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Nitrogen balance at the maize cultivation in Southern Bulgaria under anthropogenic loading

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Abstract

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The aim of the present study is to perform a "conditional" nitrogen balance at the maize cultivation and estimate its input and output rates. The influence of precipitation, irrigation and fertilizer application and N uptake by plant production and N-output by lysimetric water are evaluated in this study. The tryal is carried out on a Fluvisol, near Plovdiv, in Southern Bulgaria, under the conditions of field experiment with irrigation maize over the period 2020. The experimental design includes three treatments with nitrogen and phosphorus application, $N_{120}P_{80,}$ $N_{160}P_{120,}$ $N_{200}P_{160}$ and control $(N_0P_0)_,$ The field plots are equipped with modification of Ebermayer type of lysimeters, which collect water from 100 cm depth of soil profile. According to the data received, it was observed that compensation between the amounts of N input and output was achieved in two variants (N_{120}, N_{160}). The nitrogen balance, obtained on the long-term field experiments can be successfully used for optimizing the applied fertilizers under specific soil and environmental conditions.

Keywords: precipitation; lysimetric water; fertilizer application; uptake and output nitrogen

Introduction

The management of agricultural lands through agricultural practices, application of organic and mineral fertilizers, crop rotations, tillage, irrigation methods, etc., have a significant impact on the accumulation and movement of nitrogen through the soil profile. According to researchers Chen et al. (2020) future anthropogenic activities and land use management can play a major role in global environmental change. Nitrogen losses, which are significant on light sandy soils are also due to a large extent to the improper land management (Salo et al., 2006). In addition, anthropogenic and technogenic loads on soils are the cause of changes in the natural nitrogen cycle (Zhang, 2016; Han et al., 2020). The nitrogen is one of the most important components in plant nutrition and obtaining high yields to a large extent depend on nitrogen fertilizers application (Tilman et al., 2002). Nitrogen has significant influrnce as a nutrient, it plays a major role and at the same time is a potential acidifier. Although, the nitrogen fertilization increases yields, in the case of excessive application of N-fertilizers it is possible that they remain unused in the agroecosystem, which can have negative effects on soil and environmental quality (Sainju, 2017). The fertilizers which are not included in the biological cycle are potential sources of negative changes in the solid and liquid phase of soil (Bordoloi et al., 2013; Wang et al., 2013). Exceeding the nitrogen rates with the fertilization can lead to nitrogen losses, especially in the form of nitrates, which are mobile through the soil profile (Addiscott et al., 1996; Smith et al., 2003) and are the cause of pollution of surface and groundwaters, acidification of soils, increase of NH_3 and NOx emissions, (Pennino et al., 2020; Srivastava et al., 2020). Some researchers Gao et al. (2014), believe that there are no quantitative tools to accurately describe nutrient changes in agricultural systems. According to the study of many authors the nitrogen balance can successfully be used as an effective tool for assessing the extent of the nitrogen loss in agricultural ecosystems, as well as for, determination of the factors increasing the efficiency of fertilizer use and formulation of programs aiming its full utilization (Roy et al., 2005; Shröder et al., 2006; Stoicheva et al., 2011; Moustakas & Kosmas 2017).

The aim of the present study is to perform a "conditional" nitrogen balance at the maize cultivation and estimate its input and output rates.

Material and Methods

The field experiment was set up in 1995, at the experimental station of the "N. Poushkarov" Institute of Soil Science, Agrotechnologies and Plant Protection in the village of Tsalapitsa, located in Southern Bulgaria (24035'E; 42014'N). In 2020 the field trial was conducted with irrigated maize (*Zea mays* L.) FAO group 310. The methodology comprised three levels with N and P fertilization including an unfertilized plot (T_0). Fertilizer rates were calculated according to the nutrient availability of the soil and the type of crop grown. The average rates of fertilization with nitrogen and phosphorus for the study periods 2020 are: $T_0(N_0P_0)$, $T_1(N_{120}P_{80})$, $T_2(N_{160}P_{120})$ and $T_3(N_{200}P_{160})$ kg.ha^{-1}. Nitrogen fertilizers were applied as ammonium nitrate – 2/3 of the rate spread before sowing, and 1/3 – broadcasted in spring. Phosphorous fertilizer was applied as super phosphate each year before planting, potassium fertilizer was not applied. The scheme of the experiment is in accordance with the installed lysimetric devices. Three irrigations were made during the maize growing season at the irrigation rate 80 m^3.

The studied soil is Alluvial-Meadow, which corresponds to Eutric Fluvisol in FAO classification (FAO, 1998, WRBSR).

The region (Tsalapitsa village) possesses the traits of the transitory subzone between European and Mediterranean continental zones with hot and dry summer and mild winter (Levichanska, 1991). The region is characterized with mean annual precipitation of 458 mm in 2020. The average annual air temperature is 12.5–12.8°C. Soil management practices and other agrotechnical activites are according to the standard technology for the maize growing.

The soil profile has coarse texture, low water holding capacity and conditions for fast water movement downward the profile. The arable horizon is characterized by slightly acid soil reaction pH $_{H20}$ = 6.0, low total nitrogen content (0.052%), low cation exchange capacity (up to 23.11%) in the plough layer (Table 1). Base saturation is about 74%. The agrochemical characteristics of the Alluvial meadow soil are, mineral N content, 21.25 mg kg^{-1}, available P and K, 7.50 and 10.20 mg 100 g^{-1}, respectively for the layer 0–30 cm.

The chemical composition of every registered precipitation was analysed. Depending on the volume of water and the concentrations of chemical elements, was calculated their input. Periodically irrigation waters were also tested for nitrogen content. Lysimetric water analysis was used to assess the effect of agricultural activities on the content and leaching of nitrates and other chemical elements. The field plots were equipped with Ebermayer lysimeters (Stoichev, 1974) installed at 100 cm below the soil surface to collect leachate from the soil profile, under three replications of variants T_0, T_1, T_2 and T_3. Lyzimetric water samples were taken several times a year depending on the amount of infiltrate from the plastic containers (5.0 L) instaled at the bottom outlet of each lysimeters.

The pH values and chemical composition (K^+, Na^+, Ca^{2+}, Mg^{2+}, NO_3^-N, HCO_3^-, Cl^-, SO_4^{2-}) of precipitation, irrigation and lyzimetric waters are determined using the following methods: pH, potentiometrically (Arinushkina, 1970), nitrogen, sulphates and chloride on a spectrophotometer Spectroquant Pharo 100, potassium and sodium were determined on a flame photometer, calcium and magnesium by the ICP-OES. The nitrogen content in plants is determined by wet combustion (Petersburgii, 1986), phosphorus was determined colorimetrically with molybdenum blue, and potassium, by a flame photometer (Peterburgskii, 1986).

Table 1. Characteristics of the studied Fluvisol (Stoichev 1997)

Horizons	Depth, cm	pH_{H2O}	Organic C, %	Total N, %	C:N	$CaCO_3$, %	Cation exchange capacity, cmol.kg^{-1}	Particle size, mm		
								0.05–0.001	< 0.001	<0.01
								%	%	%
Alluvial-meadow soil – Eutric Fluvisol (WRBSR)										
A_{arable}	0–35	6.0	0.70	0.052	7.8	0.00	7.92	33	13	32
A_2	35–60	6.4	0.55	0.050	6.4	0.00	18.18	32	33	35
A_3C_1	60–87	6.5	0.42	0.042	5.8	0.00	22.77	37	36	40
C_2	87–118	6.5	0.38	0.030	7.5	0.00	23.11	47	27	–

Results and Discussion

The main factors for increasing nitrogen losses and water pollution is the improper land use management practices (Ngoye et al., 2004; Bu et al., 2014). It is known that the soil as a complex system has a certain potential to take over the anthropogenic impacts and to respond to them, respectively. However, at certain times residues can accumulate in soil and exceeding certain limits, they can have a negative impact on the other components of the ecosystem, plants, water, geological materials, microorganisms, etc. The study of the nutrients balance is a precondition for finding the ecological levels of loading with nutrients of agroecosystems. Nitrogen balance, obtained on the long-term field experiments can be successfully used for optimizing the applied fertilizers under specific soil and environmental conditions. To achieve sustainable agriculture and cultivation of agricultural crops, it is necessary to assess the input of nitrogen and monitor the potential nitrate losses. For this purpose, it is essential to make a conditional nitrogen balance, by quantifying the input (with precipitation, irrigation waters and fertilizer application) and output (exported nitrogen with plant products and drainage waters).

Conditional balance of N = input items of N
(with precipitation, irrigation waters and fertilizers)
– output items of N (with plants and lysimetric waters)

After accounting for all inputs and outputs of nitrogen the balance should be nearly zero. However, very rarely this value is obtained, due to the different soil and climatic conditions, imported fertilizers, soil management practices, the crops grown, and difficulties in measuring some parameters, such as atmospheric N deposition, biological fixation of N, nitrogen losses through various processes etc. (Sainju, 2017).

The Alluvial meadow soil in the study area is characterized by light soil texture, poor water holding capacity and relatively high water permeability. These soils have one humic-accumulative horizon overlaying parent rock or deposition layers. There is a relatively high water exchange between the layers, which creates conditions for active migration of chemical elements in the profile. For this reason, the agricultural practices applied are of significant importance regarding the nitrogen uptake.

Chemical composition and input of nitrogen with precipitation and irrigation water

The precipitation is considered as an important factor for realizing the productive potential of the soil and as an input parameter in the balance of the elements. Studies in recent years show that precipitation and dry atmospheric depositions contain and transfer chemical elements which in most cases have anthropogenic origin and are defined as pollutants with negative impact on the ecosystems, in which they are deposited and accumulated (Gauger et al., 2001). According to some studies (Nearing et al., 2005; Mitchell, 2011) the seasonal fluctuations in temperature and intensive precipitations may cause significant losses of nitrate. Precipitation also has a significant effect on the nitrogen cycle through changes in soil moisture, erosion, nitrate exports, etc. (Cregger et al., 2014). According to Wick et al. (2012), the gross nitrogen balance can be successfully used to predict groundwater nitrate pollution, especially in regions with intense and higher rainfall.

From the data obtained, the autumn-spring maximum of the precipitation was established, which is generally typical for this climatic region.

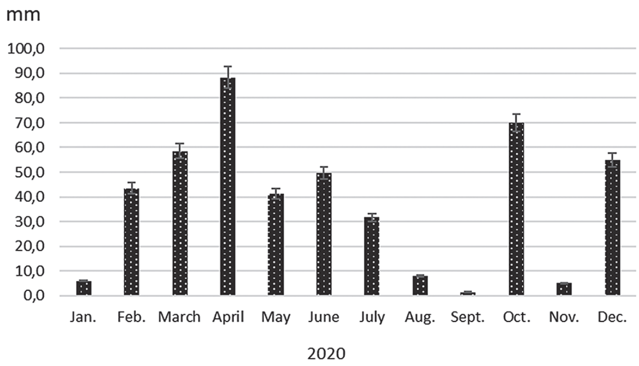

Fig. 1. Average amount of precipitation (mm) for the studied period, 2020, Tsalapitsa region

The data presented in Figure 1 show that the largest is the amount of rainfall in April and in October, 2020. The detailed analysis of the data shows that the precipitation in the studied area is characterized by slightly acidic to near neutral pH values (6.0-6.75). The analysis of data on the content of cations in the precipitation from the area of Tsalapitsa shows that it is higher in the spring and summer months of this year, when calcium levels reach 15 mg.l^{-1} in April 2020. It is found that the values of NH_4-N range from 3.10 to 8.70 mg.l^{-1}, while the reported amount of NO_{3-}N is in the range of 3.40 to 6.38 mg.l^{-1}, as it is the highest in the spring of 2020, a situation similar to that of calcium and magnesium. The average chemical composition of precipitation is presented in Table 2.

To assess the impact of atmospheric deposition upon the soil it is important to determine the total amount of the ions included in the annual precipitation. The input of nitrogen

Table 2. Average chemical composition of precipitation (mg.l^{-1}) from Tsalapitsa experimental field for 2020

	pH	K^+	Na^+	Ca^{2+}	Mg^{2+}	NH_4-N	N-NO_3	HCO_3^-	Cl^-
Mean	6.4	2.55	1.32	7.85	1.88	6.21	5.02	26.32	5.46
stdv	0.29	1.37	0.432	3.572	1.089	2.755	1.282	8.235	2.123

by the precipitation is calculated on the basis of the average chemical composition and the total annual rainfall (458 mm) in the region of Tsalapitsa. The data show that average input by the most important biogenic element – the nitrogen for the studied year is in the range (23.0 kg.ha^{-1}). According to studies of some authors Chiwa et al. (2013) with the increase of nitrogen emissions into the atmosphere the revenu of nitrogen exceed 30 kg.ha^{-1} in Europe and world wide, but according to other studies Li et al. (2016), in the last few decades a reduction in atmospheric nitrate deposition is found. The average annual input of the main compensating cation – calcium for the studied area is 26.0 kg.ha^{-1}.

For the study of irrigation water, groundwater from wells near the experimental field of Tsalapitsa village was used and represents a potential source of chemical elements for the soils and an input in the biological cycle of the elements. It is known that precipitation and irrigation water affect the balance of the elements with the nitrogen contained in them. In their research, Barros et al. (2012); Poch-Massegú et al. (2014) reported that in vulnerable areas nitrate pollution of light sandy soils with shallow groundwater is becoming a serious environmental problem, the control of the type, the way and the number of irrigations applied with simultaneous reduction of fertilizer rates are essential to reduce leaching of nitrates.

The nitrate nitrogen content is characterized by some fluctuations during the growing season. In the studies conducted in 2020 it is found that pH values vary slightly in the range of 7.70 to 7.85, and the content of nitrate nitrogen ranges from 3.70 to 10.60 mg.l^{-1}. It should be noted that monitoring of the chemical composition of the irrigation water and the nitrogen input is essential in soils of light soil texture and anthropogenic loading. The results of the data analysis show that the water used for irrigation has a hydrocarbonate-calcium composition (the most significant is the content of HCO_3^-).

The average input of nitrogen is in the range of 17.7 kg.ha^{-1}, the input of calcium is 167.5 kg.ha^{-1}, hydrocarbonates, 615.3 kg.ha^{-1}, i.e.they are a significant source of buffering ions (Table 3).

Table 3. Average chemical composition (mg.l^{-1}) of shallow groundwater (used for irrigation), Tsalapitsa, 2020

Elements mg.l^{-1}	mean± Stdv
pH	7.80±0.08
K^+	3.04±0.29
Na^+	35.83±9.88
Ca^{2+}	67.00±20.50
Mg^{2+}	20.25±7.76
N-NO_3^-	7.10±3.45
HCO_3^-	246.12±32.76
Cl^-	23.17±11.98

Chemical composition and nitrogen losses with lysimetric waters

It is known that the liquid phase of soil is a very dynamic and sensitive component, which is the first to react to various influences and can be successfully used for early prediction of possible changes in soil. Formation of the lyzismetric water flow appears, when soil water saturation exceeds field capacity and drainage determined by gravity occurs. The vulnerability of Fluvisol to anthropogenic load and the influence of different fertilization rates on the loss of chemical elements and nitrogen with lysimetric waters have been reported in many studies (Stoicheva et al., 2003; Simeonova et al., 2021). The application of unbalanced mineral fertilization and irrigation of soils with high permeability may be the reason for leaching of residual nitrogen outside the root zone and may represent a potential risk of groundwater contamination.

It is known that most of the NH_4^+-N when it is imported in soil, is adsorbed by the soil adsorption complex very often in non-exchangeable form (Nieder et al., 2011), and only a small part remains as soluble ammonium. However, nitrate nitrogen is not adsorbed, as a result of which it is mobile along the soil and available to plant roots much faster than ammonium nitrogen.

From the obtained results it is established that the pH values of the waters are in the range from 7.30 to 7.85 (Table 4). The drainage obtained under the control has the highest pH values and the lowest values are measured under the fertilized variants (T_2 and T_3).

The results show that in the lysimetric water, dominate the cations of calcium, which are indicative of Alluvial meadow soil. An increase in the content of calcium in the water of the fertilized variants – T_2 ($N_{160}P_{120}$) and T_3 ($N_{200}P_{160}$) is found,

Table 4. Average chemical composition ($mg.l^{-1}$) of lysimetric water, 2020, Tsalapitsa

Variants of fertilization	pH	Average chemical composition, $mg.l^{-1}$								SO_4^{2-}
		K^+	Na^+	Ca^{2+}	Mg^{2+}	$N\text{-}NH_4^+$	$N\text{-}NO_3^-$	HCO_3^-	Cl^-	
$T_0 N_0P_0$	7.85	4.29	38.5	70.4	20.5	1.86	10.8	138.5	15.0	71.3
$T_1N_{120}P_{80}$	7.60	4.08	36.4	51.5	12.7	1.95	17.5	89.7	13.5	48.5
$T_2N_{160}P_{120}$	7.25	4.81	25.7	76.7	10.2	3.70	25.5	68.7	34.0	84.0
$T_3N_{200}P_{160}$	7.35	5.10	22.3	106.7	23.3	1.87	39.0	66.3	19.5	70.8

which correlates with the content of nitrate nitrogen (Table 4). When maize is grown in 2020, Ca^{2+} content reaches the highest values from106 $mg.l^{-1}$. The studied ions of potassium, sodium and chloride are not significantly affected by the fertilization rates. Results from the study show that the hydrocarbonates range from 66.34 $mg.l^{-1}$ to 138.51 $mg.l^{-1}$, and decreased with increasing fertilization rates.

We observed that the greatest NO_3-N content in the lysimetric waters is observed under the variant (T_3-$N_{200}P_{160}$) for all the studied period.

The amount of elements leached out of the one-meter soil profile (Table 5) was derived from the volume and the average concentration of chemical elements of lysimetric water. The volume of the drainage water highly depends on precipitation, irrigation and evapotranspiration, as well as on the soil physical properties, that is why there are possible differences in the volumes below the different fertilization rates. Almost the whole amount of N leached was in nitrate form.

In all the cases, fertilization had led to increasing of N losses. During the study period of 2020, N leached out of the control treatment was 2–3 times lower in comparison with fertilized treatments (4.5 $kg.ha^{-1}$ of the control treatment T_0). The highest N losses from 14.3 $kg.ha^{-1}$ at the maximum fertilized variant T_3 ($N_{200}P_{160}$) are established. Annual average losses of Ca^{2+} ranged from 11.9 – 31 $kg.ha^{-1}$ depending on N fertilizer rates. Calcium leaching increased with increasing of N leaching rates. The migration of hydrocarbonates decreased with increasing fertilizer rates. The obtained losses of macroelements are determined by a large number of factors – the volume of lysimetric waters, their composition, fertilization rates, cultivated crops, as well as by the ion exchange interactions in the soil adsorbent between the cations in the soil colloidal complex and cations imported with fertilizers, mainly NH_4-N.

Uptake of nitrogen with maize biomass

The total biomass of maize ranges from 7780 to 21850 $kg.ha^{-1}$. The uptake of nitrogen with the biomass from maize under no fertilization is 69.6 $kg.ha^{-1}$ while for the maximum fertilization variant reache 190.8 $kg.ha^{-1}$ (Table 6). It should be noted that when increasing the fertilizer rate (especially above N_{200}) the uptake is lower than the amount of nitrogen imported input. The similar results were observed in our early investigations (Alexandrova et al., 2007; Simeonova et al., 2015). In most cases fertilization is the main reason for the nitrogen accumulation in the root zone and its movement in the soil profile, especially at Fluvisol, which are coarse textured soils, with significant spatial heterogeneity and great variety in the arrangement of alluvial materials.In this situation, it is possible migration of chemical elements and unutilized nitrogen by crops with the water out of soil root zone and reaching to the ground water level. The data show that approximate compensation of input with the fertilizers and the output amounts of nitrogen with biomass was observed in the T_2 variant (Table 6).

Table 5. Leaching of chemical elements ($kg.ha^{-1}$) with lysimetric water, 2020, Tsalapitsa

Variants of fertilization	pH	Leaching of chemical elements, $kg.ha^{-1}$								SO_4^{2-}
		K^+	Na^+	Ca^{2+}	Mg^{2+}	$N\text{-}NH_4^+$	$N\text{-}NO_3^-$	HCO_3^-	Cl^-	
$T_0 N_0P_0$	7.85	1.2	11.0	20.3	5.9	0.5	4.5	39.9	4.3	20.6
$T_1N_{120}P_{80}$	7.60	0.94	10.4	11.9	3.0	0.4	8.5	20.7	3.1	11.1
$T_2N_{160}P_{120}$	7.25	1.3	7.4	21.4	2.8	1.0	9.7	19.1	9.4	23.4
$T_3N_{200}P_{160}$	7.35	1.4	6.4	31.0	6.7	0.5	14.3	19.3	5.6	20.6

Table 6. Absolute dry biomass and output of macroelements in the field fertilizer experiment with maize 2020

Variants	Dry biomass kg.ha^{-1}	Output of macroelements kg.ha^{-1}		
		N	P	K
T_0	7780	69.6	14.3	83.3
$T_1N_{120}P_{80}$	19370	172.6	29.8	209.2
$T_2\ N_{160}P_{120}$	19800	179.3	35.7	236.2
$T_3\ N_{200}P_{160}$	21850	190.8	37.6	241.0

In a study with irrigated maize by Stoichev et al. (1988), the authors found that the application of nitrogen fertilizer over 210 kg.ha^{-1} does not increase yield, on the contrary it was the reason for the accumulation of nitrogen in the soil profile of the studied Alluvial-meadow soil. According to the authors, the coefficient of nitrogen utilization by plants is about 50%, and at the highest rates there is a reduction of between 10-12 times.

A similar explanation is expressed in the study of (Anas et al., 2020), who consider that, when increasing fertilization rates, higher nitrogen uptake by plants does not lead to an increase in biomass, thus reducing the efficiency of use of nitrogen and increasing production costs and environmental pollution. The authors believe that further research is needed on carbon-nitrogen metabolism at the levels of molecular changes in plants, using genetic technologies to improve the efficiency of nitrogen use.

Ding et al. (2021) in their study suggest that nitrogen balance is closely related to crop yields and its loss can be used as an indicator for determining the threshold norms for application of mineral nitrogen fertilizer. According to Okamoto et al. (2021) halving the amount of N used can improve N fertilizer use efficiency and reduce N loss to groundwater.

In order to establish a balance in the agroecosystems, a long period of time is generally required, with relatively constant management conditions, during which the inputs of the elements are compensated approximately by the corresponding losses. Therefore, to achieve the steady state of the agroecosystem under maize cultivation it is necessary to assess the imported chemical elements and to report the export from them, including the potential losses of nitrogen. The conditions under which the nitrogen balance reaches low positive or negative values, and they are maintained for a longer period of time, are defined as stable equilibrium, i.e. conditions are created for sustainable development of the crop. From the analysis of the obtained results for the nitrogen balance (Table 7) it was established that near the equilibrium state are the variants of fertilization T_1 and T_2. It should be noted that in calculating the conditional nitrogen balance the input from precipitation (23.3 kg.ha^{-1}) and irrigation water (17.7 kg.ha^{-1}) was added, which make a sensitive amount of 41 kg.ha^{-1}.

Simeonova et al. (2015) also found similar results in calculating the nitrogen balance in a trial with growing vegetables. It should be underlined that if this input is not considered excess of N in T_2 and T_3 will not be identified. This fact is very important and should be taken into account in future research to achieve a sustainable balance in agroecosystems, where technological solutions must be aimed at such a level of fertilization, which takes into account the import of nitrogen from precipitation and irrigation water. In this way, in intensive agriculture, the maximum inclusion of nitrogen in the biological cycle will be realized.

Conclusion

The results of the study show that the type of the land-use and different fertilization rates are among the factors that influenced elements leaching and losses. It was found that with lysimetric waters from 4.4 to 14.3 kg.ha^{-1} nitrogen is lost, while with plant biomass it reaches 190.8 kg.ha^{-1}. It is observed that the input of nitrogen with precipitation (23.3 kg.ha^{-1}) and irrigation water (17.7 kg.ha^{-1}) is essential (41 kg.ha^{-1}) and affects the nitrogen balance. It should be underlined that if this input is not considered will not be identified an excess nitrogen inT_2 and T_3 variants.

It is reported that it is necessary to apply such fertilization rates in the areas with intensive agriculture and, especially on Alluvial-meadow soil, order to realize the maxi-

Table 7. Conditional balance of nitrogen in the growth of maize (kg.ha^{-1})

Variants	Input with fertilization	Input with precipitation	Input with irrigation waters	Output with plants	Output with lyzim.waters	Total input	Total uptake	Balance
Maize, 2020								
T0	0	23.0	17.7	69.6	4.5	+40.7	-74.1	-33.4
T1	120	23.0	17.7	172.6	8.5	+160.7	-181.1	-20.4
T2	160	23.0	17.7	179.3	9.7	+200.7	-189.0	+ 11.7
T3	200	23.0	17.7	190.8	14.3	+240.7	-205.1	+35.6

mum incorporation of nitrogen into the biological cycle of nutrients. Under these conditions, the adverse effects on the various components of the environment will be reduced.

In conclusion, it can be noted that the nitrogen balance can be used to assess the nutrient efficiency and the risk of contamination of the agroecosystem.

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