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WASTEWATER PURIFICATION BY AN ORGANIC SOIL AND GRASS-MIXTURE

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Abstract. The paper presents results of a study concerning ammonium and nitrate(V) fixation by soil irrigated with municipal wastewaters (1 – 60 mm and 2 doses – 120 mm) and estimation of the possibility of using organic soil and grass-mixture for the wastewater treatment. It was found that the studied soil and the plant applied showed a very high capacity of binding ammonium ions (up to 96%), and lower in the case of nitrates(V) (up to 71%). It was also demonstrated that the single irrigation dose was better utilized compared to the double dose.

INTRODUCTION

There is a need, both from the ecological and the sanitary points of view, of reducing the content of nitrogen compounds in waters. In the face of the existing water deficit, actions are necessary, aimed at the protection of surface and underground water reserves from their contamination with insufficiently purified wastewaters. The strongest effect on the quality of waters is that of biogenic compounds of various origin that cause their eutrophication [28, 29]. Nitrogen leaching has been one of the issues of concern, due to its negative influence on ground water quality and the eutrophication of surface waters [9]. Nitrogen occurs in water in notable amounts, in two forms that are components of its natural circulation, i.e. in the form of ammonium nitrogen and of nitrate nitrogen. Short-term microbial immobilization can be a major player in regulation soil water N concentration in amended system [18].

Wastewater drainage to the ground is the oldest and the most natural form of its utilization. Soil is the fundamental acceptor of wastes generated in nature. Wastes purification utilizing the soil and plants is the result of complex processes – chemical, physical, physicochemical, biochemical – that take place in the unsaturation and saturation zone. The system constitutes a universal laboratory of matter transformations and energy flux. The wastewater is made to flow by gravity through a specially constructed wetland. There, the water is brought into close contact with vegetation (e.g. reed), which acts as a biological filter to the water. The organic material in the wastewater is used as nutrient by the plants.

One of the important methods of biogenic compound elimination is the use of purification plants that utilize soil and plants and the activity of specific microflora inhabiting the soil and plant roots, called "root-reed" treatment plants [5, 7, 11, 13, 15, 22, 30]

In Poland, development of wastewater treatment in constructed wetland inhabited by reed began towards the end of the 1970s [16, 17]. Currently in Poland there are about 300 wastewater treatment plants of this type in operation, in Europe about 10 000, while in the United States there are about 150 constructed wetland in one state, for example in Montana [2, 12, 19].

With the application of proper irrigations techniques, certain organogenic soils can be used in the third stage of wastewater purification. Worthy of recommendation is wastewater irrigation of muck soils and dried peat soils. Experiments performed on peat soils showed very good effects of wastewaters purification and good effects of meadow production [3].

The aim of the present work was to investigate ammonium and nitrate(V) fixation by soil irrigated with municipal wastewater and estimation of the possibility of using organic soil and grass mixture for wastewater purification.

MATERIAL AND METHODS

Studies on processes taking place under conditions of intensive irrigation of soil and plants with purified municipal wastewaters were conducted on an experimental object located in the Bystrzyca River valley. The object was irrigated with treated wastewaters from the city of Lublin, treated at the "Hajdów" treatment plant. Wastewaters from the particular plots of the experimental object were drained via a system of drainage pipes to a drainage ditch. The experiment included a number of plants and covered the area of 8 ha. This paper presents the results concerning grass mix I composed: meadow grass, reed canary grass, reed fescue, meadow fescue, smooth-stalked meadow grass, white bent grass, smooth-stalked bog grass. The experimental field was divided into three plots (A, B and C); plot A played the role of the control object and was not irrigated with wastewaters, plot B was irrigated with the single dose of wastewater (optimum total dose), while plot C – with the double dose of wastewater (double optimum dose). The plots were separated from one another by means of dykes to prevent water infiltration from the sedimentation tank of the treatment plant and from the river waters. The object was surrounded with a belt ditch on two sides – south-west and south-east. On the north-east side the role of the belt ditch was played by the drainage ditch collecting drainage waters from the particular plots of the experimental field. The drainage system covered the whole area of the object, the surface of which played the draining role. The outflow from the drainage ditch was directed on to the river. Wastewaters used for the irrigation were supplied by means of a pipeline to the supply ditch, then to the irrigation ditch that ran between dykes, and then, via inlets, to plots B and C. The experimental object was located on a muck soil developed from intensively mineralized peat. The muck layer had a depth of 35 cm, with mineral elements and ferruginous precipitations. Organic matter content in the muck varied from 15 to 56 g/100 g, $CaCO_3$ – 1–7 g/100 g, and pH in KCl was from 7.14 do 7.18. The density of soil was low, at 0.79 (± 0.04) $g \cdot cm^{-3}$. The ground water table was located at the depth of 60 cm. The water content of the soil at different water potential (0.1–1500 $kJ \cdot m^{-3}$) was determined by a standard Richards method in low- and high-pressure chambers (Soil Moisture Equipment Comp., Santa Barbara, USA). Water conductivity in the saturated zone of the soil was measured by means of a permeameter (Eijkelkamp Comp., The Netherlands), whereas unsaturated conductivity of the soil – with the TDR-meter (Easy Test Comp., Lublin, Poland) [23, 25].

In the course of the study the quality of municipal wastewaters used for irrigation was controlled. The wastewaters were characterized by low variability of physicochemical parameters, periodically slightly exceeding the concentration of eutrophic substances, yet fully suitable for soil irrigation within the framework of the experiment. Within the period of analyses, the concentration of ammonium ion varied from 1.56 to 10.8 mg NH_4^+-N·dm^{-3} and that of nitrate(V) ion from 14.6 to 23.2 mg NO_3^--N·dm^{-3}. Detailed characteristics of the wastewaters used for irrigation are given in Table 1 [10].

Table 1. Physicochemical quality of the treated wastewater [10]

Parameter	Unit	Range of value
pH	–	6.47–8.41
COD	[g O_2·m^{-3}]	30.1–56.3
BOD_5	[g O_2·m^{-3}]	8.3–22.6
N-NH_4^+	[g N·m^{-3}]	1.1–7.1
N-NO_3^-	[g N·m^{-3}]	20.2–38.4
N-tot	[g N·m^{-3}]	22.3–43.6
P-PO_4	[g P·m^{-3}]	3.1–6.8
P-tot	[g P·m^{-3}]	3.7–7.0
Na^+	[g Na·m^{-3}]	24.3–69.4
K^+	[g K·m^{-3}]	11.8–27.7
Ca^{2+}	[g Ca·m^{-3}]	59.7–95.2
Mg^{2+}	[g Mg·m^{-3}]	12.6–19.7
SO_4^{2-}	[g SO_4·m^{-3}]	43.6–116.3
Cl^-	[g Cl·m^{-3}]	67.8–121.6
Zn	[mg Zn·m^{-3}]	18–800
Cu	[mg Cu·m^{-3}]	6–198
Pb	[mg Pb·m^{-3}]	7–96

COD – chemical oxygen demand,
BOD_5 – 5 days biological oxygen demand

For the irrigation the wastewaters were applied in suitable doses, i.e. the full single dose was 600 mm, the double dose – 1200 mm, and the number of doses applied was 10. Purified wastewaters from the "Hajdów" treatment plant can supply biogenic compounds in amounts corresponding to intensive fertilization of soil; a dose of 600 mm supplies the soil with at least 180 kg·N·ha^{-1}, and a double dose, of 1200 mm, double that amount of nitrogen.

For calculation of hourly fixation of the analyzed nitrogen ions (mg·dm^{-3}·h^{-1}), the difference between the initial concentration and that after the first 24-hour period was adopted and then divided by 24. For calculations the first day from the moment of introducing the wastewaters was adopted, as the greatest drop in the concentration of the analyzed ions was observed during the first 24 hours of the experiment.

The index of efficiency of wastewater treatment (efficiency of removal) by the studied soil and plants was calculated as the difference in the concentration of the analyzed ion between the initial concentration and the final concentration (96 h), expressed as a percentage of the initial value. For comparison, the same method was applied for the calculation of the index of efficiency for the initial 24 hours from the moment of wastewaters introduction into the soil.

The linear ($y = a + bx$) and exponential ($y = e^{a+bx}$) models were used in the regression analysis and in each case the model with the highest R^2 was selected as the best fit for the experimental data.

RESULTS AND DISCUSSION

Hydrophysical characteristics of the soil

The hydrophysical characteristics of the soil on which the experiment was performed are presented in Figure 1. The shape of the water retention curve, i.e. the relation between water content in the soil and its potential, indicates that the studied soil is capable of holding notable amounts of water of all categories. The amount of free water, i.e. water subjected to the effect of gravity is 27% vol. that of capillary water – 55% vol., and inside it, water unavailable to plants, i.e. very strong bounded to soil – 30% vol. Such a characteristic of static hydraulic properties causes the dynamics of soil waters in the experimental object to be favorable. At full saturation of the soil with water, and thus with the wastewaters, outflow occurs at the rate of 183 cm·day^{-1}. When the level of ground waters goes down to 30 cm, they can filtrate at the rate of 3.5 cm·day^{-1}, and with the ground water table at 70 cm the rate of filtration is 3.1 cm·day^{-1}. Even at considerable drying of the studied soil, when it contains only water hardly available for plants, the filtration coefficient (K) is relatively high – 0.03 cm·day^{-1} [24].

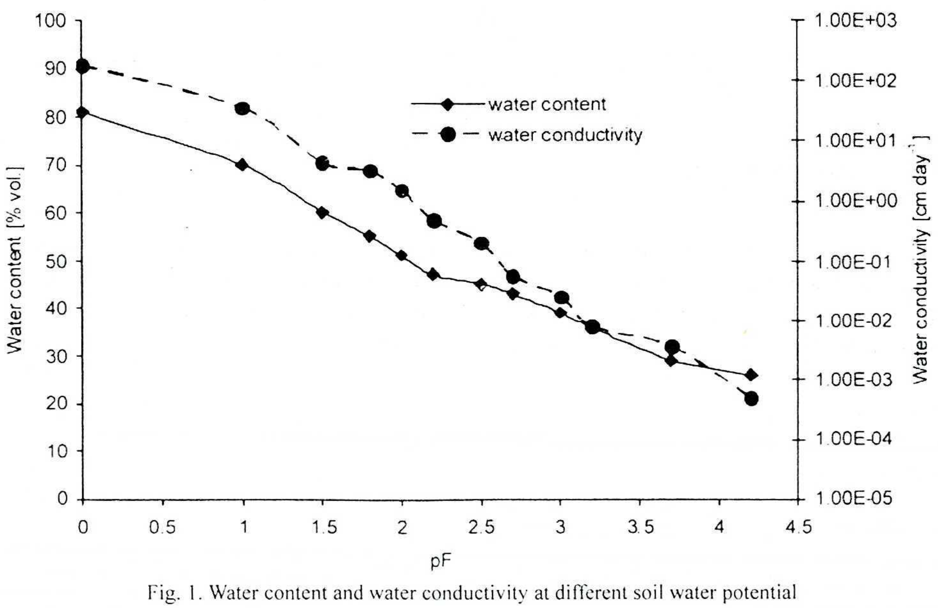


Fig. 1. Water content and water conductivity at different soil water potential

Concentration of ammonium ion in drainage waters

Ammonium ion concentration in the drainage waters from plots sowed with grass-mixture, flooded in the spring, summer and autumn with the single or double doses of wastewaters, is given in Figure 2. Additionally, the Figure shows also the concentration of NH_4^+ ion in drainage waters from the control object, where the concentration of the analyzed ion only slightly varied in time. In all analyzed cases the concentration of ammonium ion in drainage waters decreased to the value for the control plot, irrespective of the irrigation dose and of the time of its application. This indicates high sorptive capacity of the studied soil and of grass with relation to the NH_4^+ ion. Several studies have reported the effectiveness of grass buffer strips at controlling non-point sources of pollution (including N) from agriculture [1, 6, 8]. Studies have also reported that grass buffer system can be and important component of riparian buffer system [14, 20]. Włodarczyk and Kotowska [27] found decrease in the concentration of NH_4^+-N in the organic soil profile. With respect to their suitability in the process of wastewater purification, the plants grown in the experiment were arranged in the following decreasing order: grass mixture, willow and rape. It indicated that investigated grass mixture was well supplied with nitrogen and that the stands functioned as a vegetation filter. The time required for ammonium ion concentration to be reduced to a level similar to that of the control plot varied from 18 to 42 hours and did not depend on the initial concentration level and the wastewater dose applied. During summer time ammonium ion concentration decreased rapidly in the first 18 hours and then slightly increased to 42nd hour of experiment. The N mineralization process predominate over immobilization was observed. Analysis of ammonium ion concentration in the function of time showed, in a few cases, significant correlations, where the determination coefficient varied from $R^2 = 0.70$ ($P < 0.05$) to $R^2 = 0.97$ ($P < 0.001$). Earlier studies conducted on the same object [26] showed that NH_4^+ concentration in the soil solution of the profile depended on the time of filtration with a clear downwards trend of the level of its concentration. This fact is evidence for ammonium ion utilization by plants and microbes and for its facility of entering into biochemical reaction. Ammonium ion concentration in drainage waters from the control plot was virtually constant within the period of the experiment, which indicates certain equilibrium between the processes of mineralization and of immobilization of the ammonium ion.

Considering the diurnal reduction in the level of the ammonium ion in the wastewaters used for irrigation of plots B and C for the first 24 hours from the moment of introduction of wastewaters, it varied from 0.053 to 0.325 mg NH_4^+-N·dm^{-3}·h^{-1} (Fig. 3). The greatest reduction in the level of ammonium ion during the first day from the moment of flooding was observed in the autumn period, and the lowest in spring. Utilization of the single dose of wastewaters (Plot B) was slightly more effective compared to the double dose (Plot C).

From the viewpoint of ground waters protection, it was of interest to determine the purified effect by the studied soil and the plant, especially after the first 24 hours from the moment of wastewaters application, as in this case time is also a significant factor in the aspect of environment protection. Analyzing the percentage of absorbed ammonium ion one can find that the studied object had a very high capacity of reducing the concentration of NH_4^+ ion in the wastewaters. That percentage varied from 72 to 93% and from 85 to 96%, respectively, for the first day from the moment of wastewater introduction and the last day for plot B, and from 70 to 81% and from 82 to 96% for analogous times of

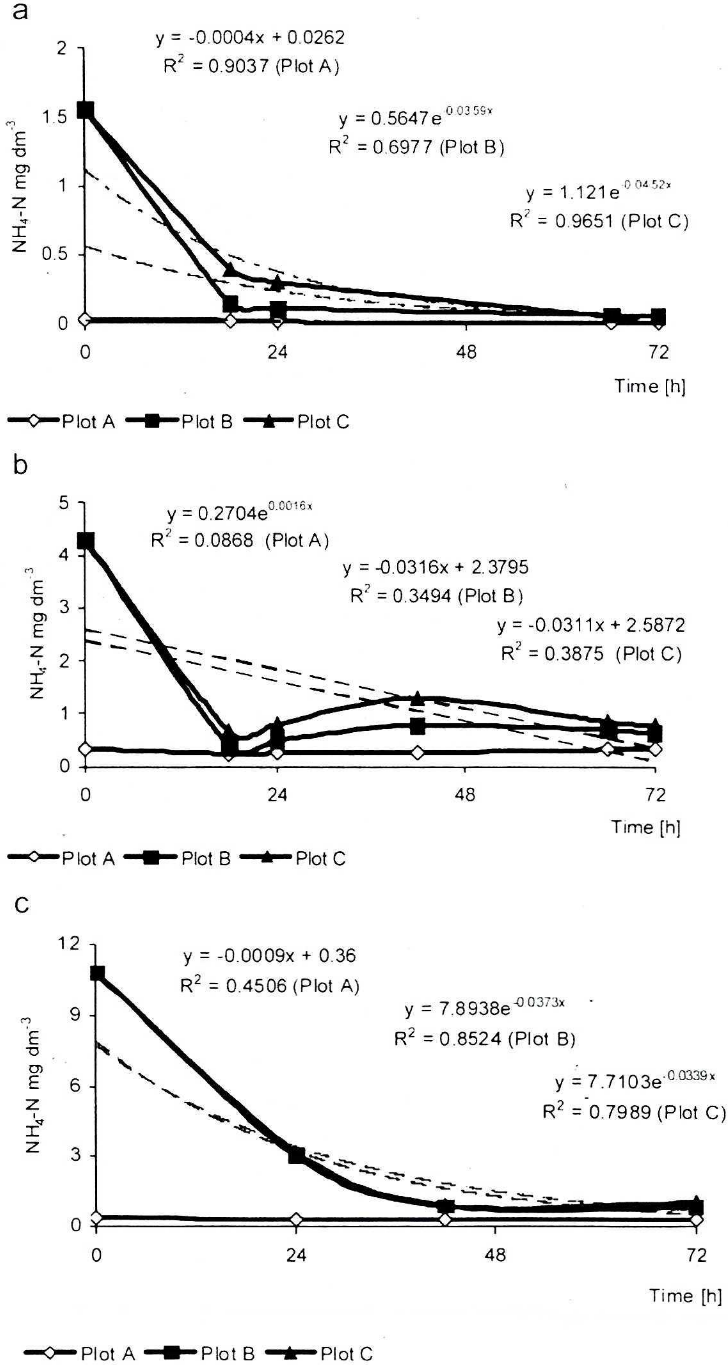


Fig. 2. Concentration of NH_4^+-N [mg·dm^{-3}] in drainage waters as a function of time and irrigation dose during a) spring, b) summer c) autumn time

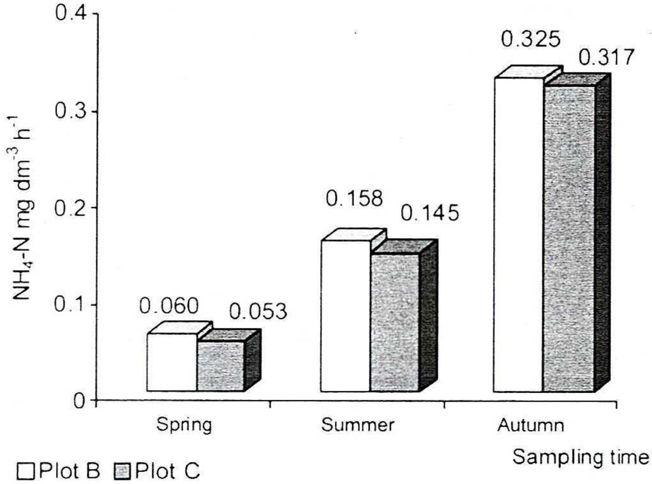


Fig. 3. Rate of reduction of NH_4^+-N [mg·dm^{-3}·h^{-1}] in drainage waters with relation to irrigation dose and season of the year for the first 24 hours of the experiment

analyses for plot C with relation to the dose introduced in the soil with the wastewaters. Higher purified effect was observed in the lower dose of wastewaters application (plot B) than in higher dose (plot C) especially in the initial period of purification. Worthy of emphasis is the very high efficiency of wastewaters purification by the studied object already after 24 hours from the moment of wastewater application, comparable at most times of analysis with the final effect (Fig. 4).

Concentration of nitrate(V) ion in drainage waters

Nitrate(V) ion concentration in drainage waters from plots sowed with grass-mixture, flooded in the spring, summer and autumn seasons with the single and double doses of wastewaters is presented in Figure 5. Additionally, the Figure shows the concentration of NO_3^- ion in drainage waters from the control plot, where the concentration of the ion in question varied only slightly within the period of analyses. Analyzing the reduction in the level of nitrate(V) ion in drainage waters, an extension of the process in time was observed as compared to ammonium ion, which may be related, among other things, to a different charge of the studied ions. Nitrate(V) ion, being an anion, is not fixed by the sorptive complex of the soil, and thus we are dealing here mainly with its biological immobilization which is notably slower and affects the rate of the reduction of NO_3^- in the wastewater during its migration down the soil profile. Therefore, the concentration of nitrate(V) ion in the function of time showed a very high coefficient of determination (varying from $R^2 = 0.61$, $P < 0.05$ to $R^2 = 0.99$, $P < 0.001$) for both the single and the double irrigation doses. The studied soil showed a somewhat higher activity in transformations of NO_3^- ion in the first 24-hour period from irrigation, especially in the case of a single dose of wastewaters. After 72 hours from wastewater irrigation the NO_3^- concentration in drainage waters was from 2 to 7 fold higher in B and C plots than in the control one and differed depending on the season of the year. The ultimate purified effect of the

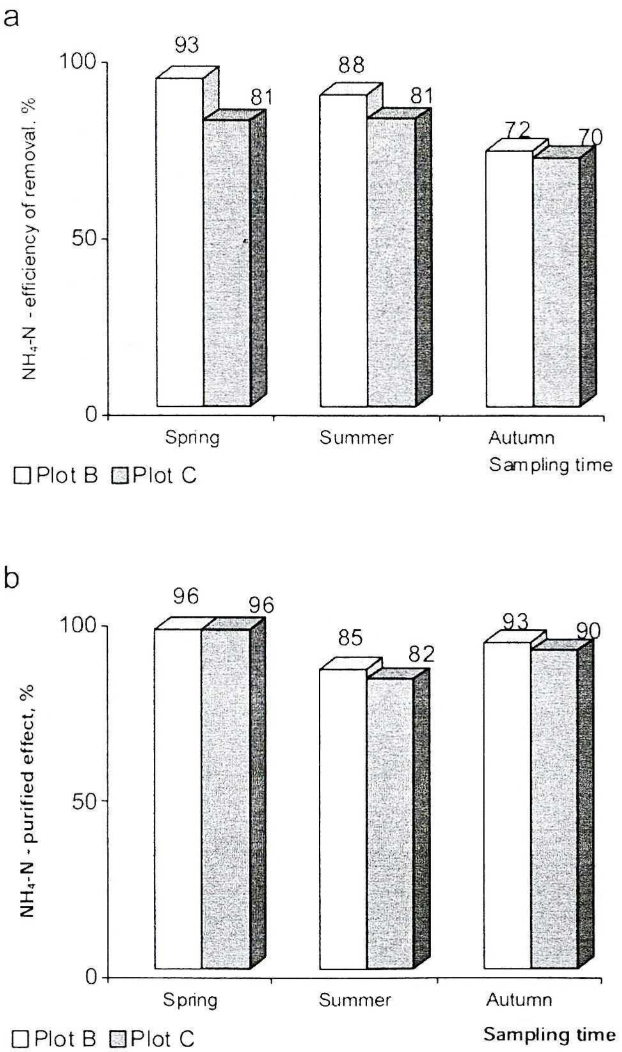


Fig. 4. Effect of wastewaters purification for ammonium ion [%] a) during the first day and b) at the end of the experiment

wastewater, expressed in the concentration of nitrate(V) ion in the drainage waters, is a resultant of the biological activity of the soil profile over the whole extent of its infiltration path. Results obtained by Yang *et al.* [29] showed that soil of 0–60 cm depth is an active rhizoplane, with strong capability to remove nitrogen. Włodarczyk and Kotowska [26] found decrease in the concentration of NO_3^--N in the organic soil profile. With respect to their suitability in the process of wastewater purification, the plants grown in the experiment can be arranged in the following decreasing order: grass mix, rape and willow.

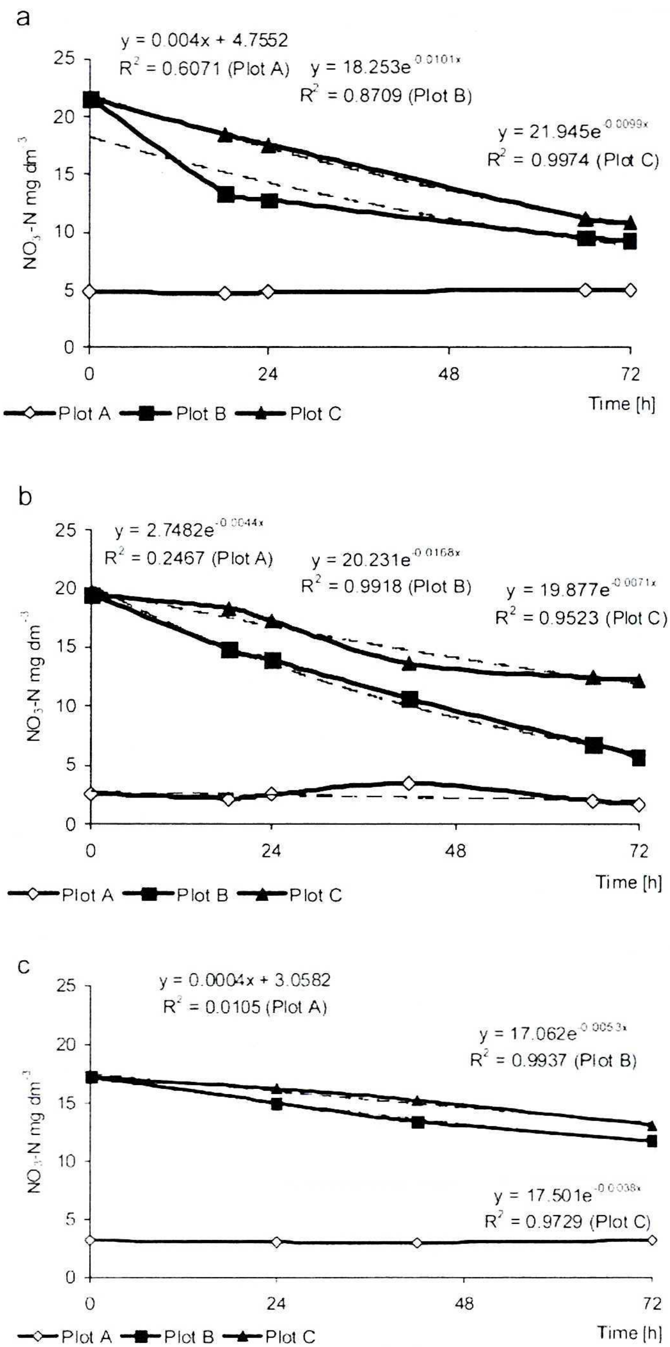


Fig. 5. Concentration of NO_3^--N [mg·dm^{-3}] in drainage waters as a function of time and irrigation dose durin a) spring, b) summer c) autumn time

Considering the diurnal reduction in the level of NO_3^- ion in the wastewaters for the first 24 hours from the moment of their introduction (Fig. 6) a notable effect of the season of the year and of the irrigation dose applied on the rate of NO_3^- immobilization was observed. The highest rate of NO_3^- reduction in the plot with the single and double dose was recorded in the spring season, and the lowest in the autumn. In the spring period the strongest effect was observed of the irrigation dose on the rate of immobilization of nitrate(V) ion. In all analyzed cases a higher rate of NO_3^- reduction was observed for a single irrigation dose. Probably in the case of double dose of irrigation was observed inhibition effect on microbiological processes by substrate.

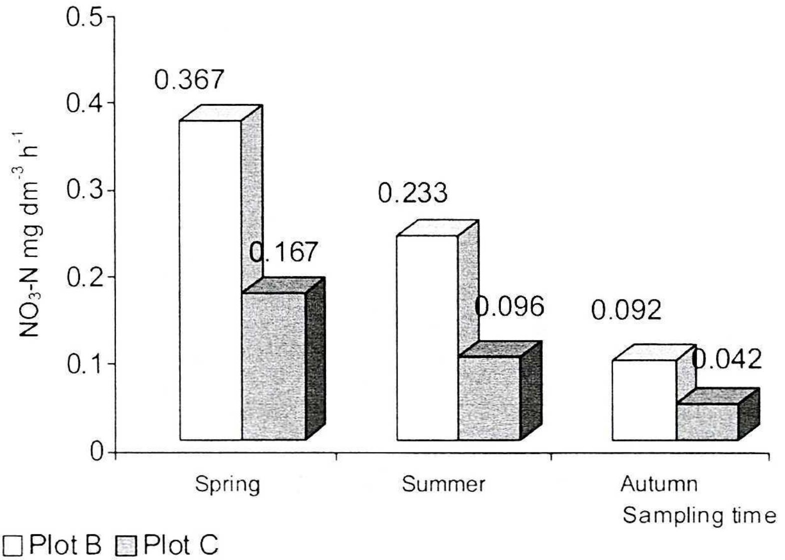
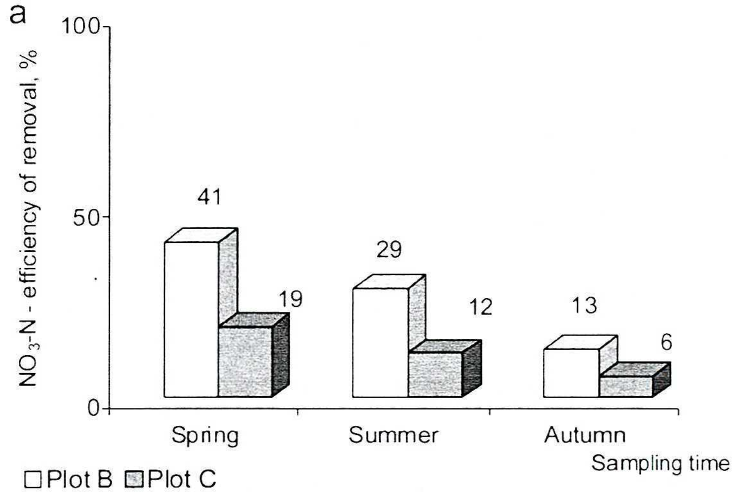


Fig. 6. Rate of reduction of NO_3^--N [$mg \cdot dm^{-3} \cdot h^{-1}$] in drainage waters with relation to irrigation dose and season of the year for the first 24 hours of the experiment

Considering the reduction in the level of nitrate(V) ion (purified effect) (Fig. 7), much lower effect of wastewater purification was observed in comparison to the ammonium ion, caused – among other things – by its mobility related to the negative charge of the NO_3^- ion. The percentage of immobilization of the nitrate(V) ion varied from 13 to 41% and from 32 to 71%, respectively, for the first day from the moment of wastewater introduction and the last day for plot B, and from 6 to 19% and from 24 to 50% for analogous times of analyses for plot C with relation to the dose introduced in the soil with wastewaters. In general, it can be stated that NO_3^- ion immobilization was higher in spring and lower in summer and in autumn at the first 24 hours from irrigation. Considering all time experiment the purified effect was highest during summer time and the lowest one during autumn. A higher purified effect of wastewaters was observed with the application of a single dose, both in the case of immobilization during the first day from the wastewaters application and in the final effect. In the case of the nitrate(V) ion we can speak of its reduction due to the process of denitrification, among others. Earlier studies [27] showed a significant relationship between the redox potential and nitrogen transformation taking place in soil irrigated with wastewater after 2^{nd} stage of treatment. Irrigation with wastewater results in a decrease of Eh value in the whole soil profile, causing a reduction of redox potential value below the level of + 200 mV, especially in lower horizons, corresponding to dissimilative reduction of nitrate(V) to the forms of N_2O and N_2. Studies by Stępniewska *et al.*, [21] conducted under the conditions of the experimental object Hajdów, indicated N_2O emission up to 208 ppm following irrigation with a double dose of wastewaters. The capacity of that soil for dissimilative reduction of nitrates was also demonstrated by Brzezinska [4] in a model experiment.



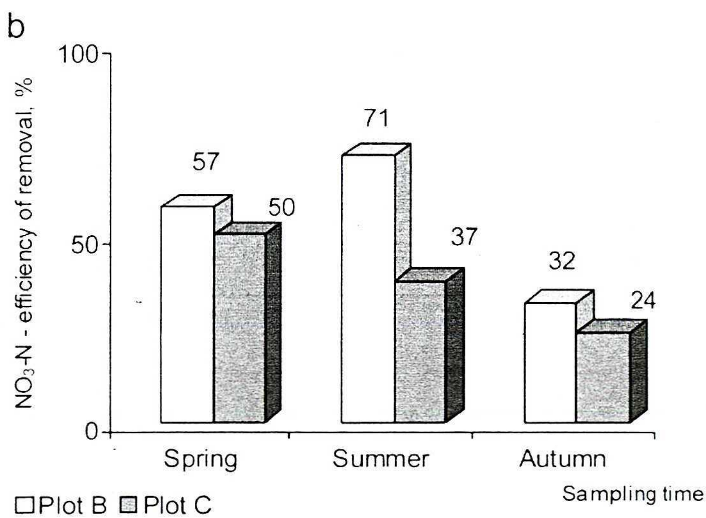


Fig. 7. Effect of wastewaters purification for nitrate(V) ion [%] during a) the first day and b) at the end of the experiment

CONCLUSIONS

- The amount of water (wastewater) subjected to the effect of gravity is about 27% vol., that of capillary water – 55% vol.
- At full saturation of the wastewater, the outflow occurs at the rate of 183 cm·day^{-1}. When the water ground level goes down to 30 cm, water can move at the rate of 3.5 cm·day^{-1}, and with the ground water table at 70 cm – unsaturated conductivity coefficient is equal 3.1 cm·day^{-1}.
- The concentration of analyzed ions (NH_4^+ and NO_3^-) in drainage waters from the control plot varied only slightly in time.
- The concentration of the NH_4^+ in drainage water dropped to the level of the control plot, irrespective of the irrigation dose and of the season of application but NO_3^- concentration in drainage water was from 2 to 7 times higher in B and C plots than in the control one.
- An effect of the season of the year on the final purified effect was observed.
- The studied soil and the applied plant showed very high capacity of fixing ammonium ion (up to 96%), but a lower capacity in the case of nitrates(V) (up to 71%).
- The single dose was utilized to a greater extent than the double dose.

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OCZYSZCZANIE ŚCIEKÓW MIEJSKICH W GLEBIE ORGANICZNEJ OBSADZONEJ MIESZANKĄ TRAW

W pracy przedstawiono wyniki badań dotyczące oczyszczania ścieków miejskich w glebie organicznej obsadzonej mieszanką traw (wyczyniec łąkowy, mozga trzcinowata, kostrzewa trzcinowa, kostrzewa łąkowa, mietlica biaława, wiechlina łąkowa i wiechlina błotna). Doświadczenie prowadzono na 3 kwaterach (A – kontrola, B – zalewanie pojedyncza dawką ścieków – 60 mm, C – zalewanie podwójną dawką ścieków – 120 mm). Badano stężenie jonów NH_4^+ i NO_3^-. Stwierdzono, że badana gleba i zastosowana mieszanka traw wykazują znaczne możliwości do wiązania zarówno jonu amonowego (do 96%) jak i azotanowego (do 71%). Wyższe wskaźniki wiązania jonów uzyskano dla pojedynczej dawki ścieków miejskich niż dla dawki podwójnej.