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Importance of grass cover in reduction of negative processes in soil affected by air pollution

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ABSTRACT

The effect of grass sward formation on soil environment was studied on a site affected by air pollution in the Moravian-Silesian Beskydy Mts. (Czech Republic). Acidophilous grasses (*Calamagrostis arundinacea* and *C. villosa*), common on clear-cut areas, were planted in blocks of soil inserted in plastic boxes modified to lysimeters. Their intensive growth resulted in a decrease of both the acidity of the soil percolates and the amount of nitrogen, especially of nitrates, in lysimetric waters leached from soils. Leaching of base cations (Ca^{2+} and Mg^{2+}) was two to three times lower as from bare soil without grasses. An excess of labile Al was substantially eliminated in variants with grasses. Formation of a grass sward also coincided with a considerable decrease of conductivity of percolates. The biomass of soil microorganisms increased by 30% in variants with grasses. Thus, it is suggested that grass sward formation has a positive effect on the reduction of nutrient losses from the soil and partly eliminates negative processes associated with soil acidification.

Keywords: base cations; conductivity; CO_2 output; labile Al; microbial biomass; nitrogen; percolates; pH

During primary succession, organic matter is gradually accumulated in the form of biomass and detritus, and as a result, loss of nutrients from ecosystem declines. In the initial stages of secondary succession taking place after environmental disturbance, high losses of nutrients were observed (Gorham et al. 1979). One of the major threats to the structure and functioning of ecosystems is the increase in air-borne nitrogen pollution (Bobbink and Roelofs 1995). Higher nitrogen inputs also increase soil acidity associated with subsequent leaching of base cations, especially Ca^{2+} and Mg^{2+} , from soils and with excess of toxic Al^{3+} ions (Nihlgard 1985, Schulze et al. 1989). Deforestation leads to high organic matter decomposition and humus mineralization, since considerable changes in microclimate cause more favourable conditions for the development and activity of soil microorganisms (Lettl and Hýsek 1994, Fiala et al. 1998, Emmer 1999). It may be assumed that biological decomposition of organic substances on polluted sites is enhanced conspicuously due to the nitrogen input which, under limited humification processes, results in more rapid leaching of nutrients from the soil profile. Rapid regeneration of vegetation cover following disturbance tends to minimize losses of nutrients from an ecosystem promoting a return to steady-state cycling (Marks and Borman 1972). Thus, both concentration of nutrients and soil pH increase in upper soil layers with age of secondary succession (Donaldson and Henderson 1990). Following the destruction of the tree canopy improved light conditions, soil acidification and increased nitrogen availability support the prolific spreading of acidophilous perennial grasses (*Calamagrostis arundinacea* and *Calamagrostis villosa*) on areas affected by air pollution. We hypothesize that these grass swards reduce losses of nutrients

from the disturbed ecosystem and improve features of the soil affected by pollution. Therefore, we established a field experiment to study changes in soil environment and leaching of nutrients from soil. The present paper summarizes results obtained in the two years of the experiment.

MATERIAL AND METHODS

The field experiment was based on the transfer of soil blocks from partly damaged Norway spruce stand situated near the top of the Malý Smrk Mtn. to a deforested site exposed to pollution. This chosen site was situated on a northeast-facing slope of the Malý Smrk Mtn. (49°31' N, 18°32' E, 1140 m above sea level) characterized by annual mean air temperature of 5.6°C and annual sum of precipitation of 1110 mm (for details see Fiala et al. 1998). An input of wet bulk deposits is characterized by 33.5 and 40.1 $\text{kg}\cdot\text{ha}^{-1}$ SO_4^{2-} , 6.3 and 8.1 $\text{kg}\cdot\text{ha}^{-1}$ $\text{N}\cdot\text{NH}_4^+$ and 4.5 and 9.4 $\text{kg}\cdot\text{ha}^{-1}$ $\text{N}\cdot\text{NO}_3^-$ during the growing seasons 1997 and 1998, respectively, at a rain water pH 4.10–4.56 and conductivity 10–47 $\mu\text{S}\cdot\text{cm}^{-1}$.

Undisturbed soil blocks were carefully inserted in plastic boxes (36 × 53 × 16 cm) on May 14, 1997. A trench of the same size was dug for each box in the soil on the chosen site and the boxes with soil were transferred to these trenches. Transferred soil, belonging to Spodo-dystric cambisols, was characterized by rather low soil pH (3.38 pH- H_2O , 2.72 pH-KCl) and Ca^{2+} content (248 $\text{mg}\cdot\text{kg}^{-1}$), and relatively high content of Al^{3+} ions (1199 $\text{mg}\cdot\text{kg}^{-1}$, determined in 1N KCl extract complexometrically – see text below). Nitrogen content of 26.2 $\text{mg}\cdot\text{kg}^{-1}$ $\text{N}\cdot\text{NH}_4^+$ and 1.61 $\text{mg}\cdot\text{kg}^{-1}$ $\text{N}\cdot\text{NO}_3^-$ were assessed in the 1% K_2SO_4 soil

extract at the beginning of our experiment (May 1997). The boxes were planted with young plants of *Calamagrostis arundinacea* and *C. villosa* (six tufts or clumps of shoots of each grass per box). Above-ground biomass of planted *C. arundinacea* and *C. villosa* was, respectively, 148 and 43 g of dry mass per one box on average. The control variant represented bare soil without grasses. Three boxes (replicates) of each variant were modified to lysimeters and soil percolates were collected and analyzed at monthly intervals. In order to describe both changes and differences in losses of nutrients from soil during grass sward formation, data recorded at the start of the experiment (June 15), in summer (August 12) and at the end of the first growing season (October 2, 1997) as well as at the beginning (June 2), in summer (August 5) and in autumn of the second growing season (October 6, 1998) are presented in this paper and the total amount of leached substances during the whole growing season 1998 is shown.

An Orion 290 A (USA) pH meter and conductometer GRYF 107 (Czech Republic) were used for measuring pH and conductivity. The content of base cations (Ca^{2+} and Mg^{2+}) was assessed complexometrically (Moravec 1972). The content of N-NH_4^+ was estimated spectrophotometrically with Nessler's reagent and that of N-NO_3^- also spectrophotometrically with sodium salicylate. The concentration of sulphates was determined by electrophoresis using DIONEX (USA) analyzer in the laboratory of the Central Institute for Supervising and Testing in Agriculture in Brno. Labile Al in lysimetric waters was assessed using the method described by James et al. (1983).

Soil samples (three replicates) were taken in the damaged Norway spruce stand at the beginning of the experiment (May 22, 1997), and then from soil blocks of all variants at the end of the first (October 2, 1997) and the second (October 6, 1998) growing seasons. These samples (soil layer 0–12 cm) were sieved using a mesh size of 2 mm and stabilized at 5°C in a refrigerator for two to three weeks and then left at laboratory temperature for 24 hours prior to the following analyses: (a) microbial biomass carbon (fumigation-extraction methods, Vance et al. 1987), (b) the intensity of CO_2 output from soil samples determined by titrametric method. CO_2 output was measured over 28 days in one to three-day intervals and results calculated per 100 g of dry soil and day.

RESULTS

Already after three months growth of planted grasses (in August 1997), a statistically significant decrease of acidity in soil percolates collected from variants of both grass species has been recorded; the pH of percolates was higher by more than one unit (mostly above 4.5 pH) in comparison with bare soil. In summer months, the content of leached mineral nitrogen ($\text{N-NH}_4^+ + \text{N-NO}_3^-$), especially nitrates, was approximately two times lower in variants with grasses than in percolates from bare soils (though the difference was significant only for the variant with *C. villosa*) (Tables 1 and 2).

At the end of the first growing season (in October 1997), the grass sward formation resulted in statistically significant differences between percolates of bare soil and both variants of grasses in all measured parameters. The concentration of nitrates was below 10% of the value assessed for bare soil without planted grasses. The conductivity of percolates collected in October under variants with grasses represented about 19% (*C. arundinacea*) and 13% (*C. villosa*) of values assessed for bare soils (conductivity 212 $\mu\text{S}\cdot\text{cm}^{-1}$). Lower contents of nitrogen and sulphates in percolates also coincided with lower losses of base cations, especially calcium, from soil. The amount of leached Ca^{2+} (in $\text{mg}\cdot\text{l}^{-1}$) represented 46% (*C. arundinacea*) and 38% (*C. villosa*) of the content of Ca^{2+} in percolates of bare soil. At the beginning of the experiment (June 1997), the contents of labile Al in lysimetric waters were very similar in all variants (Table 1). In the following months, however, percolates collected under bare soil contained a considerably higher content of Al (0.66 to 3.49 $\text{mg}\cdot\text{l}^{-1}$) than under variants with grasses (0.19–0.32 $\text{mg}\cdot\text{l}^{-1}$).

In the second growing season (1998), the further development of the grass sward resulted in more pronounced effects on lysimetric waters. The average pH values of percolates in variants with grasses were higher by 0.5 pH units, values of conductivity three to five times lower. Ca^{2+} was often two times and nitrogen two to three times lower than those in controls (bare forest soil, Tables 1 and 2). Concentrations of labile Al were three to six times (in October) lower in comparison with control variants. All differences in pH, conductivity, concentration of Ca^{2+} , Mg^{2+} , nitrates and mineral nitrogen were highly statistically significant (often at $P < 0.01$), especially in August.

In the course of the second growing season, 19.2 kg of N per hectare was leached from bare soil, whereas in variants with grasses the leaching represented only about 5 kg of N per ha (Figure 1). Losses of Ca^{2+} were more than twice as low (about 9 $\text{kg}\cdot\text{ha}^{-1}$) and of Mg^{2+} even nine times lower (0.53–0.63 $\text{kg}\cdot\text{ha}^{-1}$) than in the control variant without grasses. The amount of Al leached from bare soil represented 8.83 $\text{kg}\cdot\text{ha}^{-1}$, whereas from variants with growing grasses it represented only 1.45 $\text{kg}\cdot\text{ha}^{-1}$ (*C. arundinacea*) and 1.69 $\text{kg}\cdot\text{ha}^{-1}$ (*C. villosa*).

The total biomass of microorganisms in forest soil transferred to deforested sites attained 948 $\mu\text{g}\cdot\text{C}\cdot\text{g}^{-1}$ of dry soil at the beginning of the experiment (May 1997). A successive decrease in biomass of microorganisms (to 789 $\mu\text{g}\cdot\text{C}\cdot\text{g}^{-1}$, 87% of original value) was recorded in bare soil without grasses in October 1998. Development of planted young grasses of *Calamagrostis* species markedly supported the growth of soil microorganisms; at the end of the growing season, the biomass of microorganisms increased by 36 and 28% in variants with *Calamagrostis arundinacea* and *C. villosa*, respectively. This increase was permanent, as was documented by data on biomass of microorganisms assessed at the end of the second growing season (after 15 months) (Table 3). Positive changes mentioned above were more pronounced in the variant with planted *C. arundinacea*.

Table 1. Changes in pH, conductivity, concentration of Ca²⁺, Mg²⁺ and labile Al in soil percolates during grass sward formation in 1997 and 1998 (CA – *Calamagrostis arundinacea*, CV – *C. villosa*); mean values and I.S.E. are given where available; different letters indicate significant differences [LSD test ($P < 0.05$) after ANOVA, $n = 3$]

Time	pH			Conductivity ($\mu\text{S}\cdot\text{cm}^{-1}$)			Ca ²⁺ (mg.l ⁻¹)			Mg ²⁺ (mg.l ⁻¹)			Labile Al (mg.l ⁻¹)		
	bare soil	grass		bare soil	grass		bare soil	grass		bare soil	grass		bare soil	grass	
		CA	CV		CA	CV		CA	CV		CA	CV			
1997															
June 15	3.41a±0.08	3.47a±0.11	3.50a±0.03	119a±14.7	120.0a±26.7	114.3a±4.2	5.74a±0.71	6.95a±0.36	6.28a±0.62	2.35a±0.11	1.54a±0.43	2.11a±0.27	2.35	2.72	3.34
August 12	3.61a±0.07	4.56b±0.16	4.73b±0.11	82.7b±24.9	44.0ab±16.0	23.7a±1.8	2.81a±0.80	3.87a±0.71	2.81a±0.53	0.32a±0.11	0.16a±0.11	0.32a±0.11	0.66	0.32	0.32
October 2	3.65a±0.03	4.19b±0.17	4.32b±0.09	211.7b±8.9	40.0a±13.3	27.0a±2.0	5.61b±0.53	2.61a±0.20	2.14a±0.18	2.19b±0.16	0a	0a	3.49*	0.32*	0.19*
1998															
June 2	3.58a±0.08	4.09b±0.09	4.09b±0.06	77.7a±5.1	24.7b±4.9	19.3b±1.6	4.14b±0.18	3.21a±0.54	2.54a±0.18	0.65b±0.11	0.32a±0.11	0.24a±0.01	0.96	0.19	0.35
August 5	3.47a±0.05	3.93b±0.07	3.90b±0.02	122.7a±3.8	32.0b±5.3	26.7b±0.4	4.14c±0.36	2.94b±0.18	2.00a±0.27	0.57b±0.11	0.32a±0.11	0.24a±0.01	2.52	0.62	0.66
October 6	3.57a±0.09	4.14b±0.02	4.07b±0.03	164.3a±12.4	37.7b±3.8	33.3b±1.1	4.88c±0.26	2.51a±0.07	3.20b±0.28	1.70b±0.16	0a±0	0.08a±0.11	4.88	0.78	0.81

* assessed on September 10, 1997

Table 2. Changes in concentration of N-NO₃⁻, N-NH₄⁺, mineral nitrogen and SO₄²⁻ in soil percolates during grass sward formation in 1997 and 1998 (CA – *Calamagrostis arundinacea*, CV – *C. villosa*); mean values and I.S.E. are given where available; different letters indicate significant differences [LSD test ($P < 0.05$) after ANOVA, $n = 3$]

Time	N-NO ₃ ⁻ (mg.l ⁻¹)			N-NH ₄ ⁺ (mg.l ⁻¹)			N (N-NO ₃ ⁻ + N-NH ₄ ⁺) (mg.l ⁻¹)			SO ₄ ²⁻ (mg.l ⁻¹)		
	bare soil	grass		bare soil	grass		bare soil	grass		bare soil	grass	
		CA	CV		CA	CV		CA	CV		CA	CV
1997												
June 15	6.33a±1.02	5.65a±1.05	4.99a±0.39	0.88a±0.16	0.70a±0.05	0.83a±0.09	7.21a±1.00	6.35a±1.10	5.85a±0.42	16.0	19.1	20.9
August 12	5.50b±2.15	2.03ab±0.84	0.97a±0.14	1.20a±0.12	1.86b±0.19	1.92b±0.16	6.70b±2.03	3.89ab±0.87	2.89a±0.30	3.86	3.54	2.17
October 2	18.21b±1.22	0.81a±0.07	0.53a±0.02	0.80a±0.21	1.04a±0.12	1.17a±0.19	19.01b±1.43	1.85a±0.82	1.70a±0.21	7.31	4.29	4.22
1998												
June 2	2.80b±0.10	0.39a±0.10	0.36a±0.06	0.77a±0.19	1.11b±0.08	1.20b±0.03	3.57b±0.10	1.49a±0.04	1.57a±0.07	5.32	5.30	4.07
August 5	3.12b±0.04	0.54a±0.08	0.49a±0.02	0.65a±0.03	1.48b±0.34	1.55b±0.10	3.77b±0.07	2.02a±0.42	2.03a±0.11	5.00	4.01	2.40
October 6	4.67b±0.32	0.72a±0.11	0.46a±0.03	0.79a±0.08	1.46a±0.56	1.32a±0.16	5.47b±0.41	2.18a±0.67	1.77a±0.18	6.70	8.78	9.97

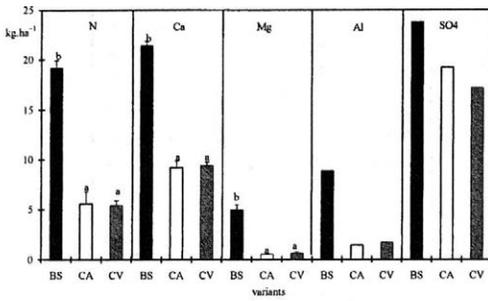


Figure 1. Amount of leached mineral nitrogen, Ca^{2+} , Mg^{2+} , labile Al and SO_4^{2-} from bare soil and from soil with planted grasses recorded in the 1998 growing season; bars show one standard error; different letters above bars indicate significant differences [LSD test ($P < 0.05$) after ANOVA, $n = 3$]

Data on CO_2 output of soil samples measured in laboratory conditions are shown in Table 3. If we take the output from forest soil at the beginning of the experiment (May, 1997) as 100%, all other measurements performed at the end of both the first and second growing seasons were characterized by an increase of this parameter by 26–42%. The highest increase of CO_2 output for bare soil without grasses corresponded to 39%. Lower CO_2 outputs, an increase by 29 and 26%, were found in variants with planted *C. villosa* and *C. arundinacea*, respectively. The soils of studied variants also differed in the dynamics of CO_2 output. Soils with growing grasses showed, in comparison with bare soil, relatively higher CO_2 output in the second phase of measurement (in days 15 to 28), when the decomposition of less available organic substances had started (Figure 2).

DISCUSSION

In comparison with bare soil, the formation of grass sward followed by the development of populations of soil microorganisms decreased the amount of mineral nitrogen, especially nitrates, leached from the soil. Burger and Pritchett (1984) found increased nitrification potentials and subsequent NO_3^- production after site

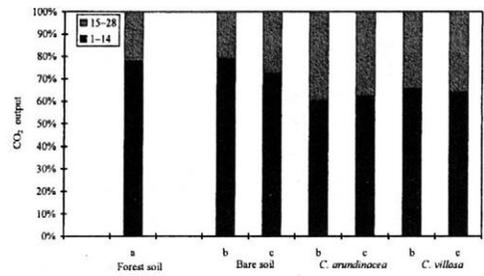


Figure 2. Dynamics of CO_2 output from original forest soil and from bare soil and soil with planted grasses measured in laboratory conditions during 28 days (100%); percentages proportion of CO_2 output during the first 14 days (1–14) and during the next period of 14 days (15–28) are shown (a – May 22, 1997, b – October 2, 1997; c – October 6, 1998)

disturbance. Donaldson and Henderson (1990) noted that the observed increase in NO_3^- production after vegetation removal results from decreased uptake by the vegetation, plus increased N mineralization due to improved soil moisture and temperature conditions for heterotrophic decomposition. *C. villosa* swards are able to take up additional quantities of nitrogen which are twice as high as the prevailing anthropogenic nitrogen immissions (Betz 1998). Hence, it is suggested that both *C. villosa* and *C. arundinacea* swards act as sinks for deposited nitrogen (Betz 1998, Fiala et al. 1998). At the end of the first (1997) and the second (1998) growing seasons, the above-ground biomass of planted *C. villosa* accumulated on the average 2.12 and 2.95 $\text{g N}\cdot\text{m}^{-2}$, respectively (Holub 1999, Holub personal communication). Live above-ground parts of old *C. villosa* swards mostly bound 3.7 to 9.9 g of N per m^2 (Fiala et al. 1998). Nevertheless, still higher values (even 16.9 $\text{g N}\cdot\text{m}^{-2}$) were also recorded in well developed *C. villosa* swards by Holub (1999). In addition, *C. villosa* prefers taking up nitrates instead of ammonium salts (Gloser et al. 1996) and therefore is likely to make the soil solution more alkaline (Kennedy 1992). The ability of these grass swards to reduce excess of soil nitrogen is a principal mechanism associated with the elimination of other negative processes caused by acid depositions.

Table 3. The biomass of soil microorganisms (in $\mu\text{g C}\cdot\text{g}^{-1}$ dry soil) and soil respiration ($\text{mg CO}_2\cdot 100\text{g}^{-1}$ dry soil per 24 h) recorded in original forest soil and in soil blocks (bare soil and planted with grasses) transferred to the deforested site; mean values and 1 S.E. are given; different letters show statistically significant differences between variants [LSD test ($P < 0.05$) after ANOVA, $n = 3$]

Time		Variants			
		forest soil	bare soil	<i>Calamagrostis arundinacea</i>	<i>Calamagrostis villosa</i>
Start of experiment (May 22, 1997)	biomass	948.0±24.5			
	respiration	2.06±0.09			
October 2, 1997	biomass		900.6a±12.5	1289.0b±52.7	1213.4b±23.1
	respiration		2.92b±0.08	2.58a±0.11	2.65ab±0.07
October 6, 1998	biomass		789.8a±19.5	1242.6b±22.7	1204.0b±47.2
	respiration		2.80b±0.06	2.60a±0.04	2.68ab±0.04

Our results agree with the findings which followed from chemical analyses of soil samples taken from grass swards on deforested areas in the Beskydy Mts.: lower soil acidity, higher contents of base cations and decrease in Al^{3+} contents were found in upper soil layers of clear-cut grass swards in comparison with those of adjacent spruce forests (Fiala et al. 1998). Similarly, *Sasa* communities had a significant role in the retention of basic cations in surface soil and in prevention of soil acidification (Takamatsu et al. 1997). In contrast, a decrease in the contents of Ca^{2+} , Mg^{2+} and the soil pH were recorded in areas devoid of grass cover after an application of herbicide on clearings (Sedláková et al. 1999).

Higher soil respiration after deforestation is attributed to the effects of elevated soil temperature and moisture (Edwards and Ross-Todd 1983, Londo et al. 1999). We found, however, that the presence of grasses, linked with changes in physical and chemical soil features, stimulated considerably the development of microbial biomass, whereas the CO_2 output relatively decreased. It means that soil microflora started to use a part of carbon released by decomposition of root exudates and soil organic matter for the synthesis of new biomass. In addition, soil microflora which is able to decompose less available substances, is involved to a large extent in the transformation processes of organic substances in soil.

We can conclude that our results confirm the positive effect of grass cover partly due to the elimination of negative processes associated with soil acidification and the reduction of nutrient losses from soil.

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ABSTRAKT

Význam porostů trav při omezení negativních procesů v půdě se zátěží škodlivin

Vliv porostů trav na půdní prostředí byl studován na plochách se zátěží škodlivin v Moravskoslezských Beskydech. Acidofilní trávy pasek (*Calamagrostis arundinacea* a *C. villosa*) byly vysázeny do bloků půdy vložených do beden z umělé hmoty, uzpůsobených jako lyzimetry. Kontrolní variantou byl holá půda bez trav. Intenzivní růst trav znamenal snížení jak acidity perkolátů, tak i množství dusíku (zvláště nitrátů) v lyzimetrických vodách vyplavených z půdy. Vytváření porostu trav bylo také spojeno se značným snížením hodnot vodivosti perkolátů. Vyplavování bazických kationtů (Ca^{2+} a Mg^{2+}) bylo dva- až třikrát nižší než z holé půdy bez trav. U variant s rozrůstajícími se trávami se zvýšil počet půdních mikroorganismů o 30 %. U těchto variant byl v perkolátech podstatně snížen nadbytek labilního hliníku. Proto lze předpokládat, že vytváření porostů trav na plochách se zátěží škodlivin působí pozitivně na snižování ztrát živin z půdy, a zčásti tak eliminuje negativní procesy spojené s acidifikací půdy.

Klíčová slova: bazické kationty; vodivost; produkce CO_2 ; labilní Al; mikrobiální biomasa; dusík; perkoláty; pH

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Persistence of *Dactylis glomerata* in grassland

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ABSTRACT

Results of the research in Strážovské vrchy (altitude of 600 m) in the years 1988–2000 in long-term experiment proved the 12-year persistency of *Dactylis glomerata* in the grassland. The experiment was based on the site with ruderal grassland, where the supply of NPK nutrients was extreme, therefore the site was not fertilised during the whole time of experiment. The revitalization by *Dactylis glomerata* (non-tillage reseeding) as a strong species in the seed mixture, caused during the 12 years distinct reduce of NPK nutrients in soil (N_t was reduced from 6693.5 to 3100 mg.kg⁻¹, K from 550 to 55.5 mg.kg⁻¹, and P from 180 to 93.8 mg.kg⁻¹). C:N proportion changed from 7.4:1 to 10.6:1. The reduction of basic nutrients in soil was reflected in the content of the elements in dry matter of the above-ground phytomass, which was higher than optimal during the experiment. The percentage of *Dactylis glomerata* culminated after the four years, and high value of cover (82%) was reached, moreover, 12 years after it was still dominant (32.2%). The increase of the share of *Dactylis glomerata* in the floristic proportion after the reseeding during the first four years caused the increase of dry matter yield to 8.9 t.ha⁻¹ in average. The decrease of percentage of *Dactylis glomerata* in the grassland caused the appearance of new empty places. They were covered by the species from the floristic group of herbs, and after 12 years the number of species increased from the former 9 to 33 species. Apart from valuable species, the part of the group of herbs came under the group of weeds, therefore the increase of biodiversity went along with the increase of the appearance of weeds.

Keywords: grassland; reseeding; persistence; *Dactylis glomerata*

Dactylis glomerata L. is considered an economically important grass in the grassland (Nösberger and Opitz von Boberfeld 1986). In the inland, under the semiarid conditions, on the soil supplied with nitrogen, it grants high yield of dry matter. It is problematic just if its growth stage of earing (as a precocious grass) is not simultaneous with the other species in the grass mixture. After the stage of earing has been finished, its feed value declines sharply, the content of fibre rises, and the cattle leaves it on the pasture ungrazed. Under the oligotroph conditions with low level of nutrients it appears just in a small rate (1–2%), or its incidence is just infrequent (Kašper 1974). Regal and Veselá (1979) indicated its rate 2–6% on non-fertilised variant. Characteristic feature of this species is the ability to form typical orchard grass cover in case of higher values of nutrients in the soil (Kašper 1974).

The results of artificial grass cover based on *Dactylis glomerata*, which is keen competitor, concur in the values of its high production, in case that higher doses of nitrogen are used (Demela and Jurečka 1957, Kašper 1974, Morhác 1987, 1992). The sufficient data about its persistency higher than 10 years in case of applying chemical fertilizers cannot be found in the literature. Kašper (1974) indicates the results in case of applying manure (300 t.ha⁻¹), but the research did not bring expected results. There have not been registered long-term experiments pursuing the reseeding the grass species to the cover on the soil well-nourished by manure.

Some of the authors indicate the culmination of the development not until the third to fifth years (Munzar

1930, Regal 1953). Klečka (1930) ascertained that new covers are typical for their uncommon ability of regeneration, afterward descend of which is caused by edaphic conditions. Other authors declare the descending of vitality and prolificacy after the fifth year (Lichner et al. 1983). Presumptive persistency in case of applying nitrogen fertilizers is 8–12 years (Regal 1953), other authors indicate maximally 10 years (Lichner et al. 1983). Dmitrijev (1948) presumed up to 15 years in case of applying manure.

As early as in the last century there were realized the experiments which proved that fertilizers caused the decrease of the content of organic matter in soil, and its degradation (Liebig 1842, quot. Moravec 1994). During the ten-year experiment with fertilizers *Dactylis glomerata* persisted, although after the fifth year (starving years), at the small amount of nitrogen fertilizers, the decline of the production was registered (Demela and Jurečka 1957). After *Dactylis glomerata* has been reseeded to the cover on the soil with the high level of manure stock, and without tilling, starving years were not recorded (Novák 1997, Novák and Bistáková 1997).

MATERIAL AND METHODS

Long-term experiment was started in 1988 in Strážovské vrchy (Chvojnica, altitude 600 m) on gentle (up to 5°) slope of northern exposition. The location of the stand is determined by geographical coordinates 48°53' northern latitude, and 18°33' eastern longitude. Long-term annual

rainfall is 848 mm (481 mm during the vegetation period) and the average annual temperature 7.5°C (during the vegetation period 11.2°C).

Ruderal grassland of the association *Rumicetum obtusifolii* Šmarda et al. 1963 formed the vegetation cover of the studied area on the cambial acidic soil (sandy loam soil). The cover grew up after the long-term grazing of heifers in the same area with the grassland of the association *Lolio-Cynosuretum cristati* R. Tx. 1973. A corral served the cattle as a shelter after the free grazing during the pasture period. The dominance of C-R strategist *Rumex obtusifolius* L. and the side-species *Poa trivialis* L. (the sward contained 22% of empty places) was caused by excessive amount of excrements (extreme amounts of nitrogen and phosphorus in the soil), and by intensive trampling. The agrochemical characteristics of the soil are shown in Table 1.

The experiment was aimed at studying the persistence of *Dactylis glomerata*. In spring 1988 after the first cutting the reseeding of simple mixture of *Dactylis glomerata* L., variety Niva (15 kg.ha⁻¹) and *Trifolium repens*, variety Huia (3 kg.ha⁻¹) was done by a non-tillage sowing machine.

After the reseeding a selective system herbicide on the base of Asulox (asulam) in the dose of 3 l.ha⁻¹ was applied on *Rumex obtusifolius* in the phase of leaf rosette. Three weeks after the application *Rumex obtusifolius* receded, and therefore the conditions for the growth of *Dactylis glomerata* were better.

In the year 1993 (the end of August) the reseeding of the same share of *Cynosurus cristatus*, *Festuca pratensis*, *Lolium perenne*, *Trisetum flavescens* (7 g.m⁻²) was done. The seeds of grass species were picked up from the wild species and reseeded with the aim to increase the number of species of the floristic group of grasses.

The floristic group of herbs was divided according to the feed value (FV) by Klapp (1965) to the group of feeding-valuable herbs (3) and the group of other herbs (4) –

less valuable, without any feed value, noxious, and toxic plants.

Within one to two weeks after the cutting botanical analysis was made (the height of vegetation 50 mm) by the Klapp's method (1965) – the method of the right covering (in %D) on the stable 15.7 m² pieces of land in four runs. The production of biomass was converted on 100% dry matter after each cutting.

The samples of soil were taken regularly in spring and autumn from the depth of 0–100 and 101–200 mm to quantify the total content of nitrogen (N_t) after Kjeldahl, available phosphorus after Schachtschabel, available potassium after Egner, and humus and pH in KCl. The C:N ratio was calculated from the oxidizable carbon (C_{ox}) and N_t.

The content of nitrogen after Kjeldahl, phosphorus by spectrophotometric method, potassium and sodium by flame photometry, and calcium and magnesium by Berstein method, were quantified in the samples of above-ground biomass taken from each cut in four runs.

The grass was cut four times during the vegetation period up to the year 1991, in the following years just three times. The grassland was not fertilised during the whole experiment forasmuch as the high amount of nutrients from the excrements (Table 1). *Dactylis glomerata* drew the nutrients from the soil, which was excessively rich in nutrients from the manure (the excrements of the heifers). In the year 2000 there is given just the botanical analysis of the grassland made in spring, as the grass was after the analysis damaged by boars and the 12-year experiment had to be finished.

RESULTS AND DISCUSSION

In the ruderal grassland (the dominant position R-strategists *Rumex obtusifolius* 30% and *Poa trivialis* 46.5%) *Poa trivialis* proved the highest feed value although it

Table 1. Agrochemical characteristics of the soil (depth 0–200 mm)

Year	N _t	P	K	pH-KCl	C _{ox} (%)	C:N
	mg.kg ⁻¹					
1988	6693.5	180.0	550.0	5.9	5.0	7.4
1989	6297.3	178.0	476.5	5.8	4.8	7.7
1990	5805.4	152.0	420.0	5.7	4.5	7.7
1991	5222.9	145.0	319.0	5.5	4.1	7.8
1992	4987.5	140.0	205.5	5.5	4.0	8.0
1993	4615.4	138.0	176.5	5.5	3.9	8.4
1994	4011.2	135.0	166.2	5.7	3.6	8.9
1995	3720.5	135.0	156.0	5.3	3.5	9.5
1996	3447.5	132.0	122.7	5.3	3.4	9.8
1997	3350.1	130.1	100.0	5.4	3.3	9.8
1998	3330.5	122.2	67.0	5.5	3.4	10.1
1999	3200.2	94.7	57.5	5.6	3.4	10.5
2000	3100.0	93.8	55.5	5.6	3.3	10.6

belonged to the non-stable grass species, as during the summer period of dry sunny weather its above-ground splits permanently ran dry after the cutting, and as the result it gradually disappeared. On the empty places weed seeds in the soil started to germinate, and the stand was more and more weed-grown. The grassland revitalised by the non-tillage reseeding (*Dactylis glomerata* and *Trifolium repens*) proved the feed value increased by more than a half, compared with the former weeded cover (Novák 1994).

Already during the first year after the non-tillage reseeding of two-component mixtures composed high competitiveness of *Dactylis glomerata* was testified. Its ratio culminated in the year 1992, when it reached 82% (Table 2). It is necessary to note, that even 10 years after the reseeding the *in situ* 40% rate remained, and 12 years after it was still relatively high (32.2%). After Kašper (1974) *Dactylis glomerata* also acquired predominance in new sown grassland, and kept it up during ten years (the rate of area rose with higher doses of nitrogen up to 51–70%, and in the 10th year it fell down to 43–52%).

Dactylis glomerata comes under the loose bushy grasses, therefore filial plants tiller concurrently with maternal ones. Therefore the rate was multiplied twice during four years. It was not as high as it was reached by Krajčovič and Vološin (1966) in drier lowland area, where it rose more than eight times. Kašper (1974) indicates results from wetter area, where *Dactylis glomerata* kept up approximately the same rate as at the beginning of the reseeding.

With the fall of the rate of *Dactylis glomerata* in the grassland empty places started to appear. They were filled by the species from the floristic group of other grasses and 12 years later the number of species rose from 9 to 33 species. Apart from valuable species, a part of other grasses came under the weeds, therefore the rise of biodiversity was accompanied by the weed-growth.

The double rate of *Dactylis glomerata* in the floristic composition during the first three years after the reseeding caused the rise of the yield of dry matter up to 9.3 t.ha⁻¹ (Figure 1). During the first four years it reached the average values of 8.9 t.ha⁻¹. It is to note that with the same variety Niva, which is the most productive of all tested variants, we reached by using different technology the yield higher than stated by Morháč (1992) on sown, fertilised grassland.

The results of Regal and Veselá (1979) proved that reduced vitality of *Dactylis glomerata* was linked with the reduce of its productive and competitive ability. The seven-year experiment proved that even with reduced vitality the high dry matter yield (5.9 t.ha⁻¹) was reached with the help of the 300 kg.ha⁻¹ dose of nitrogen. The results reached in the experiment during the same time without fertilisation, with high amount of nutrients from manure are higher (7.6 t.ha⁻¹). Regal and Veselá (1979) demonstrated in vegetation pot experiment, that six-year specimens had lower vitality and regeneration ability than four-year specimens, and higher dose of nitrogen influenced the vitality more favourably than its deficiency. In

Table 2. Botanical composition of grassland (in %D)

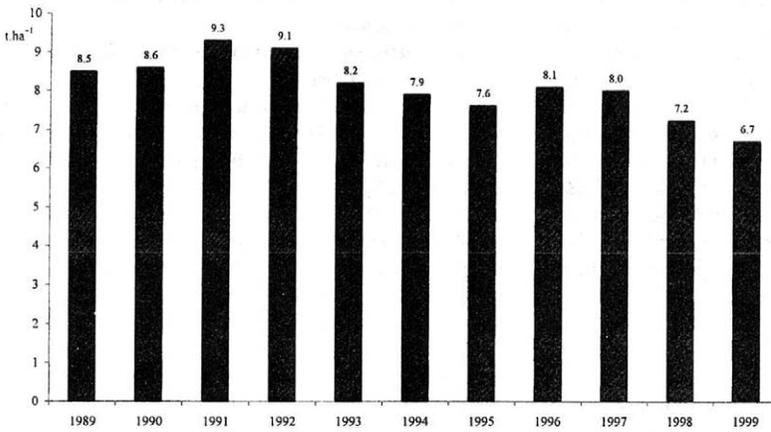
FG	RH	Species	FV	Year																
				1988°	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000			
1.		<i>Cynosurus cristatus</i> L.	6								+	5.00	5.35	5.87	5.93	5.90	6.05	6.00		
		<i>Dactylis glomerata</i> L.	7	40.00	40.35	52.50	66.77	82.00	60.23	56.80	51.27	48.37	45.10	42.07	38.14	32.21				
		<i>Festuca pratensis</i> Huds.	8					+	1.22	1.23	1.23	1.31	1.49	1.41	1.38	1.31				
		<i>Lolium perenne</i> L.	8					+	4.07	4.06	4.07	3.92	3.59	3.06	2.13	2.01				
		<i>Poa trivialis</i> L.	7	46.25	20.00	18.05	16.66	7.00	9.13	7.12	5.39	7.03	9.50	11.52	14.06	15.98				
		<i>Trisetum flavescens</i> (L.) Beauv.	7							1.82	1.95	2.02	1.92	1.91	1.85	1.82				
				46.25	60.00	58.40	70.00	83.43	89.00	74.65	76.03	69.26	68.52	67.53	65.87	63.61	59.33			
2.		<i>Lotus corniculatus</i> L.	7						+	0.90	0.96	1.01	0.25	+	+	+	+	+		
		<i>Trifolium repens</i> L.	8	30.00	32.12	20.75	8.33	0.50	5.02	2.38	3.72	3.22	3.49	3.78	4.20	4.14				
			30.00	32.12	20.75	8.33	0.50	5.02	3.28	4.68	4.23	3.74	3.78	4.20	4.14					

Table 2. Botanical composition of grassland (in %D) – continuation

FG	RH	Species	FV	Year															
				1988°	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000		
3.	*	<i>Achillea millefolium</i> L.	5								+	0.42	0.77	0.25	0.75	0.77	1.02		
	*	<i>Alchemilla xantochlora</i> Rothm.	5									+	0.25	0.26	0.52	0.99	1.01		
	*	<i>Carum carvi</i> L.	5				+	+				3.58	5.10	2.10	1.45	0.73	+		
		<i>Leontodon autumnalis</i> L.	5									1.19	2.00	2.75	1.32	0.74	0.49	0.50	
	*	<i>Plantago lanceolata</i> L.	6									+	0.25	0.85	0.35	0.48	0.73	0.79	
	*	<i>Taraxacum officinale</i> Web.	5	1.00	1.00	3.56	3.75	2.83	2.25	6.85	7.02	8.07	8.75	8.21	7.28	5.59	5.03		
4.		<i>Aegopodium podagraria</i> L.	3				+												
		<i>Anthriscus sylvestris</i> (L.) Hoffm.	4			0.38	+		1.03	1.71	1.30	1.27	2.09	2.39	2.98	3.23	3.78		
		<i>Arctium lappa</i> L.	1	0.45	0.45	+													
	*	<i>Bellis perennis</i> L.	2														+	+	
	*	<i>Capsella-bursa pastoris</i> (L.) Med.	1														+	+	
		<i>Cardamine pratensis</i> L.	-1															+	
		<i>Cerastium arvense</i> L.	3															+	+
		<i>Cirsium arvense</i> (L.) Scop.	0	0.44	0.44	+													+
	*	<i>Ficaria verna</i> Huds.	1																+
		<i>Galeopsis tetrahit</i> L.	1																+
		<i>Geranium pratense</i> L.	2												+	0.53	1.97	2.01	
		<i>Geranium pusillum</i> L.	2	+														+	+
	*	<i>Glechoma hederacea</i> L.	1			+	0.60	1.16	1.75	3.25	0.93	1.23	2.53	2.27	1.98	1.76	1.98		
		<i>Heracleum sphondylium</i> L.	4											0.25	0.27	0.28	0.31		
		<i>Chenopodium bonus-henricus</i> L.	2	+		+												+	+
		<i>Plantago major</i> L.	2			+	+	+	+	0.80	0.85	1.09	1.09	1.07	0.58	+	+		
		<i>Ranunculus repens</i> L.	2	+				+	+	3.30	1.60	1.51	0.97	1.52	2.58	3.75	4.14		
		<i>Rumex obtusifolius</i> L.	1	30.02											+	+	0.74	0.98	
		<i>Stellaria media</i> L.	2															0.49	+
	*	<i>Urtica dioica</i> L.	1	+	+					0.51								+	+
	<i>Veronica chamaedrys</i> L.	2					+			+	+	+	+	2.58	3.71	4.59	6.07		
Predominance in total				78.16	90.89	94.46	95.10	95.75	95.04	95.58	95.58	94.88	95.65	94.12	93.81	94.44	93.09		
Empty places and mosses				21.84	9.11	5.54	4.90	4.25	4.96	4.42	4.42	5.12	4.35	5.88	6.19	5.56	6.91		

FG = floristic group (1. grasses, 2. legumes, 3. feeding-valuable herbs, 4. the other herbs); RH = remedial – medicinal herbs (marker *); FV = feed value after Klapp et al. (1953); + = traces in the grassland (low rate); %D = predominance of species in %; 1988° = ruderal grassland with weed species

Figure 1. Dry matter yield in the years (t.ha⁻¹)



the third year the rate of the species reached its peak, in the fourth year its share sharply fell, but despite that it was still dominant in the ground cover.

According to the resources, the production of sown grassland falls after the fifth year as a consequence of starving years, mentioned by several authors (Klapp 1971, Kašper 1974, Morhác 1987 and others). After Morhác (1992) the yield rises up to the third year with the growing number of grass offsprings, later the intensity drops. This tendency was not approved in our experiment after non-tillage reseeding, therefore we assume that starving years occur just after the tillage violating the ecosystem relations.

High levels of nutrients, particularly nitrogen, potassium, and phosphorus help preserve the species in the grassland. After 12 years the content of N_i (6693.5 mg.kg⁻¹) fell to 3100 mg.kg⁻¹, the content of potassium (550 mg.kg⁻¹) to 55.5 mg.kg⁻¹, and the content of phosphorus (180 mg.kg⁻¹) to 93.8 mg.kg⁻¹. The C:N proportion indicates, that the parameter 7.4:1 reached in the year 1988 rose during the next 12 years to 10.6:1, and that the proportion reached the level of common grasslands.

The soil nutrients markedly influenced the above-ground biomass. As stated by Voigtländer and Jacob (1987) the readiness of nitrogen and potassium reception of *Dactylis glomerata* is very high. Our results prove this fact as well, because the rate of *Dactylis glomerata* in the grassland declines with the decline of the amount of these elements. The reduction of the content of basic nutrients in the soil was reflected on the content of the elements in dry matter of the above-ground biomass. The most remarkable decline of nitrogen and potassium in the soil (Table 1) was reflected on the above-ground biomass (Table 3). Merely the content of phosphorus, which is not so flexible, was after 12 years high, not only in the soil, but in the above-ground biomass as well. The content of calcium and magnesium, which was standard at the beginning of the experiment, rose as the result of the increase of the rate of grasses. The content of fibre as an indicator of ageing was not higher than 220 g.kg⁻¹ (Table 2), as compared with the results of Míka (1980).

The side-species in the mixture of reseeding – *Trifolium repens* appeared in the high rate just the first three years. In the year of the highest rate of *Dactylis glome-*

Table 3. Chemical analysis of the above-ground biomass (g.kg⁻¹)

Year	N	P	K	Ca	Mg	Na	Fibre
1989	38.3	5.5	44.0	7.6	2.5	0.2	259.1
1990	28.7	5.4	40.0	7.5	3.0	0.2	243.8
1991	24.9	4.9	36.9	7.4	4.2	0.2	211.1
1992	25.3	4.5	34.9	8.0	3.9	0.2	262.1
1993	26.1	4.8	33.9	8.8	3.8	0.2	257.4
1994	27.0	4.8	32.2	8.6	3.8	0.1	254.9
1995	27.3	4.4	31.6	8.4	3.9	0.1	270.5
1996	25.5	4.4	31.3	8.8	3.8	0.1	262.1
1997	25.2	4.3	29.1	8.5	3.8	0.2	243.3
1998	23.3	4.2	27.8	8.4	3.7	0.1	228.1
1999	22.9	4.0	23.9	8.3	3.8	0.1	233.8
Optimum	23.0	2.8	21.5	7.0	2.0	0.2	< 220.0

rata, it fell to 0.5% because of the overshade. During the next years the rate varied between 3.3 to 4.2%. Persistency of the species in the grassland can be evaluated just after several years. Regarding the results of the experiment, we state that even after 12 years *Dactylis glomerata* was able to keep its predominance in the grassland, with the sufficient amount of nutrients from the manure in the soil. It is possible to prove the results of Kašper (1974), Adojan (1961), and Toomer (1966), quoted by Kašper (1974). The authors presume its persistency in the grassland not less than 10 years, applying the fertilisers.

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ABSTRAKT

Vytrvalost *Dactylis glomerata* v travném porostu

Výsledky dlouhodobého pokusu v Strážovských vrchách (600 m n. m.) v letech 1988 až 2000 potvrdily dvanáctiletou vytrvalost *Dactylis glomerata* v travném porostu. Pokus byl založen na stanovišti s ruderalizovaným travním porostem, kde byla extrémní zásoba NPK z organických hnojiv, proto nebyl porost hnojen po celou dobu sledování. Revitalizace bezorebným přísevem *Dactylis glomerata* jako silného konkurenčního druhu ve směsce způsobila po dobu 12 let výrazné odčerpání NPK živin z půdy (obsah N_1 klesl ze 6693,5 na 3100 $mg \cdot kg^{-1}$, obsah draslíku z 550 na 55,5 $mg \cdot kg^{-1}$ a obsah fosforu ze 180 na 93,8 $mg \cdot kg^{-1}$). Poměr C : N se zvýšil ze 7,4 : 1 na 10,6 : 1. Odčerpání základních živin z půdní zásoby se projevilo i v obsahu prvků v sušině nadzemní fytohmoty, který byl po celou dobu sledování vyšší než optimum. Procentuální podíl *Dactylis glomerata* při dostatku živin kulminoval po čtyřech letech a dosáhl vysoké dominance (82%), po 12 letech si tento druh ještě stále udržoval dominantní postavení (32%). Téměř dvojnásobné zvýšení podílu *Dactylis glomerata* ve floristickém složení po přísevu v průběhu prvních čtyř let způsobilo zvýšení výnosu sušiny v průměru na 8,9 $t \cdot ha^{-1}$. Při ubývání procentuálního zastoupení se v drnu tvořila nová prázdná místa. Obsazovala je jiné druhy z floristické skupiny bylin a po 12 letech počet těchto druhů stoupl z původních 9 na 33 druhů. Kromě hodnotných druhů část ostatních bylin patřila mezi plevele, proto byl nárůst biodiverzity v průběhu let provázen zvýšenou zapleveleností.

Klíčová slova: travní porost; přísev; vytrvalost; *Dactylis glomerata*

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The influence of varying soil tillage on the number and vertical distribution of weed seeds in soil of the rye (*Secale cereale*) monoculture

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ABSTRACT

In 22-year continuous cropping experiment with winter rye, the effect of varying post-harvest and pre-sowing soil tillage on the number of weed seeds and their vertical distribution in soil was studied. Growing rye in crop rotation increased number of weed seeds in each layer of the soil. However, continuous cropping rye decreased weed seed numbers particularly in 1–10 cm and 10–20 cm layers of the soil. Seed densities of *Chenopodium album*, *Echinochloa crus-galli* and *Polygonum convolvulus* were similar in each of the three examined soil layers. Seeds of *Amaranthus retroflexus*, *Viola arvensis*, *Geranium pusillum* and other species were stored in the upper soil layer near the soil surface, and their number was reduced with soil depth. Seeds of *Viola arvensis* and *Geranium pusillum* were met most frequently in soil from continuous cropping rye. Most favourable tillage practice that limited accumulation of weed seeds in soil was conventional tillage, with shallow ploughing after harvesting of rye and medium ploughing in pre-sowing tillage. Other tillage methods did not influence significantly soil infestation with weed seeds.

Keywords: rye; monoculture; soil tillage; weeds

Market and economy have great effect on farming systems and agricultural practices used in crop growing. Therefore, many farms specialise in production of cereals and result is frequent occurring of these crops in rotation together with reduced soil tillage. One of the negative effects of continuous cropping of cereals is an increase in weed infestation resulting in yield decreases (Zawiślak and Grejner 1984). Surveys demonstrate that weed species dominating crop canopy have similar life cycle to the crop (Krzymuski and Niewiadomski 1974). Hence, in winter cereals these are: *Apera spica-venti*, *Galium aparine*, *Anthemideae*. Unfortunately, most research deals with infestation of the canopy, omitting its origin. Soil is the most important source of weed seeds (Kulpa and Pawłowski 1957, Rola 1962). Tillage method has also considerable influence on the level of weed infestation (Gandecki 1981).

There are different opinions on the meaning of post-harvest tillage in decreasing of weed infestation. Most researchers (Duer 1985, Witkowski 1994, Zawieja et al. 1999) reported that post-harvest soil tillage depresses weed infestation of the next crop, mainly due to reducing weed seeds in shallow near surface level of soil. But Parylak and Oliwa (1997) showed that full post-harvest tillage does not guarantee significant decrease in weed infestation and the results are in agreement with those of Witkowski et al. (1994).

The objective of this study was to assess the effect of varying post-harvest and pre-sowing soil tillage on the number and vertical distribution of weed seeds in soil profile under 22-year continuous rye.

MATERIAL AND METHODS

The research was based on soil samples taken from field experiment that started in 1976 at the Agricultural University of Wrocław Experimental Station, Swojec. The experiment consisted of randomized complete block design with three replicates. Treatments were varying post-harvest and pre-sowing soil tillage methods under 22-year continuous cropping winter rye. Details are in Table 1.

The number of seeds in soil was determined using direct method modified by Pawłowski (1963). Soil samples were taken after rye harvest in 1998, with cylinder of 25 cm² area for three soil layers: 0–1, 1–10 and 10–20 cm. Soil was washed out on the sieve and next weed seeds were separated using KJ water solution of specific density above 1.6 g/cm³.

Weed seeds were recognised mainly according to Kulpa guidebook (1988) and using own collection of seeds.

Table 1. Scheme of experiment

Treatment	Soil tillage	
	after harvest	pre-sowing
1.	skimming – harrowing	ploughing 20 cm
2.	skimming – harrowing	ploughing 12 cm
3.	skimming – harrowing	harrowing
4.	Reglone	ploughing 20 cm
5.	Reglone	ploughing 12 cm
6.	–	ploughing 20 cm
7.	continuous tillage in 4-year rotation	

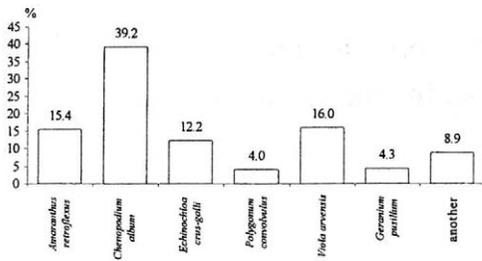


Figure 1. The dominant weed seeds depending on soil of weed infestation

RESULTS AND DISCUSSION

Weed species that seeds dominated soil samples taken from rye were as follows: *Chenopodium album*, *Viola arvensis*, *Amaranthus retroflexus*, and *Echinochloa crus-galli* (Figure 1). This great contribution of weed seeds typical for root crops resulted from excessive weed seed infestation of soil from plots in crop rotation. (Table 2). Just in the samples, number of seeds of *Amaranthus retroflexus* was almost three times, *Chenopodium album* fourfold, and *Echinochloa crus galli* was up to 22-fold higher than seed numbers of the species determined in soil from continuous cropping rye. There were different results concerning other dominating species. Soil from continuous cropping contained more seeds of *Viola arvensis* and *Geranium pusillum* compared to soil from crop rotation. These numbers were 2.9 and 2.3 times greater compared to seeds of the species from crop rotation.

Vertical arrangement of *Chenopodium album*, *Echinochloa crus-galli* and *Polygonum convolvulus* seeds was nearly the same in all of the three soil layers (Figure 2). Whereas seeds of *Amaranthus retroflexus*, *Viola arvensis*, *Geranium pusillum* and other species including seeds of *Apera spica-venti*, accumulated mostly in 0–1 cm layer and seed number of the species decreased with soil depth.

Comparing the effect of cropping system and soil tillage method on weed infestation of the soil, it appeared that cropping system mostly affected the infestation in the experiment (Table 3). Soil from rye grown in crop rotation contained more weed seeds in all of the examined layers. In 0–1 cm layer of soil from crop rotation, there

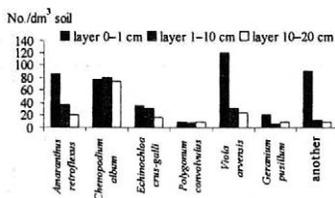


Figure 2. Number of more important diaspores weed species in particular soil layers

Table 2. Weed seeds reserve in soils (mln no./hectare)

Treatment	Soil layers (cm)			All layers
	0–1	1–10	10–20	
1.	34.0	74.0	65.0	173.0
2.	58.0	328.0	105.0	491.0
3.	41.0	120.0	111.0	272.0
4.	33.0	138.0	106.0	277.0
5.	28.0	130.0	124.0	282.0
6.	48.0	119.0	139.0	306.0
Mean for monoculture	40.3	151.5	108.3	300.1
7. crop rotation	70.0	387.0	483.0	940.0

were 73.6% more seeds than in the soil layer under monoculture. In 1–10 cm, 10–20 cm and in whole ploughing layer (0–20 cm) from crop rotation there were 155.4%, 346.0% and 213.2% more seeds than in soil from continuous cropping rye, respectively.

In the experiment, the best way for reducing weed seeds accumulated in the soil was conventional tillage practice, with shallow ploughing in post-harvest tillage and medium-depth ploughing in pre-sowing tillage. Similar findings have been reported by Zawieja et al. (1999) in surveys with 22-year winter wheat monoculture. But according to Parylak and Oliwa (1997), in experiment with rye, quitting post-harvest tillage decreased weed infestation during growing season an average of 20% compared to conventional tillage treatment.

Other tillage methods used in the experiment did not affect significantly soil infestation with weed seeds. It should be noted that for 2nd treatment (full post-harvest tillage and shallowed pre-sowing ploughing) there was greater contamination of soil surface layer and 1–10 cm layer with weed seeds. Our results agree with those reported by Parylak and Oliwa (1997) with rye and Wojciechowski and Zawieja (1999) with wheat. The authors observed increase in weed infestation of cereal canopy due to shallowing of pre-sowing ploughing. An increase in plant number of the weeds after consecutive passing of two implements that operated to the same soil depth has been reported also by Kundler et al. (1985). It promoted a vertical movement of seeds toward soil surface before sowing of rye (Cousens and Moss 1990). Short time elapsed from post-harvest tillage to pre-sowing tillage does not allow significant reduction of weed seeds through decomposition by microorganisms.

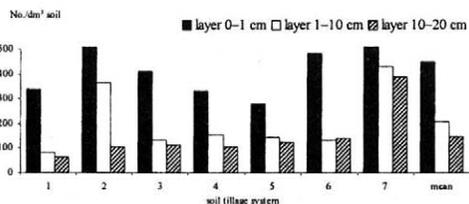


Figure 3. Soil contamination of weed seeds

Table 3. Vertical distribution of weed seeds of dominant weed species in soil layers (mln no./hectare)

	<i>Amaranthus retroflexus</i>			<i>Chenopodium album</i>			<i>Echinochloa crus-galli</i>			<i>Geranium pusillum</i>			<i>Polygonum convolvulus</i>			<i>Viola arvensis</i>		
	0-1	1-10	10-20	0-1	1-10	10-20	0-1	1-10	10-20	0-1	1-10	10-20	0-1	1-10	10-20	0-1	1-10	10-20
1.	4.0	7.0	11.0	0.0	27.0	27.0	2.0	10.0	1.0	3.0	6.0	5.0	0.0	3.0	2.0	15.0	16.0	14.0
2.	11.0	47.0	27.0	9.0	225.0	44.0	2.0	7.0	0.0	2.0	1.0	4.0	0.0	7.0	1.0	16.0	30.0	20.0
3.	4.0	30.0	30.0	6.0	45.0	39.0	2.0	3.0	6.0	3.0	7.0	8.0	1.0	2.0	3.0	8.0	17.0	20.0
4.	8.0	28.0	9.0	6.0	43.0	24.0	0.0	6.0	5.0	1.0	8.0	15.0	1.0	13.0	12.0	11.0	33.0	33.0
5.	7.0	13.0	12.0	7.0	28.0	36.0	0.0	0.0	0.6	2.0	14.0	15.0	1.0	6.0	10.0	8.0	51.0	35.0
6.	6.0	18.0	13.0	7.0	29.0	38.0	1.0	8.0	15.0	2.0	4.0	10.0	1.0	8.0	21.0	19.0	38.0	31.0
\bar{x}	6.7	23.8	17.0	5.8	66.3	34.7	1.2	5.7	5.5	2.2	6.7	9.5	0.7	6.5	8.2	12.8	30.8	25.5
7.	20.0	91.0	39.0	19.0	106.0	309.0	18.0	157.0	91.0	1.0	1.0	6.0	2.0	7.0	10.0	7.0	8.0	9.0

1.-6. treatment, \bar{x} - mean for monoculture, 7. crop rotation

Growing continuous cropping rye without post-harvest tillage contributed to greater accumulation of seeds in shallow surface layer of soil. Nevertheless, it seems interesting to replace the mechanical post-harvest tillage by chemical treatment. In the experiment, number of seeds in the soil for chemical treatment was slightly greater than for conventional tillage practice. On the other hand, chemical treatment decreased seed infestation in soil surface layer, so it can prevent soil from further collecting of weed seeds and infestation of the crop canopy. This data agree with those reported by Gandecki (1981), who demonstrated 69% decrease in weed number per unit area, after replacing shallow post-harvest ploughing with Gramoxone (paraquat 20%) spraying of the stubble. Parylak and Oliwa (1997) also showed 32% reduction in weed stand in the next crop, after spraying the stubble of the previous crop with Reglone (diquat 20%). There was a slight relationship between cropping system of rye and vertical distribution of weed seeds in soil (Figure 3). Continuous cropping system of rye gave higher soil contamination with weed seeds in 0-1cm layer, irrespective of tillage method. Weed infestation of soil decreased along ploughing layer depth. Unfortunately, growing rye in crop rotation resulted in greater accumulation of weed seeds in whole ploughing layer. It ranged from 400 to 500 seeds/dm² of soil and only in soil surface layer, amounts of weed seeds were almost the same as in soil from continuous cropping rye.

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ABSTRAKT

Vliv diferencované agrotechniky na četnost a vertikální rozmístění diaspor plevelů v monokultuře ozimého žita (*Secale cereale*)

Výzkum po dobu 22 let u monokultury žita prokázal, že příprava půdy po sklizni a před setím má vliv na četnost a vertikální rozmístění semen plevelů v půdním profilu. Pěstování žita v osevním postupu mělo vliv na četnější výskyt diaspor plevelů v každém půdním profilu. Na druhé straně pěstování žita v monokultuře způsobilo snížení jejich četnosti, zvláště ve vrstvě 1–10 a 10–20 cm. Diaspory *Chenopodium album*, *Echinochloa crus-galli* a *Polygonum convolvulus* se vyskytovaly s obdobnou intenzitou v každé zkoumané vrstvě půdního profilu. Diaspory *Amaranthus retroflexus*, *Viola arvensis*, *Geranium pusillum* a zbývajících plevelů se nejvíce shromažďovaly v podpovrchové vrstvě a se vzrůstající hloubkou se jejich četnost zmenšovala. Nejčetnějšími diasporami plevelů, které se vyskytovaly v půdě, na níž bylo žito pěstováno v monokultuře, byly diaspory *Viola arvensis* a *Geranium pusillum*. Nejlepším způsobem předsetěové a posklizňové přípravy žita pěstovaného v monokultuře, který omezoval shromažďování diaspor plevelů v půdě, byla tradiční agrotechnika, jež obsahovala podmítku (posklizňová příprava), a střední orba (předsetěová příprava). Zbývající způsoby agrotechniky neměly rozhodující vliv na diferencované zaplevelení půdy.

Klíčová slova: žito; monokultura; zpracování půdy; plevele

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Some vegetation characteristics of natural savanna ecosystems with different herbivore species in Zimbabwe

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ABSTRACT

Large areas of Zimbabwe previously used for cattle have been converted to game or game and cattle. The different effects of these animals need to be examined. The effects of cattle on the different classes of palatability of woody plants were compared to that of the effects of large indigenous African herbivores in Zimbabwe. Thirty-six plots were placed along each of seven fence-lines: plots were placed on either side of each fence at each of 18 positions. There were no differences in the species richness of the different palatability classes, but there were differences in the numbers of plants in each class for all but one fence-line. It was found that stocking rate as well as the numbers of species of large herbivore present was an important factor in influencing the numbers of plants in each palatability class. It was hypothesised that the time needed to change the numbers of woody plants present was longer than that for which the sites on either sides of the fence-lines had been established.

Keywords: herbivore; cattle; palatability; African savanna; species diversity; ecosystems

There is a movement in Zimbabwe towards the use of wildlife (game) in conjunction with, or separately from, cattle in the present farming systems. Large areas have been set up as conservancies by combining ranches and removing fences. The aims of the management of these areas is to maximise profits in fragile ecological systems using the indigenous flora and fauna. The World Wide Fund for Nature set up the Multispecies Animal Production Systems Project to examine how multispecies (game) and single species (cattle) systems compare economically and ecologically (Cumming 1988). The work for this current paper was carried out under this project.

Zimbabwe is divided into five Natural Regions based on effective rainfall and vegetation (Vincent et al. 1961). This designation is used to determine which farming systems are possible, with a gradient of decreasing rainfall from Natural Region I (intensive farming) to Natural Region V (extensive cattle farming). Sites were selected for this study which represented different Natural Regions in which cattle and game farming take place. McIlwaine National Park and Idaho Farm are in Natural Region II, Iwaba and Sultana Ranches are in Natural Region III, Mushandike Research Area is in Natural Region IV, and Buffalo Range Ranch and Humani Ranch are in Natural Region V.

It has been shown that the observed patterns in *Acaacia* woodlands could be the results of competition between woody plants (Smith and Goodman 1987). The effects of browsing are thought to modify the competition between the woody plants (Rockwood 1973, Crawley 1983): if a dominant plant is browsed this is thought to free other less common plants from competition and allow their subsequent increase in numbers (Petraitis et al. 1989). Browsers can affect the woody plant composition through the browsing of woody plant seedlings and

the dispersal of woody plant seeds (O'Connor 1996). Models of disturbance and competition have focused on grazers effects on grasses and forbs whereas this paper looks at the effects of browsers on woody plants.

For the data set presented here it has already been shown that there is no difference in the woody species richness between comparable areas with different large herbivore species, however, there is a difference in the abundance of some of the woody species present (Richardson-Kageler 1999). It is known that different large herbivores affect the vegetation in different ways (Cumming 1982), and it was hypothesised that comparable areas with different large herbivore species would have different woody plant communities. In this paper, these data are further analysed in terms of different groups of palatable woody species, to see how the different herbivores are affecting these groups and hence changing the woody plant communities.

MATERIAL AND METHODS

Study sites

Sites were selected from around Zimbabwe that had been established at least ten years. These sites are described in Table 1 and their positions are shown in Figure 1. There were five comparisons of cattle versus game: Buffalo Range Ranch game versus cattle, Humani Ranch game versus cattle, McIlwaine National Park (game) versus Idaho Farm (cattle), Mushandike Research Area (game) versus Mushandike Ranch (cattle), and Mushandike Research Area (game) versus Rabe (cattle). There were two further comparisons: Iwaba Ranch (game) versus Sultana Ranch (game and cattle), and

Table 1. Site details and comparisons made

Site and comparison	A	B	C	Vegetation type	Major herbivores in the game areas
Buffalo Range Ranch (game)	1257	605	400	dry deciduous tree savanna	game: eland, impala, kudu, sable, warthog, wildebeest, zebra
Buffalo Range Ranch (cattle)	1181				
Humani Ranch (game)	922	459	400	dry deciduous	game: elephant, impala, kudu, black rhinoceros, warthog, wildebeest, zebra
Humani Ranch (cattle)	772			<i>Colophospermum mopane</i> tree and shrub savanna	
Iwaba Ranch (game)	606	697	1200	deciduous miombo woodland with <i>Brachystegia spiciformis</i> and <i>Julbernardia globiflora</i>	Iwaba and Sultana Ranches: Bushpig, eland, impala, kudu, reedbeek, black and white rhinoceros, sable, tsessebe, warthog, wildebeest, zebra, and cattle (at Sultana Ranch only)
Sultana Ranch (game and cattle)	1588				game: eland, impala, ostrich, white rhinoceros, tsessebe, wildebeest, zebra
McIlwaine National Park (game)	1211	727	1400	deciduous miombo woodland with <i>Brachystegia spiciformis</i> and <i>Julbernardia globiflora</i>	game: eland, impala, ostrich, white rhinoceros, tsessebe, wildebeest, zebra
Idaho Farm (cattle)	3157				
Mushandike Research Area (game)	1625	568	1000	tree savanna at medium altitudes	game: buffalo, eland, giraffe, impala, kudu, reedbeek, sable, tsessebe, warthog, wildebeest, zebra
Mushandike Ranch (cattle)	814				
Mushandike Research Area (game)	1625	568	1000	tree savanna at medium altitudes	game: buffalo, eland, giraffe, impala, kudu, reedbeek, sable, tsessebe, warthog, wildebeest, zebra
Rabe (cattle)	977				
Mushandike Research Area (game)	1625	568	1000	tree savanna at medium altitudes	Mushandike Research Area: buffalo, eland, giraffe, impala, kudu, reedbeek, sable, tsessebe, warthog, wildebeest, zebra
Mushandike Sanctuary (game)	121				Mushandike Sanctuary: buffalo, impala, kudu, sable, tsessebe, wildebeest, zebra

A – stocking rate (metabolic biomass $\text{kg}^{0.75} \cdot \text{km}^{-2}$); B – mean annual rainfall (mm); C – altitude m. a.s.l.

Mushandike Research Area (game at high stocking rates) versus Mushandike Sanctuary (game at low stocking rates).

Data collection

The data were collected using plots of 3 m by 20 m. These plots were placed on either side of the fence separating the comparable areas at each of 18 randomly selected positions. The numbers of plants of each woody species in each plot were recorded.

Data analysis

The numbers of plants of each woody species were summarised for the eighteen plots on each side of the fence for each comparison in each site. Using information obtained from Parry (1955), Drummond and Coates-Palgrave (1973), Timberlake (1980), Walker (1980), Drummond (1981), Coe (1983), Owen-Smith and Cooper (1987), Coates-Palgrave (1988), Nyamapfene (1988), Tybirk (1991) and Tietema et al. (1992) each woody species was assigned to one of the functional classes of Owen-Smith and Cooper's (1987) Palatability Index (Table 2).



Figure 1. The location of the study sites of Zimbabwe

Table 2. Owen-Smith and Cooper's (1987) Palatability Index

Class	Description
1.	palatable, deciduous, unarmed
2.	palatable, deciduous, armed
3.	relatively palatable evergreen
4.	unpalatable deciduous
5.	unpalatable evergreen

This index will be referred to in this paper as the Palatability Index. The number of species and the number of plants of each functional class were then calculated for the combined set of 18 plots of each side of each fence. Each woody plant had thus been classified in terms of the side of the fence it was found on and its palatability class. The null hypothesis which was then tested is that the palatability class is independent on the side of the fence. The Chi-Square Test of Independence was used to test this hypothesis. This was then repeated for the number of plants.

RESULTS AND DISCUSSION

There was no reason to reject the null hypotheses that the numbers of woody plant species present in each palatability class are independent on the side of the fence (Table 3). Previous analysis of this data set (Richardson-Kageler 1999) showed that there were no significant differences in the species richness at the species level. Traditionally, species richness has been analysed at the species level (Chapin et al. 1992). This analysis is an attempt to analyse the species richness within functional palatability classes, where each functional palatability class contains species with a similar effect or use.

There were significant differences in the plant numbers between comparisons (sides of the fence) in the classes of the Palatability Index for all sites ($p < 0.05$) except the comparison of Mushandike Research Area with Mushandike Ranch (Table 3 and Figure 2). It has been hypothesised that the time required to change the species richness in these woodlands is centuries whereas the time to change woody plant abundances is decades (Richardson-Kageler 1999). These results confirm this for species and plants in the classes of the Palatability Index. The areas with different large herbivore communities had different woody plant communities as the numbers of plants in the different classes were different in the areas.

The percentage of plants of spinescent (armed) species is higher in areas with higher stocking rates for all but two of the sites (Table 3). This is particularly noticeable for Sultana Ranch, which has 25% of the plants being spinescent (class 1 of the Palatability Index) compared to 13% at Iwaba Ranch, and for the Mushandike Research Area which had 15% of the plants being spinescent compared to 8% at Mushandike Sanctuary. Both of these areas had the higher stocked areas having more than twice the stocking rate of the lower stocked areas and both had populations of game on both sides of the fence. Spines defend plants from herbivory (Cooper and Owen-Smith 1986), so it is expected that the areas with higher stocking rates would have a higher percentage of spinescent plants.

Higher percentages of armed and unpalatable plants (classes 2, 4 and 5 of the Palatability Index) were found for four of the game areas (Table 3). To distinguish whether the higher percentages of these plants were due to stocking rate of the herbivore species present or a combination of the two is difficult. It appears that at Buffalo Range Ranch, where the stocking rates of the game and cattle sections were similar, that the increase in armed and unpalatable plants was due to the herbivore species present. At Humani Ranch, both the stocking rate and

Table 3. Numbers of woody species and woody plants in each class of the Palatability Index

Class	Species					Plants				
	1	2	3	4	5	1	2	3	4	5
Buffalo Range Ranch (game)	13	8	1	4	0	269 (42%)	246 (38%)	10 (2%)	122 (19%)	0
Buffalo Range Ranch (cattle)	12	10	2	4	0	294 (47%)	262 (42%)	21 (3%)	54 (9%)	0
Humani Ranch (game)	16	8	2	6	0	463 (82%)	52 (9%)	9 (2%)	42 (7%)	0
Humani Ranch (cattle)	17	7	1	7	1	529 (87%)	31 (5%)	3 (0%)	41 (7%)	2 (0%)
Iwaba Ranch (game)	31	10	5	6	1	552 (57%)	116 (12%)	11 (1%)	282 (29%)	12 (1%)
Sultana Ranch (game and cattle)	32	13	3	6	3	529 (53%)	247 (25%)	4 (0%)	216 (22%)	5 (0%)
McIlwaine National Park (game)	21	8	2	9	1	422 (60%)	40 (6%)	40 (6%)	196 (28%)	1 (0%)
Idaho Farm (cattle)	24	9	3	8	0	419 (59%)	73 (10%)	16 (2%)	201 (28%)	0
Mushandike Research Area (game)	25	12	3	5	1	277 (47%)	136 (23%)	4 (1%)	163 (28%)	4 (1%)
Mushandike Ranch (cattle)	37	9	4	5	1	294 (51%)	115 (20%)	7 (1%)	152 (26%)	10 (2%)
Mushandike Research Area (game)	17	6	3	6	0	788 (89%)	25 (3%)	9 (1%)	59 (7%)	0
Rabe (cattle)	19	6	2	5	0	457 (85%)	35 (6%)	3 (1%)	44 (8%)	0
Mushandike Research Area (game)	23	8	2	3	0	331 (63%)	81 (15%)	38 (7%)	75 (14%)	0
Mushandike Sanctuary (game)	28	9	3	6	0	685 (82%)	63 (8%)	11 (1%)	77 (9%)	0

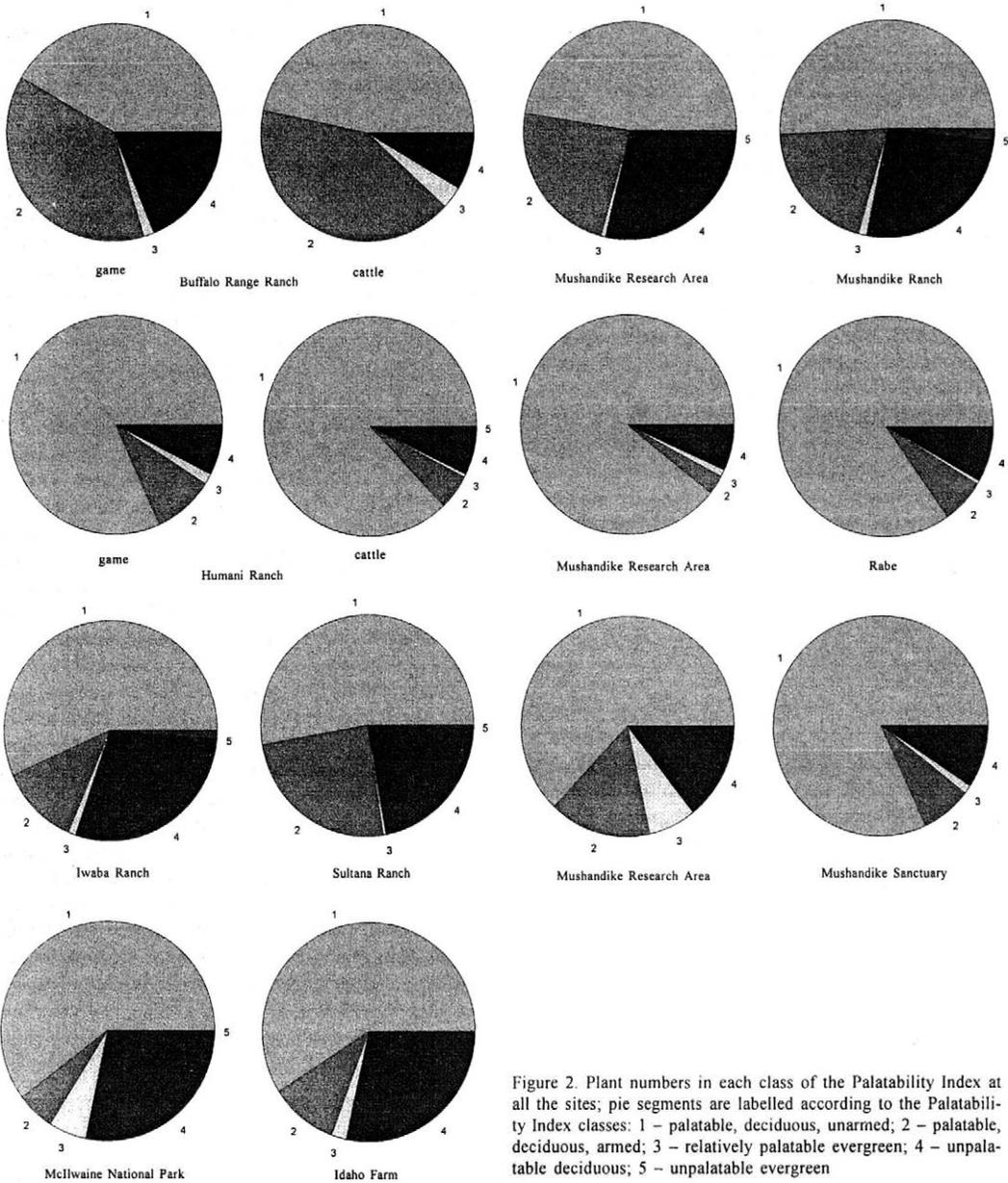


Figure 2. Plant numbers in each class of the Palatability Index at all the sites; pie segments are labelled according to the Palatability Index classes: 1 – palatable, deciduous, unarmed; 2 – palatable, deciduous, armed; 3 – relatively palatable evergreen; 4 – unpalatable deciduous; 5 – unpalatable evergreen

number of herbivore species present was greater on the side of the fence, where there were more armed and unpalatable plants. For the McIlwaine National Park and Idaho Farm comparison, where Idaho Farm had more plants in Classes 2, 4 and 5, there were more armed and unpalatable plants on the side of the fence with the higher stocking rate, which had only cattle. For the Mushandike Research Area comparisons, the armed and unpalatable plants were in higher numbers on the sides of the fence with the higher stocking rates, which was the side with game, except for the Rabe comparison.

There were lower numbers of plants in Class 1 (Palatable, deciduous, unarmed) in sample plots in game areas for all but two comparisons (McIlwaine National Park with Idaho Farm and Mushandike Research Area with Rabe). It has been shown for some game species, kudu and impala, that through selective browsing, palatable species will be reduced in an area (du Toit et al. 1990). For the McIlwaine National Park and Idaho Farm comparison, the cattle stocking rate (Idaho Farm) is almost three times that of the game stocking rate (McIlwaine National Park). Cattle do take a limited amount of browse in their diets in

savanna woodlands with the amount of browse increasing in the winter months when other food is scarce (Fritz et al. 1996). It is therefore expected that cattle will have some direct impacts on the woody vegetation, as well as impacts brought about through activities, such as trampling and hence, it was thought that woody species would be more affected in the areas with game when compared to similarly stocked areas of cattle due to direct impacts. This happened at Buffalo Range Ranch, as well as Humani Ranch (although stocking rate confused the results for this site).

Owen-Smith and Cooper (1989) proposed that browsing herbivores use different vegetation components (stepping stones) at different times of the year: palatable, deciduous woody plants in the wet season; new foliage or fruits for pregnant or lactating females; evergreen or late deciduous, relatively palatable plants for the dry season; fruits and pods available in the dry season; new leaf growth just prior to the rains and unpalatable, evergreen or succulent shrubs as an emergency food. Classes 1 and 2 of the Palatability Index are the wet season food. Class 3 is the dry season food, and Classes 4 and 5 are the emergency foods. If any one of these classes were to disappear from a system, the herbivores would not have the required stepping stones to make it through the year. This study indicates that the numbers of plants in each palatability class changes and this gives indications of overstocking of browsers or overstocking of cattle or other grazers which are switching to browse to supplement their diets in times of low food supply. The numbers of species in each palatability class appears not to be important at the time scale for which the study sites had been set up.

Palatability indices are subjective (Dicko-Teure 1980) and should be interpreted with caution. They may be derived from plant-based or animal-based observations. The allocation of the classes of the Palatability Index used here was plant-based. The use of flowers and fruit by the herbivores has yet to be built into palatability indices satisfactorily, but it is necessary as herbivores may consume entire whole fruit or flower crops. The importance of the chemical components of plants is still to be understood (Owen-Smith and Cooper 1988). This paper has been an attempt to use a palatability index which takes into account whether a plant is armed, its longevity and its palatability [although palatability is complex and difficult to define (Le Houerou 1980)], and to try and elucidate some of the patterns shown in areas with different large herbivore species.

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ABSTRAKT

Vybrané charakteristiky ekosytémů přírodních savanových lesů s různými druhy přežvýkavců v Zimbabwe

Velké plochy zemědělské půdy, užívané dříve v Zimbabwe pro pastvu skotu, jsou v současné době opět vráceny do původního stavu, určeného pro rozvoj a ochranu divokých zvířat či pro kombinované využití s pastvou skotu. Je proto třeba zabývat se vlivem jednotlivých druhů zvířat na vývoj ekosystémů. Vliv skotu na různé stupně přijatelnosti keřů a stromů byl porovnáván s jejich přitažlivostí pro velké domácí a divoké býložravce vyskytující se v africké přírodě, zejména v Zimbabwe. Bylo vytyčeno 36 dílců v blízkosti každého ze sedmi plotů v 18 lokalitách: dílce byly situovány na obou stranách plotů oddělujících dva systémy hospodaření (pastva skotu verus přírodní stav). Nebyly shledány žádné rozdíly mezi bohatstvím flóry z hlediska tříd chutnosti jednotlivých druhů stromů a keřů. Významné diference však byly prokázány v počtu rostlin každé třídy u téměř všech plotů. Bylo zjištěno, že hustota skotu, jakož i počet druhů velkých býložravců včetně jejich hustoty představují významné faktory ovlivňující počet rostlin v každé ze tříd chutnosti. Z našich pozorování vyplývá, že pro změnu ekosystému z hlediska četnosti výskytu jednotlivých druhů stromů a keřů bude třeba daleko delší doba, než je zhruba deset let existence plotů oddělujících různé způsoby hospodaření.

Klíčová slova: býložravci; skot; chutnost; africká savana; diverzita druhů; ekosystémy

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Element distribution in faba bean root nodules under salinity and its effects on growth, nodulation and nitrogen fixation

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ABSTRACT

Faba bean cv. Giza 3 was grown in hydroponic cultures and inoculated with *Rhizobium leguminosarum* bv. *viciae* TAL 1402. Salinity levels at 40, 80 and 120 mM NaCl were applied at transplanting and inoculation. The highest level of salinity level (120 mM) significantly suppressed nodulation, nitrogenase activity and plant growth. This salinity level also significantly decreased the concentrations of macro and micro nutrients in faba bean leaves. X-ray microanalyses of nodules under high levels of NaCl indicate that Ca, K, Mg and S were lower in the infected and uninfected cells of faba bean nodules than control ones, whereas, Na and Cl were higher. Nitrogen content of nodules was significantly higher in plants treated with high salinity levels than nonsalinized ones. However, the N content of shoots was lower than the controls. The inhibition of nitrogenase activity at high levels of salt stress could be explained in terms of product inhibition of the enzyme as an efficient feedback regulation mechanism. The X-ray microanalysis results revealed that the N export from nitrogen-fixing cells is sensitive to salinity and is controlled by element distribution in nodules.

Keywords: nodulation; nitrogen fixation; *Rhizobium*; *Vicia faba*; salinity; X-ray analysis

Plants in nature may be exposed, during their ontogeny, to a variety of environmental stresses, two of which are closely interrelated: water deficiency or water stress, and salt excess or salt stress. The interrelationship between the factors of two stresses is of particular significance for irrigated crops. Salt stress is a principal factor that limits legume production in many parts of the world, especially when nitrogen nutrition depends on biological dinitrogen fixation (Abd-Alla 1992). The noxious effect of salinity on *Rhizobium/Bradyrhizobium*-legume symbiosis is widely reported (Abd-Alla and Abdel Wahab 1995, Abd-Alla et al. 1998).

Legume species vary widely in their response to salt stress, ranging from extremely sensitive to tolerant species (Cordovilla et al. 1995). Serraj et al. (1994) reported that short-term (2 h) NaCl treatment resulted in decreased nitrogenase (acetylene reduction) activity, and that this inhibition became more pronounced with longer (24 h) NaCl treatment. This was attributed to an association of salt stress with a decrease in nodule permeability to O₂. Salinity can affect the legume-*Rhizobium/Bradyrhizobium* symbiosis by osmotic and non-osmotic effects (Sanchez-Diaz et al. 1982). Nodule function is impaired under salt or drought stress even though the plant might not display signs of stress (Abd-Alla 1992, Abd-Alla and Abdel Wahab 1995, Abd-Alla et al. 1998). There is appreciable information on the effect of salt stress on dinitrogen fixation and growth of soybean.

Salt stress could be impaired the ion distribution in nodules of faba bean. Such speculation led to an investigation of ion distribution in nodules of faba bean grown under different levels of sodium chloride using X-ray microanalysis (Thomas and Minchin 1992).

MATERIAL AND METHODS

Plant growth

Surface-sterilized seeds of faba bean (*Vicia faba* L. cv. Giza 3) were sown in autoclaved sand trays which were watered with 0.5 mM CaSO₄ as needed. Germination and subsequent growth were in a growth chamber programmed for a 16-h photoperiod at 22°C, and a 8-h dark period at 17°C. At 7 d after germination, seedlings were removed from the sand and transplanted to a 5 l plastic pot containing dilute nutrient solution. The nutrient solution had the following composition in µM: K₂SO₄ 175, KCl 25, MgSO₄ 125, KH₂PO₄ 25, CaCl₂ 500, FeEDTA 5, MnSO₄ 0.125, CuSO₄ 0.05, ZnSO₄ 0.025, H₃BO₃ 2.5, (NH₄)₆Mo₇O₂₄ 0.0125, CoCl₂ 0.125 and NiSO₄ 0.0025. Each pot supported four plants and was inoculated with 5 ml of *Rhizobium leguminosarum* biov. *viciae* strain TAL 1402 (10⁸.ml⁻¹), grown in yeast extract-mannitol broth for 3 d at 25°C on a shaker.

Four NaCl treatments were imposed at the time of transplanting and inoculation; 0, 40, 80 and 120 mM; throughout the growth period (five weeks after transplanting). Nutrient solution was completely changed after one week. Thereafter plants received four times concentrated nutrient solution and the solution was completely changed at 4 d intervals throughout the growth period. The nutrient solutions were maintained at pH 6.5 by NaOH titration (0.25 M). The experiments carried out in a factorial arrangement of treatments with five replications. Experimental data were subjected to analysis of variance using PC-Stat computer program.

Nitrogenase activity. Five weeks after transplanting and NaCl treatment, plants were harvested and the plant roots were detached from shoot and placed in 500-ml jars (4 roots per sample). The jars were sealed and injected with 50 ml acetylene through a rubber septum fitted into the lid, and incubated at 30°C for 30 min. Following incubation, 0.5 ml sample were analyzed for ethylene production by flame ionization gas chromatography (Hewlett Packard 5890A). After the assay, the nodules were removed from the roots. Shoots, roots and nodule were dried in a forced oven for 48 h at 85°C for dry matter determination. Nitrogen concentrations of the plant tissues were determined according to Kjeldahl (Black et al. 1965). K and Na were determined by flame photometer. Mg, Ca, Cu and Zn were determined by atomic absorption spectrophotometer (Perkin Elmer 2380). Phosphorus concentration of plant matter was determined according to Jackson (1958).

X-ray microanalysis of nodules. *In situ* mineral analysis was done using Energy Dispersive X-ray analysis (Thomas and Minchin 1992). Nodules were detached from washed root system, blotted dry, placed in holes in a copper stub containing aqueous colloidal carbon and quenched frozen in nitrogen slush (-210°C). The total operation from the removal of the plants from the growth chamber to the freezing of the nodules was achieved within 10 min. The copper stub was then transferred to a cryostat, additionally cooled with liquid nitrogen to below -50°C and the frozen hydrated specimen trimmed with a cold knife on a microtome. The stub was then returned to liquid nitrogen, rapidly mounted in a pre-cooled copper holder at -190°C and introduced into an Emscope SP 2000A sputter-cryo system. The holder was then transferred under vacuum to the cold stage of a Joel 840A scanning electron microscope fitted with a KEVEX energy dispersive X-ray microanalysis system and Quantum light-element detector. Ice crystals on the surface of the cut face of the nodules were removed by sublimation at -70°C for 1–2 min after which the temperature was reduced to -160°C for analysis. X-rays were collected using an electron accelerating voltage of 10 kV and an electron beam current set to give a standard 3000 counts.s⁻¹ when a stationary beam was focused on the copper stub holder. Spectra were processed using KEVEX software incorporating an automatic subtraction of background, Bremsstrahlung X-rays and calculation of integrated peak intensities (counts.s⁻¹) by Gaussian deconvolution. X-ray spectra were collected at a magnification of × 3000 from uncoated specimens. Although the counts.s⁻¹ is quantitative in a relative sense, it cannot be directly converted to conventional units of concentration (Thomas and Minchin 1992).

Statistical analysis. X-rays microanalyses were performed on each cell in cross-cortical file from the nodule tissues. At least five randomly selected nodules were analyzed for each treatment. At least six scans were taken at different positions in the nodule tissue. Values for

the six scans were averaged to give an estimate for a nodule and the average values for individual nodules were used to provide a mean for the treatment.

RESULTS AND DISCUSSION

Plant growth and nitrogen accumulation

An inhibitory effect of salt on the dry matter production of shoots and roots was detected at salinity levels of 80 mM NaCl. Salinity levels of 80 and 120 caused decreases in dry weight of shoots by 25 and 49%, respectively. At higher levels, salinity inhibited root growth more strongly than shoot resulting in an increase in shoot/root ratios (Table 1). This contrasts a previous report by Abd-Alla et al. (1998) who found that root growth of soybean was less affected by salinity than shoot growth. Noble and Rogers (1993) reported that roots were more resistant to salinity than plant foliage.

Nitrogen concentration of shoots and roots showed a dramatic decrease when grown at higher levels of salinity (80 and 120 mM NaCl). A decrease of 36 and 63% in nitrogen concentration of shoot was caused by salinity levels of 80 and 120 mM NaCl. These findings highlight the highly salt-sensitivity of faba bean. In this respect faba bean behaves like other legume species such as soybean (Cordovilla et al. 1995, Sinclair and Serraj 1995, Abd-Alla et al. 1998). Salt stress is usually manifested as a water deficit because of osmotic effects of the salt and toxic effects due to ion excess (Greenway and Munns 1980).

Concentration of macro and micro nutrients

Foliar concentration of macro and micro nutrients was determined. It is evident that high levels of salinity significantly decreased the concentration of macro and micro nutrients except that Na and Cl were increased (Table 2).

Table 1. The effect of salinity on plant growth and nitrogen concentration of faba plants inoculated with *Rhizobium leguminosarum* bv. *viceae* TAL 1402; each value represents the mean of five replicates

NaCl treatment (mM)	Dry weight (g ⁻¹ plant)		Shoot/root ratio	Nitrogen concentration (mg.g ⁻¹ dry matter)	
	shoot	root		shoot	root
0	8.4	3.7	2.27	16.2	8.2
40	8.7	3.8	2.28	17.3	8.9
80	6.3	2.4	2.63	10.3	5.1
120	4.3	1.5	2.86	5.9	3.2
LSD (<i>p</i> = 5%)	1.8	0.7		5.2	2.0

LSD = least significant difference

Table 2. Effect of salinity on foliar element content of faba bean

NaCl treatment (mM)	P	K	Na	Mg	Ca	Cl	Cu	Zn
	(%)							
0	0.25	2.94	0.99	0.58	1.55	1.11	0.019	0.067
40	0.30	3.12	1.11	0.53	1.67	1.98	0.022	0.059
80	0.18	1.88	1.55	0.43	1.21	2.48	0.011	0.033
120	0.12	1.22	1.89	0.33	0.88	2.99	0.008	0.037
<i>LSD</i> ($p = 5\%$)	0.09	0.96	0.67	0.21	0.44	0.89	0.010	0.020

Salt stress affects a variety of metabolic activities. Accumulation of Na and Cl in the leaves of faba bean of salt stressed plants may be due to passive transport of these elements along with the transpiration stream (Mumukkar and Chavan 1986). On the other hand, a considerable decrease in the other elements was evident at the higher doses of NaCl which might have altered the physiological activity of leaves and this could probably be due to the adverse effects of salt stress on the transport of these macro and micro nutrients.

Nodulation and nodule activity

The total number of nodules on faba bean plants was significantly inhibited as salinity levels increased. The inhibitory effect of salinity on nodulation appeared at the salt level of 80 mM NaCl. The decrease in number was 68 and 91% for 80 and 120 mM NaCl, respectively. Total dry mass of nodule per plant followed a similar pattern to nodule number. Also, a significant decline in nodule number per g root dry matter at high salinity levels indicates a stronger inhibition of nodulation than root growth (Table 3).

The reduction in nodulation at high salinity might be attributed to shrinkage of root hair. A sharp decline in total (per plant) and specific (per dry mass nodule) nitrogenase activity was observed at salinity levels of 80 and 120 mM NaCl. However, at these levels of salinity the nitrogen concentration of nodules was significantly increased than in control plants (Table 3). Several similari-

ties have been reported between salt stress and water stress. Serraj and Sinclair (1996), Abd-Alla (1992) and Abd-Alla and Abdel Wahab (1995), studying the effect of water stress on nodule physiology, found that water stress lowered the content of leghaemoglobin and decreased ATP production. A salt-induced decrease in energy generation, therefore, might at least partially explain the inhibition of nitrogenase.

The accumulation of N in nodules treated with high levels of salinity (Table 3) indicates that nitrogenase activity was limited by product inhibition in the form of NH_4^+ which may be accumulated when its incorporation into amino acids and/or amide is inhibited (Schubert 1995).

In situ element distribution in root nodules

Results for EDAX analysis of elements across nodule tissue are shown in Figures 1–4. Phosphorus, calcium and magnesium were higher in the infected cells followed by a decreasing order: uninfected, inner cortex and outer cortex. However, potassium and sulphur were higher in the outer cortex followed by infected zone. Chloride and sodium were almost equally distributed across nodule tissues. Salinity significantly disordered the distribution of elements across nodule tissue. Analysis of variance revealed that high levels of NaCl significantly decreased the distribution of P, Ca, Mg, K and S across nodule tissue. However, Cl and Na dramatically increased (Figures 1–4). Such osmotic control could involve inorganic ions and organic compounds (Hunt and Layzell 1993) and ion could also

Table 3. The effect of salinity on nodulation, nodule activity and nitrogen concentration of nodule of faba bean plants inoculated with *Rhizobium leguminosarum* bv. *viceae* TAL 1402; each value represents the mean of five replicates

NaCl treatment (mM)	Nodules.plant ⁻¹		Nodule no.g ⁻¹ dry weight root	Nitrogenase activity ($\mu\text{mol C}_2\text{H}_4$)		Nitrogen concentration (mg.g ⁻¹ dry mass nodule)
	no.	dry weight (mg)		h ⁻¹ .plant ⁻¹	h ⁻¹ .g ⁻¹ nodule dry weight	
0	108	119	29	4.6	38.7	4.2
40	116	128	31	4.9	38.8	5.1
80	35	49	14	1.0	20.6	12.2
120	9	15	6	0.2	13.3	18.3
<i>LSD</i> ($p = 5\%$)	21	43	6	0.9	11.1	5.8

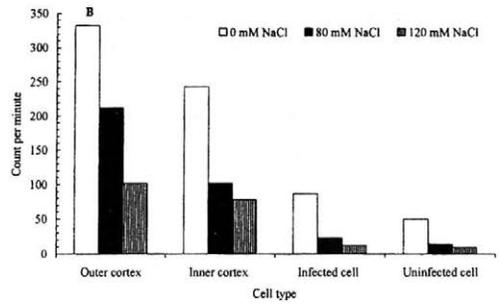
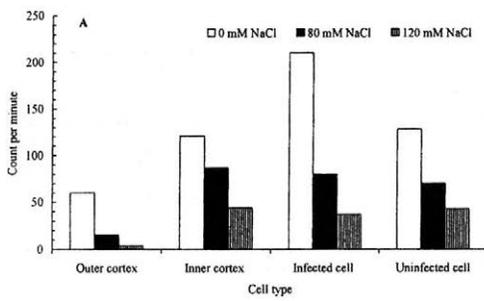


Figure 1. Microanalysis of phosphorus (A) and potassium (B) distribution (count per minute) across the tissue of faba bean nodules grown in saline solution; values represents means of six replicates for each treatment within a cell type and vertical bars are *LSD* (least significant difference) at the 0.05 level

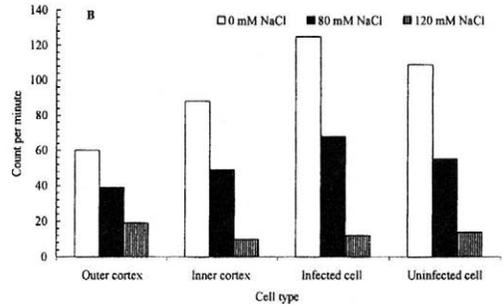
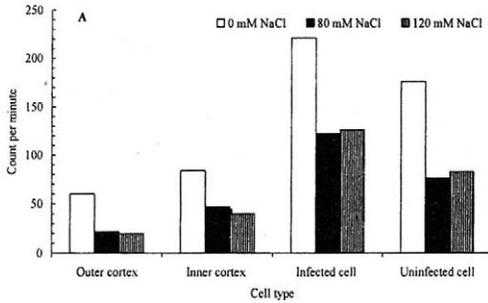


Figure 2. Microanalysis of calcium (A) and magnesium (B) distribution (count per minute) across the tissue of faba bean nodules grown in saline solution; values represents means of six replicates for each treatment within a cell type and vertical bars are *LSD* (least significant difference) at the 0.05 level

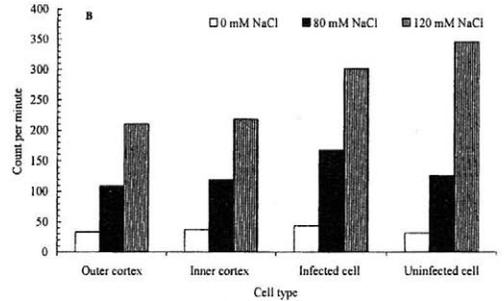
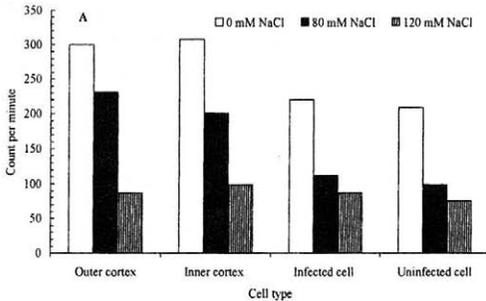


Figure 3. Microanalysis of sulphur (A) and sodium (B) distribution (count per minute) across the tissue of faba bean nodules grown in saline solution; values represents means of six replicates for each treatment within a cell type and vertical bars are *LSD* (least significant difference) at the 0.05 level

involve in changes to the water-holding capacity of glycoprotein (Witty and Minchin 1990). The possible involvement of Mg is the most intriguing as its presence in high concentrations is confined to cells of the inner cortex which are also involved in glycoprotein excretion (James et al. 1991). One function for Mg could be in a direct interaction with the glycoprotein (at either the

intra- or intercellular stage) to alter its water absorbing capacity. Minchin et al. (1994) suggested that the concentration and distribution of Mg, Ca, and S reflect an involvement in the operation of the cortical diffusion barrier. Our results using EDAX analyses are in agreement with the detailed *in situ* mineral distribution in soybean nodules (Thomas and Minchin 1992, Minchin et al.

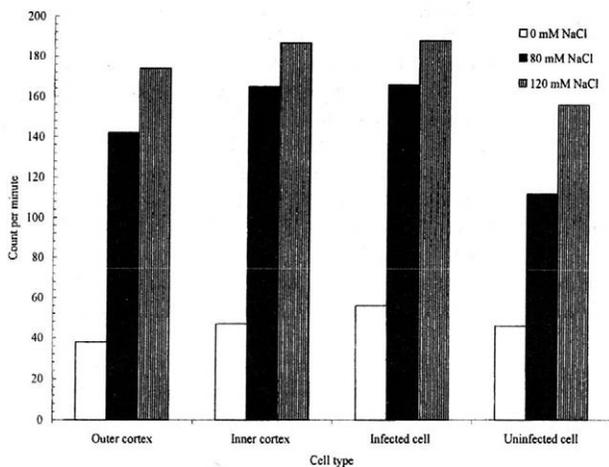


Figure 4. Microanalysis of chloride distribution (count per minute) across the tissue of faba bean nodules grown in saline solution; values represents means of six replicates for each treatment within a cell type and vertical bars are *LSD* (least significant difference) at the 0.05 level

1994) and the presentation of mineral distribution in entire soybean nodule (Mizukoshi et al. 1995). Streeter (1998) reported that calcium and magnesium were higher in the outer cortex than in the infection zone and this concentration might be sufficient to influence N transport from nodules. Tyerman et al. (1995) have demonstrated the presence of an ion channel that facilitates voltage dependent transport of monovalent cations including NH_4^+ through the symbiosom membrane. Because of the probable predominance of NH_4^+ in the peribacteroid space and the need for massive transport of N to the host, this mechanism for N transport is intuitively more attractive than the passive diffusion of NH_3 . The NH_4^+ channel was sensitive to calcium and may be controlled by other elements. Salinity disturbs the element distribution across nodule tissues and may inhibit the transport channel. High nitrogen content of nodules (Table 3) and its low content of shoots (Table 1) may confirm this suggestion under salt stress.

It might be concluded that N export from N_2 fixing cells is arrested by salinity and it is suggested, as our results indicate, to be controlled by the element distribution in nodules.

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ABSTRAKT

Distribuce prvků v kořenových hlízkách bobu obecného v podmínkách zasolení a jeho vliv na růst, tvorbu hlízek a fixaci dusíku

Odřůdu Giza 3 bobu obecného jsme pěstovali hydroponicky a k její inokulaci jsme použili bakterii *Rhizobium leguminosarum* bv. *viceae* TAL 1402. Při přesazení a inokulaci byla úroveň zasolení 40, 80 a 120 mM NaCl. Nejvyšší hladina zasolení (120 mM) významně potlačila tvorbu hlízek, nitrogenázovou aktivitu a růst rostlin. Tato hladina zasolení také významně snížila koncentraci makro- a mikroživin v listech bobu obecného. Rentgenové mikroanalýzy hlízek při vysoké hladině NaCl ukazují, že infikované i neinfikované buňky hlízek bobu obecného měly ve srovnání s kontrolou nižší obsah Ca, K, Mg a S, zatímco obsah Na a Cl byl vyšší. Obsah N v hlízkách byl významně vyšší v rostlinách z variant s vysokou hladinou zasolení než u nezasolených variant. Obsah N v nadzemních částech rostlin byl nižší než u kontroly. Inhibiči nitrogenázové aktivity při vysokých hladinách NaCl lze vysvětlit jako inhibiči produktů tohoto enzymu regulačním-mechanismem zpětné vazby (feedback effect). Rentgenová mikroanalýza ukázala, že export N z buněk vzájemných N citlivě reaguje na zasolení a řídí se distribucí prvků v hlízkách.

Klíčová slova: tvorba hlízek; fixace dusíku; *Rhizobium*; *Vicia faba*; zasolení; rentgenová analýza

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Interactions among anaerobic and aerobic N mineralization, nitrification and selected soil properties

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ABSTRACT

Nitrogen mineralization and nitrification are important soil quality parameters. The aim of our research was to determine the dependence of the microbial parameters which characterize N mineralization and nitrification on selected physical and chemical soil properties. The results from soil monitoring representing the major soil types of the Czech Republic show, that N mineralization measured under aerobic and anaerobic conditions was checked by the concentration of organic matter (N_{tot} , C_{org}). Aerobic N mineralization decreased with increasing cation exchange capacity. The values of cation exchange capacity and pH influenced the level of nitrification in our research.

Keywords: soil; anaerobic and aerobic N mineralization; nitrification; physical and chemical properties

Nitrogen mineralization and nitrification are important soil quality parameters. The nitrogen mineralized during an incubation experiment reflects a labile fraction of the soil organic nitrogen, which is available to the plants (Fyles et al. 1990, Bundy and Meisinger 1994). Nitrification is a process provided by a group of specialized chemoautotrophic bacteria which are active over a narrow range of soil conditions and from that reason it can be used as an indicator of stress conditions (Roper and Ophel-Keller 1997). Because the microbial community state is a result of physical, chemical and biological soil properties, our knowledge of mutual relationships between microbiological and abiotic parameters is necessary for the application of microbial characteristics in the system of soil quality control (Oberholzer et al. 1999).

Nitrogen mineralization is closely connected to soil organic matter (Franzluebbers et al. 1994, Ajwa et al. 1998) where N mineralization is higher in grasslands than in arable soils due to higher organic substrate accumulation. In grasslands there are lower organic matter losses from the system, because the above-ground biomass is not harvested. Tillage of arable soils also leads to soil aggregate disruption and organic matter being exposed to microbial attack. As a result lower mineralizable substrate concentration was described in arable soils (Haynes 2000). Conversion of organic N into available mineral forms is influenced by the C/N ratio. While considerable variation is found in the C/N ratio for individual soils, the mean for soils from different regions of the world is remarkably similar and as an average the proportion of C/N of soil humus is 10–12:1 (Stevenson 1986).

Mineralization rate is influenced by soil texture and cation exchange capacity. Proteins and other polymeric organic substances tend to accumulate on charged surfaces of solid soil particles rather than being dissolved freely in the liquid phase. This process leads to organic

matter stabilization and its protection against microbial attack in soils with higher CEC and fine-grained texture (Beare et al. 1994, Apple et al. 1995, Hassink 1995a, b, Franzluebbers et al. 1996, Franzluebbers and Arshad 1997).

Šimek (2000) presents substrate concentration, efficient oxygen supply, temperature, water content and soil texture as the main environmental factors influencing nitrification. Nitrification seems to be strongly dependent also on pH level. It begins at pH 4.5, and for most soil types its maximum rate is achieved within the range of pH 6.6–8.0. Nitrification in acid soils is a consequence of the co-existence of microsites with fast organic matter decay leading to NH_4^+ release and also the presence of heterotrophic nitrifiers (Paul and Clark 1996).

Nitrification is promoted by clay content and consequent cation exchange capacity. These particles are colonized by nitrifiers with a parallel adsorption of NH_4^+ leading to an increased rate of nitrification (Berg 1986). The differences in the action of various clay materials are dependent on their structure (Saratchandra 1978).

A fast and simple method for the determination of available nitrogen based on the measurement of UV spectra of soil extract (0.01 M NaHCO_3) in the range of 205–260 nm, has been proposed. A strong correlation between the absorbances of those soil extracts at 205 and 220 nm (A_{205} , A_{220}) and N plant uptake and N mineralized in the course of a 2-week-incubation period was discovered (Giroux and Sen Tran 1987). Nitrogen organic compounds and nitrate ions significantly absorb within the range 205–250 nm. At the wavelength of 230 nm, its contribution to the total absorbance is rather small, falling to zero at 260 nm. The most suitable wavelength appears to be 220 nm.

The aim of our study was to determine the dependence of N mineralization rate measured under both

aerobic and anaerobic conditions (anaerobic ammonification) and nitrification on selected physical and chemical properties (pH, CEC, texture, C_{org} , N_{tot}) in soils of monitoring observation areas of the Czech Republic. It is the first screening for such microbial parameters within the scope of soil monitoring organized by the Central Institute for Supervising and Testing in Agriculture in Brno (Czech Republic).

MATERIAL AND METHODS

Soil sampling and storage

Soil samples were taken in the years of 1994–1996 from the monitoring areas of the Czech Republic according to guidelines issued by the Central Institute for Supervising and Testing in Agriculture. Some 116 plots representing the major soil types of the Czech Republic were chosen. A total of 20 subsamples from the 0–30 cm (arable soils) and 0–10 cm (permanent grass stands after removal of surface turf) depths was taken from an area of 25 × 40 m to prepare a mean sample.

The sampling was carried out in the spring immediately after the soil had thawed. Soil temperature must not exceed 4°C. The samples were frozen (–20°C). Before analyses, they were thawed for a week and sieved (2 mm). All microbiological analyses were performed on three replicates over the course of 1 month following the thaw of the samples. The soil samples were then dried at laboratory temperature to determine pH, cation exchange capacity and total nitrogen. C_{org} determination required drying the soil at laboratory temperature followed by pulverization to get particles that would pass through a 0.25 mm sieve.

Physical and chemical parameters

Moisture was assessed as a weight decrease during 2-hour-drying at 105°C. Maximum water holding capacity was determined according to Öhlinger (1993). Dried soil was put into PE cylinders with filter paper bottoms 3 cm in diameter, 25 g each. First, the cylinders were placed into a vessel filled with water up to the top level of the soil for 1 hr. Afterwards, they were put on a sand bath for another 3 hrs, and the samples were analysed for water content (8 hrs, 105°C).

Particle size analyses of soils were carried out by means of the pipette method (Javorský et al. 1987). Particle size, used for further trials, was below 0.01 mm.

The pH was determined according to ISO/DIS 10390 (1992). Five g of soil were supplemented with 25 ml of an extractant (1 M KCl) and the suspension was shaken vigorously for 5 mins pH was recorded by means of a glass electrode after 2-hour-standing.

Organic carbon was determined by wet combustion using sulfochromic oxidation of 1 g soil sample with 5 ml 0.27 M $K_2Cr_2O_7$ solution and 7.5 ml concentrated H_2SO_4 ac-

ording to ISO/DIS 14235 (1995). Soil nitrogen was determined after mineralization and distillation into boric acid.

Cation exchange capacity (CEC) was measured after saturation of soil by Ba^{2+} (eluate 1) and its removal by $MgCl_2$ or $CaCl_2$ (eluate 2). In eluate 1 the concentration of hydrogen ions was set by using titration and in eluate 2 the concentration of barium by the use of AAS. The countdown was done according to Zbiral (1995).

To measure the available forms of nitrogen by means of UV spectra of 0.01 M $NaHCO_3$ extracts, 5 g of moist soil were mixed with 25 ml of an extractant, the suspension was agitated for 1 hr and centrifuged. The extract was diluted to get A_{205} below 1000, and measured using a spectrophotometer UV2 ATI Unicam. For statistical evaluation absorbances at 205, 220, 230 and 260 nm were used.

Ammonium was determined by means of Berthelot reaction with phenol and hypochlorite, nitrites by means of Griess-Ilosvay reaction with sulfanilamide and N-(1-naphthyl-ethylenediamine) dihydrochloride. Nitrates were measured directly at 212 nm having deducted the absorbance of the extract reduced with a Cu/Zn reductor (Kandeler 1993). All dilutions of the samples and dosage of reagents were performed by means of an autosampler Gilson 222 XL. A spectrophotometer UV2 ATI Unicam was used to carry out the measurements.

Anaerobic N mineralization (anaerobic ammonification)

Five grams of moist soil were weighed out and put in plastic vessels of 23 × 90 mm and drained with water up to 10 mm below the upper edge of the vessel. The vessels were then closed with a screw-cap and incubated at 40°C for a week. Afterwards, a suspension was taken from these vessels to 125 ml bottles. Then KCl solution was added to get a final concentration of 1 mol.l⁻¹ (soil:extractant = 1:20). The samples were agitated for 1 hr, centrifuged, and the supernatant was analysed to assess the concentration of ammonia ions (Bundy and Meisinger 1994). Anaerobic N mineralization was expressed as a net increase in ammonia ions after subtraction of the initial concentration.

Aerobic N mineralization

Ten grams of moist soil were put in 100 ml Erlenmeyer flasks, moistened to reach 60% WHC and incubated at 25°C for a week. Afterwards, the sample was supplemented with 50 ml 1 M KCl, agitated for 1 hr and centrifuged. The supernatant was analysed for nitrate concentration. Aerobic N mineralization was expressed as a net increase in the nitrate concentration after deduction of the initial concentration (ISO 14238 1997). The NH_4^+ ion concentration was not measured because in keeping with the previous measurement the result shows that its concentration in such soils during the length of the experiment

Table 1. Percentage of evaluated soil types

Soil type	No. of soils	Percentage
Chernozem	10	8.62
Regosol	1	0.86
Gleysol	9	7.76
Orthic luvisol	25	21.60
Cambisol	43	37.10
Albic luvisol	7	6.03
Fluvisol	13	11.20
Dystric planosol	5	4.31
Rendzina	3	2.59

is considerably lower than nitrate ions and its contribution to total N mineralization is negligible.

Nitrification

Twenty grams of moist soil were put in a glass bottle and supplemented with 100 ml media. The bottle was then closed with a lid having a 7 mm slot, and the suspension was agitated on a horizontal shaker at 25°C for 12 hrs. The medium (pH 7.2) was prepared by mixing 10 ml phosphate buffer and 15 ml 1 M NaClO₃ solution with an addition of 0.5 g (NH₄)₂SO₄ and water to make up 1000 ml. The phosphate buffer contained 1.25 g K₂HPO₄ and 0.38 g KH₂PO₄ per 100 ml. At 9 and 12 hours 5 ml of suspension were removed. The suspension was supplemented with 5 ml 4 M KCl, shaken vigorously, filtered (MN 619 G, Mache-rey-Nagel), and the filtrate was analysed for the nitrite content. (ISO/CD 15685 1998, adjusted). Nitrification was calculated as growth in nitrite concentration per unit time.

Statistical evaluation

The results obtained were subjected to statistical evaluation. Attention was paid to both correlations and regression models and Principal Component Analysis

(PCA analysis). The statistical evaluations were performed using programme QC Expert 3.0 (TriloByte, s.r.o., 1999) and Canoco (Ter Braak 1993).

RESULTS AND DISCUSSION

The research was carried out with typical soil types of the Czech Republic. The percentage of representation of the different soil types is summarized in Table 1. Descriptive statistics (mean, median, standard deviation, etc.) of the measured physical, chemical and microbial parameters are shown in Table 2. A wide range of physical and chemical parameters were obtained representing arable and grassland soils in the Czech Republic.

Organic matter concentration as well as both the aerobic and anaerobic N mineralization were significantly higher in grassland soils than in the arable ones. Differences in other parameters were not found. The values of the microbial parameters (anaerobic N mineralization, aerobic N mineralization and nitrification) correspond to ranges that can be found in the literature (Gregorich et al. 1994, Kandeler et al. 1999). Correlation coefficients describing relationships between physico-chemical and microbial parameters are shown in Table 3. From the results it can be seen that important correlation ($r = 0.5-0.7$) were found between anaerobic N mineralization and total nitrogen; nitrification and pH, contents of particles of size < 0.01 mm; high ($r = 0.7-0.9$) between anaerobic N mineralization and organic carbon; nitrification and CEC. The C/N ratio characterizing soil organic matter quality kept within a narrow range of values. It had no significant influence on the microbial parameters. A weak correlation was found in the case of nitrification.

Stepwise multiple linear regression generated equations that predicated N mineralization and nitrification from soil characteristics (Table 4). N mineralization measured under both aerobic and anaerobic conditions was certainly influenced by that organic matter concentration (N_{tot} , C_{org}) presenting substrate for microbial mineralization. A negative influence of CEC on aerobic N mineralization was discovered, which might be explained by the organic matter adsorption on soil particles leading to the

Table 2. Basic statistical data of evaluated soil characteristics

	No. of samples	Mean	S.D.	Median	Min	Max	Lower quartile	Upper quartile
pH	115	6.35	0.74	6.50	4.65	7.65	5.90	6.90
Particles < 0.01mm (%)	116	31.2	9.21	30.5	14.10	55.7	24.3	37.2
CEC (meuq.kg ⁻¹)	116	162	65.8	142	53.5	379	112	196
C_{org} (mg.g ⁻¹)	108	18.1	6.55	16.6	9.7	42.5	13.5	20.0
N_{tot} (mg.g ⁻¹)	105	1.65	0.59	1.51	0.81	3.72	1.27	1.82
C/N	105	11.2	2.50	10.5	7.69	26.3	9.71	12.3
Anaerobic N mineralization ($\mu\text{g NH}_4^+\text{-N.g}^{-1}.\text{d}^{-1}$)	95	5.99	3.07	4.89	1.69	16.48	3.89	7.25
Aerobic N mineralization ($\mu\text{g NO}_3^-\text{-N.g}^{-1}.\text{d}^{-1}$)	103	1.55	1.21	1.28	-0.92	8.85	0.85	1.83
Nitrification ($\mu\text{g NO}_2^-\text{-N.g}^{-1}.\text{h}^{-1}$)	75	267	249	182	-3	1199	92	302

Table 3. Correlation between physico-chemical and microbial soil parameters

	pH	Particles < 0.01 mm	CEC	C _{org}	N _{tot}	C/N
Anaerobic N mineralization	-0.040	0.204*	0.323**	0.769**	0.593**	0.057
Aerobic N mineralization	-0.291**	-0.144	-0.193**	0.258**	0.297**	0.105
Nitrification	0.554**	0.583**	0.762**	0.174	0.334**	0.350**

Means significant at * $p < 0.05$, ** $p < 0.01$

Table 4. Stepwise multiple regression of anaerobic and aerobic N mineralization and nitrification on other soil properties

Microbial parameter	Regression equation	R ²	N
Anaerobic N mineralization	= 0.32 C _{org}	0.386	81
Aerobic N mineralization	= 1.26 - 6.47.10 ⁻³ CEC + 0.70 N _{tot}	0.346	84
Nitrification	= -573 + 2.03 CEC + 78.4 pH	0.646	67

All R² values are significant at $p < 0.05$

protection of organic matter against the microbial decomposition.

Our investigations showed that anaerobic N mineralization correlated with aerobic N mineralization ($r = 0.37$) which was in agreement with data presented in the literature even though this relationship is much weaker than those published by Fyles et al. (1990) ($r = 0.96$).

Nitrification was measured as short term nitrification activity reflecting an immediate potential activity of nitrifiers. Regressions show that nitrification was positively influenced by CEC and pH. Published data show that nitrification rate is lower in acid soils and increases with increasing pH (Paul and Clark 1996). CEC has positively influenced nitrification because soils with higher CEC have a better ability to adsorb ammonium ions. This fact

leads to the local increase of ammonium ions concentration and the future colonization of such places by nitrifiers. This shortens the diffusive distance between microorganisms and the substrate (Apple et al. 1995). Stepwise analyses did not confirm the positive influence of soil particle size smaller than 0.01 mm.

Figure 1 shows the data evaluated by using PCA analysis. The results obtained correspond to the correlation analysis conclusions. A significant difference was discovered in the average sample position from both the arable soil and the perennial grasslands as shown in Figure 1. Soil samples coming from the arable soil to the grasslands and vice versa are mainly in the Cambisol soil type, which is often used for perennial grasslands as well as for arable soils in the Czech Republic, and the use of

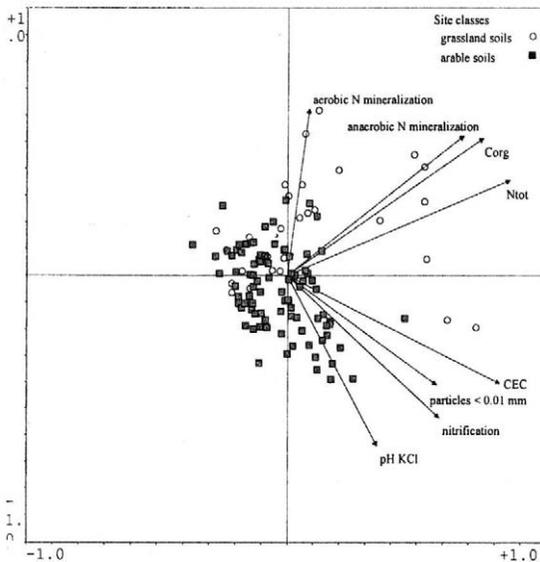


Figure 1. Results of PCA analysis based on the evaluation of physico-chemical and microbial soil parameters of different plot management

particular plots has been changing. The results from PCA analysis show the correlation between nitrification with content of particles smaller than 0.01 mm, CEC and pH. Correlation was also observed between anaerobic and partly aerobic N mineralization with C_{org} and N_{tot} .

Principal component analysis of the physico-chemical parameters of the soils was done with two management regimes (grassland and arable soils). The first axis and the second axis explain 41.3 and 26.5% of total variability in the data, respectively. Percentages are taken with respect to residual variances, i.e. variances after fitting three covariables (year of the study 1994–1996).

There are two groups of grassland soils, the first one differs from arable land in a higher content C_{org} , N_{tot} and level of anaerobic N mineralization. The second one (in the group of arable soils – mainly in the Cambisol soil type) has lower values of CEC, pH, and nitrification in relation to the group of arable soils. Both groups of grassland soils have rather higher values of aerobic N mineralization than arable soils.

Our research was also focused on the interaction between N mineralization and nitrification and absorbances of the 0.01 M $NaHCO_3$ extract at 205, 220, 230 and 260 nm. This relationship, as observed by Giroux and Sen Tran (1987), has not been proved by our investigations. We did not confirm that this method can compensate incubation methods for the evaluation of nitrogen mineralization soil.

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ABSTRAKT

Interakce mezi anaerobní a aerobní N mineralizací, nitrifikací a vybranými půdními charakteristikami

N mineralizace a nitrifikace jsou důležitými ukazateli kvality půdy. Cílem práce bylo zjistit a popsat závislost mikrobiálních parametrů charakterizujících nitrifikaci a mineralizaci dusíku na fyzikálních a chemických vlastnostech půd. Pro výzkum byly vybrány půdy ze sítě pozorovacích ploch půdního monitoringu tak, aby reprezentovaly hlavní půdní typy ČR. Obsah půdní organické hmoty (N_{tot} , C_{org}) byl nejvýznamnějším faktorem pozitivně ovlivňujícím N mineralizaci měřenou za aerobních i anaerobních podmínek. Zvýšená kationtová výměnná kapacita ovlivňovala negativně aerobní N mineralizaci. Ze sledovaných abiotických parametrů kationtová výměnná kapacita a pH měly největší vliv na rychlost nitrifikace.

Klíčová slova: půda; aerobní a anaerobní N mineralizace; nitrifikace; fyzikální a chemické charakteristiky

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The effect of growth regulator Rastim 30 DKV on the level of endogenous phytohormones in tomato (*Solanum lycopersicum* L.)

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ABSTRACT

Rastim 30 DKV is a plant growth regulator with a wide spectrum of biological effects. Its effective substance is 3-(benzoyloxycarbonyl-methyl)-2-benzothiazolinone (30% v/v). The influence of Rastim 30 DKV on ripening and quantitative yield parameters (number and weight of fruits) the levels of endogenous cytokinins, free IAA and production of ethylene of tomato (*Solanum lycopersicum* L.) were studied in field and small plot trials. The preparation was applied as spray to tomato cv. Imun and Titan prior to flowering and 10–14 days after the initial application in the dose of 15 and 30 ml in the applied volume of 500 l.ha⁻¹. The dose of active substance was thus 4.5 and 9 g.ha⁻¹, respectively. The content of endogenous cytokinins was determined in leaves, roots and fruits, while that of free IAA level and ethylene production only in the leaves. Phytohormones were determined by TLC combined with a bioassay, by GLC or HPLC with fluorimetric detection or combined with a bioassay. Following application of Rastim 30 DKV, the content of endogenous cytokinins was found to be increased in the leaves and fruits and decreased in the roots of the treated plants. The identified cytokinins were *trans*-zeatin, *trans*-zeatin riboside, *trans*-zeatin-O-glucoside, 2-isopentenyladenine and 2-isopentenyladenosine. An enhanced ethylene production, as well as a higher free IAA content were observed in leaves of the more sensitive Titan as compared to the more resistant Imun variety. The treated tomato plants had a significantly higher number of buds and total yield (123% of the control), but a lower mass of fruits (94.6% of the control). The compound accelerated and synchronized the process of crop maturation.

Keywords: auxin; cytokinins; ethylene; plant growth regulator; Rastim 30 DKV; ripening; tomato; yield

Rastim 30 DKV is a wide-spectrum growth regulator based on benzolinone, is produced by the joint-stock company Istrochem, Bratislava and registered for several crop plants (List of Authorized Preparations For Plant Protection 1999). The effective substance is that of 3-(benzoyloxycarbonyl-methyl)-2-benzothiazolinone, which exhibits effects similar to those of auxin as described by several authors (Henselová et al. 1989, Rauscherová et al. 1991, Blažková et al. 1994).

Synthetic auxinoids are known to affect profoundly plant metabolism, as may be evident from their effects on growth, development and morphology of plants (Procházka et al. 1997). The regulator Rastim 30 DKV enhanced number of buds, total fruit yield and caused also faster ripening in tomatoes and peppers (Pohanková et al. 1989). This compound also affects the yield and qualitative technological parameters in spring barley, winter rape, sugar beet and potato (Zahradníček et al. 1993, Henselová and Konečný 1995, Tománková et al. 1995, Zrůst and Henselová 1998).

An exogenous application of biologically active substances to plants in many cases affects their quantitative crop-related parameters and also alters their native hormonal status (Beckett and van Staden 1992, Chernyadev 1994, Zahradníček et al. 1995, Hradecká and Staszková 1996). The content of endogenous phytohor-

mones in plants becomes altered during the course of the vegetative season and the impact on their quantity, or the ratio of the various phytohormones leads to quantitative changes in the flux of assimilates from the site of their formation to that of their utilization (Pecho et al. 1989, Dundelová et al. 1992, Henselová and Vizárová 1999).

The present study summarizes the results of a research designed to clarify the effect of the regulator Rastim 30 DKV on the quantitative yield parameters of tomatoes in relation to changes in endogenous phytohormones that constituted a condition for obtaining registration of the agent.

MATERIAL AND METHODS

Tomato plants (*Solanum lycopersicum* L., cv. Imun and Titan) were cultivated in vessels in a substrate prepared by mixing sandy-clay soil with humus in the ratio of 3:1, with addition of supplementary NPK nutrients, viz. 1 g nitrogen (urea), 1.2 g potassium (K₂O) and 1 g phosphorus (P₂O₅) per pot containing 6 kg of substrate. Tomato plants were sprayed with the preparation Rastim 30 DKV at the beginning of flowering and again 10 to 14 days later at a dose of 30 ml per hectare in total volume of 500 l.

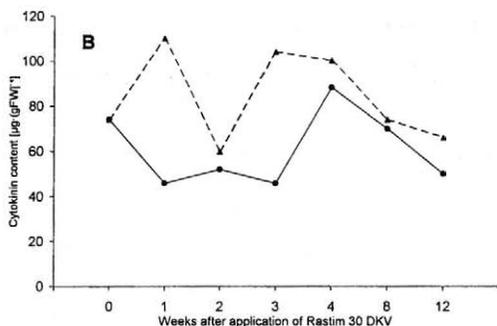
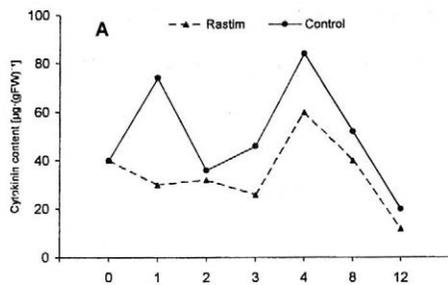


Figure 1. Cytokinin content in roots (A) and leaves (B) of tomato (*Solanum lycopersicum* cv. Imun) after application of Rastim 30 DKV in 1991; all analyses were performed twice and the results are the means; standard error did not exceed 13.5%

Tomatoes were planted under field conditions in spacing of 45×50 cm in soil fertilized with Ceretite in doses of $0.2 \text{ t}\cdot\text{ha}^{-1}$. The regulator was also applied in the same dose during the mentioned phenophase of the plant with the aid of a knapsack sprayer (medium propane-butane) operating at a pressure of 0.3 MPa and applying a volume of 500 l per hectare. The size of the trial plots was 10 m^2 in five repetitions. The average number and weight of fruits, the rate of ripening, and the total yield per plant were evaluated.

Tomato plants of Imun variety were sampled for analyses of endogenous cytokinins once a week. Averaged samples (separately roots, shoots and fruits, 5–10 g FW) were extracted in 76% (v/v) methanol and following extraction (with n-butanol from alkaline solution) and purification (on Dowex X-50 column in H^+ cycle) cytokinin biological activity was assayed by the radish bioassay according to Letham (1968) and individual cytokinins were identified by the GLC and HPLC methods after extract purification by butanol partitioning in alkaline solution and ion-exchange chromatography (Vizárová and Vozár 1984, Vedenicheva et al. 1991). For analyses of auxin levels and ethylene production, tomato plants of the Imun and Titan varieties were treated with application doses of 15 and 30 ml of Rastim 30 DKV per hectare at the

same phenophase as in previous experiments. The level of free IAA was determined after extraction with 80% methanol and purification of the extract by means of diethyl ether partitioning and PVPP (polyvinyl polypyrrolidone) columns using HPLC with fluorimetric detection (Eder et al. 1988). For analyses of IAA as the standard was used $1\text{-}^{14}\text{C}$ -IAA (Amersham Co.) and the recovery was 30–40%. Ethylene was measured by gas chromatography on a Porapak Q column (Macháčková et al. 1986).

RESULTS AND DISCUSSION

Applications of Rastim 30 DKV in tomato plants brought about changes in levels of cytokinins, auxin and ethylene. Changes in their quantity were organ-dependent. The results of analyses of endogenous cytokinins (total amount = sum of *trans*-zeatin [Z], *trans*-zeatin ribozid [ZR], *trans*-zeatin-O-glukozid [ZOG], 2-isopentyladenine [2iPA] and 2-isopentyladenozine [2iPAdo]) provided evidence that Rastim 30 DKV, as an auxinoid, increased cytokinin level in leaves and decreased it in roots, which suggests acceleration of their transport from the roots to the shoots (Figures 1 and 2). According to Davey and van Staden (1976), quantitative changes are

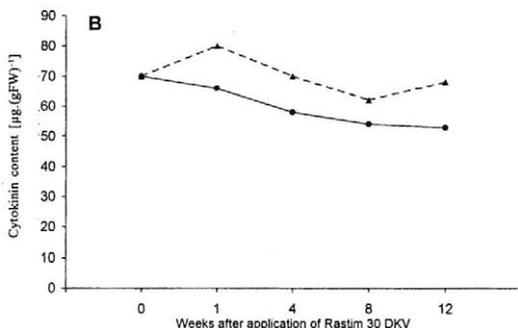
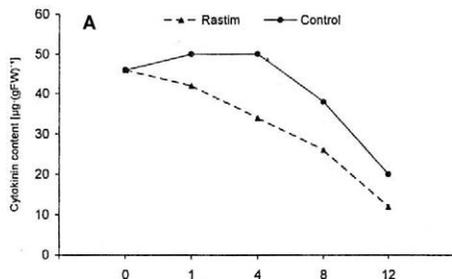


Figure 2. Cytokinin content in roots (A) and leaves (B) of tomato (*Solanum lycopersicum* cv. Imun) after application of Rastim 30 DKV in 1992; all analyses were performed twice and the results are the means; standard error did not exceed 14.1%

connected with the plant organogenesis; these authors found that the formation of flower buds was related to changes in the level of particular cytokinins in the xylem sap, as well as to changes in their overall activity. Before anthesis and at the time of fruit formation, the cytokinin level in the shoot increases, a fact also confirmed by our results in the 1991 experiment (Beever and Woolhouse 1973). The transient decline of cytokinins 2 weeks following the application (Figure 1) was probably due to a partial infection with downy mildew and the subsequent chemical treatment with Kuprikol 50 and Ripost. A higher cytokinin content was also detected in tomato fruits, in comparison with that in untreated plants (Figure 3). After chromatographic separation Z and ZR were found in both roots and shoots, with the latter being dominant. The same cytokinins were determined in green tomato fruits, but in ripe fruits we also found ZOG, 2iPA and 2iPA_{do}. Also in other plants, differences in CK accumulation in different organs were detected: Henselová and Vizárová (1999) detected the presence of three cytokinins in sugar-beet, with ZOG predominating in roots, while mainly ZR and Z were present in leaves. A wider spectrum of cytokinins was found in rice and bean seeds by Vedenicheva et al. (1991). Beever and Woolhouse (1973) described a high content of cytokinins in fruits as compared with other organs, in the short day plant *Perilla frutescens*. High cytokinin level was also determined in grains of barley (Procházka et al. 1982).

According to our findings, treatment of tomato plants of the Imun variety as well as of other cultivars with Rastim 30 DKV caused an increase in cytokinin content in leaves and fruits and at the same time higher plant resistance. Similar findings were recently described in potato plants (Zrůst and Henselová 1998). Treated plants then necessitated in a lower number of chemical treatments for fungous diseases. This corresponds to the finding of an anti-senescence action of benzolinone (Klíčová et al. 1994), and also to the results reported by Vizárová and

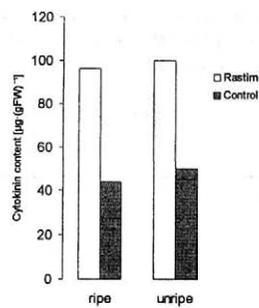


Figure 3. Cytokinin content in fruits of tomato (*Solanum lycopersicum* cv. Imun) eight weeks after application of Rastim 30 DKV; all analyses were performed twice and the results are the means; standard error did not exceed 12.6%

Vozár (1984), who found a high Z content in varieties of barley and wheat resistant to powdery mildew, as compared with more sensitive and susceptible cereal varieties.

Application of Rastim 30 DKV provokes an increased production of ethylene in leaves of both varieties Imun and Titan (Table 1). Stimulation of ethylene production in treated tomato plants probably accounts for the accelerated rate of maturation of crops achieved in our experiments with both potted plants and those cultivated on trial plots (Tables 4 and 5). According to Imaseki et al. (1982) the degree of stimulation of ethylene production rises with an increase in auxin concentration and is simultaneously associated with RNA and protein synthesis. Dundelová et al. (1992) found two ethylene production peaks in wheat leaves. One of them was in the phenophase of anthesis (Feekes's 11.5 stage), similarly as we found in our experiments following application of Rastim 30 DKV to tomato plants. Hence, Rastim 30 DKV acts similarly as etephone-related preparations

Table 1. Influence of Rastim 30 DKV on ethylene production in leaves of tomato (*Solanum lycopersicum* L.) cv. Imun and Titan; analyses were performed three times, the results given are the means; the standard error did not exceed 13.6%

Trial variant	Dose (ml.ha ⁻¹)	Production of ethylene (nl.h ⁻¹ .g ⁻¹ dry weight)			
		Imun		Titan	
		1 st treatment	2 nd treatment	1 st treatment	2 nd treatment
Control	0	106.5	351.8	106.2	106.9
Rastim A	15	209.2	286.7	126.3	299.8
Rastim	30	135.0	356.1	107.6	131.3
Control	0	218.3	263.1	199.6	220.2
Rastim B	15	222.5	247.3	226.7	204.3
Rastim	30	326.1	189.2	183.5	302.7
Control	0	255.8	–	139.2	–
Rastim C	15	160.3	–	219.3	–
Rastim	30	147.1	–	129.0	–

A = 5 hours after treatment, B = 24 hours after treatment, C = 48 hours after treatment
1st treatment: 5. 8. 1992, 2nd treatment: 18. 8. 1992

Table 2. Influence of Rastim 30 DKV on the content of free IAA in treated leaves of tomato (*Solanum lycopersicum* L.) cv. Imun and Titan; analyses were performed two times, the results given are the means; standard error did not exceed 11.8%

Trial variant	Dose (ml.ha ⁻¹)	Content of free IAA in the leaves (ng.g ⁻¹ fresh weight)			
		Imun		Titan	
		1 st treatment	2 nd treatment	1 st treatment	2 nd treatment
Before treatment	0	12.2	18.7	41.6	50.8
Control	0	17.0	19.5	43.8	48.2
Rastim A	15	23.1	19.9	253.4	65.7
Rastim	30	24.0	20.2	58.4	117.4
Control	0	nondetect	14.6	40.9	42.7
Rastim B	15	13.6	13.6	119.5	40.3
Rastim	30	19.4	19.3	46.3	117.4

A = 5 hours after treatment, B = 24 hours after treatment
1st treatment: 5. 8. 1992, 2nd treatment: 18. 8. 1992

that are utilized in vegetables, including tomatoes, to accelerate and synchronize crop maturation (Prusová 1983).

The levels of endogenous IAA in leaves are also increased by application of Rastim 30 DKV. The content of endogenous IAA was higher after the first spraying with a higher dose of 30 ml per hectare and after repeated appli-

cations at a concentration of 15 ml per hectare (Table 2). The most striking effect of the preparation on the content of IAA was noted after 5 hours; however, it is still persisting after 24 hours. The increased endogenous IAA level found in the variety Titan was not detected in the variety Imun. These differences might explain the different degree of sensitivity of the two varieties to ben-

Table 3. Influence of Rastim 30 DKV on the yield of tomato (*Solanum lycopersicum* L.) cv. Imun determined in the pot trials in the dose 30 ml.ha⁻¹

Year	Trial variant	Average fruits number per plant		Average weight of fruit		Total yield per plant	
		n	% control	g	% control	g	% control
		1991	control	25.6	100.0	42.2	100.0
	Rastim	29.3	114.4*	38.4	90.1	1125.1	104.0
1992	control	15.7	100.0	50.2	100.0	788.1	100.0
	Rastim	19.3	122.9**	49.5	98.2	955.3	121.2**
1993	control	20.2	100.0	48.6	100.0	981.7	100.0
	Rastim	26.9	133.2**	46.5	95.7	1250.8	127.4**

* significant difference $P \leq 0.05$; ** significant difference $P \leq 0.01$; using Student's *t*-test
Terms of application: 3. 6. and 15. 6. 1991; 2. 6. and 14. 6. 1992; 4. 6. and 15. 6. 1993
n = number of fruits

Table 4. Influence of Rastim 30 DKV on the yield of tomato (*Solanum lycopersicum* L.) cv. Imun determined in the locality Bratislava-Rovinka in 1992

Trial variant	Dose (ml.ha ⁻¹)	Average number of fruits, weight and yield per plant												Total yield per plant					
		17. 8. 1992						9. 9. 1992									1. 10. 1992		
		Nf	Wf (g)	Awf (g)	Nf	Wf (g)	Awf (g)	Nf	Wf (g)	Awf (g)	Nf	Wf (g)	Awf (g)	Nf	Wf (g)	Awf (g)	Nf	Wf (g)	Awf (g)
Control 0	3.0	230.0	76.7	2.6	116.0	44.6	2.6	119.0	45.8	33.3	167.0	50.1	41.5	2135	51.4				
% C	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0				
Rastim 30	4.0	286.0	71.5	5.3	262.2	49.5	3.7	163.3	44.1	56.3	1526.7	27.1	69.3	2238.2	32.3				
% C	133.3**	124.3**	93.2	203.8**	226.0**	110.9	142.3**	137.2**	96.3	169.1**	91.4	54.1**	167.0**	104.8	62.8**				

* significant difference $P \leq 0.05$; ** significant difference $P \leq 0.01$; using Student's *t*-test
Terms of application: 8. 7. and 22. 7. 1992
Nf = number of fruits, Wf = weight of fruits, Awf = average weight of one fruit, % C = percentage of control

zolinone. As a synthetic auxinoid, benzolinone, probably reinforces the effect of endogenous IAA, resulting in the undesirable morphogenic effect on the leaves of treated plants in the more sensitive variety Titan, as well as the occurrence of parthenocarpic fruits (Rozkošová, private communication). It is known that NAA- and phenoxyacids-based auxins induce an artificial parthenocarp and production of seedless fruits (Wittwer and Tolbert 1960). According to Abado and Monteire (1989), production of parthenocarpic fruits is the result of plant reaction to environmental stimuli, particularly temperature and cultivar's sensitivity to low temperatures. The Titan variety in which the application of Rastim 30 DKV had provoked the formation of such fruits is one of the more sensitive cultivars and was therefore excluded from the spectrum of varieties registered for the application of this preparation.

As regards quantitative indicators – the entire set of plants was significantly affected by the action of the preparation Rastim 30 DKV which, in combination with accelerated maturation by 7 to 10 days on average, became positively manifested principally in the first crop pickings (Tables 4 and 5). In the pot experiments (Table 3), the total crop of tomatoes was significantly higher than that in controls (by up to 21.2–27.4%). Under conditions of the small-plot trials, the crop was moderately, but insignificantly higher by 4.8–5.5% than in the control (Tables 4 and 5). On the other hand, a higher mean fruit production was accompanied with their lower mean weight. An increased fruit yield was the result of an enhanced flower formation, which may have been stimulated by an increased content of endogenous cytokinins in the treated tomato plants. This would corroborate the findings by Hradecká and Stazsková (1996) who succeeded in obtaining higher yields and a higher number of grains per ear of wheat through an exogenous application of cytokinins. Pohanková et al. (1989) reported increased yields in several varieties of consumer and commercial tomatoes and peppers after application of Rastim 30 DKV. A positive influence of Rastim 30 DKV on the yield and qualitative parameters of sugar beet and potatoes was reported by Zahradníček et al. (1993), Tománková et al. (1995) and Zrůst and Henselová (1998), respectively. In the production process of plants, a key role in attracting metabolites is played by auxin, i.e. indolylacetic acid (IAA) together with cytokinins (Procházka et al. 1997). Hence, it appears probable that Rastim 30 DKV as an exogenously applied auxinoid may still reinforce this attracting ability of native IAA and thereby also significantly influences the transport of assimilates from sites of their production to those of their utilization, i.e. in favour of the formation of an economically significant organ.

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Table 5. Influence of Rastim 30 DKV on the yield of tomato (*Solanum lycopersicum* L.) cv. Imun determined in the locality Bratislava-Rovinka in 1993

Trial variant	Dose (ml.ha ⁻¹)	Average number of fruits, weight and yield per plant																				
		20. 8. 1993				30. 8. 1993				27. 9. 1993				26. 10. 1993								
		Nf	Wf (g)	Awf (g)	%C	Nf	Wf (g)	Awf (g)	%C	Nf	Wf (g)	Awf (g)	%C	Nf	Wf (g)	Awf (g)	%C					
Control	0	6.0	300.0	50.0	24.0	129.0	53.7	9.4	544.0	57.8	16.2	967.3	59.7	7.0	201.6	28.8	9.6	166.0	17.3	72.2	2307.9	31.9
	30	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Rastim	0	7.0	450.0	64.3	27.0	147.0	54.4	7.8	510.1	65.4	12.4	477.0	38.5	8.4	483.8	57.6	24.2	368.0	15.2	86.8	2435.9	28.1
	30	116.7*	150.0**	128.6*	112.5*	113.9*	101.3	83.0*	93.7	113.1*	76.5**	49.3**	64.5**	120.0*	239.9**	200.0**	252.1**	221.7**	87.9*	120.2**	105.5	88.1*

* significant difference $P \leq 0.05$; ** significant difference $P \leq 0.01$, using Student's *t*-test
 Terms of application: 21. 6. and 6. 7. 1993
 Nf = number of fruits, Wf = weight of fruits, Awf = average weight of one fruit, % C = percentage of control

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ABSTRAKT

Vliv růstového regulátoru Rastim 30 DKV na obsah endogenních fytohormonů u rajčete (*Solanum lycopersicum* L.)

Ve vegetačních a maloplošných pokusech byl sledován vliv přípravku Rastim 30 DKV [3-(benzyloxykarbonyl-metyl)-2-benzotiazolinon] na endogenní cytokininy, hladinu volné IAA a tvorbu etylenu, na kvantitativní parametry prvků výnosu (nasazení plodů, hmotnost plodů a celkový výnos) a na rychlost dozrávání plodů u rajčete *Solanum lycopersicum* cv. Imun a Titan. Přípravek byl aplikován dvakrát, poprvé na začátku kvetení, druhá aplikace následovala o 10 až 14 dní později. Dávka 15 a 30 ml.ha⁻¹ v aplikačním objemu 500 l byla aplikována úměrně ploše kultivační nádoby nebo pokusné plochy. Vzorky pro analýzu fytohormonů (kořeny, nadzemní části rostlin a plody) byly fixovány 76% metanolem. Cytokininy byly identifikovány metodami plynové (GLC) a vysokoúčinné kapalinové (HPLC) chromatografie, jejich biologická aktivita byla stanovena biotestem. Zjistili jsme, že přípravek Rastim 30 DVK ovlivňuje hladinu endogenních cytokininů. Po aplikaci měly ošetřené rostliny v nadzemní části rostlin a v plodech až do konce sledování zvýšenou hladinu cytokininů, v kořenech byl obsah nižší. V nadzemních částech rostlin i v kořenech byl identifikován *trans*-zeatin (Z) a *trans*-zeatin ribozid (ZR). V plodech byly mimo uvedené cytokininy nalezeny i *trans*-zeatin-O-glukosid (ZOG), 2-izopentenyladenin (2iPA) a 2-izopentenyladenozin (2-iPA_{do}). Aplikace přípravku způsobila u obou sledovaných odrůd rajčete také zvýšenou tvorbu etylenu, což bylo patrně příčinou dřívějšího dozrávání plodů u odrůdy Imun o 7 až 10 dní. U ošetřených rostlin byla zjištěna také zvýšená hladina volné IAA. Zvýšení se projevilo výrazněji u citlivější odrůdy Titan než u odrůdy Imun, která se ukázala jako rezistentnější. Po aplikaci přípravku Rastim 30 DKV bylo oproti kontrolní variantě průkazně zvýšeno nasazení plodů, a to od 14,4 do 33,2 %, počet sklizených plodů byl zvýšen o 4 až 27,4 %, avšak průměrná hmotnost plodů byla nižší. V polních podmínkách bylo větší nasazení plodů o 6,7 až 20,2 %, celková sklizeň byla oproti kontrole mírně, avšak neprůkazně zvýšena o 4,8 až 5,5 %. Urychlené dozrávání plodů vlivem přípravku se projevilo pozitivně v nádobových i polních pokusech především v prvních sběrech sklizně, která byla oproti kontrole významně zvýšena o 12,5 až 103,8 %.

Klíčová slova: auxin; cytokininy; etylen; regulátor růstu rostlin; Rastim 30 DKV; dozrávání; rajče; sklizeň

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Effect of magnesium foliar application on the yield and quality of sugar beet roots

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ABSTRACT

The aim of the study conducted in 1996–1998 was to assess the effect of foliar application of magnesium (Epsom salt – $\text{MgSO}_4 \cdot 7 \text{H}_2\text{O}$, 1% w/v solution) on the yield and quality of sugar beet roots. In the three consecutive growing seasons (1996–1998), eleven field trials were set up on very fertile sandy loam soils in the Wielkopolska region (Central-Western part of Poland). The experimental design comprised of control (without application of magnesium), and three treatments: (I) 0.5 kg $\text{Mg} \cdot \text{ha}^{-1}$ applied at the 8th leaf stage, (II) 0.5 kg $\text{Mg} \cdot \text{ha}^{-1}$ applied before canopy closing, and (III) 0.5 + 0.5 kg $\text{Mg} \cdot \text{ha}^{-1}$ applied at both dates. The 8th leaf stage appears to be the most critical stage of sugar beet growth with respect to magnesium foliar application. On average, the application of 0.5 kg $\text{Mg} \cdot \text{ha}^{-1}$ increased the yield of roots by 9.9%, i.e. from 67.37 t $\cdot \text{ha}^{-1}$ in the control (without magnesium foliar application) to 74.06 t $\cdot \text{ha}^{-1}$. The yield of white sugar increased by 9.5%, i.e. from 9.18 t $\cdot \text{ha}^{-1}$ in the control to 10.06 t $\cdot \text{ha}^{-1}$. Further significant root and sugar yield increase was due to the double magnesium application, the yield increase was 12.6 and 11.1%, respectively. Technological parameters of sugar beet roots were not significantly affected by the treatments, but a tendency to increase the content of molasses forming substances (K, Na, alpha-amino nitrogen) was found. It could be concluded that the increase in sugar yield resulted from the increased yield of fresh root.

Keywords: sugar beet; magnesium foliar application; root yield; molasses forming substances; white sugar yield

The potential yield of sugar beet is very high, but is strongly dependent on weather, soil quality and fertilization practices (Draycott 1996, Werker and Jaggard 1998). It is well known that yields of sugar beet respond to increasing nitrogen application rates up to the optimal level. This does not solely depend on the amount of N applied but also on the nutritional status of the crop. Consequently, the quality of harvested roots is not always satisfactory for farmers and sugar processors (Hericly 1992, Draycott 1996, Van Tassel et al. 1996). Obviously, both groups have a direct interest in harvesting roots of the highest technological quality.

The sugar beet crop has very high nutrient requirements, including magnesium. Recent experimentation in Poland focused on the magnesium requirements of cultures yielding at the level 50 t $\cdot \text{ha}^{-1}$ of roots showed the need of about 45 kg $\cdot \text{ha}^{-1}$ Mg (Grzebisz et al. 1998). As it was stated by Grzebisz et al. (1998), in Polish conditions, satisfactory sugar beet crop growth over the growing season was strongly influenced by nitrogen and magnesium interactions.

The aim of this study was to determine the optimal stage of sugar beet growth with respect to magnesium sulphate application and to assess the production effect of foliar application of magnesium.

MATERIAL AND METHODS

In 1996–1998, eleven series of field experiments were conducted on commercial farms in the Wielkopolska region (Central-Western part of Poland). Experiments were

set up on very fertile sandy loam soils, with high contents of plant available potassium and phosphorus. The content of available magnesium ranged from below 2 mg to 9 mg $\cdot 100^{-1}$ g of soil (extracted in 0.0125 M CaCl_2). Soil reaction (in 1 M KCl) ranged from 6.4 to 7.6 pH (data available from the authors).

The experimental design comprised of control (without magnesium) and three treatments, (I) 0.5 kg $\text{Mg} \cdot \text{ha}^{-1}$ applied at the 8th leaf stage (applied in the form of Epsom salt – $\text{MgSO}_4 \cdot 7 \text{H}_2\text{O}$), (II) 0.5 kg $\text{Mg} \cdot \text{ha}^{-1}$ applied before canopy closing, (III) 0.5 + 0.5 $\text{Mg} \cdot \text{ha}^{-1}$ applied at both stages. Magnesium sulphate was applied as 1% w/v solution. Agricultural practices for soil preparation were those usually applied by farmers. Winter wheat as a forecrop, post-harvest manuring at the rate of 30 t $\cdot \text{ha}^{-1}$ and subsequent ploughing. Potassium and phosphorus application before fall ploughing at 150 kg $\cdot \text{ha}^{-1}$ of K_2O and 80 kg $\cdot \text{ha}^{-1}$ of P_2O_5 , nitrogen was applied in the form of ammonium nitrate at the rate of 120 kg $\cdot \text{ha}^{-1}$. The first rate of 80 kg $\cdot \text{ha}^{-1}$ was applied just before sowing and the second at the 6th leaf stage. The seedbeds were prepared just before sowing (the second decade of April). Experimental plots 100 m² and 18 m² in size were harvested by hand. To obtain qualitative data, i.e. sucrose content and molasses forming elements such as potassium (K), sodium (Na) and amino-nitrogen (amino-N), the Venema Autoanalyser Typ IIG was used. This instrument works on the basis of saccharimeter for polarisation measurement, the flame photometer for determining the contents of K and Na, and the fluorometry method using o-phthalaldehyde reagent for amino-N determination (ICUMSA 1994, Burba and Georgi 1976). The yields of

biological and white sugar were calculated using the following formulas:

$$Y_b = (Y_r \% S_b) / 100\% \quad (1)$$

$$Y_w = (Y_r \% S_t) / 100\% \quad (2)$$

$$\% S_t = \% S_b - [0.12(K + Na) + (0.24N) + 1.08] \quad (3)$$

where: %S_b – content of biological sugar
 %S_t – content of technological sugar
 Y_r – yield of roots (t.ha⁻¹)
 Y_b – yield of biological sugar (t.ha⁻¹)
 Y_w – yield of white sugar (t.ha⁻¹)
 K, Na, N – contents of potassium, sodium and alpha-amino nitrogen mM.(100 g fresh beet)⁻¹

Statistical analyses were carried out using classical analysis of variance and regression analysis.

RESULTS AND DISCUSSION

Root yield

Meteorological conditions during the study and soils with a good level of plant available nutrients, supplemented with farmyard manure, resulted in very high yields. The three-year average for the control plot (the treatment without magnesium application) was to 67.37 t.ha⁻¹, range from 52.5 to 79.8 t.ha⁻¹. The effects of magnesium foliar application on yields of roots were significant notwithstanding high soil fertility. The increment of root yield depended on localities, weather conditions during growing seasons and the experimental factor (Figure 1). Foliar application of magnesium significantly affected yield in 9 out of 11 experiments. Irrespective of the year of study, in six localities the highest increase in root yield was related to the treatment with double magnesium application and in three localities to plot fertilized at the 8th leaf stage. In comparison with the control, the average yield increase due to Epsom salt application on the first date was 6.69 t.ha⁻¹ (9.9%) (Figure 2). Magnesium application on the second date, i.e. just before canopy closing, was less efficient. The increase in yield was not significant and amounted to 3.33 t.ha⁻¹ only (4.9%). The double mag-

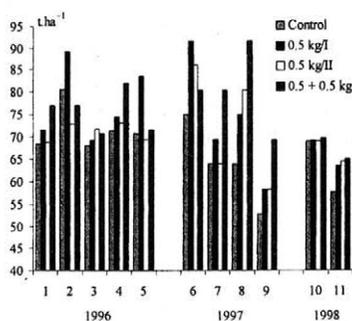


Figure 1. Effect of magnesium foliar application (kg) on the yield (t.ha⁻¹) of sugar beet roots according to localities and year of investigation ($LSD = 5.5$, $P < 0.05$)

nesium application resulted in the highest yield, which was higher by 8.5 t.ha⁻¹ (12.6%) than control. Hence, it should not be surprising that the agronomic efficiency of magnesium foliar application decreased in the following order: the 8th leaf stage (13.38 t.ha⁻¹ roots per 1 kg of Mg.ha⁻¹) > double application (8.5 t.ha⁻¹) > canopy closing (3.33 t.ha⁻¹). Results of foliar magnesium application on root yield of sugar beet can be explained only by the fact that the 8th leaf stage is the critical phase of magnesium need. According to Draycott (1996), daily magnesium uptake by sugar beet amounts to 0.65 kg.ha⁻¹ at this stage. Hence, the magnesium rate of 0.5 kg.ha⁻¹ seems to be extremely low to cover crop requirements. It is well known however that if amounts of water and nutrients are sufficient, crops grow faster, forming larger canopies that intercept more light, assimilate more CO₂ and, in turn, increase the size of the canopy (Draycott 1996). Winner (1974) stated that promotion of the early growth of beet seedlings significantly affected final yield. It was also found by Grzebisz et al. (1998) that the final yield of sugar was strongly related to the size of sugar beet canopy at the 6th leaf stage, which, in turn, was significantly affected by nitrogen and magnesium interaction.

An economic assessment of the selected Mg management options indicated a positive net return in general. This was calculated from average prices of sugar beet roots in the years 1996–1998 in the Wielkopolska Region amounting to 90 PLN.t⁻¹ of roots. Costs of Mg fertilizer (10 PLN.kg⁻¹ of Mg in the form of Epsom salt) and application (20 PLN.ha⁻¹) were subtracted from the gross return. This simple calculation showed that magnesium application on the first date can give a net return of about 577 PLN.ha⁻¹, on the second date – 275 PLN and double application – 715 PLN. Therefore, there is no doubt that foliar magnesium application may increase profitability of sugar beet production.

Root quality

Technological quality of sugar beet is assessed by means of sugar concentration and the content of molasses forming substances, such as alpha-amino nitrogen,

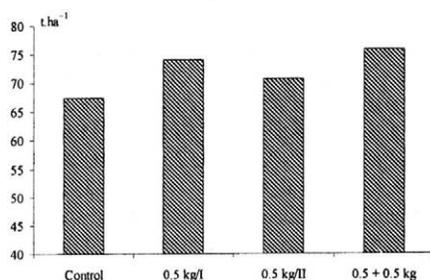


Figure 2. Effect of magnesium foliar application (kg) on the average yield (t.ha⁻¹) of sugar beet roots ($LSD = 4.6$, $P < 0.05$)

Table 1. Effect of magnesium foliar application on the quality parameters of sugar beet roots

Quality parameters	Treatments	Statistical variables					
		mean	median	mode	standard error	minimum	maximum
Sugar (%)	control	15.92	16.50	16.72	0.41	13.26	17.19
	0.5 kg/I	15.86	16.57	16.89	0.40	13.47	17.12
	0.5 kg/II	16.02	16.42	16.22	0.42	13.52	17.64
	0.5 + 0.5 kg	15.90	16.55	15.90	0.34	14.32	16.99
Amino-N (mM.100 g ⁻¹)	control	2.56	2.34	2.32	0.40	0.83	4.59
	0.5 kg/I	2.46	2.32	1.90	0.33	0.82	3.98
	0.5 kg/II	2.66	2.69	2.48	0.31	1.22	4.65
	0.5 + 0.5 kg	2.88	2.86	2.62	0.21	1.60	4.01
K (mM.100 g ⁻¹)	control	4.94	4.86	4.24	0.34	3.70	6.91
	0.5 kg/I	4.80	4.98	4.64	0.22	3.57	5.82
	0.5 kg/II	5.13	5.30	5.15	0.30	3.53	6.25
	0.5 + 0.5 kg	5.29	5.48	5.48	0.29	3.84	7.17
Na (mM.100 g ⁻¹)	control	0.59	0.43	0.20	0.14	0.20	1.58
	0.5 kg/I	0.59	0.42	0.38	0.12	0.19	1.38
	0.5 kg/II	0.56	0.54	0.50	0.07	0.30	1.08
	0.5 + 0.5 kg	0.62	0.61	0.40	0.07	0.32	1.05
White sugar (%)	control	13.84	14.04	13.79	0.44	10.19	15.17
	0.5 kg/I	13.51	14.28	14.27	0.50	10.65	15.17
	0.5 kg/II	13.63	13.93	13.74	0.51	10.69	15.70
	0.5 + 0.5 kg	13.45	14.14	14.57	0.40	11.48	14.87

potassium and sodium in fresh roots. The experimental factor did not significantly affect technological quality of harvested roots (Table 1). The same was stated by Kristek et al. (2000) in Croatia. However, some interesting trends were observed in our experiments. With respect to sugar concentration, the most positive effect of foliar magnesium application was not related to an increase in the maximum of its values but to an increase in the lowest values. Mean contents of alpha-amino nitrogen and potassium showed a tendency to increase if magnesium was applied at later stages of beet plant growth or if applied at the double rate. Hence, the technological sugar content, which reflects both biological and technological quality of roots, showed a slight tendency to decrease due to magnesium application. However, as shown by the moda parameter, plants fertilized with 0.5 kg Mg.ha⁻¹ at the 8th leaf stage and with 1 kg Mg.ha⁻¹ (double rate) were likely to achieve the highest technological sugar content. This statement is proved by the fact that the moda values of the technological sugar content were higher by 0.48 and 0.78% in comparison with the control treatment, respectively. The positive effect of foliar magnesium application resulted also from the increase in the lowest values of technological sugar content for these two treatments.

The effect of biological sugar content and contents of molasses forming substances on the technological sugar quality was assessed by means of regression analysis. As it is presented by equations (1) and (2), the content of technological sugar was significantly affected only by polarization in the first case, and by two pa-

rameters, i.e. polarization and alpha-amino N content, in the second case.

$$\%Stc = -6.667 + 1.273\%Sb \quad \text{for } R^2 = 97\%, n = 11 \quad (4)$$

$$\%Std = -2.910 + 1.085\%Sb - 0.323N \quad \text{for } R^2 = 98\%, n = 11 \quad (5)$$

where: %Stc – content of technological sugar for control treatment
%Std – content of technological sugar for double magnesium application treatment

Yield of refined sugar

The highest yield of refined (white) sugar is a target of sugar beet production. The lowest sugar yield amounting to 9.19 t.ha⁻¹ was, on average, in the control variant (without magnesium) and the highest was harvested in the treatment with the double magnesium application. As significant sugar yield increase was also observed for the first date of Mg application (Figure 3). On average, the application of 0.5 kg Mg.ha⁻¹ at the 8th leaf stage increased yield by 0.87 t.ha⁻¹ (9.5%) and, at the stage of canopy closing only by 0.48 t.ha⁻¹ (5.18%). Double magnesium increased yield by 1.02 t.ha⁻¹ (11.06%). The comparison of yield responses to magnesium application shows that the relative sugar yield response to foliar magnesium application was slightly lower than that found for yields of roots.

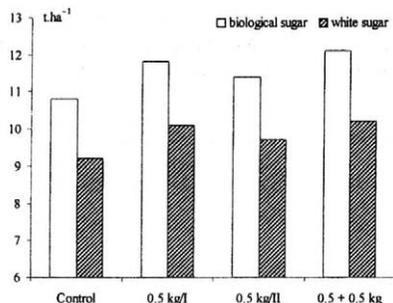


Figure 3. Effect of magnesium foliar application (kg) on the biological and white sugar yields (t.ha⁻¹) (LSD = 0.72, P < 0.05)

It is well known that the final yield of refined sugar is affected both by yield of fresh roots and technological sugar content, which in turn is affected by polarization and content of molasses forming substances. The effect of the experimental factor was evaluated by means of the multiple regression analysis. Like in the case of the technological sugar content, i.e. control and double Mg application, were taken into account. The following equations were developed:

1. Control

$$Y_w = 13.203 - 1.386N \quad \text{for } R^2 = 61\%, n = 11 \quad (6)$$

$$Y_w = 10.895 - 1.555N + 0.773K - 1.717Na \quad \text{for } R^2 = 87\%, n = 11 \quad (7)$$

2. Double Mg application

$$Y_w = -0.800 + 0.157Y_r \quad \text{for } R^2 = 90\%, n = 11 \quad (8)$$

$$Y_w = -15.988 + 0.150Y_r + 0.939\%S_b \quad \text{for } R^2 = 97\%, n = 11 \quad (9)$$

The higher values of coefficients of determination obtained for double Mg treatment suggest the more balanced of nutritional status beet plants. Equation (9) confirms the predominant effect of magnesium application on yield of fresh roots as the main predictor of final yield of sugar.

CONCLUSIONS

The specific effect of magnesium application appears to be more related to the time of fertilizer application than to its rate. Magnesium could be applied to the sugar beet foliage at any stage of plant growth, but the best time is at the 8th leaf stage. The increased yield of sugar resulted mainly from the increased yield of fresh roots. The effects of foliar magnesium application on sugar yield appeared to be profitable for farmers regardless of high soil fertility and farming practices.

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ABSTRAKT

Vliv hnojení hořčíkem na list na výnos a kvalitu bulev cukrovky

V letech 1996 až 1998 byl sledován vliv hnojení hořčíkem na list (Epsom - MgSO₄·7 H₂O, roztok 1% obj. hmotn.) na výnos a kvalitu bulev cukrovky. Ve třech po sobě jdoucích vegetačních obdobích (1996-1998) bylo na velmi úrodných písčitohlinitých půdách ve wielkopolské oblasti (středozápadní část Polska) založeno 11 polních pokusů. Schéma pokusů představovalo kontrolní variantu (bez hořčíku) a tři varianty s dávkou 0,5 kg Mg.ha⁻¹ aplikovanou ve fázi 8. listu (I), s dávkou 0,5 kg Mg.ha⁻¹ aplikovanou před vytvořením zápoje (II) a s dávkou 0,5 + 0,5 kg Mg.ha⁻¹ aplikovanou v obou termínech (III). Fáze 8. listu se ukazuje jako nejkritičtější období vývoje cukrovky s ohledem na hnojení hořčíkem na list. Aplikace dávky 0,5 kg Mg.ha⁻¹ zvýšila výnos bulev v průměru o 9,9 %, tj. z 67,37 t.ha⁻¹ u kontroly (bez hnojení hořčíkem na list) na 74,06 t.ha⁻¹. Výnos bílého cukru stoupl o 9,5 %, tj. z 9,18 t.ha⁻¹ u kontroly na 10,06 t.ha⁻¹. K dalšímu významnému zvýše-

ní výnosu bulev a cukru došlo po aplikaci dvojité dávky hořčiku, přičemž zvýšení příslušného sklizeného výnosu činilo 12,6 a 11,1 %. Technologické parametry bulev cukrovky nebyly pokusnými variantami významně ovlivněny, ale zjistili jsme tendenci zvyšování obsahu melasotvorných látek (K, Na, alfa-aminodusíku). Zvýšení výnosu cukru bylo tedy výsledkem vyššího výnosu bulev v čerstvém stavu.

Klíčová slova: cukrovka; hnojení hořčíkem na list; výnos bulev; melasotvorné látky; výnos bílého cukru

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Zahradnický slovník naučný

Pátým dílem byl ukončen *Zahradnický slovník naučný*, jehož vydávání zajistil v letech 1994–2001 Ústav zemědělských a potravinářských informací v Praze. Slovník představuje základní encyklopedické dílo, zahrnující všechny zahradnické obory – ovocnářství, zelinářství, květinářství, sadovnictví, vazačství a dekoratérství, vinařství a sklepní hospodářství, školkařství, léčivé a aromatické rostliny, pěstování hub i hlavní druhy tropického a subtropického zahradnictví. Zevrubně pojednává o šlechtění a semenářství zahradních rostlin, o jejich ochraně, uchování a zpracování zahradních produktů, o zahradnické technice a mechanizaci. Významné zastoupení mají hesla z vědních oborů, které tvoří základ zahradnictví – botaniky, fyziologie, genetiky, mikrobiologie, ekologie, fytopatologie, pedologie a meteorologie. Důležitou část tvoří informace o základní hortitechnice – výživě rostlin, závlaze, pěstování v chráněných prostorách. Velmi široce a důkladně jsou zpracována hesla z ochrany rostlin, osvětlující především biologickou podstatu chorob a škůdců. Ve slovníku jsou zastoupena i hesla z velmi speciálních oblastí – např. kaktusy, sukulenty, orchideje, palmy aj. Značná část hesel je věnována životnímu prostředí a poskytuje návod, jak zahradnický řešit jeho problémy.

Slovník obsahuje informace o zahradnický nejnávštěvnějších zemích, významných botanických zahradách a národních parcích, o zámeckých zahradách a důležitých parcích naší vlasti i nejvýznamnějších sadovnických objektech v cizině. Slovník přináší v jednotlivých heslech množství statistických údajů o stavu zahradnictví a jeho produkci v České republice i v zahraničí. Podává také přehled o historii a vývoji českého zahradnictví, organizací, spolicích a časopisech zahradníků. Významnou součástí jsou početná životopisná hesla o českých i zahraničních zahradnicích a botanicích; uvádějí jejich hlavní přínos pro rozvoj zahradnictví. Slovník encyklopedicky vykládá nejzávažnější terminologické pojmy užívané v botanice, ekologii, fyziologii, genetice a šlechtění, biotechnologii a ochraně rostlin. Je tedy užitečný pro každého, kdo pracuje s odbornou a vědeckou literaturou. Ve slovníku jsou s velkou zodpovědností uvedeny platné vědecké i české názvy rostlin, jejich systematické začlenění a autoři názvů, což umožňuje napravit časté nepřesnosti v naší odborné literatuře.

Širokým pojetím zahradnické problematiky se *Zahradnický slovník naučný* značně liší od zahraničních zahradnických slovníků, které jsou většinou zaměřené jen botanicky a také méně rozsáhlé. Obsah slovníku i jednotlivých hesel vychází ze současného vědeckého a odborného poznání. Hesla mají obecnou platnost, přitom jsou zaměřena především k potřebám českého zahradnictví a využití v našich podmínkách. Předností textu je jeho srozumitelnost i pro laika a konkrétnost údajů. Slovník také sjednocuje zahradnickou terminologii a u botanických názvů rostlin, latinských i českých, vychází z posledních botanických úprav.

Obsah slovníku je určen především zahradníkům, velmi dobře však poslouží i zemědělcům, lesníkům, šlechtitelům rostlin, pracovníkům v oblasti vědy i studentům. Pro aktuálnost a srozumitelnost jej mohou dobře využít i zahrádkáři a milovníci přírody.

Všech pět dílů Slovníku zahrnuje 13 000 hlavních a 15 000 vedlejších (navazujících) hesel celkem na 3000 stranách formátu A4. Na 208 tabulích je 1750 barevných obrázků a v textu 3800 černobílých snímků a pérovek. Obrazové jsou znázorněny především rostliny, choroby a škůdci zahradních rostlin, ale také popisované technologie, informace o zemích, parcích a sadovnických úpravách, portréty osob aj.

Slovník napsali naši přední odborníci z řad vysokoškolských profesorů, pracovníků Akademie věd ČR a výzkumných zahradnických ústavů, učitelé zahradnických škol i praktičtí zahradníci. Autorský kolektiv zahrnul 160 členů. Je to v moderní historii druhý český zahradnický slovník. Jeho předchůdcem byl *Ovocnicko-vinařský a zahradnický slovník*, vydaný koncem třicátých let minulého století. Současný slovník, koncipovaný jako základní dílo české zahradnické literatury, je plně srovnatelný s podobnými zahraničními publikacemi tohoto typu. Jistým nedostatkem je méně reprezentativní technická stránka, která je však plně vyvážena více než bohatým obsahem a množstvím informací.

Slovník, jehož pět dílů stojí 2100 Kč, lze zakoupit ve všech větších knihkupectvích. Zájemcům jej také zaslá přímo vydavatel – Ústav zemědělských a potravinářských informací, Slezská 7, 120 56 Praha 2 – za sníženou cenu 1780 Kč za celý komplet.

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Original scientific papers, short communications, and selective reviews (i.e. papers based on the study of agricultural literature and reviewing recent knowledge in the given field) are published in this journal. Papers are published in English. Each manuscript must contain an English and a Czech summary (including key words). Czech abstracts will be provided for foreign authors. The author is fully responsible for the originality of his paper, for its subject and format. The author should make a written declaration that his paper has not been published in any other information source. The board of editors of this journal will decide on paper publication, with respect to expert opinions, scientific importance, contribution and quality of the paper. The paper should not exceed 10 typescript pages, including tables, figures and graphs.

Manuscript layout: paper of standard size (210 × 297 mm), double-spaced typescript. A PC diskette should be provided with separate text and graphic files. Tables, figures and photos should be enclosed separately. The text must contain references to all these appendices.

If any abbreviation is used in the paper, it is necessary to mention its full form for the first time it is used, abbreviations should not be used in the title or in the summary of the paper.

The **title** of the paper should not exceed 85 characters. Sub-headings are not allowed.

Abstract should contain the subject and conclusions of the paper, not a mere description of the paper. It must present all substantial information contained in the paper. It should not exceed 170 words. It should be written in full sentences and contain basic numerical data including statistical data. It must contain keywords. It should be submitted in English and, if possible, also in Czech.

Introduction has to present the main reasons why the study was conducted, and the circumstances of the studied problems should be described briefly.

Review of literature should be a short section, containing only references closely related to the main topic of the paper.

Only original **methods** should be described, in other cases cite the method used and any modifications. This section should also contain a description of experimental material.

In the **Results** section figures and graphs should be used rather than tables for presentation of quantitative values. A statistical analysis of recorded values should be summarized in tables. This section should not contain either theoretical conclusions or deductions, but only experimental data.

Discussion contains an evaluation of the study, potential shortcomings are discussed, and the results of the study are compared with previously published results (only those authors whose studies are closely related to the published paper should be cited). The section Results and Discussion may be presented as one section.

The **References** section contains citations arranged alphabetically according to the surname of the first author. References in the text include the author's name and year of publication. Only the papers cited in the text of the study should be included in the list of references.

The author should give his full name (and the names of other collaborators), academic, scientific and pedagogic titles, full address of his workplace and postal code, telephone and fax number or e-mail.

The manuscript will not be accepted by the editorial office in case its format does not comply with these instructions.

OBSAH – CONTENTS

Fiala K., Tůma I., Holub P., Tesařová M., Jandák J., Pávková A.:	
Importance of grass cover in reduction of negative processes in soil affected by air pollution	
Význam porostů trav při omezení negativních procesů v půdě se zátěží škodlivin	377
Novák J.:	
Persistence of <i>Dactylis glomerata</i> in grassland	
Vytrvalost <i>Dactylis glomerata</i> v travním porostu	383
Wojciechowski W., Zawieja J.:	
The influence of varying soil tillage on the number and vertical distribution of weed seeds in soil of the rye (<i>Secale cereale</i>) monoculture	
Vliv diferencované agrotechniky na četnost a vertikální rozmístění diaspor plevelů v monokultuře ozimého žita (<i>Secale cereale</i>)	389
Richardson-Kageler S.J.:	
Some vegetation characteristics of natural savanna ecosystems with different herbivore species in Zimbabwe	
Vybrané charakteristiky ekosystémů přírodních savanových lesů s různými druhy přežvýkavců v Zimbabwe	393
Abd-Alla M.H., El-Enany A.E., Hamada A.M. Abdel Wahab A.M.:	
Element distribution in faba bean root nodules under salinity and its effects on growth, nodulation and nitrogen fixation	
Distribuce prvků v kořenových hlízkách bobu obecného v podmínkách zasolení a jeho vliv na růst, tvorbu hlízek a fixaci dusíku	399
Malý S., Šarapatka B., Němec P.:	
Interactions among anaerobic and aerobic N mineralization, nitrification and selected soil properties	
Interakce mezi anaerobní a aerobní N mineralizací, nitrifikací a vybranými půdními charakteristikami	405
Henselová M., Vizárová G., Macháčková I.:	
The effect of growth regulator Rastim 30 DKV on the level of endogenous phytohormones in tomato (<i>Solanum lycopersicum</i> L.)	
Vliv růstového regulátoru Rastim 30 DKV na obsah endogenních fytohormonů u rajčete (<i>Solanum lycopersicum</i> L.)	411
Barlóg P., Grzebisz W.:	
Effect of magnesium foliar application on the yield and quality of sugar beet roots	
Vliv hnojení hořčíkem na list na výnos a kvalitu bulev cukrovky	418
INFORMACE – INFORMATION	
Mareček F.:	
Zahradnický slovník naučný	423