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Impact of Afforestation on the Limitation of the Spread of the Pollutions in Ground Water and in Soils

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Abstract

The investigations were carried out from 1997 to 2001. It was shown the function of the leafy shelterbelt as biogeochemical barrier of total length 114 m by changes of different forms of nitrogen in soil (total, nitrate, ammonium and organic) and in the ground water under shelterbelt and also activity of urease in soil. This shelterbelt is located on two kinds of soil. It was found the impact of the edge of the shelterbelt on the changes of different forms of nitrogen in soil and in ground water and also activity of urease in soils. It was observed that the significant impact on the decrease of nitrogen in ground water and in soils exerts the distance from the edge of shelterbelt. The highest decrease of analyzed compounds was observed in the first sector of shelterbelt (16.5 m). Additionally the effect of eluted cations Ca^{+2} and Mg^{+2} on the compensation of pH value of the ground water was also observed.

Keywords: mid-field afforestation, biogeochemical barrier, different kinds of nitrogen in soil and in ground water, activity of urease, Ca^{+2} and Mg^{+2}.

Introduction

According to the long-term studies carried out in Wielkopolska seems, that the shelterbelts represent very efficient biogeochemical barrier limiting the migration of different chemical compounds from adjoining cultivated fields ground water [7, 13, 14]. Other authors [3, 4] estimated similar effect of shelterbelt and mid-field afforestation separated cultivated fields from watercourses in the migration of chemical compounds. The investigation of Prusinkiewicz et al. [6] revealed that trees take up chemical substances from ground water in different scale and this process is depend of the species. For example nitrates are the most taking up by pine, oak and birch. Ryszkowski and Bartoszewicz [9] suggested similar that forest with the predominance of needle trees decreases the content of nitrates and phosphates in ground water. Strong effect of trees on the limiting of spreading of chemical pollution in ground water is a result of developed root system, in which effective range there is more ground water than in root's system of cereal plants [15]. Ryszkowski and Kędziora [8] estimated that trees transpire 34% more water than cultivated fields and can strongly take up nutrients and effect on the change of concentration of chemical substances in ground water. The shelterbelts do not only decrease amounts of chemical compounds in comparison with the ground water under cultivated fields and also in soils under shelterbelts [9, 10, 11, 17, 18, 23, 25]. Independently of the observations significant influence of plants on the effect on the decrease of chemical substances in water under shelterbelt was also noted the impact of the type of soils on this process. Moreover during the investigation carried out in the Research Centre for Agricultural and Forest of Polish Academy of Sci-

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ences revealed the decrease of the evolution of the greenhouse gasses N_2O and CO_2 by shelterbelts in comparison with adjoining cultivated fields [14, 22].

Materials and Methods

Researches were carried out in the afforestation located in the Kościan Plain in Turew Park, which is a part of West Poland Lowland. The object of this study was ground water and soil under leafy afforestation. This afforestation includes different species of trees with the domination of the maple, ash, beech and hawthorn, but in the underground dominates elder lilac, companion crop of maple, ash and hawthorn. The afforestation is located on two different soils: mineral and mineral-organic (Tab. 1) and (Fig. 1). Samples were collected each month from 1997 to 2001. Total amount of yearly rainfall was in 1997 - 790 mm, 1998 - 824 mm, 1999 - 677 mm, 2000 - 670 mm, 2001 - 544 mm. Temperature ranged from 8.52 to 10.14 °C. Along the transect 125 m long passing through the afforestation the soils and water samples were taken in order to characterize chemical compounds (Tab. 1). The ground water was filtered by the filter paper Whatman GT/C and next determined pH, concentration Ca^{+2} and Mg^{+2} and organic and mineral carbon and the forms of nitrogen. Soil samples were taken near the piezometers from the layer at 0-20 cm depth. Soils were air dried and sieved by the 1 mm sieve. Organic carbon in ground water was tested using TOC 5050 analyzer (Shimadzu, Japan), but in soils using Tiurin method [17]. The content of organic carbon in ground water was 19.5 mg/l, and in mineral and in mineral-organic soils 0.9 and 4.6% respectively.

The following forms of nitrogen were analyzed: total, organic, ammonium and nitrate according to Hermanowicz

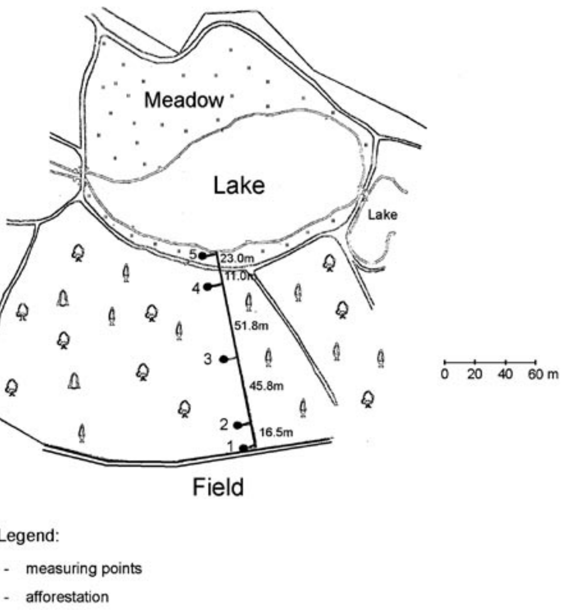

Fig. 1. The map of the afforestation.

Table 1. The kind of soils and the place of the sampling of soils and ground water.

Place of sampling	Kind of soil
Mineral soil	
I. In the bordary between field and afforestation	Division-autogenic soils, order-brown forest soils, type-hapludalfs, subtype-glossudalfs
II. 16.5 m from the edge	Division-autogenic soils, order-brown forest soils, type-hapludalfs, subtype-glossudalfs
III. 62 m from the edge	Division-autogenic soils, order-brown forest soils, type-hapludalfs, subtype-ochraquals
Mineral-organic soil	
IV. 104.0 m from the edge	Division-hydrogenic soils, order-post-bog soils, type-mucky soils, subtype-muckous
V. 125 m from the edge	Division-hydrogenic soils, order-post-bog soils, type-mucky soils, subtype-muckous

et al. [2]. Total nitrogen in soils was determined by the sulphuric acid mineralization method. Activity of urease in soils was estimated according to Hoffmann and Teicher [17].

Results and Discussion

The analysis of soil's pH under shelterbelt revealed significant effect of the type of soil on pH values. The mineral soils, which were present along transect to the first 62 m long from the edge of the afforestation characterize lower value of pH than that mineral-organic (Tab. 2). On the basic of pH mineral soils can be involved to the weak acidic (pH 5.2-5.9) and acidic (pH 3.3-4.9). Moreover pH of mineral-organic soils (8.8-7.9), classified these to neutral [16]. It is amazing, that did not find significant differences of pH values of ground water taken up from the piezometers located closely to places in which soils were analyzed. On the other hand, pH values of ground water under mineral and mineral-organic soils ranged from 6.19 to 8.10 and this classified these to neutral (Tab. 2). The reason of the higher compensation of pH values of water from the piezometers located on mineral soils in compare with the mineral-organic soils certainly influenced higher elution of the cations as Ca^{+2} and Mg^{+2} from mineral soils in compare with mineral-organic soils (Tab. 3). In the condition characterized by higher acidity of mineral soils there are higher release of Ca^{+2} and Mg^{+2} cations from inorganic complexes and complexes from organic matter into ground is observed. The concentrations of Ca^{+2} in ground water passing the shelterbelt decreased from 18 to

Table 2. pH in soils and in ground water from piezometers under shelterbelt.

The places of sampling	Years									
	1997		1998		1999		2000		2001	
	Soil	Water	Soil	Water	Soil	Water	Soil	Water	Soil	Water
I	5.6-6.1	7.3-7.8	5.2-5.9	7.1-7.9	4.5-5.1	7.2-7.9	4.3-5.3	7.2-7.8	4.1-5.3	6.2-8.2
II	4.1-4.9	7.0-7.8	3.3-4.0	7.2-7.7	3.3-4.1	7.0-7.7	3.3-4.0	7.0-7.7	3.4-3.9	6.9-8.0
III	4.4-5.2	7.0-7.6	3.9-4.2	7.0-7.6	3.7-4.3	7.0-7.5	3.7-4.2	7.0-7.7	3.5-4.4	6.5-7.9
IV	7.2-7.6	7.1-7.8	7.3-7.6	7.2-7.8	7.1-7.6	7.2-7.5	7.1-7.3	7.2-7.8	6.9-7.2	6.9-8.1
V	7.2-7.5	7.5-8.2	7.2-7.9	7.3-7.9	7.3-7.7	7.4-8.0	6.9-7.3	6.8-7.9	7.0-7.3	7.2-8.1

Where: the symbols I-V see in Table 1

Table 3. Mean contents of calcium and magnesium ions in ground water under shelterbelt (mg/l).

The places of sampling	Years									
	1997		1998		1999		2000		2001	
	Ca^{+2}	Mg^{+2}	Ca^{+2}	Mg^{+2}	Ca^{+2}	Mg^{+2}	Ca^{+2}	Mg^{+2}	Ca^{+2}	Mg^{+2}
I	278.87	61.29	239.62	50.88	173.06	35.61	179.22	46.24	152.40	36.77
II	176.52	23.88	143.68	18.30	262.65	46.34	219.78	38.36	202.49	36.17
III	147.78	20.49	129.02	19.62	142.02	22.14	132.75	34.47	119.00	24.92
IV	254.86	28.53	250.48	22.62	340.04	43.16	206.00	25.45	203.98	29.26
V	201.61	22.47	256.33	37.29	327.21	48.97	233.39	25.45	292.18	22.94

Where: the symbols I-V see in Table 1

Table 4. The content of total nitrogen in soils ($mg \cdot 100g^{-1}$) of soil and in ground water from piezometers under shelterbelt.

The places of sampling	Years									
	1997		1998		1999		2000		2001	
	Soil	Water	Soil	Water	Soil	Water	Soil	Water	Soil	Water
I	168.7	15.91	179.4	13.58	154.6	17.14	164.8	21.79	166.9	9.51
II	168.8	15.09	147.9	15.17	190.5	13.78	156.6	14.53	162.1	11.07
III	110.7	21.72	98.2	16.88	111.9	16.34	116.5	15.66	94.9	12.21
IV	234.2	19.58	243.3	19.02	170.8	23.45	210.4	21.84	183.3	16.98
V	276.3	9.23	311.4	13.81	310.5	19.91	274.4	16.54	296.5	9.06

Where: the symbols I-V see in Table 1

47%, moreover Mg^{+2} decreased from 25 to 66.5%. These cations eluted from soils contribute to the increase of pH of ground water. The strong decrease of Ca^{+2} and Mg^{+2} was observed in ground water under shelterbelt only in mineral soils. The ground water of mineral soils revealed the significant concentration of Ca^{+2} as well as Mg^{+2}.

The concentrations of total nitrogen in soils under the shelterbelt were investigated from 1997 to 2001. It was observed, relationship between the concentrations of N-total and the kinds of soil. In mineral soils characterized by lower concentrations of total nitrogen its contents ranged from 94.9 to 179 mg/100 of soils. In mineral–organic soils reached much higher content of organic matter than mineral soils and the contents of N-total were much higher and ranged from 170.8 to 311.4 mg/100g of soils. In mineral soils under the shelterbelt the content of total nitrogen decreased with an increase from the edge of the shelterbelt (Tab. 4). The highest decrease of the total nitrogen was observed in 1999 and was equal to 27.2%. The contrary direction of the changes of the total nitrogen was noted in mineral-organic soils. With an

Table 5. Activity of urease in soils under shelterbelt (μg urea hydrolyzed·g^{-1}soil·h^{-1}).

The places of sampling	Years				
	1997	1998	1999	2000	2001
I	6.4	3.8	5.2	7.6	6.2
II	2.9	2.7	5.9	5.7	4.5
III	3.0	2.2	3.7	5.2	4.3
IV	88.1	55.7	51.0	39.1	44.6
V	273.5	86.8	68.6	62.8	53.6

Where: the symbols I-V see in Table 1

Table 6. The concentrations of nitrates, ammonium and organic nitrogen in soil (mg/kg) under shelterbelt (mg N·100g^{-1} of soil).

The places of sampling	2000			2001		
	$N\text{-}NO_3^-$	$N\text{-}NH_4^+$	N-org	$N\text{-}NO_3^-$	$N\text{-}NH_4^+$	N-org
I	1.2	1.4	162.2	2.3	1.8	162.8
II	0.9	1.2	154.6	2.2	1.6	159.3
III	0.9	0.9	114.7	2.0	1.7	91.2
IV	1.0	1.3	208.1	2.5	2.2	178.6
V	1.2	1.4	271.8	2.7	2.4	291.4

Where: the symbols I-V see in Table 1

increase from the edge of the shelterbelt was determined the increase of the concentration of N-total from 15.3 to 45.0%. The highest increase was observed in 1999 and the lowest in 1997. This significant increase of the total nitrogen in 1999 results in deep of shelterbelt, where high level of the litter and its degradation impacts on the higher input of nitrogen. This phenomenon confirms the investigation of urease activity in soils. Urease is an enzyme participates in the hydrolytic degradation of urea. Ammonium ions created in this processes is included in fast conversion in soils such as nitrification and it is strong bond to clay minerals, which protect that for further conversion. In mineral soils the activity of this enzyme were ranged from 2.2 to 7.7 μg urea hydrolyzed·g^{-1}soil·h^{-1}, but in mineral-organic soils they were significant higher and ranged from 39.1 to 273.5μg urea hydrolyzed·g^{-1}soil·h^{-1}. The changes of the activity of urease in both kinds of soils under shelterbelt subjected to the similar changes, which were observed for total nitrogen (Tab. 5). In mineral soils affirmed the decrease of urease activity in the investigated period and ranged from 28.9 to 53.1%. Comparing the changes of urease in both kinds of soil revealed the regularity in simultaneous strong decrease of activity of this enzyme in mineral soils or significant the decrease of urease in mineral-organic soils [19, 20].

The concentrations of nitrate and ammonium ions in both kinds of soil under shelterbelt were similar (Tab. 6). In contrast with the total nitrogen and activity of urease were not observed the impact of the kinds of soil on the changes of the concentration of these ions. The investigation of the changes of ammonium ions in soils under shelterbelt were conducted during two years form 2000 to 2001. The changes of the nitrate and ammonium ions were similar in both kinds of investigated soil, which were observed earlier for the total nitrogen and the activity of urease. The highest decrease of the concentration of ammonium ions in soil were noted in 2000 and were equal to 55.5%,. But in 2001 the decrease was much lower and was equal to 5.6%. In mineral-organic soils the decrease of ammonium ions were similar in both analyzed years and was 71 and 8.3%, respectively. The changes of nitrate ions observed in 2000 in mineral and mineral-organic soils were higher than in 2001. The decrease of the concentrations of nitrate in 2000 in mineral soil was equal to 25% and was 1.9 times higher than in 2001. However the concentration of nitrate ions in mineral-organic soils increased 16.7% in 2000 and in 2001 only 7.4%. Probably it was the reason that 2000 was warmer and much wet than 2001. Higher moisture and temperature influenced on faster degradation of the litter under shelterbelt (Bernacki unpublished data). The decrease of ammonium ions and simultaneous with the increase of nitrate it just goes to shown that process of nitrification is continued. Szajdak et al. (2002) explained the changes of mineral and mineral-organic forms of nitrogen in soils under shelterbelt located on these two soils with aid of humification and biochemical activity. The highest biochemical activity and rate of humification was observed in the border between shelterbelt and adjoining cultivated field. With increase of

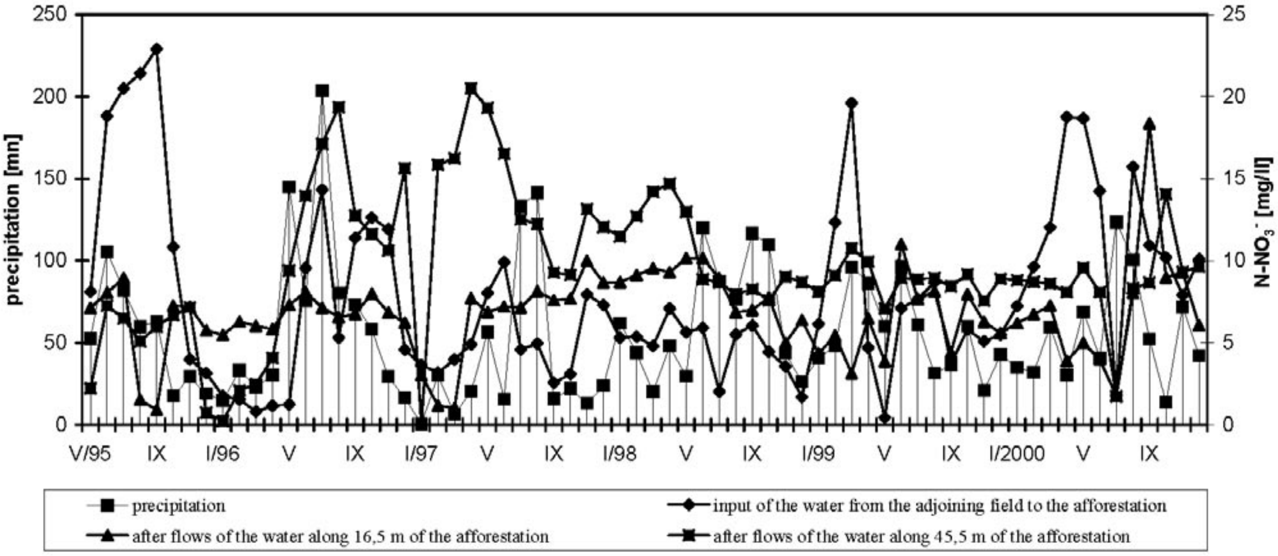

Fig. 2. Seasonal variation in the concentration of N-NO_3^- in ground water of the park-afforestation catchment during 1995-2000.

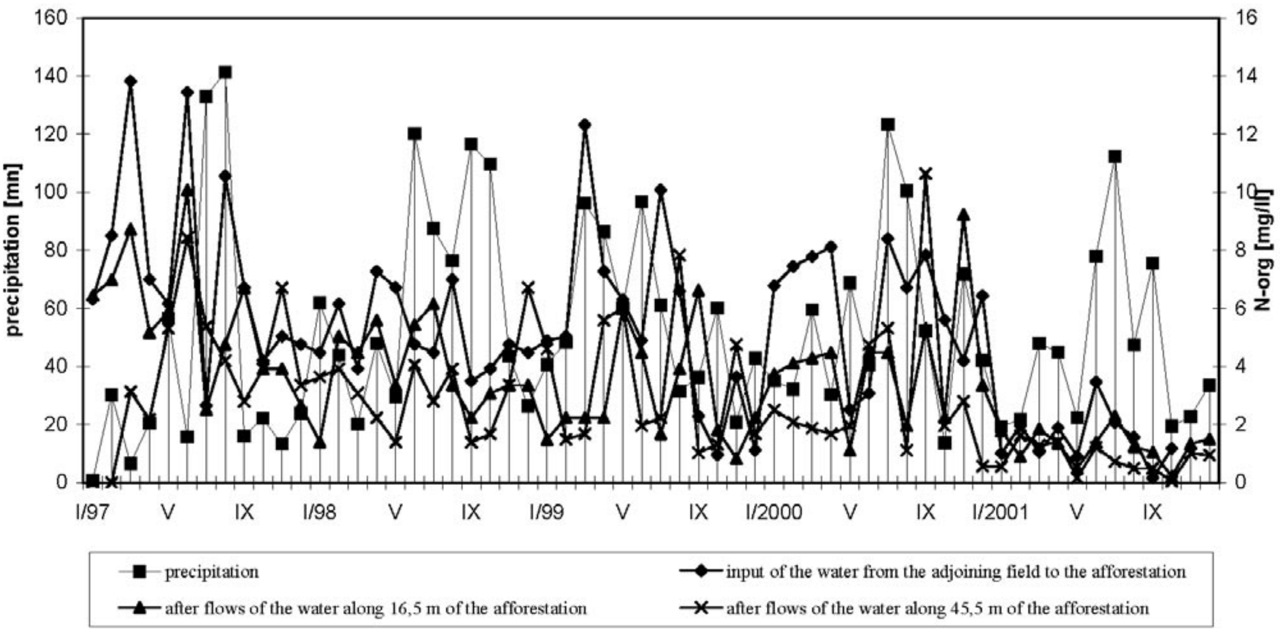

Fig. 3. Seasonal variation in concentration of N-org in ground water of the park afforestation catchment during 1997-2001.

the distance from the edge of the shelterbelt the biochemical activity and rate of humification decreased [21, 24].

At the same time ground water under the shelterbelt analyzed, which was taken from the piezometers located in different distance from the edge of the shelterbelt (Tab. 1). In ground water and in soil the same forms of nitrogen were analyzed. The mean content for 5 years of nitrate in ground water to swim up from adjoining field to shelterbelt was equal to 7.45 mg/l. Yearly mean contents of N-NO_3 were very diverse and ranged from 4.79 mg/l to 12.72 mg/l (Tab. 6). The highest concentration was measured in April 2000 after the Spring thaw, and was equal to 18.75 mg/l (Fig. 2).

In the concentrations of ammonium ions in ground water passes the shelterbelt did not observed any differences. Mean content for several years was equal to 3.24 mg/l. Yearly concentration ranged from 3.11 mg/l to 4.46 mg/l (Tab. 6). The highest concentrations were observed in June and July after longer rainfall in 1999 (9.66 mg/l) and in November 2000 (7.56 mg/l).

Mean content of organic nitrogen in ground water in the border between the field and afforestation for all the periods of the investigation was equal to 5.07 mg/l. But yearly mean content of organic nitrogen ranged from 1.54 to 7.43 mg/l (Tab. 6). The highest content was noted for nitrate in March after the spring thane in 1997 (13.38 mg/l) and in March 1999 (12.32 mg/l) (Fig. 3).

Table 7. The concentrations of nitrates, ammonium and organic nitrogen in ground water (mg/l) under shelterbelt.

The places of sampling	Years														
	1997			1998			1999			2000			2001		
	N-			N-			N-			N-			N-		
	$-NO_3$	$-NH_4$	-org	$-NO_3$	$-NH_4$	-org	$-NO_3$	$-NH_4$	-org	$-NO_3$	$-NH_4$	-org	$-NO_3$	$-NH_4$	-org
I	5.34	3.14	7.43	4.79	3.61	5.12	7.23	4.46	5.45	12.27	3.01	5.81	7.6	1.88	1.53
II	6.36	3.08	5.65	8.24	3.02	3.91	6.19	4.61	2.99	7.42	2.94	4.17	7.94	1.84	1.29
III	14.25	2.92	4.55	10.43	3.33	3.19	8.82	4.17	3.35	8.48	3.40	3.78	9.26	2.12	0.83
IV	12.19	2.69	4.79	13.12	3.42	2.48	16.22	3.93	3.39	15.48	3.08	3.22	14.34	1.96	0.68
V	3.11	2.52	3.61	4.74	4.77	4.59	11.10	3.61	4.76	8.51	3.53	4.55	5.92	2.15	1.00

Where: the symbols I-V see in Table 1

Mean content of N-total for all the periods of the investigations was equal to 15.75 mg/l. Yearly concentrations ranged from 11.01 mg/l (1998) to 21.09 mg/l (2000) (Tab. 6). The highest concentrations were observed in March after spring thane in 1999 (35.28 mg/l) as well as in 2000 (28.83 mg/l).

During flows the water passing 16.5 m first of the afforestation the concentrations of the form of nitrogen changed. The content of nitrate during 1997 and 1998 increased from 16 to 21%. In this time the rainfall was the highest (Fig. 2). But in 1999 and 2000 the concentrations of these substances decreased from 14 to 40%. These investigations revealed that in dry years during passing the ground water across afforestation the content of nitrate decreased, but in warm and wet years was observed input of nitrogen to the ground water from the litter. In these periods higher activity of urease was also measured in soil. The concentration of ammonium after passed through 16.5 m of afforestation significantly increased from 2 to 16% (Tab. 7). Very strong decrease 24% of nitrogen in 1997 and in 1998, but in 1994 the decrease of organic nitrogen reached to 45%. But in 2001 the decrease of organic nitrogen was 16% (Tab. 7). The decrease of the content of organic nitrogen in ground water after passed 16.5 m of the afforestation and simultaneous increased the nitrate (like in soil) might indicate the degradation of nitrogen compounds and nitrification [1, 5, 14, 22].

Ground water passes further 45.5 m of afforestation increased the content of nitrate. This phenomenon was the highest in 1997, where the content of nitrate increased over 2-times (Fig. 2). Organic nitrogen undergoes further changes from 9 to 19% (Tab. 7). The content of ammonium in ground water after passed further 45.5 m of the afforestation decreased only from 2 to 15%. The increase of nitrate in the ground water such as in soil after flows across further 45.5 m of afforestation indicates on the input of nitrogen to the ground water from the decomposition of the litter.

The results of Ryszkowski et al. [12, 14] suggested, that during wet and warm years significant degradation of the litter in afforestation is observed. The nitrogen compounds created as results of this process are the reason of significant input of nitrogen into the soil and ground water under leafy afforestation.

The ground water from piezometers No 4, which is located on mineral-organic soil and its distance from the edge of the shelterbelt is equal to 114 m contains the highest concentrations of nitrate. The concentration of nitrate increased from 36.0 to 38.0% compare to the concentrations of these compounds taken from piezometer No 3. However the content of ammonium and organic nitrogen were similar like in piezometer No 3. The fluxes of the concentrations of ammonium and organic nitrogen did not change significantly in this time.

The ground water taken from the piezometer No 5, which its distance of piezometer No 4 is equal to 21 m characterizes the highest decrease of nitrate, which in 1999 was 31.5% and in 1997, 74.5%, respectively (Tab. 7). It is very interesting, that this distance doesn't cover trees but only grass and the effect of shelterbelt is the strongest. This phenomenon indicates stronger effect of the decrease of nitrite by the meadow than by the leafy afforestation. Decrease of nitrate in ground water Peterjohn and Correll [4] explain by denitrification processes. It knows that on the intensity of the denitrification significant effect influence the content of organic matter in soil and in water in neutral or in weak basic conditions [1, 16, 21]. Our earlier investigations revealed, that ground water contains higher content of organic substances. Yearly mean content of organic substances during whole investigation period ranged from 43.34 mg/l to 58.62 mg/l [23]. Mineral-organic soils in compare with mineral characterized higher content of organic matter and basic values of pH. These conditions might accelerate processes of denitrification.

Conclusions

The investigations have shown that the function of leafy afforestation as biogeochemical barrier for migration of nitrogen forms is depended of the climatic condition.

1. In dry years the decrease of organic forms in ground water under shelterbelt was observed.
2. In wet and warm years the faster process of the degradation of the litter towards to the higher input of nitrogen to the soil and ground water.

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