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Influence of lime on the Ni transfer into plants

Einfluss von Kalk auf den Ni-Transfer in Pflanzen

Abstract

In a two years pot experiment with a sod-podzolic, acid sandy loam, contaminated with nickel (Ni) and treated with increased lime doses, the Ni transfer from soil to plants was studied. It was shown that lime addition significantly decreased mobile Ni concentration in soil, Ni concentration in plants and consequently its transfer factor. The sigmoidal Bolzman equation estimates the range of changes in parameters of Ca and Ni interaction. It is suggested as an estimation function for the description of related processes in the soil-plant system.

Key words: Nickel, lime, soil-plant system, transfer factor, sigmoidal Bolzman equation

Zusammenfassung

In zweijährigen Gefäßversuchen mit einem sauren, podsoligen sandigen Lehm, der mit Nickel (Ni) kontaminiert und mit steigenden Kalkgaben behandelt war, wurde der Ni-Transfer vom Boden in die Pflanzen untersucht. Es konnte gezeigt werden, dass Kalkgaben die mobile Ni-Konzentration im Boden, die Ni-Konzentration in Pflanzen und folglich den Transferfaktor signifikant vermindern. Auf der Grundlage der sigmoidalen Bolzman Gleichung wurden die Veränderungen in den Ca/Ni-Interaktionen geschätzt. Sie wird als Schätzfunktion für die Beschreibung vergleichbarer Prozesse im System Boden-Pflanze vorgeschlagen.

Stichwörter: Nickel, Kalk, System Boden-Pflanze, Transferfaktor, sigmoidale Bolzman Gleichung

1 Introduction

It is well known that the risk of heavy metal transfer into the food chain is a function of heavy metal mobility and availability in soil. Liming is considered to be an economically acceptable measure that generally helps to reduce the transport of heavy metals into the food chain.

Obviously there is by far no clear understanding of all the processes of lime influencing soils and plants. There are only a limited number of studies about plant response to liming during the vegetation period. Basically no evidences or the evaluation of specific growth rates of plants influenced by different levels of liming are available. The knowledge of the properties of liming concerning control mechanisms of pH, influence of the supply and availability of essential plant nutrients as well as toxic elements, how it affects higher plants and human beings and how liming can be improved is essential for a sustainable management of soils throughout the world.

Although it is well known that all the compartments in the soil-plant system are in a dynamic equilibrium and reactions of ion exchange play an important role in all processes of their interactions, further investigations are needed for a better understanding of agrocoenosis.

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2 Material and Methods

In order to evaluate the influence of lime on the Ni transfer from soil into plants a two years pot experiment was carried out.

2.1 Description of the test soil

The experiment was conducted during 2000 – 2001 at the Agricultural Physical Research Institute in St.-Petersburg-Pushkin, Russia. An acid sod-podzolic sandy-loam (Russian soil classification system) or alternatively a dystric cambisol (FAO-Unesco soil classification) was used in this study. It is a typical arable soil in the territories of ancient glacier transition. The soil is characterised by low organic matter content, acid soil reaction and low contents of plant available phosphorus and potassium (Tab. 1).

2.2 Experimental design

The soil was contaminated with Ni and treated with increasing amounts of lime. The experimental design included 5 treatments and one control:

Control
20 mg kg^{-1} Ni + 0.41 g kg^{-1} $CaCO_3$
20 mg kg^{-1} Ni + 0.83 g kg^{-1} $CaCO_3$
20 mg kg^{-1} Ni + 1.25 g kg^{-1} $CaCO_3$
20 mg kg^{-1} Ni + 1.66 g kg^{-1} $CaCO_3$
20 mg kg^{-1} Ni + 2.10 g kg^{-1} $CaCO_3$

All treatments were carried out in three replicates.

The control has received neither Ni nor lime. All the treatments received the complex mineral fertilizer "Ecofoska" in doses of $N_{0.15}$ $P_{0.08}$ $K_{0.14}$ g kg^{-1}. Seven days before sowing the soil was passed through a 5 mm sieve before mixing thoroughly with fertiliser, lime and water solution of $Ni(NO_3)_2 \cdot 6H_2O$ and transferred to the plastic pots, containing 5 kg dry soil.

Taking into account the high ability of *Brassica napus* (oilseed rape) to accumulate Ni this plant was chosen as experimental crop. The variety used for the experiment was Oredezh3. Weight of 1000 seeds was 2.6 – 5.0 g (GOLTSOV et al., 1983).

The plants were sown in May. In each pot 14 plants were cultivated. The pots were located outdoors under a plastic shelter. Water was applied sufficiently for optimum growth. The treatment with the lowest lime dose has been excluded since the pots were inundated with rainwater.

Tab. 1. Description of the test soil

Organic matter (%)	$pH_{(KCl)}$	Exchangeable bases Total	Ca^{2+}	Mg^{2+}	P	K
			(meq kg^{-1})		(mg kg^{-1})	
1.66	4.1	10.3	7.6	1.2	42.0	83.2

Soil and plants were sampled after 14, 21, 29, 36 and 43 days of growth. At sampling date "day 43" plants were in the flowering phase.

In the second year of investigations eight days before sowing, the soil from all pots was removed, watered, mixed and returned to the pots. The investigated variety of the used crop was "Astor" which belongs to early-maturing varieties. Oats (*Avena sativa*) are known to tolerate acid, neutral and basic (alkaline) soils and can even grow in very acid soil. This was the main criterion why it was chosen as crop in the year 2001. The plants were sown in early June. In each pot 12 plants were cultivated. Soils and plants were sampled at the 14, 21, 29, 36 and 43 day of growth. At sampling date "day 43" the plants were at the beginning of the milky-wax ripeness phase.

3 Results

3.1 Lime influence on mobile Ni concentration in soil

The concentration of mobile Ni in the soil during the vegetation period did not change significantly (Tab. 2).

The coefficient of variability of the mobile Ni concentration in soil was much less in the second year experiment, compared to the first. This may be caused by a more even distribution of elements in the soil volume in the second year of the experiment.

The concentration of mobile Ni (C_{Nis}) in the soil decreased with increasing lime doses (D) in both years of experimentation (Tab. 2, Fig. 1).

The relationship between liming and mobile Ni concentration in soil ($C(Ni_s)$) can be described well by the sigmoidal Boltzman function (Eq. 3.1):

$$C(Ni_s) = \frac{C(Ni_s)_{max} - C(Ni_s)_{min}}{1 + e^{(D - D_0)/\Delta D}} + C(Ni_s)_{min} \qquad \text{Eq. [3.1]}$$

Where:

$C(Ni_s)_{max}$ – maximum mobile Ni concentration in soil (with a low lime dose) [mg kg^{-1}]
$C(Ni_s)_{min}$ – minimum mobile Ni concentration in soil (with a high lime dose) [mg kg^{-1}]
D_0 – lime dose where the Ni concentration in soil is equal

$\frac{(C(Ni_s)_{max} + C(Ni_s)_{min})}{2}$ [g kg^{-1}] (point of inflection)

D – lime dose [g kg^{-1}]
ΔD – constant, characteristic lime dose which describes the changes in Ni concentrations in soil from the maximum to the minimum [g kg^{-1}] (valid for the conditions of the experiment)

The coefficient of determination between lime dose and mobile Ni concentration in soil was high (Tab. 2). More than 90% of the variation in mobile soil Ni concentration could be explained by changes in the lime supply.

Tab. 2. Effect of liming on the mobile Ni concentration in soil (mg kg^{-1})

Lime dose (g kg^{-1})	Concentration of mobile Ni in soil [mg kg^{-1}]						
	Sampling time (d)					Arithmetic mean	V (%)
	14	21	29	36	43		
2000							
0	Below detection limit						
0.41	6.30	6.75	5.68	6.87	7.02	6.49	7.7
0.83	6.80	6.07	5.78	5.93	6.08	6.13	6.6
1.25	5.65	5.05	5.58	5.93	6.52	5.75	8.6
1.66	4.75	5.00	4.91	5.41	4.55	4.99	8.2
2.10	4.95	5.25	4.83	5.15	5.10	5.06	3.9
LSD (5%)	1.30	1.50	0.90	0.80	1.00		
2001							
0	Below detection limit						
0.41	5.45	5.43	5.27	5.36	5.54	5.41	1.8
0.83	5.21	5.22	5.25	5.21	5.23	5.22	0.2
1.25	4.95	4.92	4.96	4.91	4.90	4.93	0.6
1.66	4.84	4.79	4.82	4.80	4.81	4.81	0.4
2.10	4.76	4.74	4.75	4.75	4.77	4.75	0.2
LSD (5%)	0.20	0.20	0.20	0.10	0.20		

Remarks: V- coefficient of variability, $V = \sigma/\bar{x}$ – ratio of standard deviation to arithmetic mean.

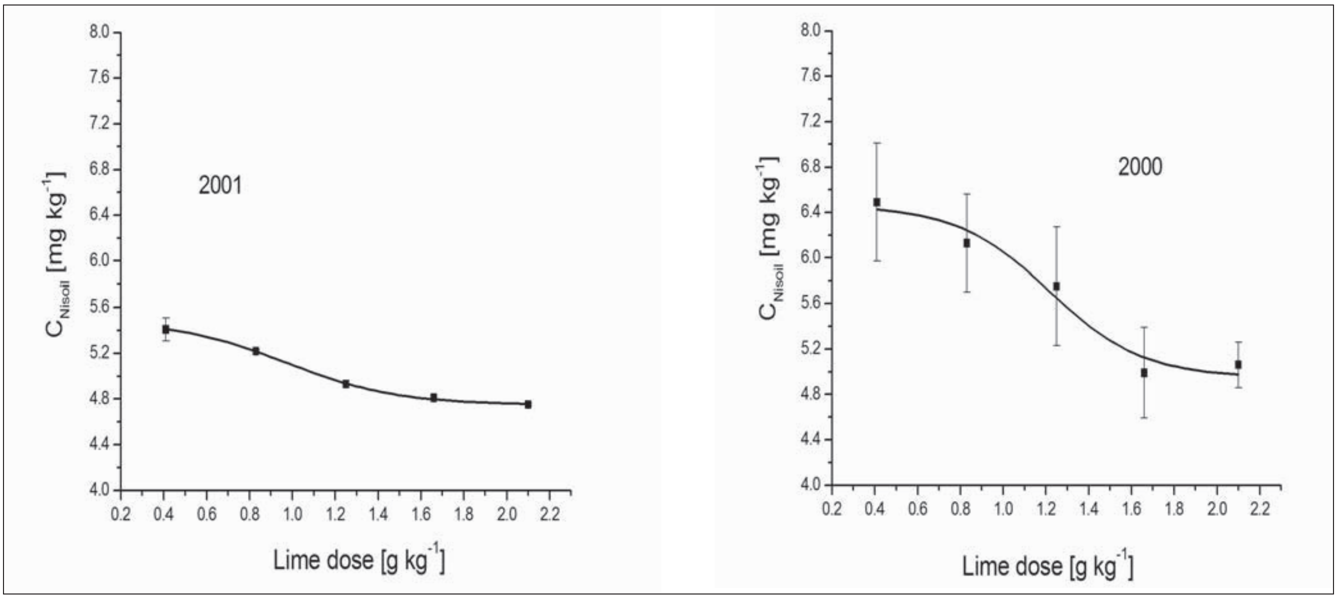

Fig. 1. Concentration of mobile Ni [mg kg^{-1}] in soil influenced by lime application (year 2000 (left) and 2001 (right), corresponding to Eq. 3.1).

It should be marked here that the parameters of sigmoidal decrease in mobile Ni concentration in soil are applicable only within the range of lime doses used in the experiment.

The calculated values of minimum and maximum Ni concentration ($C(Ni_S)_{max}$ and $C(Ni_S)_{min}$) are very close to those obtained experimentally (Fig. 1, Tab. 3). The experiment shows, that both parameters ($C(Ni_S)_{max}$ and

Tab. 3. Parameters of the sigmoidal Boltzman function for the description of changes in mobile Ni concentrations in soil depending on lime applications

Parameter	Year 2000	Year 2001
R^2	0.97	0.99
$C(Ni_s)_{max}$ [mg kg^{-1}]	6.5 ± 0.3	5.49 ± 0.05
$C(Ni_s)_{min}$ [mg kg^{-1}]	5.0 ± 0.3	4.75 ± 0.20
D_0 [g kg^{-1}]	1.2 ± 0.2	0.97 ± 0.04
ΔD [g kg^{-1}]	0.2 ± 0.2	0.26 ± 0.04

Remarks: $\pm$ – error of estimating function; R^2 – coefficient of determination between mobile Ni concentration in soil and lime dose (explained by the sigmoidal Boltzman function), figures apply to Eq. 3.1.

$C(Ni_s)_{min}$) decreased in the second year on 5 and 26% respectively, which is mainly related to the Ni uptake by plants. At the same time parameters D_0 and ΔD almost did not change. (Tab. 3). This fact possibly shows that the formation of these parameters mainly connected with the chemical mechanisms of interaction between Ni and lime and that plants only slightly influence on this process. Under the conditions of presented experiment the lime dose where the change of Ni concentration in soil per unit lime is maximum (parameter D_0) is equivalent 1 g kg^{-1}. Parameter ΔD characterises the sharpness of changes from maximum to the minimum values of Ni concentration in soil. It seems that these values are characteristic for the sod-podzolic light loam acid soils.

3.2 Dynamics of Ni concentration in plants depending on the lime dose

For the description of the dynamics of changes in Ni concentrations depending on lime dose the following equation for the sigmoidal Boltzman function similar to Eq. 3.1 was employed:

$$C(Ni)_p = \frac{C(Ni_p)_{max} - C(Ni_p)_{min}}{1 + e^{(D - D_0)/\Delta D}} + C(Ni_p)_{max} \qquad \text{Eq. [3.2]}$$

Where:

$C(Ni_p)_{min}$ – minimum Ni concentration in plants (grown on soil with a high lime dose) [mg kg^{-1}]

$C(Ni_p)_{max}$ – maximum Ni concentration in plants (grown on soil with a low lime dose) [mg kg^{-1}]

D_0 – lime dose lime dose where the Ni concentration in plants is equal

$$\frac{(C(Ni_p)_{max} + C(Ni_p)_{min})}{2} \quad \text{[g kg}^{-1}\text{] (point of inflection)}$$

ΔD – constant, characteristic lime dose which describes the changes in Ni concentrations in plants from the maximum to the minimum [g kg^{-1}] (valid for the conditions of the experiment)

During the first phase of the development of *Brassica napus* the Ni concentration smoothly decreased with increasing lime doses. This tendency continues during the more mature phases of the plant development, but in the flowering phase (day 43) there was an extremely sharp change of the Ni concentration (Fig. 2).

Uneven Ni distribution in soil and uncompleted reaction between lime and soil in the first experimental year did not allow to describe the change in Ni concentrations in plants with a reliable accuracy. The errors of estimating function were rather high. Due to the negative D_0 value at day 29 (Tab. 4) the calculated Ni concentrations

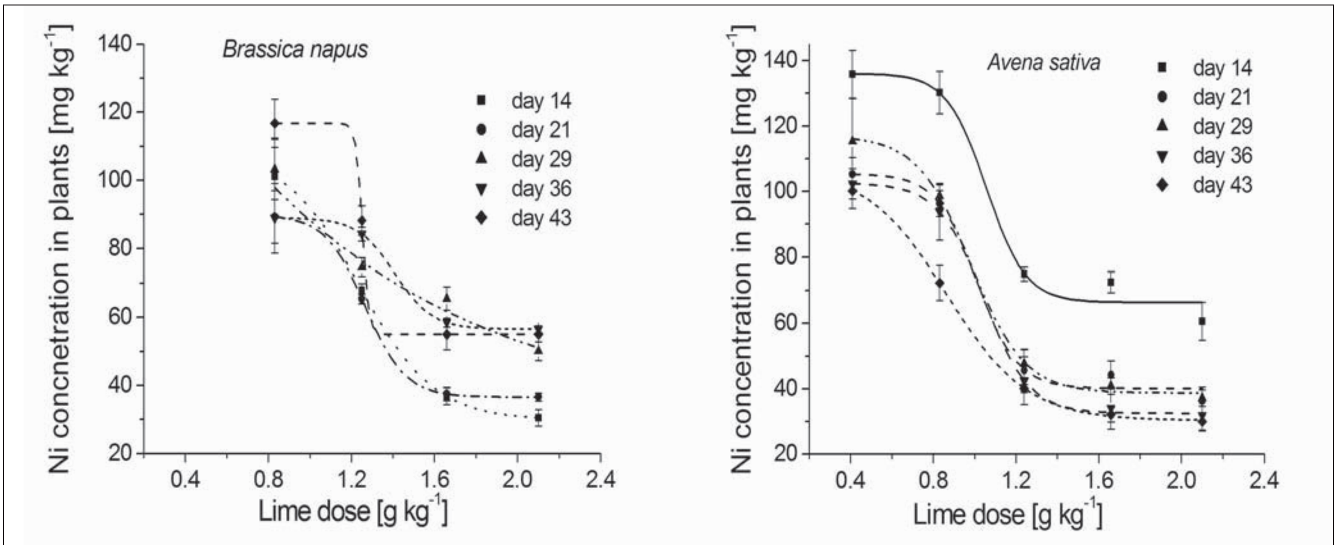

Fig. 2. Influence of liming on Ni concentration in *Brassica napus* (left) and *Avena sativa* (right) grown on a sod-podzolic soil (corresponding Eq. 3.2, model parameters see Tab. 4).

Tab. 4. Parameters of the sigmoidal Boltzman function for the description of changes in Ni concentrations in *Brassica napus* and *Avena sativa* depending on lime applications

Sampling time [d]	*Brassica napus*					*Avena sativa*				
	R^2	$C(Ni_p)_{max}$ [mg kg^{-1}]	$C(Ni_p)_{min}$ [mg kg^{-1}]	D_0 [g kg^{-1}]	ΔD [g kg^{-1}]	R^2	$C(Ni_p)_{max}$ [mg kg^{-1}]	$C(Ni_p)_{min}$ [mg kg^{-1}]	D_0 [g kg^{-1}]	ΔD [g kg^{-1}]
14	1.00	108.6	29.8	1.22	0.19	0.98	136.0 ± 7.4	69.7 ± 5.9	1.03 ± 0.10	0.09 ± 0.05
21	1.00	89.9	36.6	1.26	0.09	0.99	105.5 ± 5.4	40.2 ± 4.0	1.00 ± 0.07	0.09 ± 0.03
29	0.98	575.0	39.9	−0.60	0.38	0.99	117.1 ± 14.0	38.8 ± 1.8	1.00 ± 0.08	0.13 ± 0.03
36	1.00	88.9	56.6	1.24	0.09	0.99	102.6 ± 4.9	32.5 ± 3.8	1.00 ± 0.08	0.11 ± 0.01
43	1.00	116.8	55.0	1.24	0.01	0.99	107.0 ± 10.0	30.3 ± 2.1	0.90 ± 0.08	0.19 ± 0.04

Remarks: ± – error of estimating function; R^2 – coefficient of determination between Ni concentration in plants and lime dose (explained by the sigmoidal Boltzman function) figures apply to Eq. 3.2.

of the employed function ($C_{(Ni)max}$, ΔD) are unreliable concerning *Brassica napus*. In all periods of observation the parameter D_0 was almost constant and equivalent to 1.24 g kg^{-1}.

In the experiment with *Avena sativa* the Ni concentration in plants smoothly decreased with increasing lime doses during all time of observation (Fig. 2). The maximum Ni concentration in plants was observed on the 14 day of the experiment. Then the maximum concentration almost did not change while the minimum concentration decreased at the end of vegetation period (Tab. 4). This corresponds with the increase of parameter ΔD.

It should be marked here that parameter D_0 which is characteristic in the system lime-soil and lime-plant was almost constant and equivalent to 1 g kg^{-1} in both experimental years. This fact may corroborate the assume written above about leading role of interaction between lime and soil in comparison with the Ni transfer from soil to plants.

3.3 Development of the soil-plant Transfer Factors for Ni (TF(Ni)) as influenced by lime application

For a quantitative estimation of the heavy metal availability for plants commonly a coefficient is used, which takes plant and soil properties into account. The so called *Transfer Factor (TF)* is defined as the ratio of element concentration in plants to total element concentration in soil. In this work the Ni *Transfer Factors (TF)* were calculated as the ratio of Ni concentration in plants to mobile Ni concentration in soil. The development of the Ni concentration in plants, the mobile Ni concentration in soil and the *Transfer Factors (Ni)* for *Brassica napus* and *Avena sativa* plants are summarised in Tab. 5.

The addition of lime significantly influenced the Ni transfer (TF(Ni)) from the soil into plants. *Transfer Factors (Ni)* for *Brassica napus* and *Avena sativa* decreased with rising lime dose (Tab. 5). In the experiment with *Brassica napus* the *Transfer Factors* obtained in the treatments with the lowest lime dose were 1.8 – 2.4 times higher then those in the treatments with the highest lime dose. In the experiment with *Avena sativa* the difference between *Transfer Factors (Ni)* in the treatments with the lowest and highest lime doses was 2.0 – 2.9 times. *Avena sativa* plants showed a higher ability to accumulate Ni in their tissues in the treatments with low lime application and in the junior stage of development (up to 21 days). But in the treatments with lime doses of 1.25 – 2.10 g kg^{-1} and starting from day 29 the *Transfer Factors (Ni)* for *Avena sativa* plants are lower then those for *Brassica napus* plants.

In order to demonstrate TF(Ni) changes for *Brassica napus* plants the linear function was employed. This function fitted only low to the experimental results, but a tendency of decrease of TF with increasing lime doses was observed (Fig. 3, left).

The lime application reduced the Ni transfer into the plants significantly. The highest decrease in the *Transfer Factors* was observed in the treatments with lime doses of 1.25 – 1.66 g kg^{-1}. The minimum TF's were observed on the first phases of the plant development. A tendency of increasing TF simultaneously with increasing plant age (maturation) was observed (comparing TF obtained at the sampling days of the same treatment).

The changes of TF(Ni) for *Avena sativa* were described employing the sigmoidal Boltzman function:

$$TF(D) = \frac{TF_{max} - TF_{min}}{1 + e^{(D - D_0)/\Delta D}} + TF_{min} \qquad \text{Eq. [3.3]}$$

Where:

TF_{max} Ni *Transfer Factors* for *Avena sativa* grown on soil with a low lime dose

TF_{min} Ni *Transfer Factors* for *Avena sativa* grown on soil with a high lime dose

D_0 lime dose, where $TF = \frac{TF_{max} + TF_{min}}{2}$ [g kg^{-1}]

ΔD constant, characteristic lime dose; describes the changes in TF(Ni) from the maximum towards the minimum [g kg^{-1}] (valid for the conditions of the experiment)

D lime dose [g kg^{-1}]

Tab. 5. Effect of liming on the concentration of Ni in plants [mg kg^{-1}], the mobile Ni concentration in soil [mg kg^{-1}] and Transfer Factors (Ni) for *Brassica napus* and *Avena sativa* plants

Lime dose [g kg^{-1}]	Concentration of Ni in plants [mg kg^{-1}]					Concentration of mobile Ni in soil [mg kg^{-1}]					Transfer Factors (Ni)				
	Sampling time [d]														
	14	21	29	36	43	14	21	29	36	43	14	21	29	36	43
								Brassica napus							
0.41	No plant material					6.30	6.7	5.7	6.8	7.0	No plant material				
0.83	101.0	89.3	103.2	88.8	116.8	6.80	6.1	5.8	5.9	6.1	14.8	14.6	17.8	15.0	19.1
1.24	67.9	65.4	74.6	84.2	88.2	5.60	5.1	5.6	5.9	6.5	12.1	12.8	13.3	14.2	13.5
1.66	36.8	37.5	65.5	58.5	55.0	4.70	5.3	4.9	5.4	4.5	7.8	7.0	13.4	10.8	12.1
2.10	30.5	36.6	50.1	56.6	55.0	4.90	5.2	4.8	5.2	5.1	6.2	7.0	10.4	10.9	10.8
LSD (5%)	3.9	4.1	4.8	3.0	24.3	1.30	1.5	0.9	0.8	1.0	1.9	1.7	3.0	2.5	2.9
								Avena sativa							
0.41	135.9	105.3	115.3	102.4	100.2	5.4	5.4	5.3	5.4	5.5	25.2	19.5	21.7	19.0	18.2
0.83	130.3	96.3	98.6	93.9	72.3	5.2	5.2	5.3	5.2	5.2	25.0	18.5	18.6	18.1	13.9
1.24	75.0	45.7	47.7	42.5	40.1	4.9	4.9	5.0	5.0	4.9	15.3	9.3	9.5	8.5	8.2
1.66	72.5	44.3	40.9	34.1	32.1	4.8	4.8	5.0	5.0	4.8	15.1	9.2	8.2	6.8	6.7
2.10	60.7	36.3	37.2	31.9	30.0	4.8	4.7	4.7	4.7	4.8	12.6	7.7	7.9	6.8	6.2
LSD (5%)	12.2	17.5	6.8	10.8	6.2	0.2	0.2	0.2	0.1	0.2	2.8	3.0	1.6	3.6	1.8

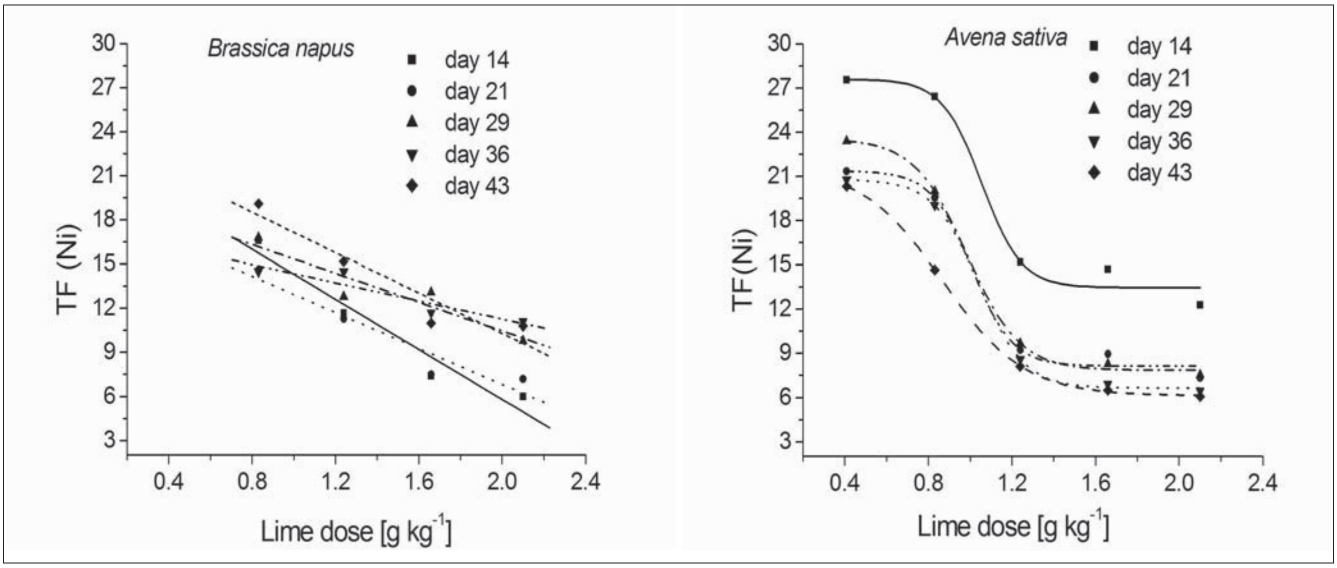

Fig. 3. The influence of lime doses on changes of the Ni *Transfer Factors* into *Brassica napus* (left) and *Avena sativa* (right) plants grown on a sod-podzolic soil.

In contrast to increasing TF(Ni) for *Brassica napus* plants, the decreasing TF(Ni) for *Avena sativa* plants during the vegetation period was observed (Fig. 3 (right), Tab. 6).

In the experiment with *Avena sativa* plants a significant lime effect on reducing of TF(Ni) was implicated. The parameters D_0 and ΔD almost did not change in all periods of the observation. Negligible decreasing of D_0 and increasing of ΔD on the day 43 were observed. That means that independently of the *Avena sativa* ontogenesis phase there is a distinct optimum of lime dose equivalent to 1 g kg^{-1} for the change of TF(Ni) for plants from the maximum towards minimum (Fig. 3 (right), Tab. 6).

Tab. 6. Parameters of the sigmoidal Boltzman function for the description of changes in TF(Ni) for *Avena sativa* plants depending on lime applications

Sampling time [d]	TF_{max}	TF_{min}	D_0 [g kg^{-1}]	ΔD [g kg^{-1}]	R^2
14	25.2 ± 1.8	13.8 ± 1.3	1.1 ± 0.3	0.1 ± 0.13	0.98
21	19.5 ± 1.1	8.4 ± 0.8	1.0 ± 0.1	0.1 ± 0.04	0.99
29	21.8 ± 0.2	8.0 ± 0.1	1.0 ± 0.01	0.1 ± 0.01	0.99
36	19.0 ± 0.02	6.8 ± 0.01	1.1 ± 0.001	0.1 ± 0.001	1.00
43	19.2 ± 0.04	6.3 ± 0.2	0.9 ± 0.02	0.2 ± 0.02	0.99

4 Discussion

The present investigations proved that the concentration of mobile Ni in soil decreased with increasing lime supply, in both years of experiment (Fig. 1 and 2, Tab. 2). There are many findings confirming this fact. CHAUDHURI et al. (2003) reported about a sequential extraction procedure that has been used to study the changes in the distribution and mobility of Cd, Cr, Cu, Ni, Pb and Zn in an acid lateritic soil amended with 2 t ha^{-1} lime. It was shown that the metal mobility in their labile forms was restricted, positive responses of peanut yield were observed.

The lime addition reduced the transfer and accumulation of metals from the soil to the plant. In an experiment with Ni contaminated soil (5.7 mg g^{-1}) the amount of Ni extracted by ammonium acetate was reduced by 36 % in the limed soil (10 t ha^{-1} lime) in comparison to the untreated soil (BISSESAR, 1989).

The experimental results confirm that liming of acid sod-podzolic soil leads to a decrease of the mobility of heavy metals. Sigmoidal function applied in the presented study for the description of this phenomenon showed very high accuracy and might be recommended as estimation function.

Plants grown on limed soils usually contained less heavy metals than those grown on soils without lime additions (ALEKSEEV, 1987; BOLAN et al., 2003; CHAUDHURI et al., 2003; LEE et al., 2004; IZOSIMOVA, 2005). In the presented experiment lime supply influenced the Ni concentration in plants the same way as the most heavy metals, it decreased with increasing lime doses.

The lime dose under which the change in the plant Ni concentration per unit of lime reaches the maximum (D_0) was different for *Brassica napus* and *Avena sativa*, but almost equal over time of observation in both experiments (Fig. 2, Tab. 4). Under the conditions of the presented experiment lime doses of 1.24 and 1.00 g kg^{-1} are distinct optimum amounts for reducing the Ni concentration in *Brassica napus* and *Avena sativa* plants, respectively. The application of lower or higher doses seems to be non-effective. If the experimental conditions are changed (another type of soil, plant, etc), it is very likely that the parameter D_0 will be different as well. The decrease in the Ni concentration in plants due to interaction with Ca is possible not more than 4 times also taking into account the variability in acidity in agricultural soils. This conclusion is in line with findings of DRICHKO and TSVETKOVA (1990) and WANG et al. (2002) who investigated other pairs of elements, such as K-Cs, Sr-Ca, Sb-P, S-Se and P-As.

The sigmoidal function used in this study allows to estimate a range of changes in parameters of Ca and Ni interaction in the soil-plant system. The use of this function requires to introduce new terms such as: “sharpness of change in concentration and TF”, characteristic value D_0 which corresponds to the point of inflection when derivative (dC(Ni)/dD) changes sign. In the conditions of presented experiments the value D_0 was almost equal in all analyzed relationships and did not depend on plant species.

Conclusion

1. Lime addition significantly affected the concentration of mobile Ni in soil. It decreased with increasing lime supply. It seems that after liming Ni is bound with CO_3 groups which have lower solubility than added $NiSO_4$. The most significant decrease in mobility of Ni was observed on the treatments with 1.24 g kg^{-1} and 1 g kg^{-1} in the first and the second years of the experiment respectively.

2. Ni accumulation by plants decreases with increasing of lime supply and reflects decrease in Ni mobility in soil. The change in TF for Ni is caused by the change of Ni mobility in soil.

3. Ca and Ni interaction under Ni transfer to plants follows sorption model of interaction of chemical elements in the soil-plant system.

4. Change in mobile Ni concentration in soil, Ni concentration in plants as well as TF for Ni are well described by sigmoidal function which is suggested as an estimation function for the description of elements behavior in the soil-plant system.

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