13.5	< 2 -24
Manures and dungs						
Northern pre-alpine region	0.50	< 0.5 - 3.2	0.62	< 0.6 - 6.3	2.4	< 2 - 39
Bohemian massive	0.35	< 0.5 - 3.5	0.76	< 0.6 - 2.8	4.2	< 2 - 27
Alpine regions	0.91	0.7 - 2.4	1.40	1.1 - 4.0	4.3	< 2 - 22
Pannonian	0.56	< 0.5 - 3.4	1.74	< 0.6 - 3.9	6.5	< 2 - 29
Composts						
Weinviertel	5.21	2.1 - 11.3	18.2	7.8 - 48	61.2	24 - 205
Bohemian massive	5.21	2.5 - 6.8	27.1	9.7 - 58	39.3	36 - 455
Northern pre-alpine region	4.25	1.0 - 8.8	31.0	7.5 - 66	206	9.5 - 392
Ammonium nitrate limes	1.30	< 0.5 - 2.03	0.36	< 0.5 - 0.75		
P-K fertilizers	1.79	< 0.5 - 6.2			3.05	< 0.5 - 7.4
N-P-K fertilizers	2.54	< 0.5 - 15.5	1.51	< 0.5 - 12.9	5.4	< 0.5 - 42.5
N-P-K +sulphate	3.07	< 0.5 - 11.2	2.01	< 0.5 - 8.3	8.2	< 0.5 - 33.5
Di-ammonium phosphates	9.04	0.86 - 29.8	5.5	< 0.5 - 18.4	4.9	< 0.5 - 16.5

Al in commercial organics covered more than 2 orders of magnitude, ranges for manures and composts were rather narrow. Commercial organics contained about as much Al as multi-nutrient fertilizers, phosphates and manures were found at a common higher level, and composts were significantly highest, but still below the amounts presumably present in the soils.

The equivalent for 100 kg N was highly variable and thus nearly unpredictable for organics (0,006-103 kg Al/100 kg N) ands manures (0.4-318 kg Al/100 kg N, whereas ranges for the ammonium phosphates were rather narrow (**Table 2**).

Arsenic

The low mean crust value of about 1.5 mg/kg can be explained from its low occurrence in acid rocks (< 1 mg/kg), like in the Bohemian Massive, till 3 mg/kg in basic rocks in some areas of the Central Alps (Thalmann *et al.* 1989). Arsenic gets enriched in schists, phyllites, and above all in sulfides. The levels in soils are higher than in rocks, and range from 2.1 mg/kg upon the Bohemian Massive to 14 mg/kg upon limestone and molasse (Danneberg 1999). Most fertilizer samples were below this range, just Di-ammonium phosphates and composts might have reached soil levels. Manures, commercial organics, and samples without P main component were lowest.

Regional differences were not significant, as many samples were below detection limits. Possible higher inputs in the Pannonian region and the Weinviertel might be compensated by higher crop yields, as theses are quite fertile areas.

The amount of arsenic equivalent to 100 kg N was lower than the atmospheric deposition for mineral fertilizers, but sometimes higher for organics and composts. Similarly, fertilization of 100 kg P/ha yielded lower arsenic input than atmospheric deposition. However, As/P from composts was about 20 times higher than from mineral sources, and clearly higher than atmospheric input (**Table 3**).

Barium

In igneous rocks of the Bohemian Massive and the Central Alps, means of 532 mg/kg and 480 mg/kg resp. were found, which is close to the tabulated mean crust value of 500 mg/kg. In magmatic environments, Ba is associated to K (K/Ba= 50), and geochemical separations occur in hydrothermal solutions and during the weathering cycle. Thus, in schists and carbonates, Ba levels may go down to 100 mg/kg (in Austria) (Thalmann *et al.* 1989).

In the Austrian soil inventory program, however, barium was not investigated.

Within the fertilizer dataset, barium was found below mean crust (500 mg/kg) and mean soil (568 mg/kg) levels throughout, probably because fractions present in silicates have not been recovered by the analytical method applied. Samples without phosphate main component were largely below 10 mg/kg, but NPK and organic fertilizers were also at a median level of just 14 mg/kg. Significantly more barium (10-fold) was found in rock phosphates and composts, manures were in between NPK and composts. Variations were larger for NPKs, DAPs and commercial organics. Regional trends in compost composition might follow geology, but manures and commercial organics clearly did not.

Fertilization of 100 kg N from mineral fertilizers contained less barium than from organics, manures and composts. However, Ba-loads from organics and manures varied more than 3 orders of magnitude.

Though data about uptake of barium into crops are variable, 100 kg P presumably cover annual plant uptake from any source. Composts contained significantly more Ba/P than others (**Table 4**).

Beryllium

Beryllium is a lithophilic element, enriched in acid rocks and shales, and depleted in ultrabasic rocks and carbonates. In igneous rocks of the Bohemian Massive and the Central Alps, a mean of 4 mg/kg was found (Thalmann *et al.* 1989). The mean soil (1.5 mg/kg) is below the mean crust level (2.6 mg/kg), but in the Austrian soil inventory program, beryllium was not investigated. After weathering of rocks, beryllium is known to be sorbed on phosphates and clays. Thus, phosphates are the main source of beryllium in fertilizers. Di-ammonium phosphates and triple phosphates may exceed mean soil levels to about double.

When concentrations and loads got grouped into regions, all ranges were overlapping. Just the higher median of composts from the Bohemian Massive might indicate higher levels of occurrence in acid rocks.

Table 4 Data for barium, sorted for the input equivalent to nitrogen.

Ba: Mean crust = 500 mg/kg mean soil = 568 mg/kg		Crop uptake: maize 27 g			Atmospheric deposition: East of Austria 1997/98: 20 g/ha.a	
Type	**mg/kg**	**Range**	**g for 100 kg N**	**Range**	**g for 100 kg P**	**Range**
Commercial organics						
Southeast	12.6	0.4 - 66	17.9	0.5 - 115	90.7	20 - 480
Alpine regions	14.0	3.0 - 55	20.4	2.7 - 150	91.2	13 - 812
Bohemian massive	17.1	5.3 - 68	22.2	4.6 - 129	102.6	21 - 472
Weinviertel	12.7	2.5 - 76	22.6	1.6 - 141	103.6	131 - 525
Northern pre-alpine region	18.5	0.5 - 92	27.2	0.6 - 620	90.4	7 - 72770
Pannonian	14.0	3.2 - 63	29.2	2.4 - 113	90.7	22 - 1197
Manures and dungs						
Northern pre-alpine region	33.5	15 - 132	41.3	17 - 333	226	84 - 634
Pannonian	58.0	15 - 250	59.7	12 - 186	325	101 - 2481
Alpine regions	71.7	36 - 122	83.8	45 - 123	673	173 - 694
Bohemian massive	52.2	15 - 77	88.1	41 - 158	478	246 - 921
Composts						
Weinviertel	209	49 - 427	646	342 - 1041	1872	1133 - 5234
Northern pre-alpine region	87	76 - 99	650	110 - 849	2354	905 - 4981
Bohemian massive	244	91 - 402	1008	615 - 2006	4442	1577 - 6074
Ammonium nitrate limes	3.53	0.18 - 16.2	0.82	< 0.05 - 6.16		
Di-ammonium phosphates	11.5	1.26 - 234	5.5	0.76 - 128	4.8	0.61 - 107
N-P-K fertilizers	13.5	< 0.05 - 118	8.2	< 0.05 - 97	31	< 0.05 - 291
N-P-K + sulphate	24.1	1.2 - 102	16.5	1.1 - 89	60	4.1 - 291
P-K fertilizers	59.1	6.9 - 196			109	23.5 - 213

Table 5 Data for beryllium, sorted for the input equivalent to nitrogen.

Be: Mean crust = 2.6 mg/kg mean soil = 1.5 mg/kg	Crop uptake: wheat 0.03 g potatoes 0.02 g	Atmospheric deposition: below detection limit

	mg/kg	**Range**	**g for 100 kg N**	**Range**	**g for 100 kg P**	**Range**
Commercial organics						
Alpine regions	0.12	< 0.04 - 1.16	0.18	< 0.08 - 4.00	0.64	< 0.2 - 13.1
Southeast	0.12	< 0.04 - 1.19	0.20	< 0.08 - 1.78	0.84	< 0.2 - 6.92
Bohemian massive	0.19	0.06 - 1.05	0.30	< 0.08 - 1.51	1.53	0.26 - 8.83
Northern pre-alpine region	0.18	< 0.04 - 1.73	0.31	< 0.08 - 13.2	0.94	< 0.2 - 58.0
Pannonian	0.19	< 0.04 - 1.24	0.37	< 0.08 - 1.43	1.02	0.26 - 18.3
Weinviertel	0.36	< 0.04 - 1.27	0.49	< 0.08 - 2.37	0.49	< 0.2 - 2.37
Manures and dungs						
Northern pre-alpine region	0.30	0.11 - 1.18	0.32	0.11 - 1.29	1.91	0.49 - 7.46
Alpine regions	0.23	0.18 - 0.54	0.39	0.16 - 0.91	2.07	0.88 - 5.06
Bohemian massive	0.22	0.04 - 1.28	0.40	0.15 - 0.85	2.25	0.54 - 7.18
Pannonian	0.28	0.08 - 0.66	0.43	0.06 - 0.94	1.71	0.70 - 7.83
Composts						
Weinviertel	2.07	0.41 - 3.18	7.1	3.4 - 11.1	23.0	6.1 - 45.0
Bohemian massive	2.30	1.69 - 2.74	12.4	5.5 - 23.7	70.6	10.9 - 182
Northern pre-alpine region	1.65	0.96 - 2.06	13.6	1.4 - 18.5	23.4	19.6 - 96
Ammonium nitrate lime	0.05	< 0.04 - 0.17	< 0.04	< 0.04 - 0.06		
N-P-K all proportions	0.35	< 0.04 - 1.27	0.24	< 0.04 - 0.93	0.84	0.07 - 3.76
N-P-K + sulphate	0.37	0.06 - 1.04	0.27	0.04 - 0.69	0.96	0.19 - 1.94
P-K fertilizers	0.53	0.21 - 1.40			0.86	0.55 - 1.67
Di-ammonium phosphates	2.85	0.60 - 3.83	1.58	0.32 - 2.12	1.41	0.30 - 1.96

Table 6 Data for cadmium, sorted for the input equivalent to nitrogen.

Cd: Mean crust = 0.11 mg/kg Soil medians (Austria) 0.12-0.34 mg/kg	Crop uptake: wheat var. potatoes 0.46 g maize 2.1 g	Atmospheric deposition: Marchfeld 1985: 1.48 g/ha.a East of Austria 1997/98: 1.21 g/ha.a

	mg/kg	**Range**	**g for 100 kg N**	**Range**	**g for 100 kg P**	**Range**
Commercial organics						
Alpine regions	0.11	<0.05 - 2.54	0.18	< 0.1 - 4.46	1.06	< 0.2 - 9.43
Southeast	0.16	< 0.05 - 2.96	0.33	< 0.1 - 2.67	1.22	< 0.2 - 12.4
Northern pre-alpine region	0.24	< 0.05 - 4.39	0.50	< 0.1 - 6.91	2.40	< 0.2 - 19.8
Bohemian massive	0.47	< 0.05 - 3.50	0.50	< 0.1 - 4.91	3.16	< 0.2 - 13.1
Pannonian	0.24	< 0.05 - 3.73	0.50	< 0.1 - 3.11	1.71	< 0.2 - 14.8
Weinviertel	0.38	< 0.05 - 3.58	0.77	< 0.1 - 4.34	2.06	0.5 - 12.7
Manures and dungs						
Northern pre-alpine region	0.33	< 0.05 - 0.85	0.34	< 0.06 - 1.00	1.91	< 0.3 - 4.8
Pannonian	0.39	< 0.05 - 0.82	0.34	< 0.06 - 1.49	2.31	< 0.3 - 12.3
Bohemian massive	0.28	< 0.05 - 0.50	0.51	< 0.06 - 1.53	3.01	< 0.3 - 8.08
Alpine regions	0.43	< 0.05 - 1.19	0.67	0.33 - 1.00	2.49	1.6 - 6.8
Composts						
Weinviertel	0.57	0.41 - 1.32	1.91	1.14 - 3.22	6.13	4.0 - 8.6
Bohemian massive	0.26	0.21 - 0.92	2.10	0.94 - 2.93	7.43	2.9 - 17.6
Northern pre-alpine region	0.35	0.29 - 0.43	2.74	0.56 - 3.91	8.91	3.5 - 22.9
Ammonium nitrate limes	0.09	< 0.05 - 0.21	0.03	< 0.02 - 0.08		
N-P-K fertilizers	0.98	< 0.05 - 10.17	0.60	< 0.05 - 7.18	2.74	< 0.1 - 18.4
N-P-K + sulphate	2.56	< 0.05 - 6.95	1.75	< 0.05 - 5.09	6.53	< 0.1 - 18.8
P-K fertilizers	3.89	0.48 - 9.84			5.85	2.56 - 12.8
Di-ammonium phosphates	19.3	0.08 - 37.1	10.51	0.07 - 21.3	10.7	< 0.1 - 18.7

Fertilization with phosphates and organics equivalent to 100 kg N exceeded the annual output to main crops, above all from composts. Equivalents to 100 kg P from all kinds of mineral fertilizers, manures and organic fertilizers contained about 10 times more beryllium than the presumable annual output to crops (**Table** 5).

Cadmium

Cadmium was not included in the geochemical map of Austria (because it was used as a spectrographic buffer for determination of Ag, Sn, Mo, W and others in the DC-arc at that time). Median background values in arable soils from various regions range between 0.12 and 0.34 mg/kg without stringent connections to the geological underground (Danneberg 1999). Cd in soils is largely influenced by fertilization and atmospheric deposition.

With respect to Cd-concentrations and Cd-loads for 100 kg N or 100 kg P, ranges were overlapping. In regions where many domestic animals are kept (alpine), the Cd load equivalent to 100 kg N was mimimum for commercial organics, but maximum for manures, and *vice versa* (Pannonian and Weinviertel).

Due to substitution of Ca in the apatite lattice, which is the main phosphate mineral, Cd in fertilizers strongly correlates with P. Medians of organics of any kind were found at about soil level, whereas mineral phosphates were higher throughout. As most of the cadmium comes from phosphate sources, a 100 kg N-fertilization from products without P as main component led to inputs clearly below atmospheric deposition and plant uptake, whereas composts and di-ammonium phosphates were above. Organics and NPKs were medium. The level of concern = 10 g/ha for Cd, was never reached for a fertilization of 100 kg N.

However, 100 kg P/ha from all kinds of mineral fertilizers might exceed this level of concern. Cd/P ranges were largely overlapping, but note that ammonium phosphates contained about double Cd/P than rock phosphates. Contrary to most other elements, Cd/P from organics and manures was lower than from minerals (**Table 6**).

Cobalt

Cobalt is rather uniformly distributed in rocks. It is enriched in basic rocks and schists, and rather low in acid rocks, sandstones and carbonates. In Austria, in igneous rocks of the Bohemian massive and the Central Alps, 12 and 16 mg/kg were found. More cobalt occurs in schists and the Molasse zone (Thalmann *et al.* 1989). Soil background values, as well as fertilizers and all phosphates, were also lower than mean crust levels. In NPK and commercial organics, significantly asymmetric frequency distribution of cobalt concentrations indicates occasional additions, because cobalt is sometimes essential for plant growth. Highest median concentrations of the cobalt, however, were found in garden moulds and composts. Cobalt in arable soil thus cannot be explained from local geology.

An annual fertilization of 100 kg N/ha together with atmospheric deposition carries along enough cobalt to balance plant uptake from main crops wheat and potatoes, whereas the input from di-ammonium phosphates, organics, and above all from composts, was clearly more.

A 100 kg P/ha fertilization from manures, and above all from composts, contained much more cobalt than the needs of wheat and potatoes, whereas input from other sources approximately balanced the crop output (**Table** 7).

Chromium

Chromium is a lithophilic element, enriched in ultrabasic rocks, and low in granites, sandstones and carbonates. In Austria, a mean of 33 mg/kg total chromium was found igneous rocks of the Bohemian massive, and 73 mg/kg in the Central Alps (Thalmann *et al.* 1989). In spite of the fact that soil data do not give total chromium, like refractory oxides and silicates, the amount found in soils depended on the acidity of the underlying layer as well (Danneberg 1999). More than 100 mg/kg acid leachable chromium in soils indicates contamination.

In fertilizers, products without P main component and organics of any kind were lower than P-rich products and soil levels, but the concentration range covered 2 orders of magnitude in commercial organics and NPKs. Di-ammonium phosphate and triple phosphates often exceeded the level of concern of 100 mg/kg.

The annual atmospheric precipitation approximately equalled crop extraction. At a fertilization rate of 100 kg N or P/ha, all kinds of fertilizers supplied (at the median values) additional chromium, except ammonium nitrate lime. Fertilization of 100 kg N never reached the level of concern for 2 years (625 g Cr/ha), except for some di-ammonium phosphates (**Table 8**). Concentration ranges and loads per nutrient contents between various regions are overlapping, and the medians cannot be explained from geology or from average landuse.

Copper

Copper occurs enriched in sulfidic deposits and has been used as the first metal in history. It it is also enriched in basic rocks, and low in granites, sandstones and carbonates. In Austria, in igneous rocks from the Bohemian massive, just 13 mg/kg and in the Central Alps, 21 mg/kg were found, whereas schists contain about 50 mg/kg (Thalmann *et al.* 1989), which is regarded as the mean crust level. Data obtained from the soil inventory (Danneberg 1999) by *aqua regia* digestion were in the same range. There were no differences in Cu-contents between the geological regions, but rather on a small scale within these regions.

In terms of Cu-concentrations, manures and composts

Table 7 Data for cobalt, sorted for the input equivalent to nitrogen.

Co: Mean crust = 20 mg/kg Soil medians (Austria) 6.5-13.7 mg/kg Mean soil = 12 mg/kg		Crop uptake: wheat 0.14 + 0.15 g potatoes 0.53 g maize 1.1 g		Atmospheric deposition: below detection limit		
	mg/kg	**Range**	**g for 100 kg N**	**Range**	**g for 100 kg P**	**Range**
Commercial organics						
Alpine regions	0.42	< 0.1 - 6.6	0.44	< 0.2 - 22.8	2.18	< 0.5 - 89
Northern pre-alpine region	0.52	< 0.1 - 8.2	0.72	0.2 - 65.8	2.83	< 0.5 - 273
Bohemian massive	0.61	0.2 - 7.1	0.88	0.2 - 8.6	4.72	0.6 - 42
Southeast	0.72	< 0.1 - 4.3	1.03	< 0.2 - 4.7	5.36	< 0.5 - 22.7
Pannonian	1.13	0.1 - 4.5	1.79	0.3 - 19.9	6.99	0.8 - 91
Weinviertel	0.81	0.1 - 2.7	2.35	0.4 - 5.0	6.86	0.7 - 18.6
Manures and dungs						
Bohemian massive	1.03	0.2 - 4.0	1.59	0.7 - 3.6	9.2	2.4 - 120
Pannonian	1.81	0.4 - 6.4	2.13	0.4 - 9.2	8.1	4.0 - 80
Northern pre-alpine region	1.78	0.6 - 6.8	2.24	0.9 - 6.9	10.7	4.5 - 38.1
Alpine regions	2.81	1.2 - 3.8	5.04	0.9 - 6.4	26.8	6.1 - 35.2
Composts						
Weinviertel	6.37	4.2 - 10.6	20.8	9.0 - 45.8	55	23 - 191
Northern pre-alpine region	4.12	2.3 - 6.9	27.2	3.0 - 63.6	73	262 - 370
Bohemian massive	6.96	5.3 - 8.4	34.6	15.1 - 74.8	133	34 - 525
Ammonium nitrate limes	0.12	< 0.1 - 0.91	< 0.1	< 0.1 - 0.34		
N-P-K + sulphate	0.29	< 0.1 - 1.95	0.21	0.03 - 1.42	0.69	< 0.1 - 5.24
P-K fertilizers	0.32	< 0.1 - 2.50			0.48	< 0.1 - 3.29
N-P-K fertilizers	0.51	< 0.1 - 81.5	0.33	< 0.1 - 46.8	1.07	< 0.1 - 228
Di-ammonium phosphates	1.71	0.84 - 4.44	1.04	0.44 - 3.50	0.91	0.37 - 2.70

Table 8 Data for chromium, sorted for the input equivalent to nitrogen.

Cr: Mean crust = 100 mg/kg	Crop uptake:	Atmospheric deposition:
Soil medians (Austria) 29 - 49 mg/kg	wheat 0.9 + 1.1 g	Marchfeld 1985: 2.3 g/ha.a
Mean soil = 84 mg/kg	potatoes 3.3 g	East of Austria 1997/98: 2.3 g/ha.a

	mg/kg	**Range**	**g for 100 kg N**	**Range**	**g for 100 kg P**	**Range**
Commercial organics						
Southeast	7.1	0.3 - 56.5	10.2	<0.5 - 94	39.2	2.5 - 353
Alpine regions	7.8	1.1 - 81	12.3	1.6 - 435	63.6	5.8 - 3743
Bohemian massive	10.5	1.9 - 37.3	13.8	2.9 - 48.1	53.1	7.8 - 160
Northern pre-alpine region	8.4	< 0.25 - 55.6	14.9	< 0.5 - 287	47.6	2.1 - 983
Pannonian	7.1	1.0 - 36.3	16.3	0.7 - 110	47.6	7.3 - 398
Weinviertel	15.9	1.7 - 55.4	23.8	4.7 - 95	60.4	12.1 - 875
Manures and dungs						
Northern pre-alpine region	7.3	0.9 - 35.5	7.6	0.8 - 28.8	46.8	5.8 - 206
Bohemian massive	4.0	0.9 - 9.0	7.6	2.9 - 39.1	41.5	15.8 - 511
Pannonian	11.3	< 0.25 - 38.1	14.4	< 0.3 - 43.0	50.9	< 3 - 300
Alpine regions	9.6	5.9 - 26.6	16.8	4.1 - 44.9	54.3	33.5 - 246
Composts						
Weinviertel	32.2	20.8 - 118	113	44 - 512	306	194 - 2094
Northern pre-alpine region	18.7	16.6 - 27.6	157	25 - 249	402	176 - 1288
Bohemian massive	30.1	20.0 - 240	230	72 - 943	1328	164 - 3822
Ammonium nitrate limes	0.97	<0.25 - 3.60	0.35	< 0.1 - 1.34		
N-P-K fertilizers	18.0	<0.25 - 161	11.1	< 0.2 - 101	45	< 0.2 - 461
N-P-K + sulfate	40.8	0.54 - 118	31	0.51 - 78	101	1.78 - 227
P-K fertilizers	56.6	4.06 - 104			89	48 - 147
Di-ammonium phosphates	263	7.4 - 464	145	2.5 - 239	133	2.30 - 222

Table 9 Data for copper, sorted for the input equivalent to nitrogen.

Cu: Mean crust = 50 mg/kg	Crop uptake:	Atmospheric deposition:
Soil median (Austria) 16 - 25 mg/kg	wheat 18 + 9 g	Marchfeld 1985: 19.6 g/ha.a
Mean soil = 26 mg/kg	potatoes 29 g	East of Austria 1997/98: 12.3 g/ha.a
	maize 60 g	

	mg/kg	**Range**	**g for 100 kg N**	**Range**	**g for 100 kg P**	**Range**
Commercial organics						
Alpine regions	11.1	4.7 - 60	14.3	6.2 - 168	100	16 - 797
Northern pre-alpine region	19.5	3.8 - 106	27.6	5.3 - 632	111	20 - 2335
Southeast	21.0	4.8 - 86	31.8	3.8 - 146	163	12 - 753
Bohemian massive	22.5	4.0 - 79	35.1	7.2 - 102	95	35 - 604
Weinviertel	27.8	3.3 - 88	54.6	7.7 - 135	196	25 - 503
Pannonian	51.8	3.6 - 120	111.2	3.8 - 456	328	29 - 951
Manures and dungs						
Bohemian massive	26.5	8 - 137	52.2	12 - 146	256	108 - 1001
Pannonian	49.2	16 - 168	52.5	17 - 199	385	111 - 1785
Alpine regions	49.0	36 - 71	76.3	65 - 134	317	273 - 384
Northern pre-alpine region	79.5	23 - 375	104.3	31 - 572	572	180 - 2809
Composts						
Northern pre-alpine region	35.0	21 - 242	218	45 - 2708	764	522 - 15880
Bohemian massive	29.5	15 - 129	242	116 - 644	988	469 - 1381
Weinviertel	119.6	38 - 141	383	20 - 721	1074	807 - 2408
Ammonium nitrate limes	0.90	0.11 - 10.0	0.29	< 0.07 - 3.81		
P-K fertilizers	6.61	2.09 - 16.5			10.6	2.92 - 23.8
N-P-K + sulfate	8.8	0.59 - 594	5.88	0.41 - 478	22.4	2.20 - 2480
N-P-K fertilizers	10.3	0.48 - 915	7.08	0.31 - 634	20.5	1.21 - 2344
Di-ammonium phosphates	12.4	0.26 - 54.7	7.24	< 0.1 - 29.8	6.70	< 0.1 - 27.1

were largely above the expectable level in soils and rocks. The general high level of copper in composts from the Weinviertel might be explained from the use of $CuSO_4$ as a pesticide in wineyards in former times. Top values appeared in manures (above all in pig manures). Some samples exceeded the level of concern for soils of 100 mg/kg, which may be due to occasional additions or contaminations. For mineral fertilizers without P as a main component, just 1-2 mg/kg can be expected, whereas phosphates of any kind and garden moulds ranged like soils.

Fertilization rates of 100 kg N/ha from mineral fertilizers did not approach plant uptake alone, but well together with atmospheric deposition. Contrary to this, manures and composts supplied clearly more. 100 kg N given via manures from pigs, chickens and turkeys easily superseded the level of concern for contaminations, which is 625 g/ha Cu within 2 years, like some NPKs and organics which may contain added Cu-salts. These intentional additions should have been marked on the respective label. 100 kg P from composts added a median of 1.1 kg Cu to the fertilized area. Atmospheric deposition together with 100 kg P/ha satisfied the needs of main crops wheat and potatoes (**Table 9**).

Table 10 Data for lithium, sorted for the input equivalent to nitrogen.

Li: Mean crust = 20 mg/kg mean soil = 31 mg/kg		Crop uptake: wheat 0.08 + 0.53 g		Atmospheric deposition: East of Austria 1997/98: 0.88 g/ha.a		
	mg/kg	**Range**	**g for 100 kg N**	**Range**	**g for 100 kg P**	**Range**
Commercial organics						
Alpine regions	0.73	0.12 - 5.3	0.84	0.08 - 18.8	4.64	< 1 - 49
Southeast	1.04	0.02 - 10.8	1.67	< 0.04 - 17.3	6.55	< 1 - 109
Bohemian massive	1.09	0.23 - 11.5	1.73	0.21 - 14.7	8.36	< 1 - 66
Northern pre-alpine region	1.14	0.20 - 20.4	1.79	0.18 - 170	6.35	< 1 - 707
Weinviertel	1.60	0.15 - 3.6	3.00	0.62 - 6.0	8.09	2.2 - 23
Pannonian	1.43	0.15 - 21.9	3.03	0.05 - 18.9	8.38	< 1 - 233
Manures and dungs						
Bohemian massive	2.28	0.64 - 5.24	2.91	1.13 - 6.77	22.4	10.4 - 44
Northern pre-alpine region	2.92	< 0.02 - 8.23	3.02	< 0.03 - 14.1	13.6	< 1 - 51
Pannonian	3.42	< 0.02 - 9.72	5.44	< 0.03 - 13.8	23.1	< 1 - 201
Composts						
Weinviertel	13.6	8.3 - 24.8	39	24 - 108	134	49 - 441
Bohemian massive	15.3	11.9 - 16.9	60	39 - 76	113	90 - 1129
Ammonium nitrate limes	0.34	0.12 - 0.65	0.13	0.03 - 0.24		
N-P-K + sulphate	0.91	0.14 - 3.38	0.67	0.11 - 2.60	2.06	0.53 - 12.3
P-K fertilizers	0.96	0.40 - 3.05			1.66	0.79 - 3.85
N-P-K fertilizers	0.99	0.04 - 4.13	0.65	0.02 - 3.09	2.09	0.06 - 12.6
Di-ammonium phosphates	3.00	1.29 - 4.55	1.65	0.62 - 2.53	1.47	0.61 - 2.51

Lithium

Lithium is largely bound to silicates (mean crust = 20 mg/kg), and its transfer to green plants is low. No soil data from Austria are currently available. In fertilizers, (acid-leachable) lithium was found to be uniformly low, about 1 mg/kg in mineral fertilizers and commercial organics, and about 2 mg/kg in limes, dolomites, Ca-Mg-phosphates, rock phosphates, PKs and NPKs. Unlike Na (see above), there was no enrichment in K-salts. No regional differences in Li-concentrations were noted, just for the median loads from commercial organics with respect to N. Median lithium input from composts was significantly higher than from elsewhere, thus Li/N seems to be a criterium to discriminate composts from any other fertilizers. Li/P in composts and garden moulds was smaller than the proportion for mean soil values (Li/P = 0.02). Data for plant uptake and atmospheric deposition are scarce (**Table 10**).

Manganese

Manganese is a lithophilic trace element, slightly enriched in basic rocks, depleted in acid rocks, and variable in schists. In the Bohemian massive, total manganese was found at a mean of 740 mg/kg, and in the Central Alps at 880 mg/kg (Thalmann *et al.* 1989). It was not included in the soil inventory.

Most fertilizer samples were below mean crust and mean soil levels. The lowest Mn-contents were found in K-salts and ammonium sulfates. NPKs, NPKs with sulfate, ammonium nitrate lime and commercial organics showed a bimodal frequency distribution of their Mn-concentrations. The first frequency maximum at 11 mg/kg for ammonium nitrate limes and NPKs with sulfate, as well at 58 mg/kg for NPKs and organics may reflect the natural abundance. A second frequency maximum of about 400 mg/kg indicates occasional additions at this level.

Concentration ranges and loads of organics of any kind were overlapping, but there was a common trend of increase from commercial organics towards manures towards composts. No connections with the regional geological base rock were recognized. In the Alpine regions, median loads from commercial organics were minimal, and from manures at maximum, whereas it was reverse for the Pannonian region. As an explanation, in the Alpine region there live a lot of domestic animals, and in the Pannonian region almost none. This might reflect additions to animal feedstuffs, or in case of no animals, to the fertilizers, to cover plant needs.

Extraction of manganese along with crops may vary widely, but is usually more than the annual atmospheric deposition. A fertilization of 100 kg/ha N from mineral fertilizers was likely not to cover plant needs, whereas supply from manures and composts was sufficient. NPKs containing sulfate supplied significantly less Mn for 100 kg N than others.

Together with atmospheric deposition, an input of 100 kg P covered plant needs from most sources, whereas organics and basic slags supplied clearly more. Too much Mn is no problem for soils, because it is precipitated, but it may be of concern for hydroponic cultures (**Table 11**).

Molybdenum

Molybdenum (Mo) mean crust level is just 1.5 mg/kg, but as a trace element it is known to be enriched in the biosphere. Carbonates and sandstones contain Mo clearly below the average. In igneous rocks of the Bohemian massive and the Central Alps, 0.6 and 0.8 mg/kg, respectively were found (Thalmann *et al.* 1989). Soil median concentrations ranged between 0.19 and 0.67 mg/kg, but there was no assignment to the large regions (Danneberg 1999). The tabulated mean soil value was never reached in Austria.

Mo concentrations in fertilizers were largely above mean crust levels and correlated strongly with P, except for commercial organics and garden moulds, which may contain excess Mo. Thus, highest median concentrations were found in triple phosphates, rock phosphates and super phosphates, and often exceeded the level of concern for contaminated sites, which has been set to 5 mg/kg. NPK fertilizers with or without sulfate frequently contained added Mo up to 200 mg/kg from intentional additions to cover special plant needs. This should marked on the label. Although plant tissues contain more molybdenum than animal tissues, manures had more Mo than composts.

Ammonium nitrate limes, limes and dolomites, K-salts and Mg-salts were at or below the detection limit of the ICP-OES.

For a fertilization rate of 100 kg N or P/ha, the presumable Mo plant uptake was covered with high probability from organics, manures and composts, but from mineral fertilizers not in any case. Organics of any kind contained more Mo/P than mineral fertilizers (**Table 12**).

Table 11 Data for manganese, sorted for the input equivalent to nitrogen.

Mn: Mean crust = 950 mg/kg mean soil = 760 mg/kg	Crop uptake: wheat 164+ 68 g potatoes 37 g	Atmospheric deposition: East of Austria 1997/98: 25 g/ha.a

	mg/kg	**Range**	**g for 100 kg N**	**Range**	**g for 100 kg P**	**Range**
Commercial organics						
Alpine regions	30.9	3.7 - 520	41.3	5.5 - 1204	159	34 - 4041
Bohemian massive	60.8	15.3 - 392	83.4	23.9 - 815	321	65 - 3340
Northern pre-alpine region	59.4	3.7 - 729	85.5	5.1 - 6017	314	49 - 24515
Weinviertel	60.3	3.4 - 602	93.0	26.3 - 1034	382	90 - 3704
Southeast	86.4	8.1 - 643	104	11.6 - 1141	571	28 - 4169
Pannonian	341	13.6 - 588	577	11.6 - 2241	1384	109 - 4828
Manures and dungs						
Pannonian	205	63 - 593	320	31 - 1207	1825	387 - 3365
Bohemian massive	220	86 - 405	399	223 - 681	2064	1362 - 6769
Northern pre-alpine region	351	150 - 791	430	136 - 792	1838	1011 - 4716
Alpine regions	319	179 - 565	589	524 - 1060	2900	2029 - 3109
Composts						
Weinviertel	471	218 - 798	1369	764 - 2531	4230	1693 - 13486
Northern pre-alpine region	474	320 - 813	2427	979 - 8406	15590	3064 - 43440
Bohemian massive	525	312 - 1114	2871	1039 - 11011	13377	2013 - 54564
N-P-K + sulfate	11.1	3.3 - 797	9.3	2.1 - 634	28.4	7.10 - 2792
P-K fertilizers	11.4	3.5 - 212			17.6	6.77 - 250
Ammonium nitrate limes	11.5	0.5 - 395	4.1	0.92 - 98.3		
N-P-K fertilizers	58.0	4.3 - 1737	46.4	2.3 - 1654	132	7.67 - 7605
Di-ammonium phosphates	70.2	22 - 407	42.5	11.6 - 213	43.2	10.9 - 200

Table 12 Data for molybdenum, sorted for the input equivalent to nitrogen.

Mo: Mean crust = 1.5 mg/kg Soil medians (Austria) 0.19-0.67 mg/kg Mean soil = 1.9 mg/kg	Crop uptake: wheat 3.1 + 1.1 g potatoes 2.1 g maize 1.3 g	Atmospheric deposition: Below detection limit

	mg/kg	**Range**	**g for 100 kg N**	**Range**	**g for 100 kg P**	**Range**
Commercial organics						
Alpine regions	1.22	< 0.5 - 7.0	1.83	< 1 - 21.8	9.8	< 2 - 64
Northern pre-alpine region	1.42	< 0.5 - 10.5	2.46	< 1 - 87	9.6	< 2 - 342
Bohemian massive	2.31	< 0.5 - 7.6	2.90	< 1 - 12.2	10.3	< 2 - 132
Southeast	2.19	< 0.5 - 5.9	2.95	< 1 - 10.9	13.2	< 2 - 147
Weinviertel	2.65	< 0.5 - 4.5	3.12	< 1 - 11.7	11.8	< 2 - 26
Pannonian	2.64	< 0.5 - 7.2	4.89	< 1 - 28.1	12.9	< 2 - 74
Manures and dungs						
Pannonian	2.19	0.8 - 12.3	1.93	1.0 - 23.2	17.2	3.9 - 204
Bohemian massive	1.14	< 0.5 - 2.3	2.18	1.2 - 4.5	12.7	< 2 - 26.5
Alpine regions	4.31	3.0 - 5.0	5.42	5.0 - 8.5	24.2	16.0 - 28.8
Northern pre-alpine region	4.63	1.5 - 11.6	5.71	1.4 - 15.7	22.5	10.3 - 79.8
Composts						
Weinviertel	1.29	0.55 - 2.55	4.2	3.1 - 9.1	16.9	10.5 - 31.0
Bohemian massive	1.02	< 0.5 - 3.05	6.9	2.4 - 10.7	23.6	8.2 - 45.3
Northern pre-alpine region	1.37	0.55 - 5.15	6.4	1.8 - 57.7	29.6	9.7 - 339
Ammonium nitrate limes	< 0.5	< 0.5 - 0.8	< 0.2	< 0.2 - 0.28		
N-P-K + sulphate	0.87	< 0.5 - 156	0.60	< 0.5 - 92	2.21	< 0.5 - 420
N-P-K fertilizers	1.41	< 0.5 - 195	0.89	< 0.5 - 122	2.64	< 0.5 - 383
P-K fertilizers	2.02	< 0.5 - 8.2			3.42	0.55 - 10.1
Di-ammonium phosphates	4.00	< 0.5 - 9.2	2.16	< 0.5 - 5.41	2.11	< 0.5 - 5.10

Contrary to many other elements, regional differences of Mo concentrations and loads were larger than differences between commercial organics, manures and composts. This results from different landuse, and not from geology.

Sodium

Sodium (Na) occurs in the earth crust at a mean of 2.3%, but an appreciable part is dissolved in the oceans. In the geological baserock, 1.55% total Na were found in the Bohemian massive, and 1.45% in the Central alps, with rather broad log-normal frequency distributions. Much lower levels are encountered in carbonates and sandstones (Thalmann *et al.* 1989). Large parts of Na rocks and soils (mean soil = 1.1%) are bound to silicates, but probably all Na is soluble in fertilizers. Though salinization of soils is an unwanted process, i.e. increase of available Na from irrigation or fertilization, sodium was not included in the recent soil inventory.

Among the fertilizer samples, most Na was contained in manures (median 0.97% Na) and K-salts (median 0.63%), but varied over more than 2 orders of magnitude. K-salts contained top values like up to 5.6% Na. Manures contained about 20 times more Na than composts. PK fertilizers con-

Table 13 Data for sodium, sorted for the input equivalent to nitrogen.

Na: Mean crust = 23 g/kg mean soil = 11 g/kg					Atmospheric deposition: Highly variable	
	g/kg	**Range**	**kg for 100 kg N**	**Range**	**kg for 100 kg P**	**Range**
Commercial organics						
Alpine regions	2.85	0.50 - 13.8	5.10	1.27 - 19.4	17.6	5.5 - 207
Bohemian massive	3.66	1.46 - 18.7	5.58	1.29 - 21.0	19.6	4.4 - 168
Weinviertel	2.95	0.73 - 21.2	5.75	1.69 - 50.2	20.7	5.0 - 183
Southeast	3.70	0.78 - 15.5	6.57	1.22 - 23.2	18.3	2.9 - 165
Northern pre-alpine region	3.48	0.49 - 19.3	6.86	0.52 - 30.7	25.6	5.0 - 196
Pannonian	3.79	1.86 - 18.6	7.68	1.39 - 22.0	20.0	5.5 - 220
Manures and dungs						
Bohemian massive	1.84	0.30 - 5.44	3.44	2.23 - 7.21	19.6	7.0 - 44.9
Alpine regions	6.83	4.41 - 12.5	10.3	7.94 - 21.2	42.0	27.4 - 116
Northern pre-alpine region	8.46	1.69 - 67.6	10.6	2.65 - 36.3	51.7	11.9 - 437
Pannonian	15.5	2.10 - 98.1	24.0	4.88 - 44.5	84.1	16.3 - 1155
Composts						
Weinviertel	0.85	0.61 - 2.30	2.57	1.46 - 4.67	7.32	4.7 - 59.4
Northern pre-alpine region	0.60	0.34 - 1.16	3.18	0.79 - 12.0	22.9	3.2 - 62.2
Bohemian massive	0.96	0.64 - 2.34	6.98	1.97 - 13.9	37.3	5.9 - 69.6
Ammonium nitrate limes	0.078	0.034 - 0.134	0.029	0.013 - 0.05		
Di-ammonium phosphates	2.33	0.87 - 4.25	1.12	0.45 - 2.34	1.06	0.37 - 2.3
N-P-K + sulphate	2.62	0.91 - 8.50	1.82	0.60 - 9.87	6.9	2.83 - 28.0
N-P-K fertilizers	2.96	0.54 - 9.38	1.94	0.25 - 11.0	6.2	1.61 - 25.1
P-K fertilizers	5.78	2.09 - 11.4			9.2	4.76 - 21.5

tained more than double the amount of Na per weight than DAP or NPKs. At the low end of the scale there were the ammonium nitrate limes (median 78 mg/kg), limes and dolomites (median 353 mg/kg), and garden moulds (median 334 mg/kg).

If salinization becomes problematic, it should be considered that 100 kg N might bring up to 100 kg Na from manures, 17 kg from composts, and 33 kg from other organics. Inputs from mineral fertilizers equivalent to 100 kg N were 10 times lower, and inputs from ammonium nitrate lime were almost negligible. Regional differences of Na loads in manures reflect human population density, but not geology. Though composts should be of plant origin, regional differences in Na loads parallel domestic animal density.

Appreciable loads for an equivalent of 100 kg P came from composts (median 15 kg Na/100 kg P), organics (median 21 kg Na/100 kg P), and manures (median 52 kg Na/100 kg P) (**Table 13**), whereas Na loads from the mineral sources were significantly lower.

Nickel

Apart from its occurrence in sulfides and arsenides, nickel (Ni) is geochemically enriched in basic rocks, and low in granites, sandstones and carbonates. The mean for igneous rocks in the Bohemian massive was 33 mg/kg and in the Central Alps 32 mg/kg, but the occurrence was rather patchy according to the basicity of rocks. The tabulated mean crust occurrence of 80 mg/kg was hardly reached. In the *aqua regia* extract of arable soils, lower levels were found (about 21 mg/kg), possibly due to incomplete dissolution. Due to its cancerogenic action, the level of concern for (*aqua regia* leachable) Ni in soils has been set to 60 mg/kg.

Among the fertilizers, highest median concentrations were found in triple phosphates (27.7 mg/kg), and composts (24.5 mg/kg). Di-ammonium phosphates, however, contained till 90 mg/kg, apart from outliers, and 1/5 of the samples had Ni concentrations larger than the levels of concern. On the other end, very low Ni (detection limit to 10 mg/kg) was found in minerals without P as main component.

100 kg N given via mineral fertilizers approximately balanced plant uptake, whereas ammonium nitrate lime supplied less, and di-ammonium phosphates, organics, manures and above all composts supplied much more. The level of concern would be an input of 375 g/ha in 2 years, which was not reached by any 100 kg N fertilization (except for some composts).

Though data about atmospheric deposition of Ni differ widely, the median input 100 kg P per hectare was higher from any source and exceeded crop outputs about 10-fold. Ni/P from composts was 20 times higher than from mineral phosphates, other organics were in-between. The level of concern of 375 g/ha in 2 years was not reached from 100 kg P, however (**Table 14**).

Regional differences in Ni-concentrations and loads were not significant, and might be explained by anthropogenic influences (steel cages and tools) rather than from land use or geology.

Lead

Apart from sulfidic ores, lead (Pb) is enriched in acid igneous rocks, and generally depleted in basalts, carbonates and sandstones. Mean abundances in igneous rocks of the Bohemian massive and in igneous rocks of the Central Alps were 32 and 25 mg/kg, respectively, and thus above the mean crust level (Thalmann *et al.* 1989). The soil background levels of 15 mg/kg may indicate incomplete recovery in *aqua regia* (Danneberg 1999).

Most kinds of mineral fertilizers and commercial organic fertilizers contained Pb at median concentrations below 2 mg/kg. Composts had significantly more Pb, 37 mg/kg as the median (range 14-66 mg/kg), but no sample reached the level of concern, which has been set at 100 mg/kg.

Though annual atmospheric deposition of lead has been strongly declining within the last 20 years and is currently below 10 g/ha, inputs of 100 kg N from any source were lower from the atmosphere, except from composts. Similarly, inputs of 100 kg P/ha were below annual atmospheric deposition, except from basic slags and organics. The level of 375 g/ha might have been reached by 100 kg P/ha added via composts (**Table 15**).

Concentrations and nutrient-based loads among all groups of organics in **Table 15** increase with population density, thus showing the anthropogenic influence on Pb levels.

Table 14 Data for nickel, sorted for the input equivalent to nitrogen.

Ni: Mean crust = 80 mg/kg Soil medians (Austria) 19-29 mg/kg Mean soil = 34 mg/kg	Crop uptake: wheat 2.7 + 1.1 g potatoes 6.5 g maize 5.7 g	Atmospheric deposition: Marchfeld 1985: 15.2 g/ha.a East of Austria 1997/98: 5.0 g/ha.a

	mg/kg	Range	g for 100 kg N	Range	g for 100 kg P	Range
Commercial organics						
Alpine regions	5.1	0.7 - 37	5.6	< 1 - 94	30.0	2.4 - 520
Southeast	4.2	< 0.5 - 37	5.7	< 1 - 62	31.9	< 2 - 195
Northern pre-alpine region	5.6	< 0.5 - 43	8.5	< 1 - 241	33.2	< 2 - 809
Bohemian massive	6.8	0.9 - 25	8.9	2.3 - 34	34.7	7.0 - 132
Pannonian	5.4	< 0.5 - 21	10.5	< 1 - 52	28.3	< 2 - 293
Weinviertel	15.7	1.0 - 46	25.3	2.7 - 86	52.6	7.2 - 321
Manures and dungs						
Northern pre-alpine region	9.6	4.2 - 29.2	9.4	4.8 - 26.6	46	29 - 205
Bohemian massive	6.6	1.2 - 12.2	11.7	4.5 - 47.7	66	18 -. 332
Pannonian	10.6	2.1 - 46.9	12.4	2.9 - 65.2	48	22 - 462
Alpine regions	9.2	7.0 - 13.8	13.6	6.4 - 23.4	51	33 - 128
Composts						
Northern pre-alpine region	13.9	6.4 - 21.2	92	10 - 237	157	96 - 1391
Weinviertel	34.8	10.9 - 38.8	118	22 - 254	279	90 - 672
Bohemian massive	18.1	14.4 - 37.4	124	42 - 187	443	146 - 996
Ammonium nitrate limes	0.43	< 0.5 - 3.7	< 0.3	< 0.3 - 1.40		
N-P-K fertilizers	6.51	< 0.5 - 30.5	4.0	< 0.5 - 22.2	16.0	< 0.5 - 582
N-P-K + sulphate	7.31	< 0.5 - 18.7	5.2	< 0.5 - 19.0	16.8	< 0.5 - 101
P-K fertilizers	11.4	2.2 - 23.4			16.3	4.2 - 44.2
Di-ammonium phosphates	16.4	4.0 - 89.5	10.3	1.7 - 52.3	10.0	1.6 - 46.8

Table 15 Data for lead, sorted for the input equivalent to nitrogen.

Pb: Mean crust = 14 mg/kg Soil medians (Austria) 5.7 - 22.2 mg/kg Mean soil = 29 mg/kg	Crop uptake: wheat variable potatoes < 0.1 g	Atmospheric deposition: Marchfeld 1985: 86 g/ha.a East of Austria 1997/98: 16.5 g/ha.a

	mg/kg	Range	g for 100 kg N	Range	g for 100 kg P	Range
Commercial organics						
Southeast	1.2	< 0.5 - 7.4	1.6	< 1 - 12.8	6.9	< 2 - 53
Alpine regions	1.3	< 0.5 - 12.2	1.7	< 1 - 26.3	6.2	< 2 - 137
Northern pre-alpine region	1.4	< 0.5 - 17.3	2.1	< 1 - 130	6.6	< 2 - 523
Bohemian massive	1.8	< 0.5 - 7.4	2.4	< 1 - 12.3	8.2	< 2 - 50
Pannonian	1.8	< 0.5 - 10.2	3.4	< 1 - 34	12.1	< 2 - 129
Weinviertel	1.8	< 0.5 - 10.0	5.3	< 1 - 16.6	10.2	< 2 - 62
Manures and dungs						
Bohemian massive	1.7	< 0.5 - 8.8	2.9	1.7 - 11.5	16.9	5.1 - 93
Northern pre-alpine region	4.1	1.2 - 28.7	4.7	1.4 - 44.5	23.8	5.4 - 247
Alpine regions	3.6	1.4 - 7.6	4.9	1.7 - 12.0	23.8	6.5 - 34
Pannonian	4.7	0.6 - 50.5	6.3	1.9 - 70.8	22.4	4.9 - 837
Composts						
Northern pre-alpine region	19.5	12 - 27	93	21 - 305	494	112 - 1787
Bohemian massive	31.7	11 - 55	141	43 - 325	354	176 - 1628
Weinviertel	48.6	17 - 74	164	53 - 297	459	216 - 1214
Ammonium nitrate limes	1.12	< 0.5 - 10.0	0.35	< 0.3 - 3.7		
N-P-K + sulphate	1.21	< 0.5 - 7.0	0.89	< 0.5 - 9.2	3.08	< 0.5 - 27.4
N-P-K fertilizers	1.25	< 0.5 - 18.4	0.83	< 0.5 - 9.1	2.74	< 0.5 - 75.1
Di-ammonium phosphates	1.30	< 0.5 - 3.2	0.70	< 0.5 - 2.0	0.65	< 0.5 - 2.2
P-K fertilizers	1.95	< 0.5 - 12.3			3.33	0.55 - 12.6

Strontium

Strontium (Sr) mean crust level is 370 mg/kg, but it is known to be strongly enriched in certain carbonates (calcite, aragonite). In the largely acid rocks of the Bohemian massive, the frequency distribution of Sr concentrations was found rather ample, with a mean of 171 mg/kg, and in the Central Alps, the Sr concentration frequency distribution was clearly asymmetric (mean 190 mg/kg) (Thalmann *et al.* 1989). Among fertilizers, most of the strontium was found in rock phosphates (median 1420 mg/kg), and in Ca-Mg-phosphates (median 948 mg/kg). Strontium concentrations in limes, NPKs, and PKs were at about mean crust levels (370 mg/kg), but some of them also exceeded 1000 mg/kg. Lowest levels were met in ammonium salts, K-salts and garden moulds.

Green plants cannot discriminate between calcium and strontium. Therefore, plant uptake and atmospheric deposition may vary widely, due to the geological formation and Ca- occurrence, but were less than loads from fertilizers (except from ammonium nitrate lime). For an equivalent of 100 kg N, inputs from NPKs containing sulfate was largely more than from those without. An input of 100 kg/ha P from all sources was higher than the presumable annual preci-

Table 16 Data for strontium, sorted for the input equivalent to nitrogen.

Sr: Mean crust = 370 mg/kg Mean soil = 278 mg/kg			Crop uptake: wheat variable maize 61 g		Atmospheric deposition: Highly variable	
	mg/kg	**Range**	**g for 100 kg N**	**Range**	**g for 100 kg P**	**Range**
Commercial organics						
Southeast	40	3.1 - 315	60	5.2 - 425	266	70 - 1525
Alpine regions	45	2.9 - 347	63	4.5 - 1088	223	53 - 1665
Northern pre-alpine region	70	1.6 - 386	101	2.2 - 869	462	14 - 2782
Bohemian massive	81	27 - 465	130	34 - 1031	645	128 - 2323
Pannonian	63	2.9 - 458	133	4.4 - 649	354	75 - 3657
Weinviertel	70	2.4 - 244	176	44 - 471	410	161 - 1579
Manures and dungs						
Northern pre-alpine region	55	31 - 92	63	30 - 158	359	156 - 1028
Alpine regions	52	43 - 60	77	36 - 101	406	248 - 563
Bohemian massive	55	20 - 79	94	58 - 146	580	295 - 812
Pannonian	72	26 - 161	116	19 - 234	423	246 - 1788
Composts						
Weinviertel	155	98 - 238	407	277 - 901	1439	917 - 4425
Northern pre-alpine region	89	41 - 109	462	117 - 766	2207	967 - 3407
Bohemian massive	116	59 - 259	513	365 - 784	1847	1203 - 2872
Ammonium nitrate limes	17.1	8.9 - 86.8	6.2	2.9 - 32.9		
Di-ammonium phosphates	96	48 - 317	52	23.5 - 141	48.0	22.2 - 349
N-P-K fertilizers	260	0.5 - 6789	77	0.4 - 935	261	0.5 - 12578
N-P-K + sulfate	173	12.1 - 1473	124	11.0 - 1086	416	53 - 6293
P-K fertilizers	486	43 - 1137			867	259 - 1415

Table 17 Data for vanadium, sorted for the input equivalent to nitrogen.

V: Mean crust = 160 mg/kg Mean soil = 108 mg/kg			Crop uptake: wheat 0.03 + 0.34 g potatoes 0.04 g		Atmospheric deposition: Marchfeld 1985: 29.2 g/ha.a East of Austria 1997/98: 1.5 g/ha.a	
	mg/kg	**Range**	**g for 100 kg N**	**Range**	**g for 100 kg P**	**Range**
Commercial organics						
Southeast	1.9	< 0.5 - 35	2.5	< 1 - 39	12.5	< 2 - 173
Alpine regions	3.3	< 0.5 - 41	7.5	< 1 - 66	22.2	< 2 - 213
Pannonian	3.9	< 0.5 - 28	7.6	< 1 - 31	20.3	2 - 332
Bohemian massive	7.5	< 0.5 - 29	7.8	< 1 - 41	28.2	< 2 - 187
Northern pre-alpine region	4.7	< 0.5 - 30	8.3	< 1 - 218	30.9	< 2 - 1009
Weinviertel	9.1	< 0.5 - 20	18.3	< 1 - 37	63.2	14 - 138
Manures and dungs:						
Bohemian massive	3.1	0.7 - 16.6	5.2	2.1 - 23	28	10 - 112
Pannonian	7.2	< 0.5 - 16.8	5.4	< 0.6 - 15.8	37	< 2- 117
Northern pre-alpine region	4.5	< 0.5 - 14.1	5.5	< 0.6 - 34	25	< 2 - 170
Alpine regions	5.6	3.4 - 6.4	8.3	2.3 - 10.4	39	19 - 57
Composts						
Weinviertel	21.7	17 - 35	68	35 - 153	219	75 - 626
Northern pre-alpine region	18.9	10 - 30	70	25 - 308	435	88 - 1589
Bohemian massive	29.3	22 - 39	142	54 - 335	614	145 - 1949
Ammonium nitrate limes	1.33	0.80 - 3.13	0.5	0.2 - 1.2		
N-P-K fertilizers	29.1	< 0.5 - 252	18.5	< 0.5 - 107	62	< 0.5 - 503
N-P-K + sulphate	34.0	0.88 - 116	26.9	1.0 - 77	84	2.4 - 213
P-K fertilizers	44.8	13.9 - 90.3			70	35 - 110
Di-ammonium phosphates	121	62 - 411	66	34 - 225	64	28 - 203

pitation, except for di-ammonium phosphates. Sr/P in composts were highest, but might be exceeded by some NPKs, which covered a very broad range (0.005–12.6 kg Sr for 100 kg P) (**Table 16**). Regional differences in loads might be rather due to differences in N and P contents than to strontium contents itself.

Vanadium

Vanadium (V) occurs enriched in basic rocks, and is depleted in granites, sandstones and carbonates. It is frequently found in heavy minerals like garnets and magnetite. Mean values for the Bohemian massive and the Central Alps were 50 and 112 mg/kg, respectively, which is below mean crust (Thalmann *et al.* 1989). From sediments and soils, V may be recovered in *aqua regia* just at 1/3, but from fertilizers to a much greater extent. The tabulated mean soil value of 108 mg/kg surely refers to total contents, and not to *aqua regia*. V was not included in the Austrian soil inventory.

In mineral fertilizers without P as main component, as well as in manures and garden moulds, vanadium was found to be largely below 10 mg/kg. V concentrations largely correlated with phosphate, and some phosphates easily exceeded the mean soil value. Composts had significantly more V than manures and garden moulds.

Export to crops as well as mobility of vanadium in soils

Table 18 Data for zinc in soils, sorted for the input equivalent to nitrogen.

Zn Mean crust = 75 mg/kg Soil medians (Austria) 56 - 89 mg/kg Mean soil = 60 mg/kg	Crop uptake: wheat 104 + 42 g potatoes 72 g maize 375 g	Atmospheric deposition: Marchfeld 1985: 289 g/ha.a East of Austria 1997/98: 160 g/ha.a

	mg/kg	Range	g for 100 kg N	Range	g for 100 kg P	Range
Commercial organics						
Alpine regions	61	6 - 320	84	9 - 854	250	66 - 2602
Bohemian massive	79	15 - 293	94	31 - 537	358	119 - 2209
Southeast	86	10 - 1407	116	9 - 2349	462	39 - 9083
Weinviertel	91	5 - 1860	122	25 - 2190	361	35 - 16780
Northern pre-alpine region	79	6 - 1042	123	10 - 2134	378	78 - 6591
Pannonian	189	10 - 574	332	11 - 2188	1413	149 - 3986
Manures and dungs						
Bohemian massive	123	33 - 205	208	149 - 494	1180	594 - 3839
Pannonian	262	86 - 893	319	87 - 934	1703	684 - 7688
Alpine regions	344	202 - 727	528	341 - 1227	1917	1477 - 3300
Northern pre-alpine region	400	151 - 2561	620	196 - 2156	2879	1378 - 9929
Composts						
Northern pre-alpine region	126	75 - 277	775	167 - 1826	3077	2280 - 7881
Bohemian massive	116	75 - 488	958	454 - 2066	3606	1841 - 5380
Weinviertel	268	139 - 551	976	545 - 2159	3224	2369 - 4206
Ammonium nitrate limes	4.2	1.3 - 63.2	1.4	0.4 - 23.5		
N-P-K + sulphate	75.8	8.2 - 753	56.8	5.3 - 438	168	35 - 2637
N-P-K fertilizers	85.5	2.0 - 715	59.0	1.4 - 501	172	5.2 - 2590
P-K fertilizers	94.4	42.2 - 157			152	77 - 255
Di-ammonium phosphates	206	8.4 - 605	110	4.4 - 339	99	4.3 - 306

are very low. Like for Pb, atmospheric V deposition has been declining within the last 20 years. For 100 kg/ha N, the input of V from ammonium phosphates and composts significantly exceeded atmospheric deposition. Similarly, 100 kg/ha P from all mineral fertilizers and also many organics supplied more vanadium than annual atmospheric deposition. Top V/P values were found in basic slags, but median V/P were by far highest for composts (0.53 kg V for 100 kg P) (**Table 17**).

Regional differences in V concentrations and loads were largely insignificant, because a lot of data were smaller than the detection limit.

Zinc

With respect to its mean crust abundance, zinc (Zn) is moderately enriched in basalts and shales, and depleted in sandstones and carbonates. Igneous rocks from the Bohemian massive contained a mean of 94 mg/kg, and from the Central Alps a mean of 77 mg/kg (Thalmann 1989). Soil data are in the same range (Danneberg 1999), and *aqua regia* yields approximately the total contents.

Zinc concentrations in K-, ammonium- and Mg-salts without P as main component were below the mean crust level of 75 mg/kg. They covered a quite narrow concentration range (less than a factor 10) in garden moulds and phosphates. To the contrary, Zn concentrations in NPKs as well as in commercial organics had a bimodal frequency distribution, one at about ambient level (soil background = 71 mg/kg), and a second peak at 300 mg/kg for organics, and at 400 for NPKs, due to occasional additions, with some samples well above 700 mg/kg. More than half of the manures and many phosphates exceeded the level of concern for soils, which has been set to 300 mg/kg.

The input of Zn from an equivalent of 100 kg N as well as of 100 kg P plus atmospheric deposition easily covered plant uptake of wheat and potatoes. For 100 kg N, inputs from composts and manures may exceed the level of concern which is a load of 2500 g/ha within 2 years. Soils in the fertile eastern plains were slightly lower than soils in the mountains, but they got the highest Zn load from commercial organic fertilizers. Zn load from manures with respect to nutrient N or nutrient P, was at maximum in the region where most domestic animals are fed with commercial feedstuffs, which contain additional Zn (Sager 2006).

100 kg P from manures and organics add much more to the soil than the plant needs and may exceed the level of concern for contaminations also. Composts may be lower in mg/kg than manures, but supply more Zn load per nutrient N or P (**Table 18**).

Factor analysis

Multi-element datasets can be simplified by creating new variables, which are linear combinations of the primary components. High factor weights within the same obtained factor show, which primary components are correlated, and the plots of the factor scores might reveal distinguishable fields with respective trends. Within the given datasets, the uncertainty of the results of trace elements is surely higher than for main and nutrient elements. Therefore, ruggedness was tested by making at least three runs of each dataset, omitting some variables, as well as Varimax rotation. **Table 19** shows the combinations of elements which were found from common factor weights > 0.6 appearing in all element combinations tried, after rotation. Elements not specified could not be assigned significantly to one of the components given, because either their factor weights was too low, or they got assigned to different groups, when different subsamples of elements were selected. SPSS statistics package was used throughout. Graphs were exported into Power Point for future presentations.

Whereas the factor analysis for manures and for composts extracts about 90% within the first 2-4 factors, the commercial fertilizers (= all others containing organic carbon) yields some more components.

Relations of the main nutrients P resp. K to different groups of elements justifies the distinction, which is given *a priori* by the fertilizer act. In commercial organics, P-Cd appeared, which is well known from mineral fertilizers; obviously, P-minerals were mixed with carbon sources. In manures, P correlated with the essentials Cu-Mo-Zn, whereas in composts, it was within a larger group of siderophilics and essentials (P-Al-Fe-Cu-Mo-Zn-Be).

Table 19 Element combinations found from factor analysis, grouped as nutrients- main elements - essentials - non essentials, for the datasets presented.

Organic fertilizers				**Organic fertilizers, equivalent to N**			
-	Al-Fe	-	Be-Li	-	Fe	Co	As-Cd-Cr-Li-Ni-Pb-V-
K	Mg	-	V	-	Al-Ca-Mg	Mn	Ba-Be-Sr
P	-	-	Cd	-	-	Cu-Mo-Zn	-
-	-	Co-Mn	-	K	Na	-	-
-	-	Cu-Mo	-				
-	-	-	Cr				
Manures and dungs				**Manures and dungs, equivalent to N**			
-	Al-Fe-Mg	Co	Ba-Be-Cr-Ni	-	Al-Fe	Co-Mn	As-Be-Cr-Pb-V
N-K	Ca	-	Cd-Li-Sr	P-K	Ca-Mg	Mo	Cd-Li-Ni-Sr
P	-	Cu-Mo-Zn	-	-	-	Cu-Zn	-
-	Na	-	-	-	Na	-	-
Composts				**Composts, equivalent to N**			
P	Al-Fe	Cu-Mo-Zn	Be	P	Al-Fe-Ca-Mg	Mn-Zn	Ba-Cd--Li-Sr
-	Ca	-	Sr	-	-	-	As-Co-Cr-Ni-Pb-V
-	Mg	-	Cr-Ni-V	-	-	Cu-Mo	-
-	-	Mn	Cd	K	Na	-	-

Nutrient N and K went along Ca-Sr-Cd-Li in the manures, whereas nutrient K correlated with Mg and V in the organics. In the composts, they could not be assigned clearly.

In the organics, the essentials Cu-Mo and Co-Mn formed 2 groups, and Cr was independent from the siderophilic group Al-Be-Fe-Li. In the manures, however, a strong siderophilic group without correlations to nutrient elements was found (Al-Ba-Be-Co-Cr-Fe-Mg-Ni). Na stood alone. In the composts, a group of siderophilic traces (Cr-Ni-V) paralleled Mg (but not Al-Fe), independent from Ca-Sr as well as from Cd-Mn.

When the manure data were taken referring to equal N load, P and Mo moved away from the Cu-Zn to the Ca group. Within the compost data referring to N-load, a large group of trace elements appeared (As-Co-Cr-Ni-Pb-V), independent from the essentials Cu-Mo and from K-Na. Among the data for organics taken for equal N-load, P could not be assigned clearly to one of the components, and Al and Fe appeared in different groups, whereas the traces were linked together. Cu-Mo-Zn over N seemed to have a similar source, independent from K-Na.

DISCUSSION AND CONCLUSION

Will intense fertilization lead to long- term changes of soil composition? Which differences might appear between conventional farming using mineral fertilizers, and organic farming using only organic fertilizers? Are there regional differences due to geology, landuse and population density?

If there is a reduction in water resources due to climatic changes, an expansion of the agricultural lands affected by salinity will occur. Salinization is a process of soil degradation which occurs at a worldwide scale.

Fertilizers, soils, and regional effects

Fertilizers contain many elements at concentrations below soil levels, like Al, As, Ba, Li, Ni, Pb, and V. In addition, mineral fertilizers contain less Co, Cu, and Mn than soils. To the contrary, Cd-Be-V in phosphates, Mo in all organics, and Pb-V in composts occur usually above soil level.

With respect to regions, local geology can just explain local differences of Al-Ba-Be in composts. Population density seems to correlate with Na in manures, and Pb in all organics. (Among the manures, there are increasing numbers of biogas residues which also receive human inputs). Differences in Ni and Cr might derive from variable equipment used (steel, ceramics, wood), but this cannot be proved here. As special crops have more requirements for Co, Cu, Mn, Mo, or Zn, these have been sometimes added to NPKs, and organic fertilizers produced in the region might reflect these additional inputs.

Excrements from pigs and poultry carried higher metal loads, particularly zinc and copper. Pig manures frequently exceeded the acceptable limits for sewage sludge with respect to copper and zinc (details given in Sager 2007). Lead, nickel, chromium, cadmium and mercury, however, were significantly lower than in sewage sludges. The data for manures and dungs are similar to a report for the Provincial Government of Upper Austria with respect to manure and dung samples from the same kind of domestic animals (Aichberger 1995).

Long term effects of mineral fertilizer compositions can be recognized by comparison with similar compilations from former periods (Sager 1997; Sager and Scholger 2002).

Austria shares almost all landscape types occurring in Central Europe. In can be roughly parted from North to South into Bohemian massive, Weinviertel (= part of pre-Carpathian), Pannonian, Northern pre-alpine, Alpine, and Southeast lowlands. When the factor scores were grouped into these geological regions, the plots obtained from the concentrations did not show visible discriminations. Manures and dungs over N, however, were visibly lower in factor 3 (Cu/Zn). Factor score 2 (P-K-Mo-Ni) versus factor score 3 (Cu/Zn) was distinctly negative just for the Weinviertel and Northern pre-alpine. Cu and Zn are present in a close proportion in commercial feedstuffs. Similarly, regional effects were also seen for composts over N. The data from the Weinviertel showed a linear correlation of factor score 1 (Al-Ba-Ca-Fe-Li-Mg-Sr) versus factor score 2 (K-Na), whereas data from other regions did not. Also, the traces As-Ba-Co-Cr-Fe-Mn-Ni-Pb-V correlated positively with Ca-Cd-Fe-P-Zn just for the Weinviertel, and negatively for the data from the Pannonian region.

Among the data for commercial organic fertilizers referring to equal N-load, the factor containing the group of essential (Cu-Mo-Zn) was about negatively linear versus the factor containing the traces (As-Cd-Co-Cr-Fe-Li-Ni-Pb-V) as well as versus the factor containing K-Na, but only in data from the Southeastern Lowlands and from the Pannonian region, but scattered elsewhere.

Atmospheric deposition versus fertilizer input and crop output

The farmer can influence the inputs via fertilizers, and the crop output; he can leave straw and the like at the field, or feed it to animals or compost it or burn it. He cannot influence atmospheric deposition. For As-Cd-Ni-Pb-Zn, the input via atmospheric deposition is more than from a fertilization of 100 kg/ha N, and for Pb even more than 100 kg/ha P. Cleaning of emissions and substitution of coal has led to significant reductions in depositions of at least As, Pb and V, but it may be still more than the input from fertilizers. Loads equivalent to 100 kg N or 100 kg P from composts

Table 20 Mean atmospheric emmissions in Austria in g/ha.year. Calculated from moss samples (after Zechmeister 1997).

1993-1995	**Pb**	**V**	**Zn**	**Cu**	**Cr**	**Ni**	**Cd**	**Mo**	**Co**	**As**
Austria average	12.8	3.67	70.9	13.6	1.50	3.74	0.52	0.87	0.37	0.28
Bohemian crystalline	13.4	5.63	76.7	13.8	2.25	3.62	0.55	0.74	0.39	0.29
Northeast pre-Carpathian	14.4	9.41	78.6	16.1	4.93	7.50	0.49	0.91	0.39	0.29
Southeastern pre- alpine hills	13.6	3.93	66.0	13.0	1.72	4.62	0.61	2.47	0.40	0.30
Northern pre-alpine	14.5	4.16	100.9	19.7	1.70	4.24	0.70	0.95	0.42	0.32
Northern flysch and limestone alps	14.8	4.00	71.2	14.8	1.42	2.86	0.62	0.82	0.35	0.26
Crystalline central alps	10.3	2.98	61.3	11.9	1.24	3.31	0.41	0.68	0.36	0.27
Southern alps	13.0	4.24	66.3	13.4	1.50	3.46	0.50	2.23	0.37	0.28

were always highest, because their N and P contents was lower. Nevertheless, composts have merits for sustaining the carbon cycle, which is not discussed here.

Regional variations in atmospheric depositions may be significant. Therefore, in addition to the data given in **Tables 2-18** from own measurements, data obtained from samplings of mosses are given below (Zechmeister 1997; see **Table 20**).

In the **Tables 2-18**, a rough estimation of the crop output is given for each element. This has been obtained on non-contaminated sites and calculated for average yields. Real uptake, however, depends upon availability to the roots and transport inside the plant; therefore these figures are just estimations.

For a fertilization rate of 100 kg N given as compost, this estimated crop uptake is smaller than the added load for all elements investigated. Either plant uptake or soil concentrations will increase. 100 kg N from manures and commercial organics roughly supply more Be-Co-Cr-Li-Mn-Ni-V-Zn than the estimated crop uptake, but the other elements are about balanced. More crop uptake, which means insufficient supply, is predicted for a 100 kg N fertilization from mineral fertilizers for Ba-Co-Cu-Mn-Mo, whereas Be-Cd-Cr-V would be presumably more than crop output. This needs an explanation why Co-Cu-Mn-Mo-Zn have sometimes been added to NPK fertilizers.

ACKNOWLEDGEMENTS

Permission from the Austrian Agency for Health and Food Safety to compile and extend the required dataset of officially investigated fertilizer samples is greatly appreciated.

REFERENCES

Aichberger K (1995) Die Ergebnisse einer Untersuchung von Wirtschaftsdüngern in Oberösterreich. *Report of Bundesamt for Agrarbiologie*, Linz/ Austria

Bieber W, Uhl A (2005) Biomonitoring mit Flechten in Österreich - eine Studie zur Luftgüte in der Steiermark und im Burgenland. *Report of Umweltbundesamt Wien*, 44 pp

Bonten LTC, Römkens PFAM, Brus DJ (2008) Contribution of heavy metal leaching from agricultural soils to surface water loads. *Environmental Forensics* **9**, 252-257

Bowen HJM (1979) *Environmental Chemistry of the Elements*, Academic Press, London, 333 pp

Codling EE, Chaney RL, Mulchi CL (2008) Effects of broiler litter management practices of P, Cu, Zn, Mn, and As concentrations in Maryland Coastal Plain soils. *Communications in Soil Science and Plant Analysis* **39**, 1193-1205

Dachler M, Kernmayer I (1997) Düngemittelaufwand in Österreich, in: *Bodenschutz in Österreich*, BMFL (Federal Ministry of Agriculture and Forestry) Wien

Danneberg OH (1999) Hintergrundwerte von Spurenelementen in den landwirtschaftlich genutzten Böden Ostösterreichs, *Mitteilungen der Österreichischen Bodenkundlichen Gesellschaft* **57**, 7-24

Danneberg OH, Aichberger K, Amann H, Buchgraber K, Dachler M, Dersch G, Edinger E, Feichtinger F, Galler J, Gerhold KH, Hacket M, Hölzl F, Holzner H, Humer J, Pötsch EM, Prosenbauer M, Raab F, Peszt W, Wilhelm H, Wunderer W (1999) Richtlinien für die sachgerechte Düngung ("Guidelines of Adequate Fertilization"), BMLF (Federal Ministry of Agriculture and Forestry) (5th Edn), 31 pp

Donald CM, Prescott JA (1975) Trace elements in Australian crop and pasture production 1924-1974. In: Nicholas DJD, Egan AR (Eds) *Trace Elements in Soil-Plant-Animal Systems*, Academic Press, New York, pp 7-37

EdDE Dokumentation Nr. 11 (2007) Entsorgungsgemeinschaft der Deutschen Entsorgungswirtschaft, Köln, 30 pp

Harmens H, Norris D (2008) Spatial and temporal trends in heavy metal accumulations in mosses in Europe (1990-2005), Gwynedd, UK, 54 pp

Houba VJG, Uittenbogaard J (1994) *Chemical Composition of Various Plant Species*, Wageningen Agricultural University, The Netherlands, 226 pp

Kehres B (2008) Bioabfälle vom Nawaro-Bonus ausgenommen. *Humuswirtschaft und Kompost Aktuell* **01**/2008

Kehres B (2007) Perspektiven der Kompostierung in der Biomassewirtschaft. *Humuswirtschaft und Kompost Aktuell* **07**/2007

McConnell D (1973) *Apatite, its Crystal Chemistry, Mineralogy, Utilization, and Geologic and Biologic Occurrences*, Springer, Berlin, 91 pp

Naramabuye FX, Haynes RJ (2007) The liming effect of five organic manures when incubated with an acid soil. *Journal of Plant Nutrition and Soil Science* **170**, 615-622

Otero N, Vitòria L, Soler A, Canals A (2005) Fertiliser characterisation: major, trace and rare earth elements. *Applied Geochemistry* **20**, 1473-1488

Peszt W, Claupein W, Ruckenbauer P, Wutzl Ch, Spanischberger H (1997) Düngung. In: *Bodenschutz in Österreich*, BMLF (Federal Ministry of Agriculture and Forestry) Wien, 455 pp

Sager M (1986) Ökologie des Aluminiums. *Schweizerische Zeitschrift für Hydologie* **48**, 71-103

Sager M (1997) Possible trace metal load from fertilizers. *Die Bodenkultur* **48**, 217-223

Sager M, Scholger R (2002) Magnetic measurements as a rapid screening method for fertilizers. *Journal of the Korean Institute of Mineral and Energy Resources Engineers* **39**, 307-313

Sager M (2005) Multi-Elementbestimmung in Fleisch, Leber und Nieren. *Ernährung/ Nutrition* **29**, 151-156

Sager M (2006) Micro- and macro-element composition of animal feedstuffs sold in Austria. *Ernährung/Nutrition* **30**, 455-473

Sager M (2007) Trace and nutrient elements in manure, dung and compost samples in Austria. *Soil Biology and Biochemistry* **39**, 1383-1390

Scherer J, Buhmann D, Kopf M (2008) 15 Jahre Vorarlberger Bodenschutzkonzept, eine Bilanz. *Schriftenreihe Lebensraum Vorarlberg* (Vol. 58), Bregenz, Austria, 51 pp

Sery A, Manceau A, Delubac G (1995) Chemical state of cadmium in phosphate ores by EXAFS spectroscopy. *Proceedings of the 3rd International Conference on the Biogeochemistry of the Elements*, Paris, 525 pp

Spiegel H, Sager M (2008) Elementzusamensetzung von Weizen und Kartoffeln in Österreich unter Berücksichtigung des Einflusses von Sorte und Standort. *Ernährung/Nutrition* **32**, 297-308

Thalmann F, Schermann O, Schroll E, Hausberger G (1989) *Geochemischer Atlas der Republik Österreich 1:1000000*, Austrian Geological Survey, Wien, 141 pp

Ure AM, Berrow ML (1982) The chemical constituents of soils. In: Bowen HM (Ed) *Environmental Chemistry*, Royal Society of Chemistry, Burlington House, London, pp 94-202

Van Cauwenbergh SJ (1997) *Cadmium and Other Minor Elements in World Resources of Phosphate Rock*, The Fertiliser Society, York, UK, 40 pp

Zechmeister H (1997) Schwermetalldeposition in Österreich, erfasst durch Biomonitoring mit Moosen. *Umweltbundesamt Monographien* **94**, Wien, 184 pp