THE IMPACT OF NITROGEN ON CROP YIELDS AND FOOD QUALITY

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Abstract

Nitrogen is outstanding among equally important deficient nutrient elements, because it has the greatest influence on yield. At the same time nitrates in vegetables, milk or meat, once they end up in the human body, can convert to nitrosamines which are extremely carcinogenic. The content of nitrates found in vegetables, milk and meat is directly correlated to their concentration in soil. Nitrates in soil originate from organic and mineral fertilizers. High yields of cultivated plants can be achieved through rational fertilization, with a minimum content of nitrates.

Key words: *fertilization, food, nitrates*

1. INTRODUCTION

Revolutionization of agriculture during 20th century was marked by intensive chemical application, use of modern agricultural machinery, great improvements in the selection of cultivated crops, and a tenfold increase in the yield of certain crops. On the other hand, excessive application of chemicals and mineral fertilizers brought about new scientific and technical problems or challenges in agriculture.

Modern and/or intensive application of chemicals has caused vast land degradation. Uneconomical and often uncontrolled, “thriftless” use of pesticides and mineral fertilizers caused soil and groundwater contamination.

Intensive agriculture has lead to significant decrease in humus content on the farms in Vojvodina. Average humus content is 1% - 3% in 47.9% of plots, and 3% to 5% in 51% of plots, whereas it used to be 4 to 6% and above before the use of intensive agriculture. The content of humus which exceeds 3% is found only in 50% of the soils in Vojvodina, while it is lower than 3% in 70% of the soils in Vojvodina.

Responsible implementation of appropriate cultivation practices by agricultural producers could prevent many problems.

Yields of cultivated crops depend on numerous abiotic and biotic factors, most importantly on nitrogen nutrition. Uneconomical use of excess nitrogen in plant production causes nitrification of deeper soil layers and groundwater and, as a final result, production of plants high in nitrate concentration and their use for human and animal nutrition. Problems caused by excess nitrogen and higher concentrations of nitrates in food have recently been given increased attention. Nitrates can be converted to nitrites which can form highly carcinogenic chemicals - nitrosamines. Similar problems can be caused by pesticide residues.

Reduction in the use of non-renewable energy sources in plant production represents one of the priorities in maintaining long-term sustainability of agricultural systems. High amounts of energy are used in the production of mineral nitrogen fertilizers. It takes 296 $x10^5$ J of energy, i.e. 1373 l of diesel to produce 1 kg of nitrogen in the form of ammonium-nitrate. If the application of nitrogen in Vojvodina farms was reduced by 1 kg N ha^{-1}, it would result in saving 2059.5 t of diesel. Economical

use of nitrogen fertilizers helps preserve natural resources and enables the production of food without the increased nitrate concentration.

The microbial application has great potential in different areas of sustainable agriculture (biofertilizers, biopesticides, plant growth stimulators). Replacement of mineral fertilizers with microbial fertilizers is energetically, economically, and ecologically justified. Application of microbial fertilizers significantly decreases the use of non-renewable energy sources necessary for mineral fertilizer production.

The aim of the study was to analyze the previous research results on food nitrate concentration, obtained by other authors. Most studies of nitrate concentration in food included examination of increased nitrate content in soil caused by mineral or organic fertilization.

2. NITRATES AND THEIR HARMFUL EFFECT ON HUMAN HEALTH

Besides causing a number of environmental problems, accumulation of nitrates in nature directly harms human and animal health.

Different values have been stated in reference sources as doses of nitrates which are toxic or lethal to humans. Corre & Braimer (1979) report that the levels of nitrate for a 60-kg adult human range from 4.8 to 200g as a lethal level, 2g - 5g as toxic, and 0.4g - 1g as tolerant. The main source of nitrates entering into human body is found in plants (about 70%), followed by water (20%), and foods of animal origin (10%). Some plant species have the capacity to accumulate larger amounts of nitrates. Presuming that 400 mg nitrates is the acceptable daily intake of an adult human being, the allowed quantity would be 182 g vegetables containing 220 mg nitrates per 1 kg of fresh weight. Most nitrates (> 50%) are removed from the body through urine. The remaining 20-40% nitrates are returned through the bloodstream into the oral cavity, and later on excreted through saliva. Out of this amount, 20% is reduced to nitrites (4-8% of the total nitrate amount). Reduction of nitrates to nitrites is significantly affected by pH in the organs (stomach and oral cavity). According to Hartman (1983) and Mirvish (1983), over 80% nitrate compounds have a mutagenic and carcinogenic effect.

3. NITRATES IN SOIL, ANIMAL FEED, AND MILK

Studies were carried out by Marinković et al. (2009) which included monitoring nitrates from nitrate concentrations in soils, through animal feed, to nitrate concentrations in milk. The authors conducted an analysis of soil mineral nitrogen according to the method introduced by Scharpf & Werhmann (1978). Samples of animal feed were taken from localities 24h before milk samples were taken. Nitrate concentration in milk was monitored individually per each head of cattle (cow). Determination of nitrate concentration was carried out using a quantitative method, by breakdown of hydrogen peroxide and measurement at 420 nm.

Based on the calculation of balanced nitrogen fertilization for 11 t ha^{-1} of maize yield, the authors confirmed a surplus of 155 kg N ha^{-1} in Plot 1. The surplus of 34 kg N ha^{-1} was determined in Plot 3, while Plot 2 required additional fertilization in the amount of 31 kg N ha^{-1} (Table 1).

Table 1. Distribution of nitrates along soil profile (kg NO_3 ha^{-1})

	0-30 cm	30-60 cm	60-90 cm	90-120 cm	Σ	Yield, (t ha^{-1})
Maize 1	77.68	89.50	54.60	71.72	293.56	9.8
Maize 2	51.70	45.96	21.10	9.30	128.06	10.2
Maize 3	49.21	76.60	32.58	14.76	173.14	10.4
Alfalfa 1	54.76	42.96	18.54	12.56	128.84	10.0
Alfalfa 2	52.32	74.61	38.58	16.76	182.27	9.3
Alfalfa 3	47.25	81.55	55.79	26.24	210.83	8.1

(Marinković et al., 2009)

The authors showed that the nitrate concentration in alfalfa hay was in direct correlation with the nitrate content in soil. The highest nitrate concentration was recorded in hay on the plot Alfalfa 3 (1108, 1217, 1260 ppm), which also had the highest soil nitrate content (211 kg NO_3 ha^{-1}). Lower nitrate concentration was recorded on the plot Alfalfa 2 (643, 708, 762, 820 ppm), with the soil nitrate content of 182 kg NO_3 ha^{-1}. The lowest nitrate concentrations in soil (129 kg NO_3 ha^{-1}) and alfalfa hay (480, 510, 550, 610 ppm) were determined on the plot Alfalfa 1, during the first season after planting (Table 1, Table 2).

Table 2. Nitrate contents in cattle feed and milk (ppm)

Sampling	Cattle feed			Milk (head of cattle (cow))			Average
	Hay	Maize stalks	Grain	1	2	3	
1	708	-	307	5.1	27.5	22.5	18.4
2	643	250	75	5.4	16.0	15.0	12.1
3	1217	-	250	5.8	22.5	22.5	16.9
4	550	19	-	4.8	9.4	7.0	7.1
5	762	150	75	5.2	15.2	18.4	12.9
6	610	170	60	4.9	15.7	20.0	13.5
7	820	156	80	5.8	17.2	18.6	13.9
8	1108	250	170	6.1	26.5	27.2	20.6
9	1260	250	190	5.8	27.0	28.6	20.5
10	480	50	-	4.2	14.8	16.2	11.7
11	510	60	-	3.8	15.1	17.0	12.1

(Marinković et al., 2009)

Nitrate concentrations in maize stalks and grain were also directly correlated to nitrate concentration in the soil. A surplus of 155 kg N ha^{-1} was recorded on the plot Maize 1 during spring, while nitrate concentration in maize stalks and grain was 250 ppm and 170-307 ppm, respectively. Lower NO_3 concentration was recorded in maize stalks (156-170 ppm) and grain (60-80 ppm) on the plot Maize 3,

and the lowest NO_3 concentration was found in plot Maize 2 (grain 0 ppm, maize stalks 50-60 ppm), with an overall low N concentration (Table 2).

The highest nitrate concentration in milk (20.5 and 20.6 ppm) was recorded when livestock was fed with the highest nitrate concentrations in animal feed which originated from plots with excess N content (Alfalfa 3 and Maize 1). Nitrate concentration in alfalfa hay, maize stalks, and grain was 1108 and 1260 ppm, 250 ppm, and 170 and 190 ppm, respectively. Lower nitrate concentrations in milk (12.1; 12.9; 13.9 ppm), were recorded when cows were fed alfalfa hay with medium nitrate levels (643, 762, 820 ppm), maize stalks with nitrate levels of 250, 150 and 156 ppm, or grain with nitrate levels of 75 and 80 ppm. Nitrate concentration in milk was significantly lower (7.1 ppm) when alfalfa, maize stalks, and grain for feed were taken from plots with the lowest soil nitrate content (129 kg NO_3 ha^{-1} and 128 kg NO_3 ha^{-1}). Maize stalk nitrate concentration did not exceed 19 ppm in this case (Table 2).

According to the authors, nitrate concentrations in water used for livestock watering significantly affected nitrate concentrations in milk.

4. NITRATES IN VEGETABLE CROPS

Many authors studied the effects of applied mineral fertilizers on NO_2 and NO_3 concentrations in different vegetable crops.

Research results of Ilin et al. (1999) indicated that different vegetable crops have different nitrate and nitrite concentrations in plant parts used in human nutrition. Results in Table 3 show the highest nitrite concentration in spinach (1.01-3.28 mg kg^{-1}) and lettuce (0.65-4.82 mg kg^{-1}). High nitrite levels were determined in radish (up to 3.20 mg kg^{-1}), carrot (up to 2.62 mg kg^{-1}), and cauliflower (up to 2.44 mg kg^{-1}). Somewhat lower nitrite concentration was recorded in green beans, pepper and brussels sprotus, whereas the lowest levels were observed in tomato, eggplant and young potato. Nitrate levels are often in correlation to nitrite levels, as confirmed in lettuce and spinach, where both nitrite (4.82 and 3.28 mg kg^{-1}) and nitrate (579 and 442.5 mg kg^{-1}) levels were high. However, the lowest nitrate levels were observed in brussels sprotus within the range from 71 to 82 mg kg^{-1} (Table 3).

Table 3. Content of NO_2 and NO_3 in vegetable crops

Species	Variety	Content mg kg^{-1}		Year
		NO_2	NO_3	
Green beans	Blue Lake	0.06-1.05	162.5-357.7	1984-1986
	Niagara 773	0.05-2.10	109.0-255.2	
Carrot	Scarlet Nantes	0.80-2.62	111.5-363.0	1984-1986
	Formula	0.77-1.97	128.5-323.4	
Pepper	Šorokšari	0.83-1.50	140.9-276.8	1987-1988
	Zlatna medalja	0.74-1.37	116.4-204.1	
	Beli kalvil	0.41-1.64	146.3-510.0	
	Duga bela	0.28-0.97	63.3-246.3	
Lettuce	11 Varieties	0.65-4.82	118.9-579.0	1986-1987
Spinach	10 Varieties	1.01-3.28	339.9-442.5	1986-1987
Cauliflower	11 Varieties	0.32-2.44	131.8	1986-1987
Radish	11 Varieties	0.61-3.20	54.5-253.8	1986-1987

Eggplant	Poludugi	0.52-0.64	110.0-168.0	1986
Tomato	Heinz	0.30-0.51	208.0-269.0	1986
Brussels sprotus	8 Varieties	0.31-1.69	70.73-81.73	1986-1988
Young-Potato	2 Varieties	0.28-0.80	125.9-309.7	1988-1990

(Ilin et al., 1999)

Results of the three-year-study emphasize that the differences in NO_2 and NO_3 concentrations were found in cultivars of the same plant species. The largest variation in nitrate and nitrite concentrations was determined in different pepper cultivars. Cultivar Duga bela had the lowest mean nitrite (0.625 mg kg^{-1}) and nitrite (154.8 mg kg^{-1}) concentrations, while the highest nitrate concentration (328.15 mg kg^{-1}) was determined in cultivar Beli kalvil, and the highest nitrite concentration was found in cultivar Šorokšari (1.165 mg kg^{-1}). It is important to point out a large variation in nitrate and nitrite concentrations in different periods of the study. Variations in nitrate concentrations in the same cultivar ranged from 16% in brussels sprotus (70.73-81.73 mg kg^{-1}) to 387% in lettuce (118.9-579 mg kg^{-1}), while nitrite concentrations showed the lowest variations in eggplant (0.52-0.64 mg kg^{-1}), and the highest in green bean cultivar Niagara 773 (0.05-2.1 mg kg^{-1}). The authors did not investigate this fact in their study. It cannot be confirmed with certainty whether these variations are the result of seasonal weather conditions or soil nitrate content (Table 3).

Table 4 shows the results of nitrate and nitrite concentrations in vegetable crop species under different treatments with N-fertilizer (Ilin et al., 1999). Under increased N fertilization, most examined vegetable crops exhibited increased levels of nitrates in plant parts used for human nutrition. Nitrite concentrations in radish, cauliflower, spinach, broccoli, and carrot were not affected by the applied doses of N mineral fertilizer, while increased N fertilization resulted in increased nitrite concentration in cabbage and beetroot.

Table 4. Influence of nitrogen on nitrate (NO_3) and nitrite (NO_2) content in vegetables (mg kg^{-1})

Variant of fertilization	Radish		Cauliflower		Spinach		Broccoli		Cabbage		Carrot		Beetroot	
	NO_2	NO_3	NO_2	NO_3	NO_2	NO_3	NO_2	NO_3	NO_2	NO_3	NO_2	NO_3	NO_2	NO_3
Control	0.4	81.3	2.3	107	1.1	17.4	1.2	45.1	1.1	18.1	0.6	126	2.5	371
$N_{50}P_{100}K_{100}$	0.5	71.0	1.8	106	1.2	31.4	1.7	46.0	1.3	28.8	1.0	110	3.2	153
$N_{100}P_{100}K_{100}$	0.5	76.9	1.7	104	0.8	35.8	2.1	39.6	1.9	21.6	0.7	144	3.8	292
$N_{150}P_{100}K_{100}$	0.5	97.0	1.7	117	0.9	35.2	2.0	53.8	2.6	35.1	0.8	177	3.3	364
$N_{200}P_{100}K_{100}$	0.5	78.8	2.2	134	1.1	30.9	1.7	46.8	1.2	21.5	1.0	190	4.2	363

(Ilin et al., 1999)

The three-year-study of Đurovka et al. (1990) focused on determination of nitrate concentrations in inflorescences of different cauliflower cultivars. The same doses of mineral nitrogen were applied during the three years of research. The obtained results showed the highest nitrate concentration in cauliflower during the 3rd year of the study, ranging from 657 to 1289 ppm (cultivars Imperial and Snow flower). In the same year, cultivars Snow ball, Cervina and White rock had high nitrate concentrations (about 1000 ppm), while lower concentrations (714 - 784 ppm) were recorded in

cultivars White fox, Vernon, and Jura. This undoubtedly shows that yield must not be the prevailing decision-making factor in the assortment selection and that the quality of vegetables must be given due attention. An extremely important fact in this research, one which must not be ignored, is a very high content of NO_3 in the third year of research. Similarly to the research of Ilin et al. (1999), the authors did not analyze and explain the cause of the obtained results. Different nitrate concentrations during the research years might have been caused by the level of mineral nitrogen in soils or seasonal weather conditions. It is interesting that cultivar Snow flower exhibited the lowest (18 ppm) and the highest (1289 ppm) nitrate concentration during the three-year-period of research. Similar results were recorded in cultivars Snow ball (18 and 1041 ppm) and Cervina (29 and 1042 ppm). Cultivars Idol, Imperial, Jura and White fox, had stable low nitrate concentrations in inflorescence during the three-year-period of research (257-298 ppm on average) (Table 5).

Table 5. Nitrate (NO_3) content in cauliflower inflorescence

Variety	**NO_3 (mg kg^{-1})**			**variation**	**average**
	1	2	3		
Snow ball	55	18	1041	18-1041	371
Idol	33	24	714	24-714	257
Imperial	128	19	657	19-657	268
Snow Crown	131	23	1178	23-1178	444
Vernon	116	27	752	27-752	298
Cervina	65	29	1042	29-1042	379
Andes	118	29	957	29-957	368
Jura	94	16	784	16-784	298
Snow Flower	105	18	1289	18-1289	471
White rock	94	26	1112	26-1112	411
White fox	111	22	751	22-751	294
Prosek-average	95	22	932		

(Đurovka et al., 1990)

These results indicate the need for adequate application of mineral fertilizers in each plot and each production year, as stated by Marinković et al. (2009).

The reported study suggests that the technology of field and vegetable crop cultivation must consider each individual factor. Implementation of a random strategy and technology based on experience cannot be the suitable solution in modern agricultural production. The selection of varieties, environmental conditions in the growing season, the content of mineral nitrogen in the soil, and use of mineral fertilizers, predominantly influence the yield and its quality. Only a harmonious relationship of all these factors can result in a successful production.

Proper nutrition means a daily intake of vitamins and minerals to ensure proper development and preservation of the health status of human organism (Lazić et al., 1990; Lazić et al., 1999; Vučetić et al., 1998). With a view to providing these substances, a dominant role have vegetables, especially vegetables of excellent quality, mentioned by Mayer (1997) in the research. The author draws attention that the quality of vegetables decreased dramatically in the last 60 years (especially after the 1990s). Many authors warning of unacceptable amount of NO_3 in food (Đurovka t al., 1990; Lazić et

al., 1992; Lazić et al., 1994; Drews et al., 1996; Volkova & Kudums, 1996; Drews et al., 1997; Ilin et al., 1999). On the effect of nitrogen on maize yield and accumulation of nitrates in feed and milk in their papers stood out: Jelenić 1984; Marinković, 1989; Marinkovic et al., 2008; Marinković et al., 2009.

5. CONCLUSIONS

On the basis of the results can be drawn the following conclusions:

The maize yield is significantly affect by the amount and distribution of mineral nitrogen along soil profile.

Optimal yield (10,2 t ha^{-1}) was at the field with 128 kg N ha^{-1}.

The smaller yield by 400 - 600 kg ha^{-1} was at the field with a high nitrogen content of 29.6 kg ha^{-1}.

At the field with the high mineral nitrogen content, hay yield was lower by 1.2 and 1.9 t ha^{-1}.

The highest nitrate concentration in milk was recorded in 8^{th} and 9^{th} sampling, when nitrate concentration in alfalfa hay and maize stalks was 1108 and 1260 ppm, and 250 ppm, respectively.

Among the examined cattle (cows) there is a difference of 4.5 to 4.7 times in the amount of nitrate in milk.

The highest nitrate concentration in cauliflower inflorescence was during the 3^{rd} year of the study, ranging from 657 to 1289 ppm. The same doses of mineral nitrogen were applied during the three years of research.

The reason for great amounts of NO_3 and NO_2 in soil is fertilization and / or weather conditions

In the same year, cultivars Snow ball, Cervina and White rock had high nitrate concentrations (about 1000 ppm), while lower concentrations (about 750 ppm) were recorded in cultivars White fox, Vernon, and Jura.

Cultivar Snow flower exhibited the lowest (18 ppm) and the highest (1289 ppm) nitrate concentration.

Similar results were recorded in cultivars Snow ball (18 and 1041 ppm) and Cervina (29 and 1042 ppm).

Cultivars Idol, Imperial, Jura and White fox, had stable low nitrate concentrations in inflorescence (257-298 ppm on average).

With an adequate fertilization, each variety can give excellent results. It is essential that producers have knowledge.

The highest nitrite concentration was recorded in spinach (1.01-3.28 mg kg^{-1}), lettuce (0.65-4.82 mg kg^{-1}) radish (up to 3.20 mg kg^{-1}).

Somewhat lower nitrite concentration was recorded in green beans, pepper and brussels sprotus, whereas the lowest levels were observed in tomato, eggplant and young potato.

Nitrate levels are often in correlation to nitrite levels, as confirmed in lettuce and spinach, where both nitrite (4.82 and 3.28 mg kg^{-1}) and nitrate (579 and 442.5 mg kg^{-1}) levels were high.

The differences in NO_2 and NO_3 concentrations were found in different pepper cultivars. NO_2 concentrations ranged from 0.625 mg kg^{-1} to 1.165 mg kg^{-1}, NO_3 concentrations ranged from 154.8 mg kg-1 to 328.15 mg kg^{-1}.

Nitrogen fertilization is directly correlated with the amount of NO_2 and NO_3 in products for human consumption.

Preserve health today, and the nature for generations to come.

Varietes, selection of heads (cows), environmental conditions, N-mineral content in the soil, application of mineral fertilizers have dominant influence on the yield and the content of NO_3.

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