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The Effect of Combining N-Fertilization with Urease Inhibitors and Biological Preparations on Maize Biological Productivity

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Abstract: After evaluating the ecological and economic aspects, it is predicted that the use of urease inhibitors and biological preparations should reduce the risk of nutrient leaching by using fertilizers containing amide, ammonium, and nitrate forms of nitrogen and would increase nitrogen use efficiency. Moreover, with lower nitrogen fertilizer rates, it would be possible to achieve or even increase planned maize biomass yield. The field experiment was performed in 2019–2021 at the Experimental Station of Vytautas Magnus University Agriculture Academy. The soil of the experimental field was Endohipogleyic-Eutric Planasol. The aim of this study was to investigate the effect of urease inhibitors and biological preparations in combination with nitrogen fertilizers on the productivity of aboveground maize (*Zea mays* L.) biomass. A two-factor experiment was carried out: factor A included nitrogen fertilizer rates of (1) 100 kg N ha^{-1}, (2) 140 kg N ha^{-1}, and (3) 180 kg N ha^{-1}; and factor B included the use of preparations of (1) no use of urease inhibitors (UIs) and biological preparations (BPs) (control), (2) the urease inhibitor ammonium thiosulphate (UI ATS), (3) the urease inhibitor (UI URN)—N-Butyl-thiophosphorus triamide (NBPT), (4) the biological preparation of suspension of humic and fulvic acids (BP HUM); and (5) the biological preparation (BP FIT) of suspension of *Ascophyllum nodosum* The studies showed that the dry matter yield of maize was significantly increased not only by increasing nitrogen fertilizer rates but also by the use of UIs and BPs. The highest dry matter yield of maize (24.1 t ha^{-1}) was obtained with N_{180} fertilizer and UI ATS. UI ATS significantly increased the dry matter yield of the aboveground maize in all nitrogen fertilization backgrounds. The UIs and BPs tested had a greater and significant ($p < 0.05$) effect on the dry matter yield of maize at lower rates of N_{100} and N_{140} nitrogen fertilizer. Increasing nitrogen fertilizer rates up to N_{180} had a positive significant effect on dry matter yields of the aboveground part of maize, its cobs, leaves, and stems. Positive, moderate, strong, and very strong correlations were found in most cases between the latter variables. These correlations were statistically significant ($r^2 = 0.62$–0.98). The UIs and BPs increased the efficiency of nitrogen fertilizer; therefore, the lower rates of nitrogen fertilizer (N_{100} and N_{140}) could be used to produce maize productivity the same as that obtained with a high rate of nitrogen fertilizer (N_{180}).

Keywords: *Zea mays* L.; fertilization; N fertilizer; urease inhibitors; biological preparations; biomass

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1. Introduction

Due to its high genetic potential for aboveground yield compared to other cereals, maize is commonly referred to as the king of crops [1]. Given its genetic yield potential and rapid growth, maize is more demanding of nitrogen than of other essential elements throughout the growing season [2]. The impact of climate change on agricultural production and food security is becoming a focus of attention in global agriculture. Extensive studies covering changes in production potential in different regions and crops worldwide have found that many crops have experienced significant declines due to climate change [3–5]. In order to overcome the current challenges related to agricultural production, it is necessary to continuously improve its efficiency and productivity by introducing the necessary tools and solutions to increase the quantity, safety, and quality of agricultural production using fewer resources (water, energy, fertilizers, pesticides, etc.) [6–8]. Kumar et al. [9] argued that the yield of field crops was closely linked to three key components of soil ecosystems: nutrients that are bioavailable to plants, soil microbiota, and soil organic matter content.

Maize (*Zea mays* L.) is one of the world's most widespread and oldest crops, as well as one of the most important crops in modern agriculture due to its high yield potential and versatility of use [10]. Many studies have been carried out worldwide with the aim of increasing the yield of maize and improving yield quality. In order to increase crop productivity, the use of nitrogen fertilizers needs to be optimized, avoiding any negative impact on the economic performance of a farm, while preserving the environment and ensuring the sustainability of crop production technologies. The increased adoption of sustainable farming technologies by growers—such as reduced tillage, post-tillage, and crop rotation—due to economic considerations highlights the need to improve plant nutrition technologies, particularly nitrogen fertilization [11]. Researchers have reported that maize hybrids differ in all cases in terms of productivity and their responses to nitrogen fertilizer rates. Nitrogen fertilizer rates can be classified as one of the most limiting factors of maize productivity. The efficiency of nitrogen use from fertilizer is relatively low, as losses of this element can be as high as 50% depending on soil and meteorological conditions [12–14].

Some researchers have suggested that maize growers should use nitrogen fertilizer rates with optimal rates of 25 to 50 kg N ha^{-1}. After increasing the nitrogen rate from 50 up to 100 kg N ha^{-1}, the efficiency of nitrogen assimilation and utilization and the yield of maize do not increase. Therefore, it is suggested that nitrogen fertilizer rate increase may not be necessary, especially for small farmers. On the other hand, in intensive farms, depending on the meteorological conditions, soil properties, and the genetic potential of the maize variety, rates higher than 200 kg N ha^{-1} can be effective. However, indicators of environmental factors contribute to some uncertainty with the use of high fertilizer rates. Researchers from China have reported that high rates of nitrogen fertilizers (N_{180}) increase the accumulation of $N_{min.}$ in the soil after maize harvest and also increase the risk of environmental pollution related to nitrogen compounds [15,16].

Uncertainty about the nitrogen demand of maize (*Zea mays* L.) remains [17] due to the common misuse of nitrogen fertilizer and low nitrogen efficiency [18,19]. Nitrogen uptake efficiency is estimated to be less than 50% of applied nitrogen in most cases, which may indicate a higher uptake efficiency from the soil than from the fertilizer applied [20]. This scenario involves a complex process of nitrogen fertilizer loss, such as leaching, denitrification, and evaporation [13]. Despite genetic improvements in nitrogen use efficiency, there is further scope for the development of algorithms to improve nitrogen uptake and to develop fertilizer application recommendations. It cannot be said that maize productivity is limited only by meteorological conditions during the growing season, but researchers believe that nitrogen supply has a significant impact on this plant's productivity [21]. Specialized nitrogen fertilizers or additives combined with nitrogen fertilizers are commercially available to slow down the transformation of nitrogen in the soil. Both technologies control the leaching of nitrogen compounds to groundwater or emissions to the atmosphere and maintain long-term nitrogen uptake [22]. In practice, higher fertilizer rates are commonly used to compensate for insufficient fertilizer efficiency in order to achieve higher predictable crop productivity. Irrational and unbalanced fertilization is often cited as one of the reasons for the reduction in soil organic matter content [23]. In the scientific literature, urease and nitrification inhibitors have been discussed as a means of improving nitrogen uptake and increasing plant productivity. The addition of inhibitors was reported to regulate the distribution of nitrogen in individual plant parts and to increase the amount of stored nitrogen in plants [24]. Inhibitors that increase nitrogen efficiency should be combined with nitrogen rates to simultaneously ensure fertilizer efficiency, optimal yield, and reduced emissions [6,25].

Researchers from Spain stated that a single application of urease inhibitors (UIs) with nitrogen fertilizers could help reduce the risk of nitrate leaching during the growing season and after harvest in maize. The use of UIs is associated with economic benefits when compared to the same amount of conventional nitrogen fertilizers without it. Researchers have confirmed that the use of UIs can significantly reduce fertilizer rates, and the number of fertilizer applications can be reduced from the usual two times to one. Researchers also found that, when UIs and fertilizers were applied to maize twice a day, nutrient demand was unrelated to maize plant development, resulting in lower grain yield and increased nitrogen losses. When using nitrogen fertilizers with an inhibitor, the effects of nitrogen in the soil persisted for more than 100 days, suggesting that the inhibitor reduced the nitrogen migration into deeper soil layers. It was observed that the benefits of using UIs became apparent in the presence of insufficient soil water, making UIs a very promising strategy for adaptation to climate change in arid and semi-arid regions [26].

The use of N-(*n*-butyl) thiophosphorotriamide (NPBT) (N-(*n*-butyl) thiophosphoric triamide (*n*BTPT)) was shown to increase plant productivity by an average of 0.8 to 10.2%, depending on the crop grown in different countries [27]. However, depending on the climatic zone or meteorological conditions, UIs and other products may be less efficient [28]. The use of biostimulants, such as amino acids, phytohormones, humic or fulvic acids, or algal extracts, increases the resistance of plants to abiotic factors [29]. In addition to plant residues or green manure, other organic matter is used to compensate for the lack of soil organic matter. Humic substances have been investigated in various agricultural fields. Their impact on soil chemical properties, soil health, plant physiological changes, and the environment has been analyzed, as these substances play multiple roles that can benefit plant growth (increase nutrient uptake, availability, and improve soil properties) [30,31]. Humic acids have a large specific surface area, a complex structure, and a large number of functional groups, resulting in a strong adsorption capacity that can lead to a higher content of nitrogen compounds in the soil [32].

Seaweed-derived biostimulants are new class of agricultural input that is being widely investigated for the improvement of various nutrient-use efficiencies in plants. *Ascophyllum nodosum* is a brown, intertidal seaweed common to the Northern Hemisphere and has been extensively studied as a source of various commercial biostimulants with the specific aim of improving plant growth and productivity by increasing nutrient availability and uptake [33]. The aim of this study is to investigate the effect of urease inhibitors and biological preparations in combination with nitrogen fertilizers on the productivity of aboveground maize (*Zea mays* L.) biomass.

2. Materials and Methods

2.1. Location and Arrangement of the Experiment

The field experiment was performed in 2019–2021 at the Experimental Station of Vytautas Magnus University Agriculture Academy. The soil of the experimental field was Endohipogleyic-Eutric Planasol according to the World Reference Base (WRB) [34] classification, with medium loam on sandy light loam. The plowing layer was 23–27 cm thick. The soil was neutral (pH ~ 6.7) and had a medium humus content ~2.86%, a medium potassium content ~154 mg kg^{-1}, and a high phosphorus content ~266 mg kg^{-1}.

The decision of selected nitrogen fertilizer rates for maize was made at the field level with the expectation that the key to increasing maize yield could be nitrogen assimilation during the growing season of the plants, as well as considering economic and ecological aspects. There were 45 fields in the field experiment, each with an initial (gross) area of 66 m^2 (width 5.5 m, length 12 m). The area of the accounting (net) field was 45 m^2 (width 4.5 m, length 10 m). The field experiment was performed in 3 replications, and the fields in the replication blocks were randomized. The studied factors were the following: factor A—nitrogen fertilizer rates of (1) 100 kg N ha^{-1}, (2) 140 kg N ha^{-1}, and (3) 180 kg N ha^{-1}; and factor B—the use of preparations of (1) no use of urease inhibitors (UIs) and biological preparations (BPs) (control); (2) the urease inhibitor ammonium thiosulphate (UI ATS); (3) the urease inhibitor (UI URN)—N-Butyl-thiophosphorus triamide (NBPT);

(4) the biological preparation of suspension of humic and fulvic acids (BP HUM); and (5) the biological preparation (BP FIT) of suspension of *Ascophyllum nodosum*.

In 2019, maize was sown on 23 April; in 2020, on 27 April; and in 2021, on 11 May. Hybrid maize variety P7326 with short early maturity P7326 (DuPont Pioneer, Johnston, IA, USA) was cultivated. The seed rate was 80,000 seeds ha^{-1}, and spacing between rows was 75 cm.

The following PK fertilizers were spread in all fields and applied before maize sowing: phosphorus fertilizer (double superphosphate Ca $(H_2PO_4)_2$ H_2O) at a fertilization rate of 60 kg ha^{-1} P_2O_5; and potassium fertilizer (potassium chloride KCl) at a fertilization rate of 60 kg ha^{-1} K_2O. At BBCH stage 16, the maize crop was sprayed with a herbicide containing the active substances mesotrione at 75 g L^{-1} and nicosulfuron at 30 g L^{-1}–1.0 L ha^{-1}.

The characteristics of factors A and B tested in the field experiment are given in Tables 1 and 2 [35].

Table 1. Factor A—nitrogen (N) fertilizer rates.

Factor A	Characteristics
N_{100}	238 L ha^{-1} KAS-32 (a solution of urea $(CO(NH_2)_2)$ and ammonium nitrate $(NH_4\ NO_3)$) applied to the soil surface immediately after sowing
N_{140}	333.2 L ha^{-1} KAS-32 (a solution of urea $(CO(NH_2)_2)$ and ammonium nitrate $(NH_4\ NO_3)$) applied to the soil surface immediately after sowing
N_{180}	428.4 L ha^{-1} KAS-32 (a solution of urea $(CO(NH_2)_2)$ and ammonium nitrate $(NH_4\ NO_3)$) applied to the soil surface immediately after sowing

Table 2. Factor B—use of urease inhibitors (UIs) and biological preparations (BPs).

Factor B	Characteristics
UI and BP not used (control)	Urease inhibitors and biological preparations were not used
UI ATS	Urease inhibitor—ammonium thiosulphate ($(NH_4)_2S_2O_3$ 12-0-0-26 S) (10% spraying with KAS-32: in fields fertilized with N_{100}—23.8 L ha^{-1}; in fields fertilized with N_{140}—33.3 L ha^{-1}; in fields fertilized with N_{180}—42.8 L ha^{-1}
UI URN	Urease inhibitor—N-butyl-thiophosphorus triamide (NBPT) at 188 g L^{-1} and N-propyl-thiophosphorus triamide (NPPT) at 87 g L^{-1} (1.0 L ha^{-1} sprayed with KAS-32)
BP HUM	Biological preparation—15% suspension of humic and fulvic acids, pH 4–5 (1.0 L ha^{-1} sprayed with KAS-32)
BP FIT	Biological preparation—20% suspension of *Ascophyllum nodosum* (0.6 L ha^{-1} sprayed at the 6-leaf stage (BBCH 26) of maize

In the experiment, maize was monitored throughout its growing season. The plant density was determined when at least 75% of the plants reached BBCH 20. The BBCH scale [36] was used to describe plant development. When maize reached its physiological maturity, i.e., when a black dot appeared on the grain at the point of attachment to the cob, plant samples were taken from each field, randomly selecting 10 plants per field (30 plants per treatment for a total of 450 plants), and sampled to determine the dry matter yield of the maize. Each sample was weighed and separated into the following fractions: (a) leaves; (b) stems (including ochreas, panicles, and undeveloped cobs); and (c) cobs (grains, kernels, and cotyledons). The prepared samples of the different parts of the maize plants were dried at 105 °C to constant dry matter and weighed [37]. The partial factor productivity of applied N (PFPN) was calculated as follows [38]: PFPN = YN/FN, where YN is the yield with applied N (kg ha^{-1}), and FN is the amount of N applied (kg ha^{-1}).

2.2. Statistical Analysis

Statistical data analysis was performed using computer ANOVA and STAT from the statistical software package SELEKCIJA [39]. The research data were statistically evaluated using the method of two-way analysis of variance. The significance of the differences between the treatments was assessed using the *F*-criterion and the *LSD* test. Significant interactions of the studied factors were identified; therefore, the averages are not presented when analyzing the research data. The differences between the means of treatments without the same letters (a, b, c...) are significant ($p < 0.05$). The regression coefficient and the correlation were determined. At $p \leq 0.05$, the dependence was statistically significant at the 95% level of probability; at $p \leq 0.01$, the dependence was statistically significant at the 99% level of probability [40].

2.3. Weather Conditions

During the maize growing season in 2019, the sum of the air temperatures was 2558.4 °C (Table 3). The highest temperature (442.5 °C) occurred during the BBCH 26–27 maize growing period, with an average daily temperature of 20.1 °C. The lowest (10.7 °C) average daily air temperature was in the development period BBCH 09–13, with a sum of air temperatures of 128.3 °C. The lowest (66.8 and 90.0 °C) sums of temperatures were recorded at BBCH 61–69 and 69–73, respectively, despite average daily temperatures of 16.7 and 18.0 °C during these periods. The low sum of air temperatures could be explained by the short duration of these development periods (4–5 days).

Table 3. Meteorological conditions (air temperature and precipitation) during the maize growing season in 2019.

Growing and Development Period by BBCH (from–to)	Sum of Temperatures per Period, °C	Average Daily Temperature per Period, °C	Sum of Precipitation per Period, mm	Precipitation Intensity per Period, mm day^{-1}
00–09	164.4	12.6	2.10	0.2
09–13	128.3	10.7	6.00	0.5
13–26	209.5	17.5	21.4	1.8
26–27	442.5	20.1	45.9	2.1
27–29	262.1	18.7	9.60	0.7
29–51	248.6	15.5	29.9	1.9
51–61	268.0	19.4	28.1	2.0
61–69	66.8	16.7	3.90	0.1
69–73	90.0	18.0	25.1	5.0
73–83	278.9	18.6	31.4	2.1
83–87	255.3	18.2	5.00	0.4
00–87	2558.4	16.7	218.4	1.4

In 2019, maize growth was affected by the amount of precipitation during the growing season. The precipitation at the beginning of the growing season was low, with the sum of precipitation equal to 2.1 mm and 6.0 mm at BBCH 00–09 and 09–13, respectively, and a daily precipitation intensity of 0.2–0.5 mm. The highest precipitation intensity (5.0 mm day^{-1}) was recorded in BBCH 69–73 (8–12 August).

In the second year of the experiment (2020), during the maize growing season, the sum of the air temperatures was 104 °C lower, and the precipitation was 142.6 mm higher (Table 4). The highest daily air temperature (22.5 °C) was recorded at BBCH 61–69 during the growth and development period. The highest amounts of precipitation in particular periods of growth were recorded at BBCH 27–29 at 63.8 mm, BBCH 83–87 at 61.9 mm, and BBCH 09–13 at 58.9 mm. The highest daily precipitation intensity was observed in BBCH 27–29.

Table 4. Meteorological conditions (air temperature and precipitation) during the maize growing season in 2020.

Growing and Development Period by BBCH (from–to)	Sum of Temperatures per Period, °C	Average Daily Temperature per Period, °C	Sum of Precipitation per Period, mm	Precipitation Intensity per Period, mm day^{-1}
00–09	142.7	10.2	27.6	2.0
09–13	109.7	8.40	58.9	4.5
13–26	134.8	13.5	8.70	0.9
26–27	264.4	17.6	35.5	2.4
27–29	279.7	21.5	63.8	4.9
29–51	467.4	17.3	52.9	2.0
51–61	178.6	17.9	31.1	3.1
61–69	67.4	22.5	0	0
69–73	111.4	18.6	0	0
73–83	165.2	20.7	15.5	1.9
83–87	347.8	15.1	61.9	2.7
00–87	2454.0	15.9	361.0	2.3

The meteorological observations show that there was little variation in the sum of the air temperatures in the individual years of the experiment, with the highest temperature of 2558.4 °C recorded during the growing season in 2019, suggesting that this year was more favorable for maize growth and yield formation. In 2021, the average daily temperature was higher in the growing stages BBCH 00–09 and 09–13, with average daily temperatures of 14.6 °C and 11.9 °C, respectively (Table 5), compared to 2019 and 2020 (Tables 3 and 4). The precipitation intensity in 2021 was the highest (3.3 mm day^{-1}) in the BBCH 00–09 growth period of maize compared to 2019 and 2020, when the precipitation intensity was 0.2 and 2.0 mm day^{-1}, respectively. No precipitation was recorded during BBCH 13–26 of maize, and the average daily temperature was 16.1 °C. The highest precipitation (59.3 mm) during the period was recorded at BBCH 83–87, with a daily precipitation intensity of 2.1 mm.

Table 5. Meteorological conditions (air temperature and precipitation) during the maize growing season in 2021.

Growing and Development Period by BBCH (from–to)	Sum of Temperatures per Period, °C	Average Daily Temperature per Period, °C	Sum of Precipitation per Period, mm	Precipitation Intensity per Period, mm day^{-1}
00–09	131.0	14.6	29.6	3.3
09–13	118.7	11.9	46.7	4.7
13–26	128.7	16.1	0	0
26–27	337.9	19.9	7.2	0.4
27–29	251.2	20.9	53.3	4.4
29–51	480.6	22.9	9.9	0.5
51–61	180.2	20.0	38.2	4.2
61–69	83.8	16.8	28.5	5.7
69–73	70.3	17.6	3.70	0.9
73–83	251.5	15.7	39.0	2.4
83–87	340.8	12.2	59.3	2.1
00–87	2492.7	16.6	319.8	2.1

To summarize the meteorological conditions during the experiment, the years 2020 and 2021 were less favorable for plant maturity due to the lower average daily temperature at the end of the growing season and the higher precipitation during the BBCH periods of 73–83 and 83–87, with respective precipitation intensities of 1.9 and 2.7 mm day^{-1} in

2020 and 2.4 and 2.1 mm day^{-1} in 2021, while in 2019 they were 2.1 and 0.4 mm day^{-1}, respectively.

3. Results

3.1. The Influence of Different Rates of Nitrogen Fertilizer, Urease Inhibitors, and Biological Preparations on the Yield of the Aboveground Part of the Maize in the First Year of the Experiment

Plant biomass is a naturally occurring, non-fossil organic matter with internal chemical energy that can offset fossil fuel emissions and may be an alternative to fossil fuels [4]. Biomass resources consist of a variety of different materials, including plant residues, straws, etc. Not only can maize be grown for grain or fodder, but its biomass can also provide an alternative energy source to address the increased demand for energy in global markets [11]. Maize cultivation can increase the amount of plant-based bioenergy and related high-value products and reduce the need for fossil fuels. When it comes to the use of maize biomass for biofuels, it is important to generate the highest productivity of the aboveground part of the plant with the lowest cost [5].

In our experiment on maize in 2019, it was found that increasing the nitrogen fertilizer rate without UIs and BPs resulted in a significant increase in dry matter yield by 1.9 t ha^{-1} when increasing the nitrogen fertilizer rate from N_{100} to N_{140}, while no significant difference was found when increasing the nitrogen fertilizer rate from N_{140} to N_{180} (Table 6). The highest yield (24.1 t ha^{-1}) of maize dry matter was obtained when maize was fertilized with N_{180} and with UI ATS, and yields were not significantly different from maize fertilized with N_{140}. Maize N_{100} fertilized with UI ATS resulted in a 1.2 t ha^{-1} higher dry matter yield of maize than N_{180} fertilized without UIs and with BPs, which although a non-significant difference in yield, indicated the efficiency of the tested preparation. The highest efficiency of the test preparation UI URN was found with N_{180}, with a yield of 23.1 t ha^{-1}, which was significantly higher by 2.5 t ha^{-1} compared to N_{100}, but no significant difference was found between the fertilization rates of N_{180} and N_{140}. The efficiency of the investigated bioagent BP HUM in 2019 was highlighted at the N_{100} rate, with a significant yield increase of 2.6 t ha^{-1} compared to fertilization without UIs and BPs. At higher nitrogen fertilizer rates (N_{140} and N_{180}), the efficiency of BP HUM was not evident. In conclusion, it was not purposeful to increase the nitrogen fertilizer rates during the year of the experiment with BP HUM, as the dry matter yield of the aboveground maize only tended to increase. A similar trend was observed with BP FIT, with no significant differences observed when increasing the nitrogen fertilizer rate.

When assessing the yield structure components of the aboveground parts of the maize, it was found that increasing the nitrogen fertilizer rate from N_{140} to N_{180} without the use of UIs and BPs did not have a significant effect on the yields of maize cobs, leaves, and stems. The highest maize cob yield (15.7 t ha^{-1}) was found with N_{180} and UI ATS, while there was a significant difference in cob yield (2.1 t ha^{-1}) with N_{100} but no significant difference with N_{140}. A significant difference of 1.3 t ha^{-1} in cob yield was observed when comparing the N_{100} and N_{140} fertilizer rates. Maize leaf and stem yields (2.8 and 5.6 t ha^{-1}, respectively) were also highest with N_{180} and UI ATS. When the efficiency of UI URN was assessed, it was found that a significant increase of 1.8 t ha^{-1} in cob yield was obtained when the fertilizer rate was increased from N_{100} to N_{180}, while increasing the fertilizer rate from N_{140} to N_{180} did not have a significant effect on the cob yield. With UI URN, the yield of maize leaves increased significantly (0.3 t ha^{-1}) with the increase in fertilizer rate to N_{180} compared to N_{100} and N_{140}, while the yield of maize stems increased significantly with the increase in fertilizer rate from N_{100} to N_{180}, and there were no significant differences in fertilizer rates between either N_{100} and N_{140} or N_{140} and N_{180}.

The biological preparations of BP HUM and BP FIT did not have a significant effect on maize cob yield when fertilizer rates were increased, with the highest cob yield (13.8 t ha^{-1}) obtained with N_{180} and BP FIT. BP FIT had a significant positive effect on the yield of maize leaves when N_{180} fertilization was used. The application of BPs at higher fertilizer rates did not have a significant effect on maize stem mass.

Table 6. The influence of different nitrogen fertilizer rates, urease inhibitors, and biological preparations on the dry matter yield and yield structure of maize in 2019.

Fertilization		Yield of Aboveground Dry Matter t ha^{-1}			
		Whole	Including		
			Cobs	Leaves	Stems
N_{100}	Without UIs and BPs	17.48 ± 0.37 g	11.29 ± 0.23 g	2.06 ± 0.05 g	4.13 ± 0.09 g
	UI ATS	21.17 ± 0.44 cde	13.59 ± 0.26 cde	2.54 ± 0.06 cd	5.04 ± 0.12 bcde
	UI URN	20.59 ± 0.41 cdef	13.2 ± 0.26 cdef	2.45 ± 0.05 def	4.94 ± 0.11 cdef
	BP HUM	20.11 ± 0.39 ef	12.89 ± 0.23 ef	2.40 ± 0.06 def	4.82 ± 0.11 def
	BP FIT	20.56 ± 0.50 cdef	13.2 ± 0.34 cdef	2.46 ± 0.06 def	4.90 ± 0.13 cdef
N_{140}	Without UIs and BPs	19.39 ± 0.50 f	12.47 ± 0.33 f	2.32 ± 0.07 f	4.60 ± 0.11 f
	UI ATS	22.85 ± 0.53 ab	14.85 ± 0.36 ab	2.67 ± 0.06 abc	5.33 ± 0.14 ab
	UI URN	21.57 ± 0.61 bcd	14.0 ± 0.46 bcd	2.50 ± 0.06 cde	5.07 ± 0.13 bcd
	BP HUM	20.52 ± 0.47 cdef	13.3 ± 0.32 cdef	2.45 ± 0.06 def	4.77 ± 0.12 def
	BP FIT	20.92 ± 0.51 cde	13.58 ± 0.40 cde	2.48 ± 0.06 def	4.86 ± 0.09 cdef
N_{180}	Without UIs and BPs	20.04 ± 0.50 ef	13.03 ± 0.36 def	2.33 ± 0.05 ef	4.68 ± 0.12 ef
	UI ATS	24.09 ± 0.58 a	15.68 ± 0.34 a	2.80 ± 0.07 a	5.61 ± 0.17 a
	UI URN	23.06 ± 0.59 ab	14.95 ± 0.40 ab	2.75 ± 0.07 ab	5.36 ± 0.13 ab
	BP HUM	21.34 ± 0.57 cde	13.82 ± 0.40 cde	2.50 ± 0.07 cde	5.02 ± 0.14 bcde
	BP FIT	22.01 ± 0.48 bc	14.2 ± 0.34 bc	2.60 ± 0.06 bc	5.21 ± 0.14 bc

Note. UI—urease inhibitor; ATS—ammonium thiosulfate; URN—N-butyl-thiophosphoric triamide (NBPT) and N-propyl-thiophosphoric triamide (NPPT); BP—biological preparation; HUM—suspension of humic and fulvic acids; FIT—suspension of *Ascophyllum nodosum*. Means ± standard error; $n = 3$. The differences between the means of treatments with different letters are significant ($p < 0.05$).

3.2. The Influence of Different Rates of Nitrogen Fertilizer, Urease Inhibitors, and Biological Preparations on the Yield of the Aboveground Part of the Maize in the Second Year of the Experiment

In the second year of the experiment (2020), it was found that increasing the nitrogen fertilizer rate and not using UIs and BPs resulted in a significant increase in the dry matter yield of maize (Table 7). The highest yield (17.6 t ha^{-1}) was found when maize was fertilized with N_{180}. In the experiment, the dry matter yield of maize was the same when N_{100} was applied with UI ATS and when N_{180} was applied without UIs and BPs. The highest yield (21.5 t ha^{-1}) was obtained with N_{180} and UI ATS, but there was no significant difference between the application rates of N_{140} and N_{180}. In the case of UI URN, the highest yield (20.5 t ha^{-1}) of the aboveground part of maize was also obtained with N_{180}. The experimental data showed that the yield of the aboveground part of maize was significantly—by 1.1 t ha^{-1}—higher at the N_{100} rate when using UI URN compared to the N_{100} rate without UIs and BPs. It could be concluded that, in 2020, UI URN and UI ATS were effective to use for reducing nitrogen fertilizer rates and producing similar dry matter yields of maize to those of higher fertilizer rates (N_{140} and N_{180}).

The biological preparations BP HUM and BP FIT were efficient in 2020 as well. When comparing the preparations with each other, a significant difference (1.5 t ha^{-1}) was observed with N_{100}, while no significant difference was found between the BPs when the fertilizer rate was increased to N_{140} and N_{180}. With the use of BPs, the highest (20.7 t ha^{-1}) yield of the aboveground part of maize was observed with N_{180} and BP FIT, but no significant difference was found with the lower fertilizer rate of N_{140}. The highest cob yield (13.9 t ha^{-1}) was found with N_{180} and UI ATS, but no significant difference was found when comparing the N_{180} and N_{140} fertilizer rates. The data suggested that, with the right choice of additives to increase the efficiency of nitrogen fertilizers, it is possible to increase the efficiency of fertilizer and reduce environmental pollution by nitrogen compounds. The investigated biological preparations BP HUM and BP FIT were also efficient, with significantly higher cob yields (by 1.1 and 2.2 t ha^{-1}, respectively) in maize fertilized with N_{100} compared to N_{100} without BP. Similar trends were obtained when analyzing leaf and stem yields in the overall yield structure of the aboveground plant part. The highest

(2.5 t ha^{-1}) dry matter yield of maize leaves was obtained with UI ATS and N_{140} fertilizer. Maize stem yields were the highest in all cases at the highest nitrogen fertilizer rate (N_{180}).

Table 7. The influence of different nitrogen fertilizer rates, urease inhibitors, and biological preparations on the dry matter yield and yield structure of maize in 2020.

Fertilization		Yield of Aboveground Dry Matter t ha^{-1}			
		Whole	Including		
			Cobs	Leaves	Stems
N_{100}	Without UIs and BPs	14.75 ± 0.38 g	9.19 ± 0.24 g	1.82 ± 0.04 f	3.74 ± 0.08 h
	UI ATS	17.62 ± 0.45 e	11.28 ± 0.30 e	2.10 ± 0.04 d	4.24 ± 0.13 e
	UI URN	15.94 ± 0.37 fg	10.07 ± 0.21 f	1.96 ± 0.05 def	3.91 ± 0.12 gh
	BP HUM	16.18 ± 0.37 f	10.31 ± 0.24 f	1.95 ± 0.04 def	3.92 ± 0.12 fgh
	BP FIT	17.66 ± 0.42 e	11.37 ± 0.32 e	2.09 ± 0.06 de	4.20 ± 0.11 efg
N_{140}	Without UIs and BPs	16.22 ± 0.36 f	10.38 ± 0.20 f	1.93 ± 0.06 ef	3.91 ± 0.12 gh
	UI ATS	20.86 ± 0.46 ab	13.57 ± 0.31 a	2.53 ± 0.07 a	4.76 ± 0.09 abc
	UI URN	18.62 ± 0.34 de	11.74 ± 0.24 de	2.31 ± 0.06 c	4.57 ± 0.09 cd
	BP HUM	19.47 ± 0.32 cd	12.5 ± 0.15 cd	2.34 ± 0.05 c	4.63 ± 0.13 bc
	BP FIT	19.69 ± 0.46 bcd	12.66 ± 0.30 bc	2.36 ± 0.09 bc	4.67 ± 0.08 bc
N_{180}	Without UIs and BPs	17.61 ± 0.45 e	11.25 ± 0.32 e	2.10 ± 0.06 d	4.26 ± 0.10 de
	UI ATS	21.47 ± 0.54 a	13.91 ± 0.40 a	2.52 ± 0.06 ab	5.04 ± 0.12 a
	UI URN	20.47 ± 0.47 abc	13.2 ± 0.32 abc	2.40 ± 0.06 abc	4.87 ± 0.10 abc
	BP HUM	19.67 ± 0.46 bcd	12.61 ± 0.29 bc	2.36 ± 0.06 bc	4.70 ± 0.11 bc
	BP FIT	20.73 ± 0.56 ab	13.35 ± 0.38 ab	2.43 ± 0.07 abc	4.95 ± 0.15 ab

Note. UI—urease inhibitor; ATS—ammonium thiosulfate; URN—N-butyl-thiophosphoric triamide (NBPT) and N-propyl-thiophosphoric triamide (NPPT); BP—biological preparation; HUM—suspension of humic and fulvic acids; FIT—suspension of Ascophyllum nodosum. Means ± standard error; $n = 3$. The differences between the means of treatments with different letters are significant ($p < 0.05$).

3.3. The Influence of Different Rates of Nitrogen Fertilizer, Urease Inhibitors, and Biological Preparations on the Yield of the Aboveground Part of the Maize in the Third Year of the Experiment

In 2021, the highest dry matter yield (18.3 t ha^{-1}) of maize was obtained with N_{180} fertilizer and UI ATS (Table 8). There was a trend in which the effect of fertilizing maize with the average rate of N_{140} using UI ATS was similar to that of N_{180} without UIs and BPs. Fertilization at the lowest N_{100} fertilizer rate tested with UI ATS resulted in a significant yield increase by 2.2 t ha^{-1} of the aboveground part of maize compared to fertilization without UI ATS. A comparison of the N_{140} and N_{180} fertilization rates with UI ATS and without UIs and BPs showed significant yield increases by 2.7 and 1.8 t ha^{-1}, respectively. UI URN was equally effective in 2021, with significant yield increases in all the fertilization treatments. The highest yield (17.3 t ha^{-1}) of the aboveground plant part was obtained with N_{180}. UI URN showed a significant increase by 0.9 t ha^{-1} in 2021 when comparing the N_{140} and N_{180} fertilizer rates. The performance of BP HUM showed significant differences in the aboveground yields in all the fertilizer backgrounds, with a positive effect when increasing nitrogen fertilization rates. The highest yield (17.9 t ha^{-1}) was obtained with N_{180}. When comparing BP HUM and BP FIT, no significant difference was found between them in the case of N_{180}. In addition, no significant difference was found in the case of BP FIT with N_{180} and N_{140} fertilization backgrounds.

Table 8. The influence of different nitrogen fertilizer rates, urease inhibitors, and biological preparations on the dry matter yield and yield structure of maize in 2021.

Fertilization		**Whole**	**Yield of Aboveground Dry Matter t ha^{-1} Including**		
			Cobs	**Leaves**	**Stems**
N_{100}	Without UIs and BPs	13.41 ± 0.20 i	8.69 ± 0.15 h	1.42 ± 0.02 h	3.30 ± 0.06 g
	UI ATS	15.64 ± 0.04 f	10.00 ± 0.16 def	1.74 ± 0.03 f	3.90 ± 0.12 de
	UI URN	14.64 ± 0.31 h	9.45 ± 0.23 g	1.73 ± 0.03 fg	3.46 ± 0.09 fg
	BP HUM	15.07 ± 0.20 gh	9.79 ± 0.12 fg	1.61 ± 0.02 g	3.67 ± 0.07 ef
	BP FIT	15.43 ± 0.09 fg	9.95 ± 0.14 efg	1.83 ± 0.03 ef	3.65 ± 0.09 ef
N_{140}	Without UIs and BPs	15.16 ± 0.16 fgh	9.78 ± 0.21 fg	1.73 ± 0.03 fg	3.65 ± 0.07 ef
	UI ATS	17.87 ± 0.35 ab	11.2 ± 0.19 ab	2.07 ± 0.07 abc	4.60 ± 0.10 a
	UI URN	16.41 ± 0.09 e	10.49 ± 0.15 cd	1.92 ± 0.07 de	4.00 ± 0.09 d
	BP HUM	16.82 ± 0.17 de	10.81 ± 0.13 bc	1.96 ± 0.05 cd	4.05 ± 0.09 cd
	BP FIT	17.71 ± 0.21 bc	11.16 ± 0.22 ab	2.02 ± 0.04 bcd	4.53 ± 0.07 ab
N_{180}	Without UIs and BPs	16.5 ± 0.17 e	10.42 ± 0.19 cde	1.98 ± 0.04 bcd	4.10 ± 0.10 cd
	UI ATS	18.25 ± 0.09 a	11.4 ± 0.20 a	2.12 ± 0.04 ab	4.73 ± 0.08 a
	UI URN	17.28 ± 0.09 cd	10.93 ± 0.19 abc	2.05 ± 0.04 abc	4.30 ± 0.07 bc
	BP HUM	17.92 ± 0.10 ab	11.22 ± 0.22 ab	2.10 ± 0.05 ab	4.60 ± 0.09 a
	BP FIT	18.22 ± 0.17 ab	11.37 ± 0.18 a	2.15 ± 0.04 a	4.70 ± 0.08 a

Note. UI—urease inhibitor; ATS—ammonium thiosulfate; URN—N-butyl-thiophosphoric triamide (NBPT) and N-propyl-thiophosphoric triamide (NPPT); BP—biological preparation; HUM—suspension of humic and fulvic acids; FIT—suspension of *Ascophyllum nodosum*. Means ± standard error; $n = 3$. The differences between the means of treatments with different letters are significant ($p < 0.05$).

The highest proportion of cobs (11.4 t ha^{-1}) in the total mass of the aboveground plant part was found with N_{180} fertilizer and with UI ATS and BP FIT. It was found that, when comparing the fertilizer backgrounds, there were no significant differences in cob yields in most cases between the UI and BP preparations tested. The highest efficiency (11.2 t ha^{-1}) was obtained with UI ATS applied at N_{140}, with a significant difference of 1.4 t ha^{-1} compared to fertilization without UIs and BPs. As in previous years, a trend emerged that, with UI ATS, increasing the nitrogen fertilizer rate from N_{140} to N_{180} did not have a significant effect on cob yield. The yields of maize leaves were positively affected by higher nitrogen fertilizer rates, but no significant differences were found in most cases between the preparations tested. Similar trends were observed in the analysis of the yields of maize stems. Significantly higher yields were observed with UI ATS, BP HUM, and BP FIT in all the fertilizer treatments compared to those without UIs and BPs.

The highest partial nitrogen utilization efficiency (PFPN) was determined in 2019–2021. In 2019, fertilization with N_{100} using UI ATS resulted in the highest amount of 211.7 kg dry biomass yield of maize per kilogram of nitrogen. When increasing the rate of nitrogen fertilizers, the efficiency of nitrogen utilization decreased; when fertilizing N_{180} using UI ATS, 133.8 kg of biomass yield was obtained per kilogram of nitrogen. In 2020, the highest PFPN was determined when N_{100} and UI ATS were applied, with 176.2 kg of dry mass yield of the aboveground part of maize per kilogram of nitrogen (Table 9).

Table 9. Agronomic indices of nitrogen use efficiency dry biomass yield of maize for 2019–2021.

Fertilization		**PFP_N (kg Dry Biomass kg^{-1} N)**		
		2019	**2020**	**2021**
N_{100}	Without UIs and BPs	174.8	147.5	134.1
	UI ATS	211.7	176.2	156.4
	UI URN	205.9	159.4	146.4
	BP HUM	201.1	161.8	150.7
	BP FIT	205.6	176.6	154.3
N_{140}	Without UIs and BPs	138.5	115.9	108.3
	UI ATS	163.2	149.0	127.6
	UI URN	154.1	133.0	117.2
	BP HUM	146.6	139.1	120.1
	BP FIT	149.4	140.6	126.5
N_{180}	Without UIs and BPs	111.3	97.8	91.7
	UI ATS	133.8	119.3	101.4
	UI URN	128.1	113.7	96.0
	BP HUM	118.6	109.3	99.6
	BP FIT	122.3	115.2	101.2

Note. UI—urease inhibitor; ATS—ammonium thiosulfate; URN—N-butyl-thiophosphoric triamide (NBPT) and N-propyl-thiophosphoric triamide (NPPT); BP—biological preparation; HUM—suspension of humic and fulvic acids; FIT—suspension of *Ascophyllum nodosum*; PFP_N—partial factor productivity of applied N.

The lowest PFPN (98.7 kg of dry biomass) was found for N_{180} fertilization without UIs and BPs. In 2021, the highest partial efficiency of nitrogen use was determined when fertilizing with N_{100} using UI ATS at 156.4 kg of dry mass yield of the aboveground part of maize per kilogram of nitrogen. Researchers from Kenya also stated that increasing nitrogen fertilizer rates in maize was usually less effective.

3.4. Correlation and Regression Analysis of Nitrogen Fertilizer Rate, Urease Inhibitor, and Biological Preparation Influence on the Yield of the Aboveground Part of the Maize

The results of the 2019 correlation and regression analysis are presented in Table 4. Positive, strong, and statistically significant correlations were found between the different nitrogen fertilizer rates and dry matter yield of maize ((Y_1): $r = 0.82$, $p < 0.01$) when UIs and BPs were not used, $r = 0.85$ ($p < 0.01$) when UI ATS was used, and $r = 0.79$ ($p < 0.05$) when UI URN was used (Table 10). In these cases, the variation in dry matter yield (Y_1) of the aboveground part of the plant was determined at 62–72% by the different rates of nitrogen fertilizer (factor A). No dependence was found between the dry matter yield of the aboveground part of the plant when BP HUM and BP FIT were applied.

In 2019, in the fields where BP HUM and BP FIT were used, no significant differences were found when fertilizing with different fertilizer rates, and only trends of biomass increase were obtained when increasing the nitrogen fertilizer rate. It is likely that, in 2019 during the maize vegetation period, the precipitation was evenly distributed and there was sufficient warmth; as a result of this, the effectiveness of BP HUM and BP FIT increased when fertilizing with N_{100}, and the effectiveness of the N_{140} fertilization rate did not become evident. Researchers from China also noted that, in some years, a 15% reduction in nitrogen fertilizer rates did not significantly reduce maize grain yield [17].

When assessing the dependence of the dry matter yield (Y_2) of cobs on different nitrogen fertilizer rates (factor A), positive, strong, and statistically significant correlations were found: $r = 0.83$ and $p < 0.01$ when UIs and BPs were not used; $r = 0.88$ and $p < 0.01$ when UI ATS was used; and $r = 0.80$ and $p < 0.01$ when UI URN was used. In these cases, factor A influenced the variation of Y_2 by 64–77%. Positive but weak dependencies were found in the cases when BP HUM ($r = 0.64$, $r^2 = 0.41$, $p < 0.05$) and BP FIT ($r = 0.62$, $r^2 = 0.39$, $p < 0.05$) were used.

Table 10. Dependence of maize productivity on nitrogen fertilizer rates (factor A: x—kg ha^{-1}) in 2019.

Dependent Variables Y	UIs and BPs (Factor B)	Regression Equation	Correlation Coefficient *r*	Coefficient of Determination r^2	*p*-Value
Y_1—dry matter yield of the aboveground part of the plant, t ha^{-1}	Not used	y = 14.5 + 0.03x	0.82	0.68	$p < 0.01$
	UI ATS	y = 17.6 + 0.04x	0.85	0.72	$p < 0.01$
	UI URN	y = 17.4 + 0.03x	0.79	0.62	$p < 0.05$
	BP HUM	-	-	-	$p > 0.05$
	BP FIT	-	-	-	$p > 0.05$
Y_2—dry matter yield of cobs (grains, kernels, and cotyledons), t ha^{-1}	Not used	y = 9.21 + 0.02x	0.83	0.70	$p < 0.01$
	UI ATS	y = 11.05 + 0.03x	0.88	0.77	$p < 0.01$
	UI URN	y = 10.99 + 0.02x	0.80	0.64	$p < 0.01$
	BP HUM	y = 11.68 + 0.01x	0.64	0.41	$p < 0.05$
	BP FIT	y = 11.91 + 0.01x	0.62	0.39	$p < 0.05$
Y_3—dry matter yield of leaves, t ha^{-1}	Not used	y = 1.76 + 0.003x	0.74	0.55	$p < 0.05$
	UI ATS	y = 2.22 + 0.003x	0.78	0.61	$p < 0.05$
	UI URN	y = 2.04 + 0.004x	0.79	0.62	$p < 0.05$
	BP HUM	-	-	-	$p > 0.05$
	BP FIT	-	-	-	$p > 0.05$
Y_4—dry matter yield of stems (ochreas, panicles, and undeveloped cobs), t ha^{-1}	Not used	y = 3.51 + 0.007x	0.79	0.62	$p < 0.05$
	UI ATS	y = 4.33 + 0.007x	0.75	0.56	$p < 0.05$
	UI URN	y = 4.39 + 0.005x	0.69	0.48	$p < 0.05$
	BP HUM	-	-	-	$p > 0.05$
	BP FIT	-	-	-	$p > 0.05$

Positive, strong, and statistically significant correlations were found between the nitrogen fertilizer rates and dry matter yield of leaves (Y_3): $r = 0.74$ and $p < 0.05$ when UIs and BPs were not used; $r = 0.78$ and $p < 0.05$ when UI ATS was used; and $r = 0.79$ and $p < 0.05$ when UI URN was used. In these cases, 55–62% of the variation in the dry matter yield of leaves (Y_3) was determined by the nitrogen fertilizer rate (factor A). Statistically insignificant relationships between the selected factor (A) and Y_3 were found in the fields where the BPs HUM and FIT were applied ($p > 0.05$).

The correlation of the dry matter yield of maize stems (Y_4) with the nitrogen fertilizer rates (x) was found to be positive, strong, and statistically significant in the following cases: when UI and BP were not used—$r = 0.79$, $r^2 = 0.62$, $p < 0.05$; when UI ATS was used—$r = 0.75$, $r^2 = 0.56$, $p < 0.05$; and when URN UI was used—$r = 0.69$, $r^2 = 0.48$, $p < 0.05$. No correlations were found when BP HUM and BP FIT were used.

The results of the correlation and regression analysis for 2020 are presented in Table 11. In 2020, the nitrogen fertilizer rate (factor A) was chosen as the independent variable, which influenced the variation in dry matter of the aboveground part by 71–91%. In all cases, positive, strong, and very strong statistically significant correlations were found, with $r = 0.84$–0.95 and $p < 0.01$.

Nitrogen fertilizer rates determined 72–92% of the variation in the dry matter yield of cobs (Y_2): positive, strong, and very strong statistically significant correlations were found, with $r = 0.85$–0.96 and $p < 0.01$.

Positive and strong statistically significant correlations were found in all cases between nitrogen fertilizer rates (Factor A) and the dry matter yield of leaves (Y_3): $r = 0.84$ and $p < 0.01$ when UIs and BPs were not used; $r = 0.79$ and $p < 0.05$ when UI ATS was used; and $r = 0.88$ and $p < 0.01$ when UI URN was used. When BPs were used, $r = 0.83$ and $p < 0.01$ with BP HUM application, and $r = 0.78$ and $p < 0.05$ with BP FIT application.

Table 11. Dependence of maize productivity on nitrogen fertilizer rates (Factor A: x—kg ha^{-1}) in 2020.

Dependent Variables Y	UIs and BPs (Factor B)	Regression Equation	Correlation Coefficient r	Coefficient of Determination r^2	p-Value
Y_1—dry matter yield of the aboveground part of the plant, t ha^{-1}	Not used	$y = 11.2 + 0.04x$	0.90	0.81	$p < 0.01$
	UI ATS	$y = 13.2 + 0.05x$	0.86	0.74	$p < 0.01$
	UI URN	$y = 10.4 + 0.06x$	0.95	0.91	$p < 0.01$
	BP HUM	$y = 12.3 + 0.05x$	0.84	0.71	$p < 0.01$
	BP FIT	$y = 14.0 + 0.04x$	0.87	0.75	$p < 0.01$
Y_2—dry matter yield of cobs (grains, kernels, and cotyledons), t ha^{-1}	Not used	$y = 6.67 + 0.03x$	0.91	0.84	$p < 0.01$
	UI ATS	$y = 8.32 + 0.03x$	0.85	0.72	$p < 0.01$
	UI URN	$y = 6.19 + 0.04x$	0.96	0.92	$p < 0.05$
	BP HUM	$y = 7.78 + 0.03x$	0.85	0.72	$p < 0.01$
	BP FIT	$y = 9.0 + 0.02x$	0.85	0.72	$p < 0.01$
Y_3—dry matter yield of leaves, t ha^{-1}	Not used	$y = 1.46 + 0.004x$	0.84	0.71	$p < 0.01$
	UI ATS	$y = 1.65 + 0.005x$	0.79	0.63	$p < 0.05$
	UI URN	$y = 1.45 + 0.006x$	0.88	0.77	$p < 0.01$
	BP HUM	$y = 1.50 + 0.005x$	0.83	0.68	$p < 0.01$
	BP FIT	$y = 1.70 + 0.004x$	0.78	0.61	$p < 0.05$
Y_4—dry matter yield of stems (ochreas, panicles, and undeveloped cobs), t ha^{-1}	Not used	$y = 2.85 + 0.008x$	0.87	0.75	$p < 0.01$
	UI ATS	$y = 3.25 + 0.01x$	0.88	0.78	$p < 0.01$
	UI URN	$y = 2.77 + 0.01x$	0.91	0.84	$p < 0.01$
	BP HUM	$y = 3.05 + 0.01x$	0.82	0.66	$p < 0.01$
	BP FIT	$y = 3.29 + 0.009x$	0.87	0.76	$p < 0.01$

Positive, strong, and very strong statistically significant correlations were found between different fertilizer rates and the dry matter yield of stems (Y_4): ($r = 0.82$–0.91) and $p < 0.01$. The variation in Y_4 was 66–84% determined by nitrogen fertilizer rates.

Positive, strong, and very strong statistically significant correlations were found between the nitrogen fertilizer rates and the dry matter yield of the aboveground part of maize (Y_1) in 2021 (Table 12): $r = 0.89$–98 and $p < 0.01$. The selected factor (A) accounted for 79–96% of the variation in the dependent variable Y_1.

When assessing the dependence of the dry matter yield of cobs (Y_2) on nitrogen fertilizer rates (factor A), positive and very strong statistically significant correlations were found: $r = 0.93$ and $p < 0.01$ when UIs and BPs were not used; and $r = 0.91$ when BP HUM was used. Factor A influenced the variation in Y_2 by 73–86%.

Positive and very strong statistically significant correlations were found between the different nitrogen fertilizer rates and the dry matter yield of maize leaves (Y_3): $r = 0.98$ and $p < 0.01$ when UIs and BPs were not applied; and $r = 0.93$ and $p < 0.01$ when BP HUM was applied. A statistically insignificant correlation was found when BP FIT was applied. Applications of UI ATS and UI URN showed strong and statistically significant relationships: $r = 0.86$–0.88 and $p < 0.01$.

A positive, strong, and statistically significant correlation was found between the nitrogen fertilizer rates and the dry matter yield of stems (Y_4) when UI ATS was used: $r = 0.86$ and $p < 0.01$. In other cases, for factor B, very strong and statistically significant correlations were obtained: $r = 0.91$–0.95 and $p < 0.01$.

Table 12. Dependence of maize productivity on nitrogen fertilizer rates (factor A: x—kg ha^{-1}) in 2021.

Dependent Variables Y	UIs and BPs (Factor B)	Regression Equation	Correlation Coefficient r	Coefficient of Determination r^2	p-Value
Y_1—dry matter yield of the aboveground part of the plant, t ha^{-1}	Not used	y = 9.61 + 0.039x	0.98	0.96	$p < 0.01$
	UI ATS	y = 12.78 + 0.032x	0.89	0.79	$p < 0.01$
	UI URN	y = 11.50 + 0.033x	0.95	0.90	$p < 0.01$
	BP HUM	y = 11.70 + 0.035x	0.97	0.95	$p < 0.01$
	BP FIT	y = 12.34 + 0.034x	0.92	0.85	$p < 0.01$
Y_2—dry matter yield of cobs (grains, kernels, and cotyledons), t ha^{-1}	Not used	y = 6.60 + 0.022x	0.93	0.86	$p < 0.01$
	UI ATS	y = 8.42 + 0.018x	0.85	0.73	$p < 0.01$
	UI URN	y = 7.68 + 0.019x	0.89	0.79	$p < 0.01$
	BP HUM	y = 8.10 + 0.018x	0.91	0.82	$p < 0.01$
	BP FIT	y = 8.34 + 0.018x	0.86	0.73	$p < 0.01$
Y_3—dry matter yield of leaves, t ha^{-1}	Not used	y = 0.73 + 0.007x	0.98	0.96	$p < 0.01$
	UI ATS	y = 1.31 + 0.005x	0.86	0.73	$p < 0.01$
	UI URN	y = 1.34 + 0.004x	0.88	0.77	$p < 0.01$
	BP HUM	y = 1.03 + 0.006x	0.93	0.87	$p < 0.01$
	BP FIT	-	-	-	$p > 0.05$
Y_4—dry matter yield of stems (ochreas, panicles, and undeveloped cobs), t ha^{-1}	Not used	y = 2.28 + 0.01x	0.95	0.90	$p < 0.01$
	UI ATS	y = 2.96 + 0.01x	0.86	0.75	$p < 0.01$
	UI URN	y = 2.45 + 0.01x	0.93	0.87	$p < 0.01$
	BP HUM	y = 2.48 + 0.01x	0.95	0.90	$p < 0.01$
	BP FIT	y = 2.46 + 0.01x	0.91	0.84	$p < 0.01$

4. Discussion

Researchers are looking for innovative ways to reduce nitrogen losses in agroecosystems through a variety of measures, such as changing the methods, timing, and types of fertilizer [41,42]. Studies have shown that deep fertilizer application is effective in reducing NH_3 volatilization and N_2O emissions [43,44]. Xia et al. [45] found that deeply applied nitrogen reduced the intensity of gaseous nitrogen losses, but reductions in gaseous nitrogen emissions from cropland ecosystems can vary with the climate, soil quality, water conditions, and agronomic measures in different regions, and the mechanism of emission reduction is still not well-understood [46]. Growers usually opt for spreading fertilizer on the soil surface and increasing fertilizer rates. Fertilizers are applied annually around the world to meet the growing demand for food [47]. However, due to a lack of research and guidance, it is common to overfertilize in order to maintain maximum yields [48,49].

When analyzing the influence of meteorological conditions on crop productivity, it should be noted that the formation of maize is closely related to sensitive stages of growth. The yield of maize is reduced if there are water shortages at individual stages of growth. In favor of the growth of maize in the year 2019, the precipitation was distributed over the entire vegetation period, and in 2020, no precipitation occurred during the period of maize flowering and grain milk maturity, while the average daily temperature was higher than that in 2019 and 2021. In 2021, there was no precipitation in the BBCH 13–26 stage, and in the flowering and milk maturity stage, precipitation was abundant, and low air temperature prevailed. It can be concluded that, in the climate zone studied, air temperature and precipitation influenced the extension or shortening of the durations of individual stages of the development of maize plants; in addition, a lack or excess of water in the period from the appearance of the panicles to the beginning of grain filling affected the productivity of the plants. The fertilization factor was insignificant for the duration of the stages of maize development. Researchers from Croatia also showed that the amount of precipitation during the stage of formation of the generative organs of maize affected the productivity of the plants [50].

The trends in our experimental results are consistent with the findings of Mansouri-Far et al. [51] on the inefficiency of increasing nitrogen fertilizer rates. That is, recommended fertilizer rates for high yields do not always correspond to the fertilizer rate that promotes an increase in agronomic fertilizer efficiency [52–54]. Therefore, appropriate fertilization measures need to be implemented to reduce NH_3 volatilization and N_2O emissions and to improve plant productivity in the context of sustainable agricultural development [55].

In our experiment, the investigated preparations of UI ATS and UI URN significantly increased the dry matter yield of maize at lower rates of nitrogen fertilizer. The results obtained in the field experiment confirmed the claims of Guardia et al. [56] and Rose et al. [57] that the use of UIs increases the efficiency of nitrogen fertilizer, which is why it is very important to select appropriate rates of nitrogen fertilizers for sufficient yields and, at the same time, protect the environment. Blennerhassett et al. [58] argued that urease activity in the soil must be controlled under adverse and, sometimes, extreme conditions, for which UIs, such as N-(*n*-butyl) thiophosphorus triamide (NBPT), have been proposed as an effective way to inhibit urease activity and slow urea hydrolysis, as well as to reduce the loss of ammonium from ammonium fertilizer application. In our experiment, there was a trend in which the efficiency of UI ATS was higher when fertilizing with the N_{180} fertilizer rate in the year 2019, which was more favorable for maize growth, while fertilizing with the N_{100} and N_{140} rates, respectively, increased the efficiency in the years 2020 and 2021, which were less favorable for maize growth. Chen et al. [59] suggested that UI application reduced the availability of ammonium (NH_4^+) and nitrates (NO_3^-) in the soil, which could be a simple means of reducing N losses due to ammonia volatilization and NO_3^- leaching, leading to better nutrient utilization by the plants and increased plant productivity. Dawar et al. [60] observed that UIs significantly improved maize yields throughout the growing season. The findings of Dawar et al. [60] confirm the results of our field experiment where the highest grain yield was obtained with UI, but no significant difference was found between the inhibitors tested.

Dawar et al. [60], Zaman et al. [61], and Robles-Aguilar [62] have argued that the use of UIs can improve the efficiency of nitrogen fertilizers, leading to an increase in plant productivity and a change in the ratio of yield structure components. Our field experimental data are consistent with these researchers' findings that the use of UIs and the application of low (N_{100}) and medium (N_{140}) rates of nitrogen fertilizers significantly increased the proportion of maize cobs in the total aboveground yield structure in all years of the experiment. Studies by Majidian et al. [63] showed that total maize yields could be increased by applying organic and chemical fertilizers simultaneously, which in turn helped to reduce the negative effects of chemical fertilizer use on soil health and improved the overall sustainability of the crop. Hindersah et al. [64] argued that, in sustainable agriculture with a nutrient management system, the integrated use of biological fertilizers had an impact on soil health and productivity. Santner et al. [65] stated that plant hormones were signaling molecules synthesized in plants and acted at very low concentrations. Plant hormones contribute to almost all functions of plant growth and development. However, most of the previous studies on maize have focused only on the relationship between seed germination and plant hormones. Maize, like other plants, is sensitive to environmental factors during seed germination and plant establishment, which is why the use of biological agents, especially hormones, can be very effective [66]. BP HUM, studied in our experiment, significantly increased the dry matter yield of aboveground maize compared to fertilization without UIs and BPs but was inferior in efficiency compared to UI ATS.

Rhaman et al. (2018) found that high precipitation could lead to unfavorable conditions for plant growth, and phytohormones could initiate physiological processes such as stem elongation or grain filing [67]. Research publications have suggested that seaweeds and phytohormones may interact with each other to control physiological processes in plants under different biotic and abiotic stresses. In our experiment, we found that BP FIT significantly increased the yield of maize cobs when fertilized with N_{100} in the favorable year of 2019 and the less favorable years of 2020–2021, while the phytohormone formulation of BP FIT did not show any effectiveness at increasing fertilizer application rates, with an upward trend in the yield of the aboveground part of maize.

5. Conclusions

Increasing nitrogen fertilizer rates had a positive effect on the dry matter yields of the cobs, leaves, and stems of maize. Positive, moderate, strong, and very strong statistically significant correlations were found in most cases between nitrogen fertilizer rates and the latter indicators. The use of urease inhibitors (UIs) and biological preparations (BPs) increased the dry matter yield of maize in all the nitrogen fertilizer backgrounds studied (N_{100}–N_{180}). The highest average dry matter yields of the aboveground maize in the period of 2019–2021 were found with N_{180} and UI ATS (18.3–24.1 t ha^{-1}). It was found that the dry matter yields of the aboveground part of maize were significantly higher or showed an increasing trend with the application of UIs and BPs, as well as with the application of lower rates of N_{100} and N_{140} compared to the N_{180} rate without UIs and BPs. The proportion of maize cob yield in the total aboveground mass was highest (11.4–15.7 t ha^{-1}) with N_{180} and UI ATS, but no significant differences were found between the N_{180} and N_{140} fertilization rates. The UIs and BPs increased the efficiency of nitrogen fertilizer; therefore, the lower rates of nitrogen fertilizer (N_{100} and N_{140}) could be used to produce a plant productivity the same as that obtained with a high rate of nitrogen fertilizer (N_{180}).

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