The effectiveness of N-fertilization and microbial preparation on spring wheat

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ABSTRACT

The efficiency of the application of microbial preparations enhancing soil properties as well as the diversified fertilization of spring wheat nitrogen was evaluated in the field experiment. Factors of the experiment referred to the levels of nitrogen fertilization: 0, 40, 80, 120 and 160 kg/ha as well as the application of microbial preparations, namely, Proplantan (disaccharide, and polysaccharide, lactic acid, carotene, riboflavin, thiamine, amylase, sea salt, minerals), Effective microorganisms (milk bacteria, photosynthetic bacteria, yeast, actinomycetes, moulds) and UG_{max} microorganisms (lactic acid bacteria, photosynthetic bacteria, nitrogen-fixing bacteria, actinomycetes, macro- and microelements). The quantity of N_{min} in the soil layer of 0–0.9 m ranged in respective years from 72.8 to 98.5 kg/ha before the spring wheat seeding and from 58.6.8 to 68.2 kg/ha after the crop was harvested, whereas the amount of N mineralization ranged from 18.9 to 53.3 kg/ha. Grain yields of wheat developed at a high level from 3.26 to 8.31 t/ha. To create the biomass, spring wheat plants absorbed nitrogen ranging from 78 kg N/ha in objects not fertilized to 184 kg N/ha in objects fertilized with the dose of 160 kg N/ha, and the share of nitrogen accumulated in the seeds amounted on average to 82% of the total uptake of that element. The highest N use efficiency, N physiological efficiency, N agronomic efficiency and N apparent recovery fraction were detected in objects fertilized with the dose of 40 kg N/ha. Each increase in the level of nitrogen fertilization affected lowering of the values of evaluated fertilization efficiency ratios.

Keywords: grain yield; N uptake; N mineralization; performance indicators fertilization

Nitrogen constitutes a most important fertilization macroelement considerably modifying the amount and quality of yield, and is responsible for the environment contamination. Agro-ecosystems face dynamic changes of the content of N_{min} in soil resulting from the uptake of that element by crop plants, weeds and soil microorganisms, losses resulting from leaching and volatilization, as well as the inflow of nitrogen as a consequence of mineralization of the organic matter, the emission of nitrogen compounds from the atmosphere and fertilization (Deng et al. 2000). Mineral fertilizers constitute the main source of nitrogen for crop plants. The average uptake of nitrogen by cereals, including wheat, is low and amounts to about 33% (Raun and Johnson 1999). Nitrogen that is not absorbed by crop plants or soil microorganisms undergoes numerous processes, in the effect of which a considerable amount of nitrogen is subjected to losses (Sztuder and Strączyński 2008). Moreover, nitrogen in the soil environment exerts a considerable influence on the number, as well as quality selection of soil microorganisms. A high level of fertilization with mineral nitrogen evokes recession of, on average, 50% of the number of *Azotobacter* and *Streptomyces* bacteria, total destruction of *Artrobacter*, *Rhizobium* and *Bradyrhizobium* bacteria, and an increase of the biomass of *Eubacterium*, *Pseudomonas*, *Bacillus* microorganisms as well as *Aspergillus*, *Fusarium*, *Penicillium* and *Verticillium* fungi (Barabasz et al. 2002). It leads to a disturbance of microbiological balance, and consequently to soil degradation. Elaboration of methods of restoring the soil biological activity constitutes a challenge for agricultural practice. The literature shows that the application of microbial preparations enhances physical and chemical properties of soil, improves assimilability of compounds hardly available to plants as well as it increases the amount and improves the quality of crops (Tokeshi et al. 1998, Shah 2001, Javaid and Shah 2010).

The efficiency of nitrogen fertilization is evaluated most often with respect to the amount of qualitative or quantitative changes in grain yield. However, a thorough evaluation of the results of fertilization requires a wider approach. Thus the purpose of conducted studies was to determine the grain yield of wheat, N uptake and nitrogen fertilization performance indicators.

MATERIAL AND METHODS

Experimental designs and agronomic management. Field experiment was conducted in the Experimental Station of the Agricultural University in Krakow, Poland (50°07'N, 20°05'E) in 2006–2008. Factors of the experience included the levels of nitrogen fertilization (0, 40, 80, 120 and 160 kg/ha) as well as the application of microbial preparations: Proplantan (AM); Effective microorganisms (EM) and UG_{max} microorganisms soil-applied before the spring cultivation and afterwards, mainly in the phase of the first node (BBCH 31–32) in the total dose of 3 L/ha. The preparations shall be respectively referred to as AM, EM and UG_{max}. Proplantan contains disaccharide, and polysaccharide, lactic acid, carotene, riboflavin, thiamine, amylase, sea salt and minerals. Effective microorganisms preparation contains milk bacteria (*Lactobacillus casei*, *Streptococcus lactis*), photosynthetic bacteria (*Rhodopseudomonas palustrus*, *Rhodobacter space*), yeast (*Saccharomyces albus*, *Candida utilis*), actinomycetes (*Streptomyces albus*, *S. griseus*) and moulds (*Aspergillus oryzae*, *Mucom hiemalis*). UG_{max} soil fertilizer contains yeast, lactic acid bacteria, photosynthetic bacteria, bacteria of *Azotobacter*, *Pseudomonas*, actinomycetes, macroelements (g/L): K – 3.5; N – 1.2; S – 1.0; P – 0.5; Na – 0.2; Mg – 0.1 and microelements (mg/L): Zn – 20.0; Mn – 0.3.

Prior to performing the spring tillage, phosphorus and potassium fertilizers were applied, namely: 26 kg P/ha; 91 kg K/ha; and the pre-sowing nitrogen fertilizing was carried out with a 40 and 80 kg/ha (ammonium nitrate). The objects fertilized with doses of 120 and 160 kg N/ha, applied before sowing 80 kg N/ha (ammonium nitrate), and the rest of the top dressing in the stage of stem elongation (30 and 60 kg N/ha in the form of ammonium nitrate) and heading (10 and 20 kg N/ha in the form of urea). Evaluated spring wheat cv. Bombona.

Soil and meteorological conditions. The soil type on the experimental field was a Luvic Chernozem. Arable layer of soil was characterized by a slightly acidic reaction, a medium phosphorus and potassium, and high magnesium content (Table 1).

The vegetation period in 2006 was characterized by the average air temperature higher by 0.9°C and lower rainfall total than the multiannual average by 70 mm (Figure 1). In 2007, the period from April to August was characterized by the highest air temperature and the total precipitation approximating the multiannual average. On the other hand, in a three-year cycle of the research the vegetation period of spring wheat in 2008 was characterized by the highest average air temperature and the total rainfall, whereas a considerably deficient rainfall amount occurred in May and June.

Plant and soil analysis. Soil samples were collected prior to wheat-sowing and from each wheat plot after harvesting, to a depth of NO_3-N and NH_4-N in a 0–0.9 m. Soils were analyzed for nitrate and ammonium content using colorimetric method. The amount of nitrogen from mineralization was calculated as the difference between

Table 1. Soil characteristics of Luwic Chernozems from traial location (0–0.25 m layer)

Properties	Value
pH_{KCl}	6.1
Total organic C (g/kg)	10.2
Total N (g/kg)	1.14
C:N ratio	8.9
P (mg/kg)	65.3
K (mg/kg)	140.4
Mg (mg/kg)	67.5
Sand (g/kg)	120
Silt (g/kg)	540
Clay (g/kg)	340

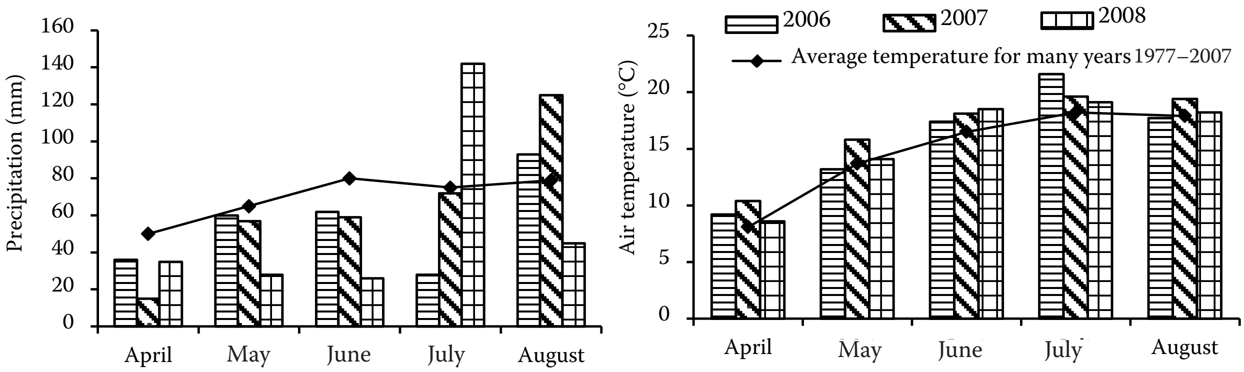


Figure 1. Meteorological conditions during study in the 2006–2008

the content of mineral nitrogen in the soil before sowing and after harvesting and the total uptake of this component in the spring wheat crop in control (0 kg N/ha) plots. The nitrogen content in plant material was determined by the Kjeldahl method.

The following parameters were calculated for each treatment:

N use efficiency (NUE; kg/kg) as the ratio of yield to N supply.

N agronomic efficiency (NAE; kg/kg) as the ratio of (yield at N_x – yield at N_0) to applied N at N_x.

N physiological efficiency (NPE; kg/kg) as the ratio of (yield at N_x – yield at N_0) to (N uptake at N_x – N uptake at N_0).

N apparent recovery fraction (NRF; %) as the ratio of (N uptake at N_x – N uptake at N_0) to applied N at N_x.

Statistics. The results were statistically analyzed by the variance analysis method using the Statistica 10.0 software. Honestly significant difference (*HSD*) for the wheat grain yield and N-efficiency parameters were verified using the Tukey's test at significance level $P = 0.05$.

RESULTS AND DISCUSSION

Soil N supply. The amount of mineral nitrogen appearing in soil up to the depth of 0.9 m, before spring wheat sowing ranged in respective years from 72.8 to 98.5 kg N/ha, and after harvesting it ranged from 58.6 to 68.2 kg N/ha (Table 2). The application of AM and EM preparations affected the reduction of the content of mineral nitrogen in soil after wheat harvesting. Mineral nitrogen levels reported significantly diversify the content of this element in the soil after harvest of spring wheat. The lowest amount of nitrogen in soil was reported in plots not fertilized with that element, whereas the highest amount was reported after the application of 160 kg N/ha.

The amount of soil nitrogen derived from mineralization of organic matter was considerably verified in individual years of the research (Table 2). The highest amount of nitrogen from that source of inflow was reported in 2006, amounting on average to 53.3 kg/ha, whereas the lowest amount was reported in 2008, amounting on average to 18.9 kg/ha. Low inflow of nitrogen in the vegetation period of spring wheat in 2008 could result from deficient precipitation amounts in April, May and June. This fact has a significant meaning, as according to Bloem et al. (1994), mineralization of nitrogen takes place most intensively within the period from April to June. The significance of the influence of weather conditions on the amount of inflow of nitrogen from mineralization processes was stated additionally by Kolberg et al. (1999), Sieling et al. (1999) and López-Bellido and López-Bellido (2001). In the conducted research the attempt to increase microbiological activity of soil through the application of microbial preparations did not result in the intensification of N mineralization. The reason of the above mentioned phenomenon could result from bigger N immobilization than N mineralization by soil microorganisms.

Grain yield. The optimal amount of rainfall for wheat cultivated in heavy soil conditions in the period from April to June ranges from 151 mm to 200 mm. During the three-year period of research the greatest grain yield, on average to 6.44 t/ha was obtained in 2006 (Table 2), when the rainfall total from April to June was 186 mm. The lowest grain yields, amounting on average to 5.23 t/ha, were obtained in 2008, the year that was characterized by the total rainfall within the analogical period 231 mm.

The level of nitrogen fertilization considerably influenced the grain yield of spring wheat. The

Table 2. Mineral nitrogen in soil, N mineralized (0–0.9 m), wheat grain yield, N uptake, N use efficiency (NUE), N physiological efficiency (NPE), N agronomic efficiency (NAE) and N apparent recovery fraction (NRF)

Treatment	N_{min} in the soil sowing (kg/ha)	N_{min} in the soil harvest (kg/ha)	N mineralized (kg/ha)	Grain yield (t/ha)	N uptake grain (kg/ha)	N uptake total (kg/ha)	NUE (kg/kg)	NPE (kg/kg)	NAE (kg/kg)	NRF (%)
Microbial preparation										
Control	84.0^{a}	68.3^{a}	38.3^{a}	5.52^{c}	109^{b}	133^{b}	27.7^{c}	43.4^{ab}	33.4^{b}	77.2^{a}
AM	83.3^{a}	60.3^{b}	36.7^{a}	5.91^{a}	114^{a}	136^{ab}	30.1^{a}	45.0^{a}	33.0^{b}	72.6^{b}
EM	86.5^{a}	61.3^{b}	38.0^{a}	5.92^{a}	113^{a}	138^{a}	29.7^{a}	41.5^{b}	30.6^{c}	71.2^{b}
UG_{max}	83.6^{a}	66.3^{a}	36.5^{a}	5.66^{b}	111^{ab}	137^{a}	28.6^{b}	45.8^{a}	36.0^{a}	77.1^{a}
N rate (kg/ha)										
0	84.8^{ab}	43.2^{e}		3.40^{e}	65^{e}	78^{e}	28.0^{b}			
40	84.4^{ab}	55.5^{d}		5.24^{d}	93^{d}	113^{d}	32.4^{a}	54.2^{a}	45.8^{a}	82.8^{a}
80	82.0^{b}	63.7^{c}		6.32^{c}	118^{c}	141^{c}	31.7^{a}	46.8^{b}	36.5^{b}	78.9^{a}
120	83.5^{ab}	73.4^{b}		6.79^{b}	135^{b}	163^{b}	28.2^{b}	39.7^{c}	28.2^{c}	70.8^{b}
160	87.0^{a}	84.3^{a}		7.02^{a}	149^{a}	184^{a}	24.7^{c}	34.9^{d}	22.6^{d}	65.5^{c}
Year										
2006	72.8^{c}	58.6^{b}	53.3^{a}	6.44^{a}	118^{a}	145^{a}	31.0^{a}	58.1^{a}	43.6^{a}	74.7^{a}
2007	81.7^{b}	68.2^{a}	40.0^{b}	5.60^{b}	111^{b}	135^{b}	28.8^{b}	38.1^{b}	30.1^{b}	74.7^{a}
2008	98.5^{a}	65.4^{ab}	18.9^{c}	5.23^{c}	106^{c}	128^{c}	27.2^{c}	35.5^{c}	26.2^{c}	74.2^{a}

Values followed by the same letters do not differ at 5% level of significance. AM – Proplatan; EM – Effective microorganisms; UG_{max} – microorganisms

highest rise in yield with regard to the controlled area was reported after the application of the dose of 40 kg N/ha, amounting on average to 53.8% for the years of research. The average increase in grain yield of spring wheat fertilized with the dose of 80 kg N/ha amounted to 20.8% in comparison to the yield of wheat fertilized with the dose of 40 kg N/ha. The application of doses of 120 and 160 kg N/ha resulted in an increase of the grain yield with regard to the lower dose, by 7.3% and 3.5%, respectively. Natural soil fertility constitutes a factor reducing the efficiency of high doses of nitrogen. Additionally, the research indicated a significant influence of microbial preparations on the yield of spring wheat grain. The highest increase in grain yield was reported in plots where AM and EM preparations were applied, by 0.39 and 0.40 t/ha, respectively, whereas the lowest increase was reported after the application of UG_{max}, amounting on average to 0.14 t/ha.

It was also a significant interaction between microbial preparations and doses of nitrogen fertilizers (Figure 2). Preparations of AM and EM in relation to control resulted in uplift of grain yield in all objects fertilizer, while the preparation UG_{max} objects fertilized only in quantities of 120 kg N/ha.

Nitrogen uptake. The biggest total uptake of nitrogen, amounting on average to 145 kg/ha, was reported in the vegetation period in 2006, considerably lower uptake was reported in 2007, amounting on average to 135 kg/ha, whereas the lowest uptake of nitrogen was reported in 2008, with the amount of 128 kg/ha (Table 2). The amount of nitrogen uptake together with the biomass of spring wheat plants was increasing along with the increase in the level of nitrogen fertilization from the level of 78 kg/ha on the non-fertilized plot to 184 kg/ha on the plot fertilized with the dose of 160 kg N/ha. A relatively high uptake of nitrogen, both together with the yield of dry mass of whole plants and the grain yield resulted from spring wheat cultivation in Luvic Chernozem. This is confirmed by the research of Masaka (2005), who cultivating spring wheat in chernozem showed the uptake of nitrogen above 140 kg/ha in the control plot.

Microbial preparations evaluated in the research exerted a slight influence on the amount of the up-

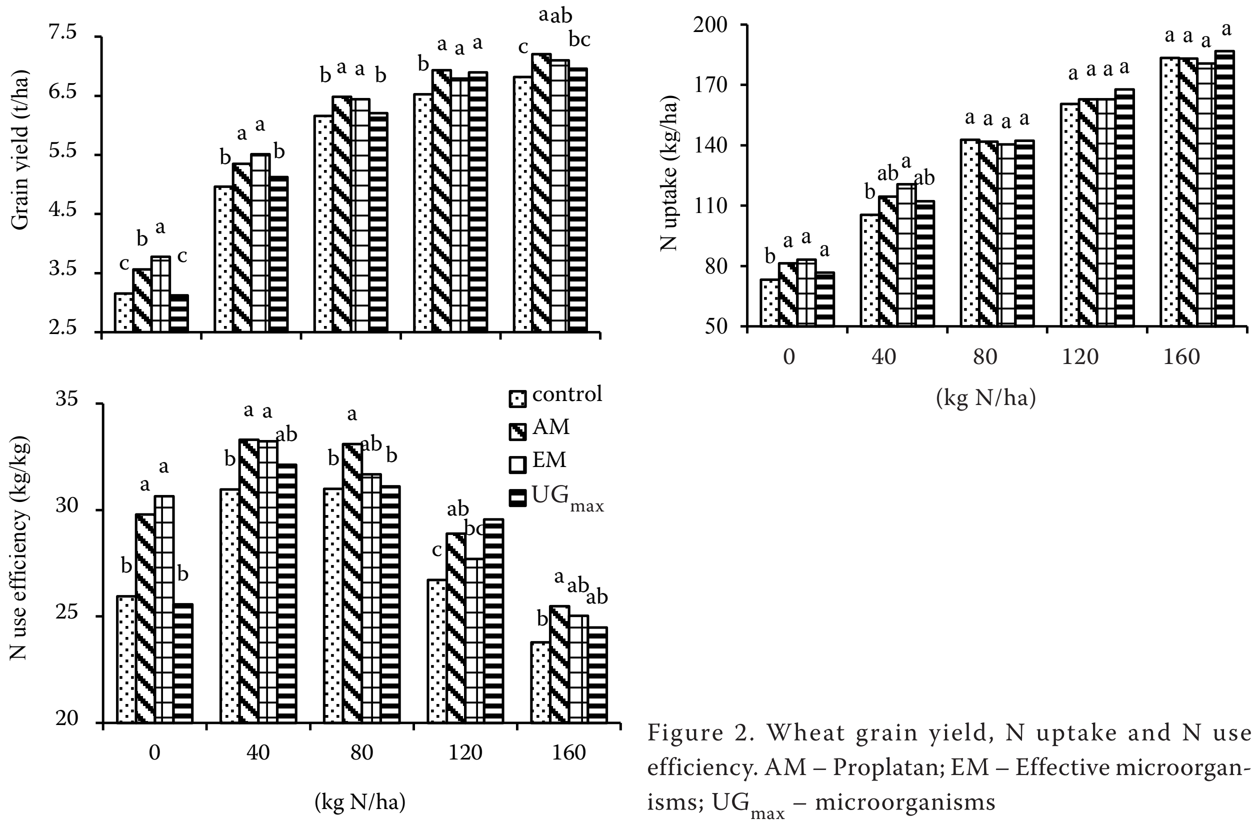


Figure 2. Wheat grain yield, N uptake and N use efficiency. AM – Proplatan; EM – Effective microorganisms; UG_{max} – microorganisms

take of nitrogen. A significant increase in the total uptake of nitrogen was reported merely after the application of EM and UG_{max} preparations (Table 2). The biggest influence of microbial preparations on the N uptake was recorded in objects without nitrogen fertilization (Figure 2).

N uptake with grain yield of wheat was similar as the uptake of this element together with the biomass of whole plants. The highest amount of nitrogen accumulated in grain yield was reported in 2006, amounting on average to 118 kg/ha, whereas the lowest amount was reported in 2008, with the amount of 106 kg/ha. The amount of the uptake of nitrogen together with the grain yield was increasing significantly together with the increase in the level of nitrogen fertilization from 65 kg/ha in the non-fertilized plot to 149 kg/ha in the object fertilized with 160 kg N/ha. The uptake of nitrogen with grain yield constituted on average 82% of the total uptake of nitrogen by spring wheat plants. In the research of Delogu et al. (1998) the participation of nitrogen accumulated in grain amounted to 69% of the total uptake of nitrogen.

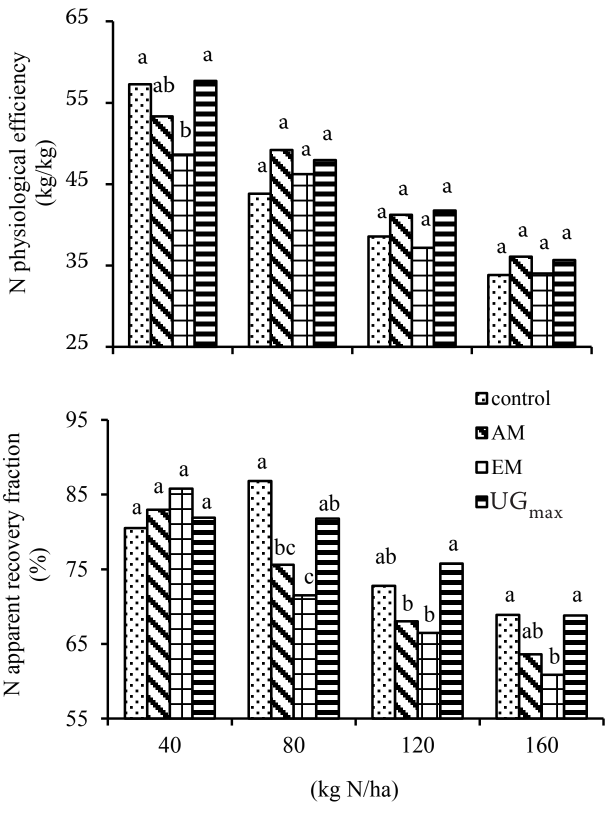
Nitrogen efficiency. The biggest value of NUE, on average 31.0 kg/kg, was reported in 2006, facilitating spring wheat crop productivity, whereas the lowest value, amounting on average to 27.2 kg/kg, was reported in 2008, when the grain yield was the smallest (Table 2). NUE was additionally influenced by evaluated in the research microbial preparations. A significant increase in the NUE was reported after the application of AM and EM preparations. Moreover, the level of nitrogen fertilization affected the NUE. The highest value of this indicator, on average 32.4 kg/kg, was reported in objects fertilized with the dose of 40 kg N/ha. Each subsequent increase in the level of fertilization resulted in a considerable reduction of the efficiency of nitrogen consumption. The lowest value of N use efficiency, on average c.a. 24.7 kg/kg, was reported in objects fertilized with the rate of 160 kg N/ha. During the three-year period of the research, NAE in non-fertilized objects was similar to the efficiency of nitrogen utilization in the objects fertilized with the 120 kg N/ha. On the other hand, in the research of Limon-Ortega et al. (2000), López-Bellido and López-Bellido (2001) as well as Zhao et al. (2006) each dose of nitrogen resulted in lowering N use efficiency index in control objects.

N agronomic efficiency expressed in terms of the increase in grain yield per kilogram of nitrogen applied in fertilizers was lowering along with the increase of doses of that element from 45.8 to 22.6 kg/kg N, (Table 2). Moreover, N physiological efficiency specified as the increase of the grain yield per a unit of nitrogen absorbed by plants was lowering along with increasing of the level of nitrogen fertilization. The highest efficiency of nitrogen absorption, both from the mineral fertilizer as well as soil reserves, was reported in case of wheat plants fertilized with the dose of 40 kg N/ha, whereas the lowest efficiency was reported in case of plants fertilized with the dose of 160 kg N/ha. López-Bellido and López-Bellido (2001) indicated that there was no significant impact of nitrogen fertilization within the range from 50 to 150 kg/ha on NPE. The authors showed, however, a significant impact of fertilization with relation to NAE.

Microbial preparation evaluated in the research had a significant impact on NAE as well as NPE. The application of EM preparation affected a considerable decrease in NAE, whereas the application of UG_{max} preparation had a positive impact on NAE in objects fertilized with doses 40 and 120 kg N/ha (Figure 3). NAE and NPE were significantly dependent on the course of weather conditions. The lowest increase in the grain yield per a unit of nitrogen applied in fertilizers, amounting on average to 26.2 kg/kg was reported in 2008 when the rainfall amounts were deficient in May and June, and the rainfall amount was excessive in July. On the other hand, the highest NAE was reported in 2006, amounting to 43.6 kg/kg.

N apparent recovery fraction (NRF) specified as the relation of nitrogen absorbed by spring wheat plants to the amount of nitrogen used in the mineral fertilizer ranged from 60.9% to 86.8% (Figure 3). The applied nitrogen was best utilized by plants fertilized with doses of 40 and 80 kg N/ha, amounting to 82.8% and 78.9%, respectively, and worst utilized by plants fertilized with the dose of 160 kg N/ha, amounting on average to 65.5% (Table 2). Alessi and Power (1973) showed 79% N apparent recovery fraction in objects fertilized with the dose of 34 kg N/ha and a slightly lower N apparent recovery fraction (76%) after the application of the dose of 68 kg N/ha. On the other hand, in the research of López-Bellido and López-Bellido (2001) NRF in objects fertilized with doses from 50 to 150 kg N/ha ranged from 18.8% to 25.1%.

In the evaluation of the impact of microbial preparations on NRF, an unfavorable influence of EM and AM preparations on that ratio was reported (Table 2).



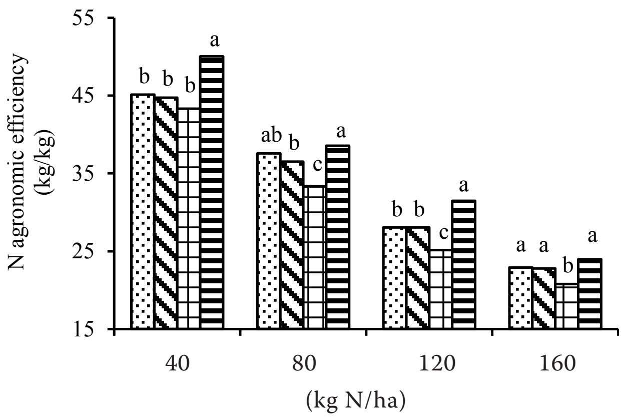


Figure 3. N physiological efficiency, N agronomic efficiency, N apparent recovery fraction. AM – Proplatan; EM – Effective microorganisms; UG_{max} – microorganisms

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