A FIELD STUDY ON THE INFLUENCE OF SOIL pH ON TRACE ELEMENT LEVELS IN SPRING WHEAT *(Triticum aestivum)*, POTATOES *(Solanum tuberosum)* AND CARROTS *(Daucus carota)*

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Abstract. Soil pH is one of the main factors influencing the solubility and availability of trace elements in arable soils. Thus pH can affect the trace element contents of agricultural crops and thereby indirectly influence human health. The aim of this study was to determine Cd, Ni, Zn, Cu, Mn, Cr, Al and Se contents in spring wheat, potatoes and carrots (Cd, Ni and Zn) and estimate their correlations with certain soil factors (surface and subsurface soil pH and organic matter content) governing the plant availability of these elements. Commercial fields were sampled in Sweden in order to cover a wide range of soil types with respect to pH, soil texture and organic matter content. Concentrations of Zn, Mn, Ni (grain) and Cd (straw) in spring wheat (n=43); Cd, Ni, Zn, Mn, Cu and Al in potatoes (n=69); and Cd, Ni and Zn in carrots (n=36) showed significant negative correlations with surface soil pH (0-25 cm). The Se content of potatoes and Cr content of spring wheat straw were positively correlated with soil pH. Stepwise multiple regressions including a combination of soil pHs (0-25 and 25-50 cm) and organic matter contents (0-25 cm) showed that the organic matter content as well as the surface and subsurface soil pH significantly influenced concentrations of several trace elements in one or more of the studied crops. It was concluded that, if acid deposition together with other acidifying processes (fertilisation, harvest of biomass, etc.) are not balanced by a sufficient amount of liming there might be a decrease in the pH of arable soils, which, in turn will lead to decreased levels of Se in edible crops but an overall increase concentrations of other trace elements.

Key words: acidification, arable soils, trace elements (Cd, Ni, Zn, Cu, Mn, Cr, Al, Se), plant uptake, field study

1. Introduction

Soil pH is, together with the contents of trace elements and organic matter, one of the main factors influencing the solubility and availability of trace elements in arable soils (e.g. Hamdy and Gissel-Nielsen, 1977; Eriksson, 1990; Andersson and Simán, 1991; Johnsson, 1991; Hornburg and Bruemmer, 1991. Thus pH can affect the trace element contents of agricultural crops and thereby indirectly influence human health. The aim of this study was to determine contents of cadmium (Cd), nickel (Ni), zinc (Zn), copper (Cu), manganese (Mn), chromium (Cr), aluminium (Al) and selenium (Se) in spring wheat, potatoes and carrots (Cd, Ni and Zn) and to focus on their correlations with surface soil pH (0-25 cm). In addition, the influences of organic matter content and subsurface soil pH (25-50 cm) on the plantavailability of these elements were estimated.

2. Materials and methods

2.1 SAMPLING SITES, SAMPLING AND SAMPLE PREPARATION

Commercial fields were sampled in order to cover a wide range of soil types with respect to pH and soil texture as well as contents of organic matter and trace elements. The carrots (n=36) were sampled in 1993. The sampling strategy was to cover the most

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important areas of production (85 %). The spring wheat (n=43) and potatoes (n=69) were sampled in 1992 in two and three areas, respectively.

In each sampled field, a representative site was selected where plant and soil samples were taken at harvest time. Four 0.25 m^2 squares (in total 1 m^2) of spring wheat were hand cut. For potatoes and carrots, two meters of a row was dug up and mixed, and a random subsample of 2 kg was taken for analyses. Soil samples were taken by auger in the harvested squares or rows (the soil surface was first leveled out) at two depths, 0-25 cm (Ap or Hp) and 25-50 cm (upper B).

The wheat was dried at 35-40° C and handthreshed to avoid contamination. Whole wheat grains were used for the trace metal analyses, whereas the straw was milled. A subsample of grain was milled for Se determination. The potatoes and carrots were washed under deionized water while being thoroughly brushed. The potatoes were peeled with a plastic knife, and the potatoes and carrots were cut with plastic knives into 0.5 cm cubes and freeze dried.

2.2 CHEMICAL AND STATISTICAL ANALYSES

For trace metal analyses (Cr, Ni, Al, Cd, Zn, Mn and Cu) 2 g plant material (1 g wheat straw) was extracted by wet-digestion (Tecator Digester) in 15 ml conc. HNO_3 (supra pure). Cd, Ni, Cr and Al were analysed by atomic absorption spectrophotometry (AA) (Perkin Elmer Zeeman 3030 with HGA-600 graphite furnace) using addition calibration to correct for nonspectral interference in the plant extracts. Contents of Zn, Mn and Cu were determined by flame AA. Se in plants was analysed after digestion in a mixture of conc. HNO_3-$HClO_4$-H_2SO_4 (7:2:1) by AA using the hydride method (Johnsson, 1989).

Soil pH was measured on fresh samples in deionized water (soil-solution ratio 1:2.5). Total-C in the carrot soils was determined by analysing finely ground, air-dried samples on an elemental analyser (Carlo Erba). In soils having a pH above 6.7 the carbonate-C content was determined and subtracted from total-C to get the organic-C content. In the potato and spring wheat soils the organic matter content was estimated from the loss on ignition, and the clay content was calculated using empirical formulas as described in Eriksson (1990).

The results were analysed statistically using simple and stepwise multiple regression in the Systat for Windows version 5 (SYSTAT, 1992). The adjusted regression coefficient (R^2_{adj}) is given in the text and in the figures, and the significance level used was 0.05. In stepwise multiple regression, the combination of factors giving the best model is chosen.

3. Results

3.1 SOIL PROPERTIES

The sampled sites showed a wide variation in soil properties, and the soils were classified within the soil orders Histosols, Inceptisols and Entisols (Soil Survey Staff, 1992) or the major soil groupings Histosols, Gleysols, Arenosols, Regosols and Cambisols (FAO, 1988). Acid sulphate soils as well as calcareous soils were included.

The surface soil pH (0-25 cm) ranged from 4.5 to 8.1 and the subsurface soil pH (25-50 cm) from 2.8 to 8.0. Carrots were mainly sampled on sandy or organic soils. Potatoes were sampled on sandy (n=17), loamy (n=35) and organic soils (n=16), and spring wheat was sampled on loamy (n=25), clayey (n=8) and organic soils (n=10).

3.2 TRACE ELEMENT LEVELS IN CROPS AND THEIR CORRELATIONS WITH SURFACE SOIL PH

The levels and distribution of trace elements in the sampled spring wheat (grain and straw), potatoes and carrots are shown in Table I.

Table I. Trace element contents in spring wheat (grain and straw), potato tuber and carrots (roots). The contents are given in µg or mg per kg dry weight. The dry matter content was about 90% in spring wheat grain and straw, 20% in potatoes and 11% in carrots

Crop	Cd µg kg^{-1}	Ni µg kg^{-1}	Zn mg kg^{-1}	Cr µg kg^{-1}	Cu mg kg^{-1}	Mn mg kg^{-1}	Al mg kg^{-1}	Se µg kg^{-1}
Spring wheat grain, n=43 (selenium n=42)								
mean	**69**	**319**	**43.4**	**(9.3)**[1]	**4.7**	**45.2**	**2.0**	**8.8**
std	41	191	9.0		1.5	22.7	0.8	8.5
median	56	252	42.2		4.7	42.9	1.8	7.2
min	14	56	5.2		1.8	9.9	1.0	2.0
max	163	780	78.8		7.6	105	4.5	56.4
Spring wheat straw, n=43 (selenium n=42)								
mean	**164**	**98**	**21.8**	**96**	**1.9**	**47.8**	**13.3**	**11.7**
std	107	50	15.3	24	0.5	50.8	5.7	12.0
median	132	83	16.1	89	1.8	25.1	11.8	8.0
min	20	32	6.3	56	1.1	3.8	5.1	1.4
max.	454	209	79.2	153	3.0	252	28.1	65.7
Potato tuber, n=69								
mean	**53**	**401**	**15.1**	**(2.3)**[1]	**4.9**	**7.9**	**0.8**[2]	**6.1**
std	35	383	3.0		1.9	3.0	0.6	5.1
median	46	265	14.7		4.7	7.2	0.6	3.6
min	7	23	9.7		0.9	3.6	0.1	0.8
max.	194	1660	22.3		10.6	21.1	3.9	24.2
Carrots, n=36								
mean	**276**	**210**	**16.7**	n.d.	n.d.	nd	nd	nd
std	206	233	9.3					
median	214	120	13.4					
min	62	10	6.2					
max.	873	1000	53.1					

n.d. = not determined

1) Many samples were below the detection limit (< 11 µg Cr kg^{-1})

2) A few samples were below the detection limit (< 0.2 mg Al kg^{-1})

Simple linear regression between surface soil pH (0-25 cm) and the trace element content (log) of plants showed a significant negative correlation with the content of Ni (R^2_{adj}=0.39), Zn (0.32) and Mn (0.58) in spring wheat grain; Cd (0.26), Zn (0.41) and

Mn (0.56) in spring wheat straw; Cd (0.21), Ni (0.40), Zn (0.19), Mn (0.30), Cu (0.26) and Al (0.10) in potatoes; and Cd (0.30), Ni (0.15) and Zn (0.50) in carrots (Figures 1a-f). The Cr content of spring wheat straw (0.14) and the Se content of potatoes (0.08) showed positive correlations with pH (0-25 cm) (Figures 1g-h).

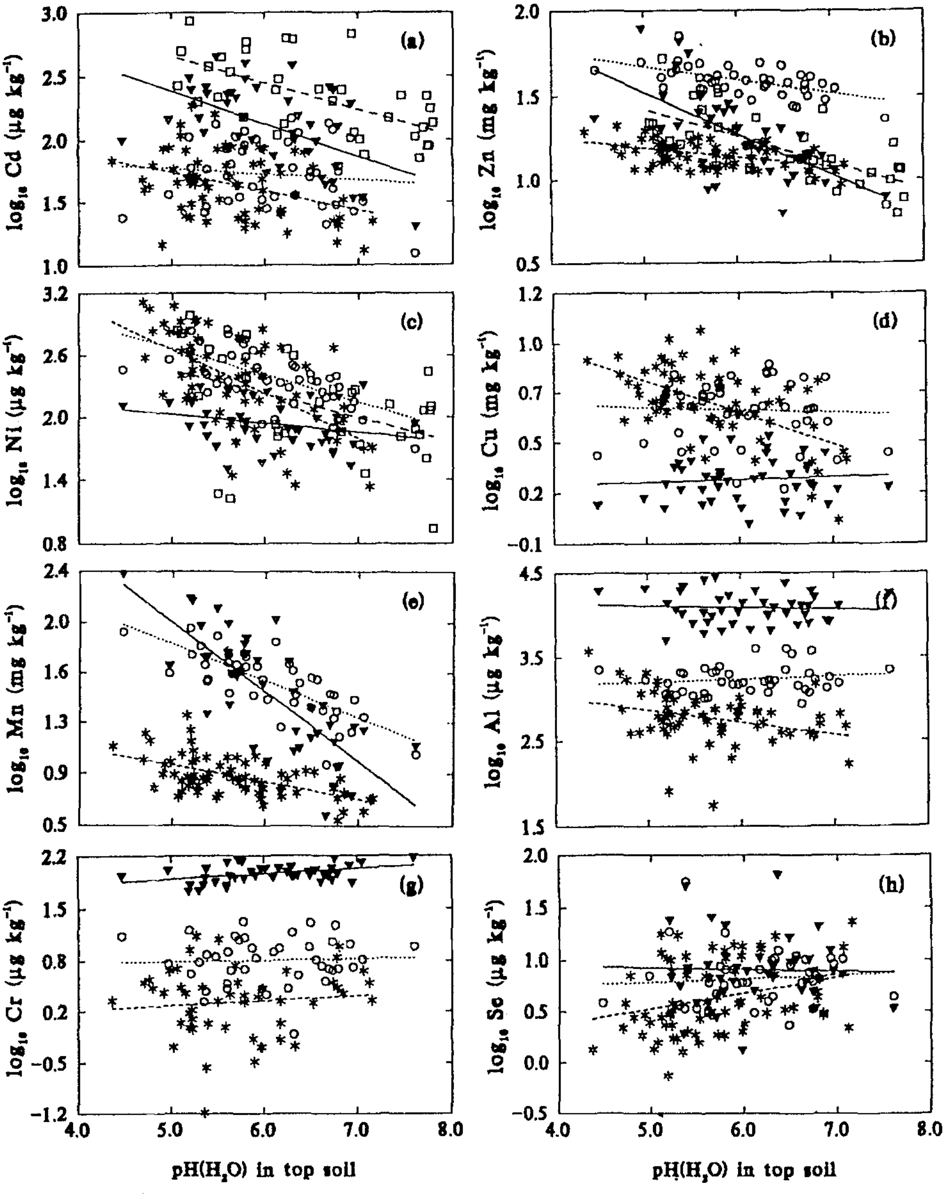

Fig. 1. Simple linear regression between surface soil pH (0-25 cm) and the trace element contents of spring wheat grain (O ....), spring wheat straw (∇____), potato tuber (* _ _) and carrots (□ __ __); *(a)* cadmium, *(b)* zinc, *(c)* nickel, *(d)* copper, *(e)* manganese, *(f)* aluminium, *(g)* chromium and *(h)* selenium.

3.3 THE INFLUENCE OF ORGANIC MATTER CONTENT AND SURFACE AND SUBSURFACE SOIL PH ON THE TRACE ELEMENT CONTENTS OF CROPS

Stepwise multiple regressions were carried out with the studied crops in which trace element contents were related to soil organic matter content (0-25 cm) as well as surface (0-25 cm) and subsurface soil pH (25-50 cm). A combination of these soil factors explained 68, 28 and 26% of the total variation in the Cd content of carrots, potatoes and spring wheat straw, respectively (Table II).

Table II. Stepwise multiple regression relating trace element contents of spring wheat (grain and straw), potato tuber and carrots to soil organic matter content (0-25 cm) and surface (0-25 cm) and subsurface soil pH (25-50 cm). The adjusted regression coefficients are given in the table (R^2_{adj})

Crop	*Cd*	*Ni*	*Zn*	*Cu*	*Mn*	*Al*	*Cr*	*Se*
Wheat *grain*	n.s.	0.46	0.32	0.11	0.63	n.s.	n.s.	n.s.
straw	0.26	0.20	0.46	0.22	0.63	0.23	0.14	n.s.
Potato tubes	0.28	0.51	0.19	0.33	0.33	0.20	n.s.	0.17
Carrots (root)	0.68	0.24	0.58	n.d.	n.d.	n.d.	n.d.	n.d.

n.d.= not determined; n.s.= not significant

In the stepwise multiple regressions the organic matter content was a significant factor negatively correlated with the Cd, Ni and Zn contents of carrots, the Cd and Al contents of potatoes and the Cu, Ni (grain) and Mn (straw) contents of spring wheat. Subsurface soil pH was a significant factor influencing the Ni content of carrots, the Ni, Cu, Mn, Al

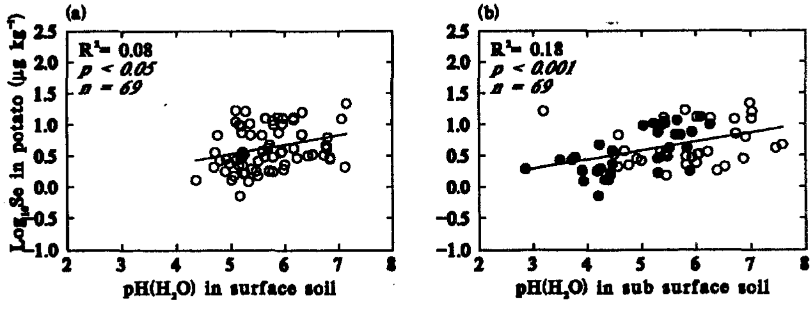

Fig. 2. Se concentrations ($\log_{10}$) in potatoes as related to (a) pH in surface soil (0-25 cm) and (b) pH in subsurface soil (25-50 cm). Filled symbols in (b) show samples with ≥ 12 % organic matter content.

and Se contents of potatoes and the Ni, Mn, Zn (straw) and Al (straw) contents of spring wheat. The influence of the subsurface soil pH on the plant-availability of Se was most pronounced in the soils rich in organic matter (Figure 2). The influence of subsurface soil conditions on trace element uptake needs to be further investigated. It has to be noticed that the soil content of trace elements, which was not included in this study, could be expected to increase the correlation further (e.g. Eriksson, 1990; Eriksson, et al., 1990).

4. Summary and conclusions

We found that levels of Ni, Zn and Mn in all of the studied crops tended to increase with decreasing surface-soil pH. Cd levels in carrots, potatoes and spring wheat straw were also negatively correlated with surface-soil pH, but the correlation was weaker. By contrast, the Cd content of wheat grain was not influenced significantly by this factor. In addition, Cu and Al levels tended to increase with decreasing surface-soil pH, but only in potatoes. The study showed that in crops grown on soils with a low pH (<5.5-6) there was a risk for enhanced levels of potentially toxic elements like Cd. On the other hand, the results demonstrated that the plant availabilities of certain essential micronutrients (Zn, Mn and Cu) were enhanced at lower pH levels. The Se content of potatoes showed a weak positive correlation with surface soil pH but was strongly correlated with subsurface pH. The subsurface soil pH as well as the organic matter content seemed to influence levels of several trace elements in crops.

Our findings suggest that if acid deposition together with other acidifying processes (fertilisation, harvest of biomass, etc.) lead to a decrease in soil pH, levels of Se will tend to decrease in edible crops, whereas those of other elements will show an overall increase. Such trends could, however, be counteracted by liming arable land. On average, present liming rates in Sweden (SCB, 1994) do not meet more than 50% of the estimated needs of maintenance liming (Ericsson & Bertilsson, 1982).

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