# PROCESSES OF NITRATE ACCUMULATION IN VEGETABLE CROPS

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In period 1982–1993 we have established several trials to study nitrate accumulation in spinach and carrot. It resulted from this that farmyard manure (FYM) efficiency, after its uniform rate changed in dependence on application time. At long-term FYM absence, nitrate offer of soil and accumulation in spinach and carrot were minimum. Nitrogen fertilization effect on nitrate accumulation in spinach and carrots was changeable in condition of uniform FYM rate in dependence from application time.

- Ammonium sulphate efficiency in nitrate accumulation in spinach and carrot in FYM absence was minimum. This was confirmed also by means of $^{15}N$ isotope. The carrot responds even most strict standard requirement concerning childish nutrition.
- Nitrate levels in spinach statistically significant correlated with N-nutrients levels in soil.
- In carrots this relationship was not confirmed. Only at radical soil N-nutrients was registered evident reduction of nitrate accumulation.

nitrates; spinach; carrots; nitrate; ammoniacal nitrogen; inorganic nitrogen; soil; manure; ammonium sulphate; hydrometeorological conditions; dynamics

## INTRODUCTION

Nitrate accumulation in plants results from an imbalance between the intake of nitrates from soil and their biochemical inbuilding. Its elimination to a level acceptable in hygienic terms by regulation of conditions of nutrition is aggravated by dynamics of all quality-forming processes running in various combinations and intensity during the growing season of plants.

To re-evaluate the share of organic and mineral fertilization in nitrate accumulation in select species of vegetable crops, trials were performed for several years.

The content of nitrates in plant products is affected by every available source of nitrogen, both from soil resources and organic, mineral fertilizers, rainfalls, irrigation, air pollutants, etc. The prevailing form of nitrogen in soil is organic: it is then transformed through mineralization processes into inorganic nitrogen. This process enables to release an annual amount of up to 200 kg of nitrogen. $ha^{-1}$ in soil. The transformation rate depends on quality of the organic matter of soil and the manner of its agronomic use (crop, undercrop, fallow) as well as on the entire complex of site conditions, weather conditions and cultivation measures during the growing season. Such factors tend to be more important than nitrogenous fertilization itself, especially in soils of a higher fertility and content of humus (Prugar, Hadačová, 1995).

The supply of nitrates in soil increases through the transformation of ammoniacal nitrogen originating in mineral and organic fertilizers and plant residues by oxidation through nitrites to nitrates (Bielek, 1980).

Their intake by plants is affected by soil-hydrometeorological conditions. The absorption and assimilation of nitrogenous substances depend on temperature. Increasing temperature boosts the activity of nitrate reductase in plant organisms, which results into a lower amount of accumulated nitrates (Bengtsson et al., 1967; Cantliffe, 1972). The assimilation of nitrates ends up with the synthesis of proteins, nucleotides and other compounds (Šebánek et al., 1983).

Too high temperatures inhibit the activity of nitrate reductase. Oertli (1987) points at the interaction of light and temperature. In his trials of spinach grown under higher temperatures (18 or 28 °C) in days of a short daytime (8 or 16 hrs), he determined high morning contents of nitrates which reduced during the period of light by up to 40 per cent. Low temperatures and long daytimes produced low contents of nitrate with no fluctuations during the day.

The intensity of nitrate accumulation is a generic as well as, to a certain extent, varietal property of crops as shown by an observation of the content of nitrates in an extensive sample of vegetable crops, including some non-traditional species (Pechová, 1985).

The content of nitrates in vegetable crops is affected to a great extent by water regime during the growing season.

The effect of precipitation on the intake of nitrates from soil depends on the type of soil. Nitrate accumulation in vegetable and forage crops in lighter soils decreases with higher precipitation due to the drifting of nitrates towards the lower layers of soil profile. Soil moisture, especially in hot areas, affects chemical and biological processes in soil, mainly the biological activity and release of nutrients into soil solution. Furthermore, the application of nitrogenous fertilizers has to be adjusted to fit nitrate accumulation (Kaniszewski, Rumpel, 1978; Polách, 1985).



Regulated irrigation affected nitrate accumulation in vegetable crops both in the positive and the negative sense as it contributed both to a high intensity of dynamics of the nitrification process in soil and the flow of N-nutrients through the soil profile (Medveď et al., 1992).

Miklovič et al. (1993, 1994) observed the effect of nitrogenous mineral fertilizers (ammonium sulphate and urea in an amount of 80 kg of $N.ha^{-1}$) and irrigation (70 or 130 mm of irrigation water) on biomass production and the content of nitrates in carrots. The extreme weather conditions in 1992 (drought and intensive sunshine) sent the content of nitrates deep below the standard values regardless of the type of nitrogenous fertilizer and depth of the irrigated layer of soil. The values were obtained on a trial plot with a long-term exclusion of the application of manure.

A significant reserve in increasing the yields of vegetable crops, especially under irrigation conditions, is fertilization during the growing season. However, such agrotechnical measure tends to boost the content of nitrates in the grown products (Jarvan, 1980).

The application of a nitrogenous mineral fertilizer results into a growing nutrification activity which can increase under certain conditions nitrate accumulation in crops. The effect of gradually increased amounts of nitrogenous fertilizers on nitrate accumulation in vegetable crops was studied by a number of researchers (Počinkova, Alipieva, 1969; Venter, 1982; Uher, 1983; Polách, 1982; Pechová, 1985; Pechová, Prugar, 1990, etc.). Besides the amount of nitrogen, nitrate accumulation in plants is greatly affected also by the form of nitrogenous fertilizers. Nitric forms tend to increase nitrate accumulation more than ammoniacal ones (Kick, Massen, 1973; Venter, 1979; Kathan, 1983, etc.).

In their evaluation of results of three years' field experiments Pechová and Prugar (1985, 1986) determined the effect of manure (60 $t.ha^{-1}$) and nitrogenous nutrition (80 or 160 kg of $N.ha^{-1}$) in form of ammonium sulphate on nitrate accumulation in vegetable crops. Sampling was made in the first and second year after the application of manure. The gradually increased amounts of N-fertilizer increased the content of nitrates mainly in leafy vegetable crops.

The intensity of nitrification processes in soils of an aerated structure is much higher. The organic matter and its quality have a great effect on the physical as well as chemical properties of soil. A low content of nitrogen vs. carbon in the organic matter of soil causes microorganisms consume inorganic nitrogen in soil, which can reduce the supply of nitrates to plants (Bielek, 1984; Pechová, Prugar, 1990; Pechová, 1992).

For an extensive list of references to nitrate accumulation in vegetable crops (see Prugar, Prugarová, 1985; Prugar, Hadačová, 1995, 1996).

## MATERIAL AND METHODS

In the period 1982–1993 several trials were established to study nitrate accumulation in spinach and carrots.

In 1990 the above mentioned trial variants served to study also the immobilization effect of wheat straw on nitrate accumulation in spinach.

The trial plots were sized 2 $m^2$; the experiments were repeated three times. Samples of soil (at depths between 0 and 0.30 m) and vegetable crops (10 pcs of an average size) were taken at the same time.

**Sowing:**
Spinach (Matador) – April, July
Carrots (Delicia) – April

**Site characteristics:**
Vrakuňa – a fluvial type of sand-clay soil, pH KCl = 7.0, CaCO3 = 20.0 per cent
Macov – a carbonated black type of medium-weight clay soil, pH KCl = 7.6, $CaCO_3$ = 25.0 per cent, content of humus = 3.2 per cent.

A survey scheme of the application of manure and sampling

| Trial plot | Manure (60 $t.ha^{-1}$) | | |
|---|---|---|---|
| | Vrakuňa | Macov I | |
| Month | XI. | II. | XI. |
| Year | 1980, 1981, 1982 | 1984 | 1988 |
| Sampling | | | |
| Year | 1982, 1983, 1984 | 1984, 1987, 1988 | 1989, 1990 |

Notes:
- The application of farmyard manure in the check variant is identical with that in N-fertilization variants.
- Manure was applied to the Vrakuňa plot every year with sampling made in the second year after the application of manure.
- Manure was applied to the Macov I plot every 5th year with sampling made at different intervals after the application of manure.
- In 1992 and 1993, a new trial was established on the Macov II plot detached from a farmland (with a long-term exclusion of the application of manure).



The application of ammonium sulphate (kg of N . $ha^{-1}$) in April after the 1st sampling of soil

| Year | kg of $N.ha^{-1}$ |
|---|---|
| 1982–1993 | variant A – 0 |
| 1987–1989 | 0, 40, 80, 120, 160 |
| 1990[xx] | 0, 50, 100 |

Notes:
- No ammonium sulphate was applied in the check trial (A).
- The trials with 0, 50, 100 kg of $N.ha^{-1}$ were established in 1990xx with/without the application of wheat straw (5 $t.ha^{-1}$).
- The 1990 summer spinach was sown without re-application of ammonium sulphate (the trial plot after lettuce grown in the same N-fertilization variants as the spring spinach).

**The application of phosphate and potash fertilizers** to the trial plots was the same, based on soil analyses.

### Analytical methods

The content of nitrates and ammoniacal nitrogen in soil was determined by the colorimetric method with phenol disulphonic acid or Nessler agent, respectively.

The content of nitrates in vegetable crops was determined by the ion-selective method CRYTUR in a mixed extract of $Al_2(SO_4)_3$ and $CuSO_4$ (Hubáček, Bernatzik, 1979).

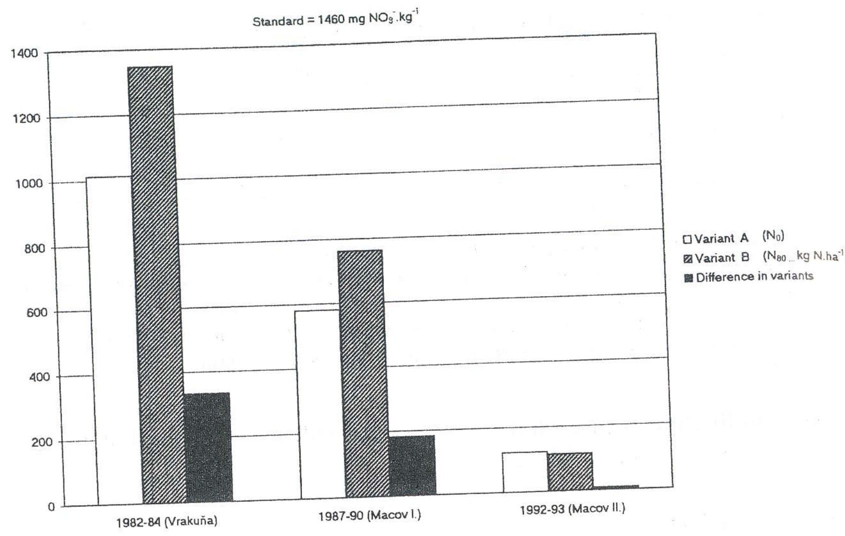
### Form of results

The content of nitrates in vegetable crops is specified in mg of $NO_3^-.kg^{-1}$ of fresh mass and that in soil in mg of $N_{inorg.}$, $N\text{-}NH_4$ and $N\text{-}NO_3.kg^{-1}$ of dry mass.

Nitrate accumulation in vegetable crops is evaluated in relation to the standard regulation (Vestník MP SR, 1996) which allows of a maximum value of 1460 and 511 mg of $NO_3^-.kg^{-1}$ of fresh mass of spinach or carrots, respectively.

## RESULTS AND DISCUSSION

Figs. 1–4 show the average content of nitrates in vegetable crops and inorganic nitrogen in soil on the Vrakuňa (1982–1984), Macov I (1984–1990) and Macov II (1992–1993) plots.




1. Nitrate accumulation in the 1982–1993 spring spinach (mg of $NO_3^-.kg^{-1}$)

The variant of nitrogenous mineral fertilization (B) shows a higher content of nitrates in soil and vegetable crops than the check variant (A).

The differences between the N-fertilization variants (B – A) are bigger at a shorter interval of manure application (Vrakuňa) than at a longer one (Macov I).

The top nitrate accumulation in spinach was determined at Vrakuňa where manure was applied every year with samples taken the second year after the application of manure.

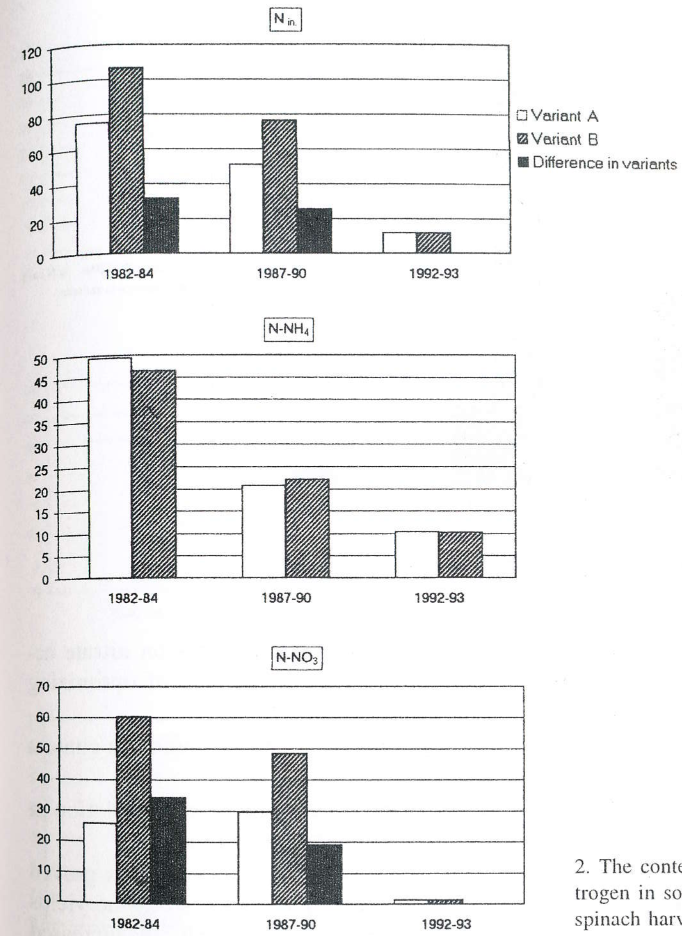
The top nitrate accumulation in carrots was determined at Macov I where manure was applied every five years.

The bottom nitrate accumulation in spinach and carrots was determined on the Macov II plot with a long-term exclusion of application of manure. The differences between the check variant and the N-fertilization one (B – A) were at a level of non-homogeneity of samples of soil and vegetable crops.

A regular application of high-quality manure or compost to soil boosts the share of organic nitrates in nitrate accumulation in crops. When mineralized, organic matter supplies plants gradually with every nutrient it has accumulated (B l a n c et al., 1983; P e c h o v á , P r u g a r , 1984; P o l á c h , 1985; P e c h o v á , M i k l o v i č , 1995; P e c h o v á et al., 1996).

The effect of N-fertilization on nitrate accumulation in vegetable crops decreases with a long-term exclusion of application of manure (M e d v e ď et al., 1992; P e c h o v á et al., 1994, 1996).



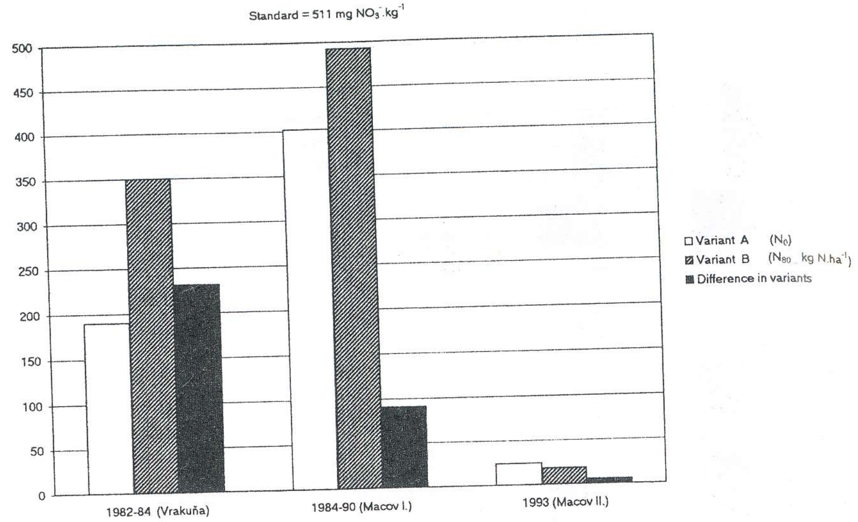



2. The content of inorganic nitrogen in soil at the early-June spinach harvest (mg of $N.kg^{-1}$)

Figs. 5 and 6 draw a more detailed picture of the relation between the variable supply of ammoniacal and nitrate nitrogen in soil and nitrate accumulation in vegetable crops in variants A ($N_0$) and B ($N_{80}$) (kg of $N.ha^{-1}$) in individual years of trial.

The content of nitrate, ammoniacal and inorganic nitrogen in soil and nitrate accumulation in the spring spinach show an exponential relation (at a level of statistical significance $\alpha = 0.01$) (Fig. 7).

Figs. 8 and 9 show results obtained in the fourth year after the last application of manure (February 1984).




3. Nitrate accumulation in the 1982–1993 carrots (mg of $NO_3^-.kg^{-1}$)

The effect of gradually increasing amounts of N-fertilizers on nitrate accumulation in vegetable crops was observed for the purpose of optimizing nitrogenous nutrition from the aspect of nitrate accumulation.

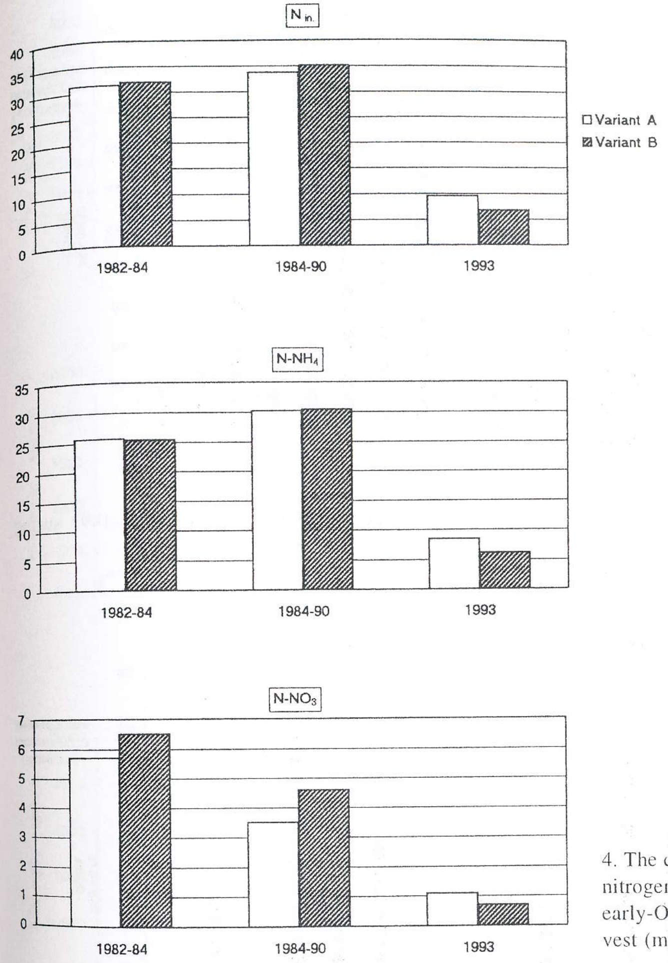
The applied amount of mineral nitrogenous fertilizer increased the content of nitrates in soil and the spring spinach.

A correlation ($\alpha = 0.05$) was determined between nitrate accumulation in spinach and the content of nitrate and inorganic nitrogen in soil.

The trials by Schuphan et al. (1967) lasting for several years proved that gradual nitrogenous fertilization of spinach increased besides the yields also the content of total and protein nitrogen. The content of nitrates increased dramatically with a major effect of the meteorological conditions in the years under trial. While a concentration of mere 600 mg of $NO_3^-.kg^{-1}$ of fresh matter was determined in the variant of intensive nitrogenous fertilization in one of the years of trial, the same variant produced up to 2,600 mg of $NO_3^-.kg^{-1}$ of fresh matter in the following year.

Nitrate accumulation in carrots was lower in the October sample with some differences still determined between the variants of N-fertilization. In November sampling was registered higher nitrate accumulation, differences among N-fertilization variants were minimum. In both samplings were lowest and identic nitrate accumulation in control ($N_0$).



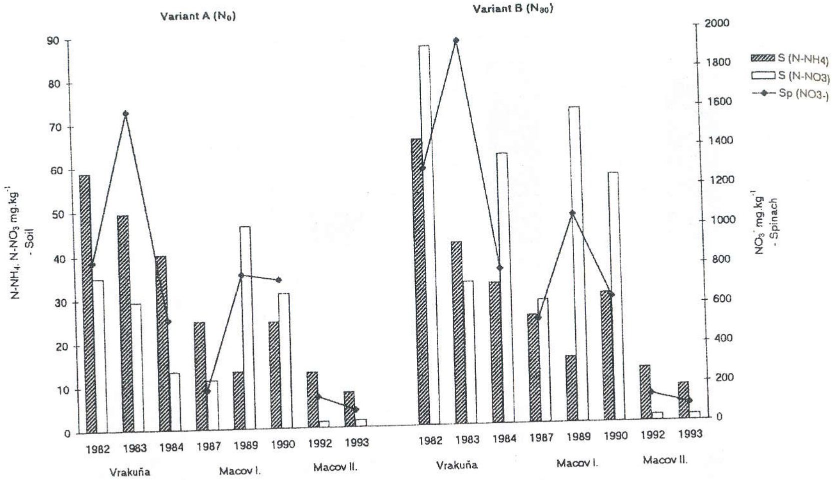



4. The content of inorganic nitrogen in soil at the the early-October carrots harvest (mg of $N.kg^{-1}$)

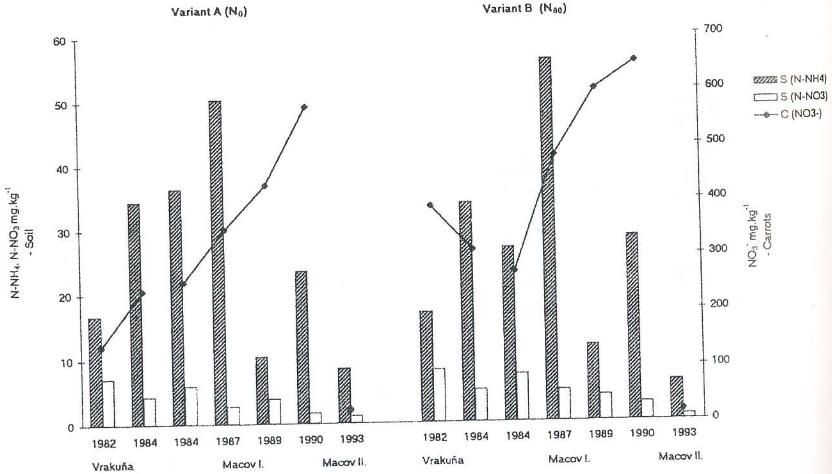
In given nutritional conditions was grown hygienically sufficient spinach (spring planting).

In carrots also lowered N-fertilizer (40 kg $N.ha^{-1}$) caused higher nitrate accumulation in time of harvest.

Having made a big number of observations, Chessin and Hicks (1987) did not determine significant differences in the content of nitrates in carrots fertilized with 90 or 146 kg of $N.ha^{-1}$ compared to the check variant despite a linear growth of the percentage of total root nitrogen.

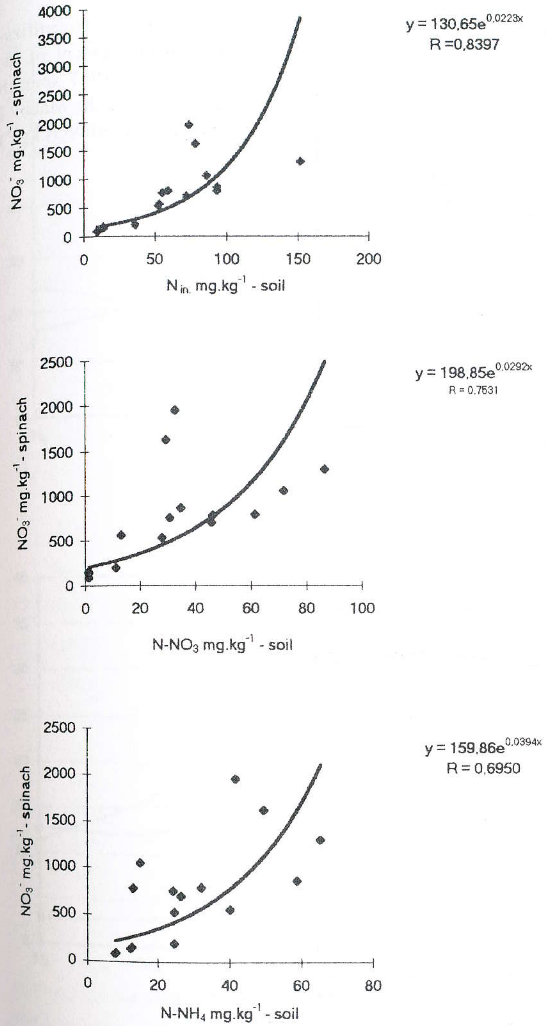



5. The effect of inorganic nitrogen in soil on nitrate accumulation in the 1982–1993 spring spinach




6. The effect of inorganic nitrogen in soil on nitrate accumulation in the 1982–1993 carrots

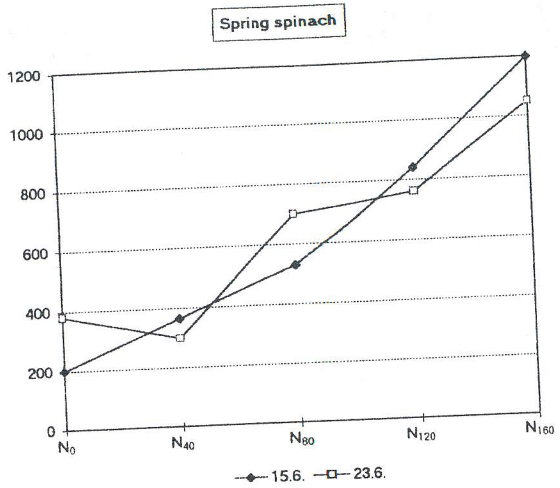


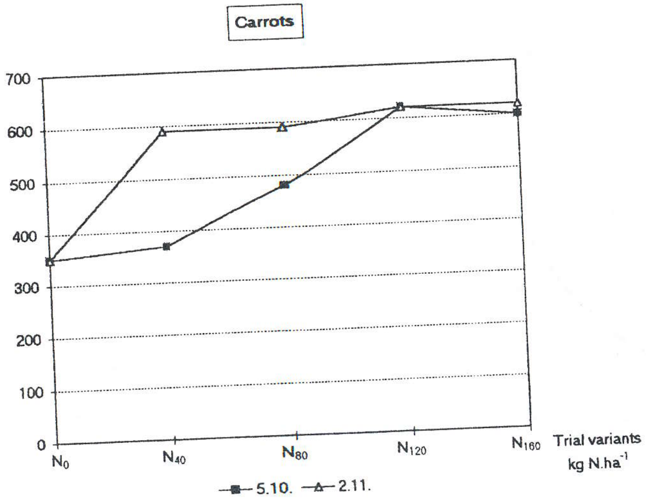



7. The effect of N-nutrition on the content of nitrates in the 1982–1993 spring spinach

G e i s s l e r and W a c k w i t z (1986) arrived at similar conclusions. The content of root nitrates in carrots harvested from the mid-July was approximately stable with different amounts of fertilizers up to 150 kg of $N.ha^{-1}$ (approx. 130 $mg.kg^{-1}$ of fresh matter).

According to N a z a r j u k (1988a) an amount of 60 kg $N.ha^{-1}$ produced the same results as the check variant without fertilization. The increase in



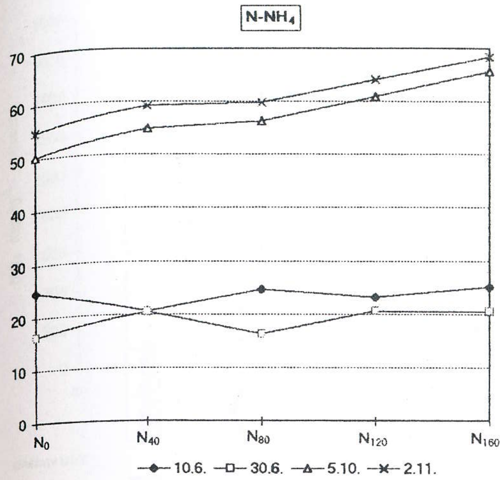



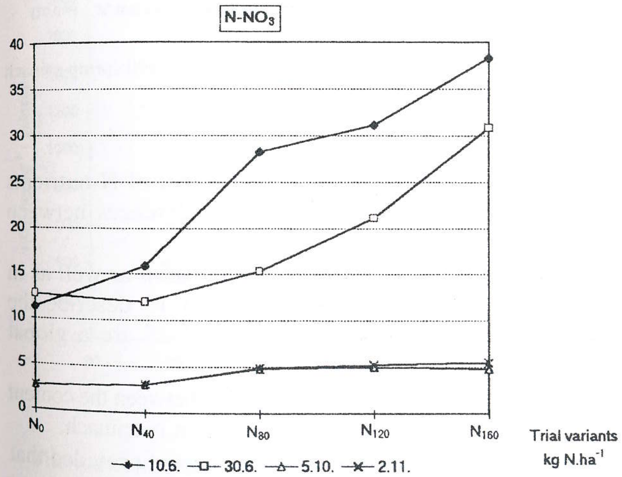

8. The effect of N-fertilization on the content of nitrates in the 1987 spinach and carrots on the Macov I trial plot (mg of $NO_3^-.kg^{-1}$)

nitrate accumulation in carrots with an increasing amount of N-fertilizers from 200 to 400 kg $N.ha^{-1}$ was negligible.

The application of wheat straw reduced nitrate accumulation in spring spinach in the trial variants marked x at a level of statistical significance (Lordov test "*u*") (Fig. 10).



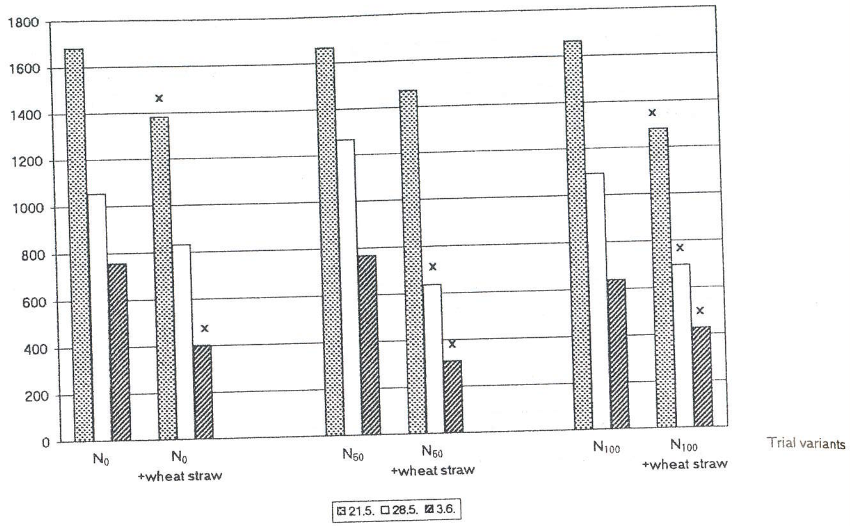



9. The content of inorganic nitrogen in soil at the 1987 harvest of spinach and carrots on the Macov I trial plot (mg of $N.kg^{-1}$)

Increasing the content of inorganic nitrogen in soil resulted into a linear growth of nitrates in the spring spinach (Fig. 11).

Increasing the content of nitrate nitrogen in soil resulted into an exponential growth of nitrates in the spring spinach.




x ... nitrate accumulation in spinach in the variant with wheat straw at a level of statistical significance (Lord test "u" ... P=0,01)

10. The effect of wheat straw on elimination of the content of nitrates in the 1990 spring spinach on the Macov I trial plot (mg of $NO_3^-.kg^{-1}$)

A correlation was determined in 1990 between the content of N-nutrients and nitrate accumulation in spinach with insignificant differences between the variants of N-fertilization.

The information about dynamics of inorganic nitrogen in soil as well as in vegetable crops has a practical significance. Figs. 12 and 13 describe the dynamics at the specific times of sampling. Figs. 14 and 15 are a global expression of the evaluated relations.

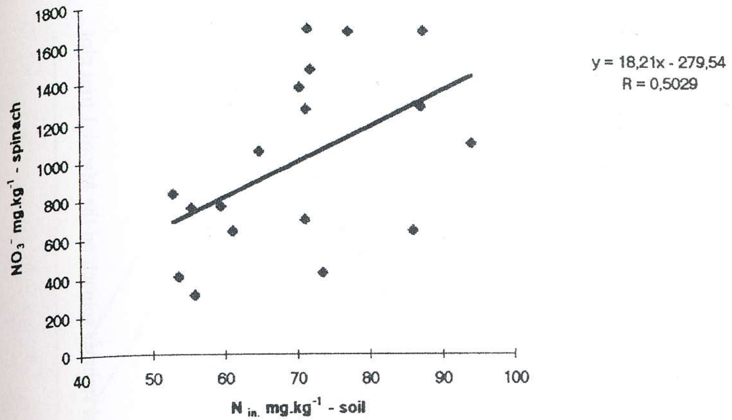
These graphic representations show again a clear correlation between the content of inorganic and nitrate nitrogen in soil and nitrate accumulation in spinach.

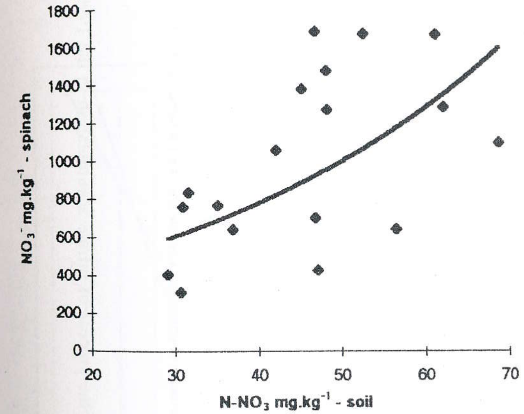
Summer spinach is recommended from the qualitative aspect provided that no ammonium sulphate is re-applied (the trial plot after lettuce with variants of N-fertilization identical with those of spring spinach).

The bottom nitrate accumulation in carrots appeared in the summer season. The choice of an optimum time of harvest is recommended on the basis of the obtained results.

An increased nitrate accumulation in carrots was observed in the autumn season with a dramatic decrease in nitrate and an increase in ammoniacal nitrogen in soil.



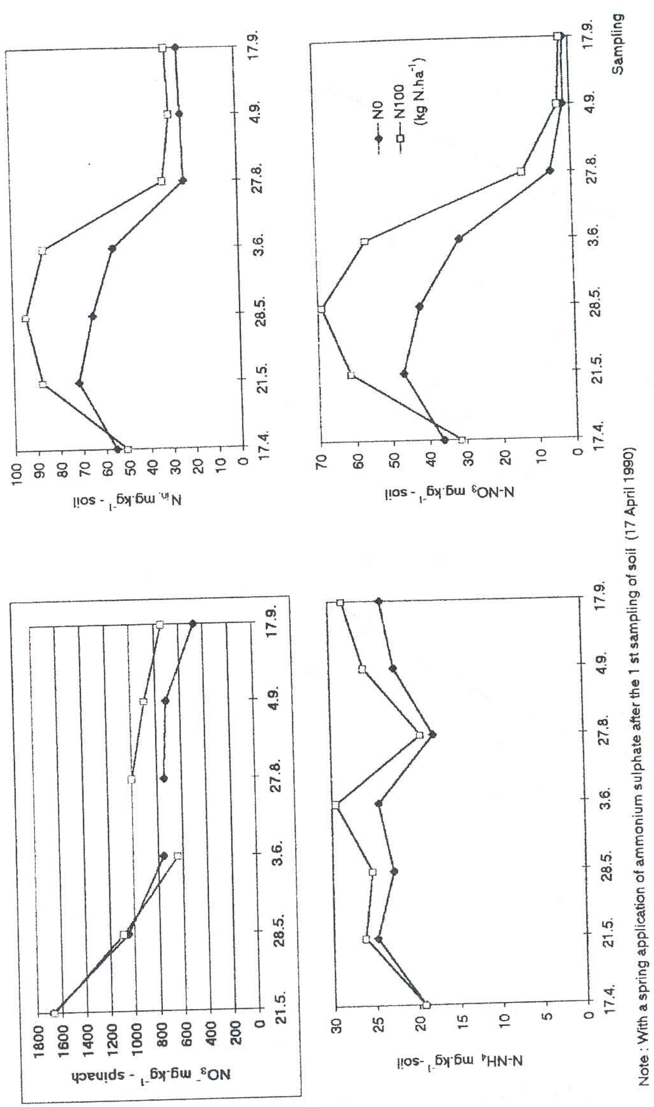



11. The effect of N-nutrition on the content of nitrates in the 1990 spring spinach on the Macov I trial plot

The same trend in nitrate accumulation in carrots was observed also in other years of trial. The intake of nitrates from soil by carrots is smaller in the summer (drier) season. Moreover, the optimum sunshine conditions increase the intensity of biochemical processes in crops, which contributes to an improvement of their quality.

Besides worse sunshine conditions, the autumn (wetter) season boosts the intake of nitrates from soil. Alongside of nitrogenous nutrition this results into an increasing content of nitrates in carrots (P e c h o v á, P r u g a r, 1990).

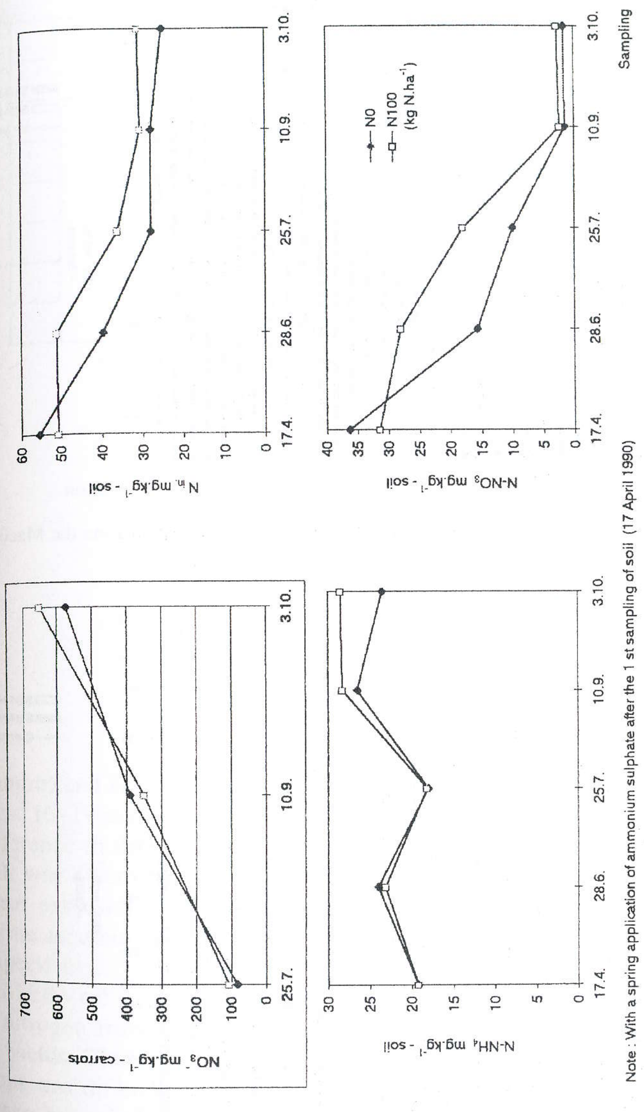



Note : With a spring application of ammonium sulphate after the 1 st sampling of soil (17 April 1990)

12. Dynamics of the process of nitrate accumulation in the 1990 spring and summer spinach on the Macov I trial plot

According to Szwonek and Michalik (1986) a significant nitrate accumulation can appear also in earlier stages of growth of carrots in June and July, especially with a heavier precipitation.

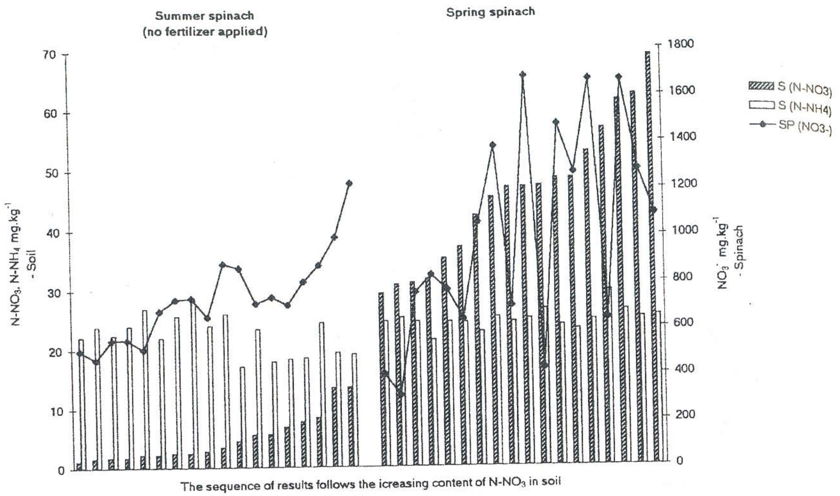




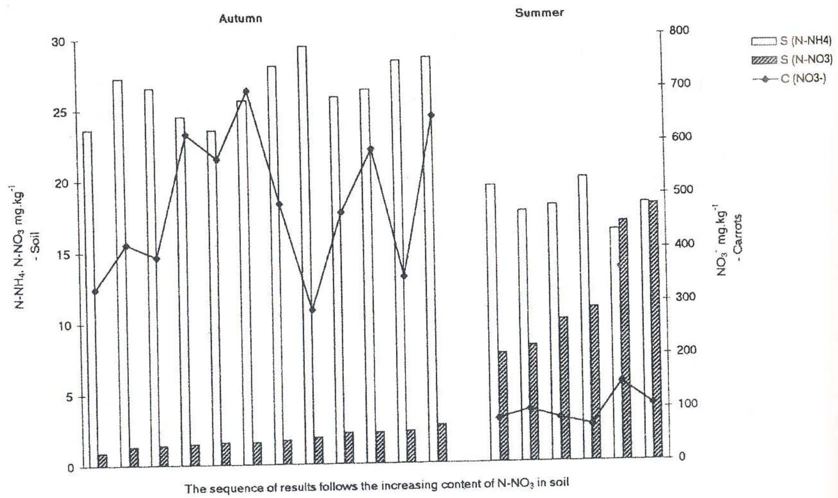

Note : With a spring application of ammonium sulphate after the 1 st sampling of soil (17 April 1990)

13. Dynamics of the process of nitrate accumulation in the 1990 carrots on the Macov I trial plot

The effect of manure on nitrate accumulation in vegetable crops can be assessed especially on the basis of a comparison of the average values obtained on the trial plot at Macov I (at a five years' interval of application of

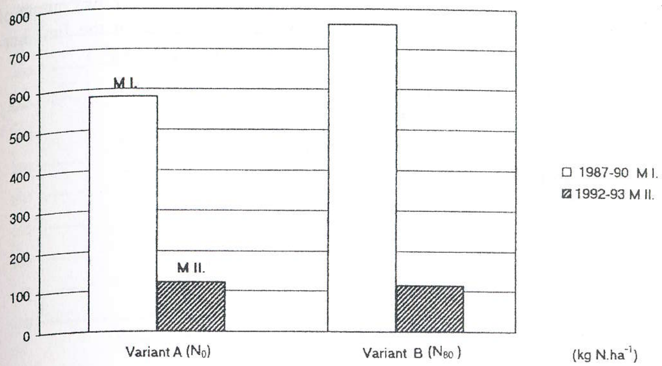


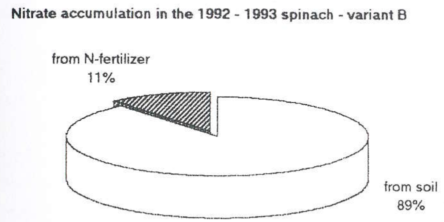

14. Differences in nitrate accumulation in the 1990 spring and summer spinach on the Macov I trial plot




15. Differences in nitrate accumulation in the 1990 summer and autumn carrots on the Macov I trial plot





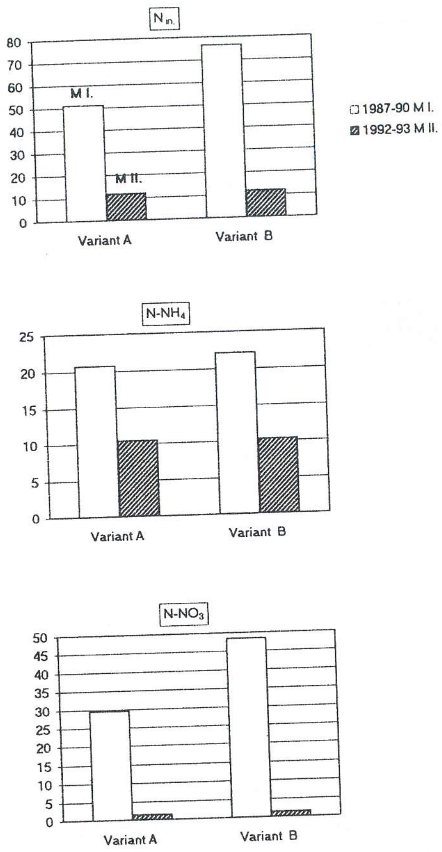




16. The effect of manure on nitrate accumulation in the 1987–1993 spring spinach on the Macov I, II trial plots (mg of $NO_3^-.kg^{-1}$)

manure) and Macov II (with a long-term exclusion of application of manure). Figs. 16–19 compare the same trial variants (A to A, B to B) with the only difference in the content of organic matter in soil.

It was determined by means of the $^{15}N$ isotopic analysis that after a long-term exclusion of application of manure N-fertilizers reached a share in nitrate accumulation of 11 per cent and only 5 per cent in spinach and carrots, respectively.

Medveď et al. (1994) used the $^{15}N$ isotopic analysis to test the utilization of nitrogen from nitrogenous fertilizers by spinach and carrots and its effect on yields. The utilization of the tested nitrogenous fertilizers by the grown crops was different under different moisture conditions. Most of the nitrogen intake by spinach and carrots in two irrigation variants came from urea, namely 27.3 to 31.8 per cent for spinach and 33.2 to 40.8 per cent for carrots, against the intake from ammonium sulphate of 14.6 to 16.4 per cent for spinach and 17.3 to 24.5 per cent for carrots. A higher utilization of nitrogen from fertilizers increased the yields of grown crops with a minimum nitrate




17. The effect of manure on the content of inorganic nitrogen in soil at the June harvest of spinach (mg of $N.kg^{-1}$)

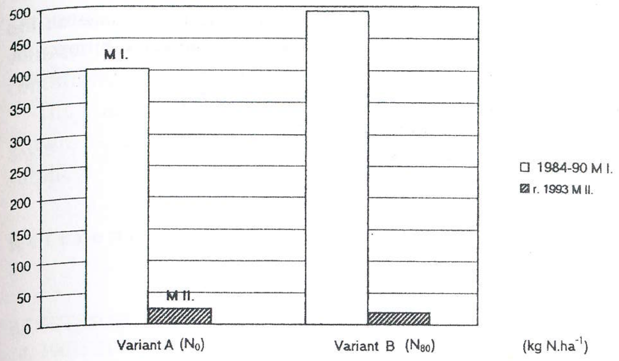
accumulation. The trial was established on our trial site at Macov on a plot with a long-term exclusion of application of manure. This data adds to the above mentioned qualitative evaluation.

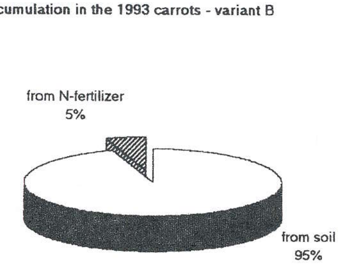
## CONCLUSIONS

The evaluation of results shows that nitrate accumulation in spinach and carrots was caused to a dominant extent by the application of manure with only a potential effect of mineral nitrogenous fertilization.

The effect of mineral nitrogenous fertilization (ammonium sulphate) on nitrate accumulation in spinach and carrots with the application of the same





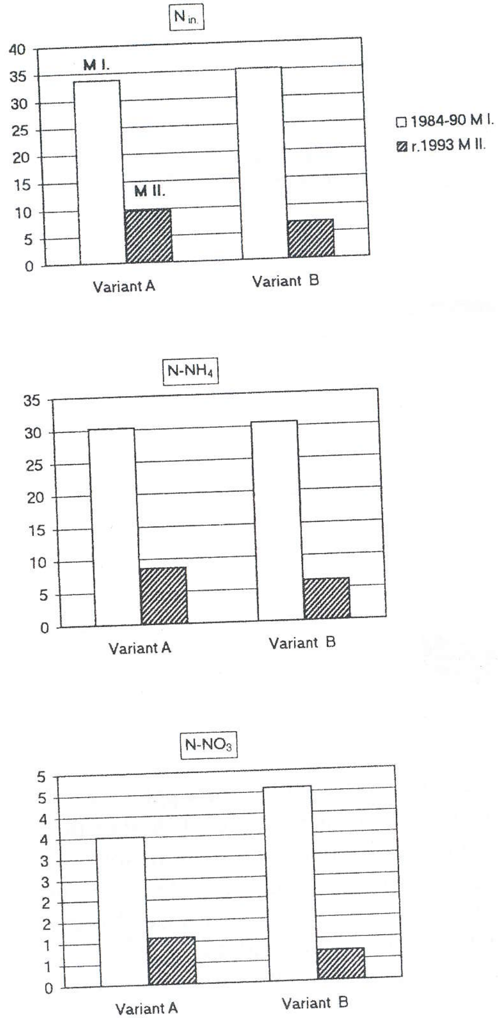

18. The effect of manure on nitrate accumulation in the 1984–1993 spring carrots on the Macov I, II trial plots (mg of $NO_3^-.kg^{-1}$)

amount of manure varied with the application interval. The application of wheat straw reduced nitrate accumulation in spinach at a level of statistical significance as a consequence of the immobilization of nitrogen in soil.

A correlation between the content of nitrates in spinach and that of N-nutrients in soil was determined at a level of statistical significance. No evidence of such correlation was found in carrots where nitrate accumulation dropped clearly only after a radical decrease in the content of N-nutrients in soil.

The effect of ammonium sulphate on nitrate accumulation in spinach and carrots with no application of manure was minimum, which was confirmed also by the isotope $^{15}N$. Carrots met the most demanding requirements on baby food.

The recommended interval of application of manure is four to five years with respect to the care of soil productivity even despite certain risk of an increased nitrate accumulation in the grown vegetable crops. The vegetable




19. The effect of manure on the content of inorganic nitrogen in soil at the October harvest of carrots (mg of $N.kg^{-1}$)

crops grown in the control variant (without ammonium sulphate) after an application of manure had an appropriate quality. The notorious standard amounts of ammonium sulphate for growing vegetable crops need to be reduced according to the content of inorganic nitrogen in soil.

The graphic representation of results indicates a possibility of utilizing the dynamics of nitrate accumulation in vegetable crops for the choice of an



optimum time of harvest. The best-quality carrots were harvested in the summer time (July to August) with less precipitation and under good sunshine conditions.

The content of nitrates in summer spinach was lower but only when it was grown as an aftercrop (after lettuce) without re-application of ammonium sulphate.

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**Procesy akumulácie dusičnanov v zelenine.**

Scientia Agric. Bohem., *29*, 1998: 93–118.

V rokoch 1982–1993 sme založili niekoľko pokusov na sledovanie akumulácie dusičnanov v špenáte a mrkve. Z nich vyplýva, že po dlhodobom vylúčení aplikácie maštaľného hnoja bola ponuka dusičnanov z pôdy a akumulácia dusičnanov v špenáte a mrkve minimálna.

Vplyv dusíkatej výživy na akumuláciu dusičnanov v špenáte a mrkve závisel pri jednotnej dávke maštaľného hnoja od intervalu aplikácie.

- Účinnosť síranu amonného na akumuláciu dusičnanov v špenáte a mrkve bola po vylúčení aplikácie maštaľného hnoja minimálna. To bolo potvrdené aj pomocou izotopu $^{15}$N. Mrkva spĺňala najprísnejšie požiadavky kladené na detskú výživu.
- Obsah dusičnanov v špenáte štatisticky významne koreľoval s obsahom dusíkatých živín v pôde.

- V mrkve sa takýto vzťah nedokázal. Až pri radikálnom znížení obsahu dusíkatých živín v pôde sa zisťoval evidentný pokles akumulácie dusičnanov.
- Z grafického znázornenia výsledkov vyplýva dynamika akumulácie dusičnanov v zelenine, ktorú možno využiť pre výber vhodného termínu zberu. Koreňové zeleniny majú dlhšie vegetačné obdobie. V suchšom a slnečnom lete obsahovala mrkva nižší obsah dusičnanov ako na jeseň. Špenát mal v letnom období nižší obsah dusičnanov, ale iba vtedy, ak sa pestoval ako následná plodina (po jarnom hlávkovom šaláte) bez ďalšej aplikácie síranu amonného.

dusičnany; špenát; mrkva; dusičnanový; amoniakálny dusík; anorganický dusík; pôda; maštaľný hnoj; síran amónny; hydrometeorologické podmienky; dynamika

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