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Research Article

Long-term experiments with fertilizers-essential fertility changes

Mihai RUSU[1], Constantin TOADER[1]*, Mihaela MIHAI[1],
Valentin MIHAI[1], Mihai FLOREA[2], Lavinia MOLDOVAN[1]

[1]University of Agricultural Sciences and Veterinary Medicine, 3-5, Mănăștur Street, 400372, Cluj-Napoca, Romania;
mrusu@usamvcluj.ro; mihaela.mihai@usamvcluj.ro; valentin.mihai@usamvcluj.ro; Lavinia.moldovan@usamvcluj.ro;
*toader.constantin@usamvcluj.ro (*corresponding author)*
[2]The Office of Pedological and Agrochemical Studies, Alba, Romania; mihai.florea@orkas.ro

Abstract

The paper presents soil analytical data and their interpretation from samples in long-term experiments as a result of NP, NPK and organo-mineral fertiliser applications in a stationary system for 20 years and wheat-maize-soybean rotation system. The results show that NP fertilisation (from ammonium nitrate and superphosphate) leads to acidification of soils (regardless of soil type) depending on increasing N a.i./ha. The acidification phenomenon is higher in typical preluvosol (taxonomically acidic soil) due to activation of adsorbed (potential) acidity and solubilisation of Al ions, with devolatilisation of adsorbent complex, which updates for this soil the need for correction of the reaction (pH) by means of calcium amendments. In contrast, for the alluvial mollisol, with neutral - weakly alkaline pH and higher humus % and high buffering capacity, the multiannual acidification due to N is reduced. NP, NPK mineral fertilisation, in balanced doses, can maintain the organic-C and humus content constant, balanced, within the specific limits of the soil type over a period of 20 years, with wheat-maize-soybean crop rotation. In contrast, amendment and processing conventional intensive tillage (on maize) decrease the content of these indicators, a phenomenon that can be attributed to the enhanced mineralisation of the soil organic component. Organic and organo-mineral fertilisation can lead to a favourable modelling of humus content. The mobile forms of the essential elements of nutrition and fertilisation (N, P, K) are improved in terms of their bioavailability with the objective that these forms will maintain their quantity and quality at the level required by crops and their supply by fertilisation technologies is ensured rationally and preventively for the soil-plant system. In summary, the analytical results from long-term experiments with fertilisers are of direct benefit to soils, their productivity and fertility, with the implementation of sustainability principles.

Keywords: environment; fertilizers; soil-plant effect

Introduction

Long-term experiments represent particular type of experimental research, usually aimed at evaluating vegetation factors (frequency, tillage, fertilization, crop rotation), following the effect of long-term action and in relation to changes in the soil-plant system. They are spread onto more than 700-800 locations in the world, with the latest records comprising 616 long-term experiments located primarily in Europe, mainly in

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the north of the continent, alongside several other experiments in the USA, African countries, Russia, (Körschens, 1997; Debreczeni and Körschens, 2003; Donmez *et al.*, 2022).

Their development begins after Liebig (1840-1843) outlines the "law of the minimum" and John Bennet Lawes (1843), at Rothamsted, conceives and proposes the initial "long-range" model continued by his disciple Gilbert (Liebig's doctoral student at the University of Giessen). Further development of long-term experiments was initiated at the beginning of the 19th century, when Mitscherlich (1913, 1918, 1928, 1929) developed his concepts in accordance with the "law of interaction of vegetation factors". It is however worth noting that the histogram of the initiation date for experiments at European level shows that most of them were carried out and completed between 1950 and 2000. In the 2003-2022 period, 14 long-term experiments from Romania (Borlan and Hera, 1984) were also archived, with the structure of variants including NP, NPK and organo-mineral experiments, in a unique and representative concept for all agricultural areas in Romania (Hera, 2016). Their assessment was conducted in the 1966-2023 period in terms of quantitative and qualitative production results, in 3-5 years soil crop rotation systems and data on soil fertility evolution in relation to fertilization systems.

In Romania, the experiments on the effect of fertilization in relation to soil fertility and crop nutrient requirements have a fundamental scientific and experimental basis starting with Gheorghe Ionescu Șisești and collaborators of the "Agrochemical and Soil Science School" and were founded and developed especially following the establishment of the Institute of Agronomic Research of Romania in 1927 (1925-1945), (Hera, 2016). After the establishment and consolidation of research units and university institutions, research and consistent studies in all branches of soil science (chemistry, physics, microbiology, fertility-fertilization), research related to the rational use of fertilizers and amendments was developed and diversified in conditions of the increasing fertility and protection of soils, environment and consumer beneficiaries.

In 1966/1967 a new concept was founded and promoted for the location and development of research in the field of fertilizer use, in a stationary and "long-term regime", with a unitary and diversified distribution according to pedological, agrochemical and technological conditions. At the level of 2022-2023, 55-56 years of research are recorded, through NP, NPK, organo-mineral long-term experiments in our country (Hera, 2016).

The results obtained and capitalized on by appropriate means bring probity and authenticity due to the concepts embedded therein but also to the duration of research and its applicability. They lead to such results in the production of agricultural crops under 3-5 years of crop rotation, but also to product quality and regularity in the changes determined in soil fertility (Mihăilă and Hera, 1994), (Hera, 2010, 2016), (Borlan and Hera, 1984; Borlan *et al.*, 1994), (Davidescu and Davidescu 1981), (Kurtinecz *et al.*, 2023), (Rusu *et al.*, 1988; Rusu, 2021), (Ștefănescu, 1998).

This paper presents the main changes produced in the agrochemical status of some representative soils - typical preluvosol and alluvial mollisols- by experiments with the "long term" concept, towards assessing NP, NPK and organo-mineral effects following 20 experimental years, in the Agrochemical Centre of OSPA Alba Iulia, Romania. The goal was to obtain information and recommendations regarding the protection of soil fertility and modelling measures, and the design of sustainable fertilization systems, which would ensure the protection of the soil and the consumer of agricultural products.

Materials and Methods

Soil conditions

The soil types and their main characteristics were:

- Typical preluvosol, located on the upper terrace of the Mures river, in the Băcăinți - Șibot area, with pH - 5.8; V% - 75-80; humus - 2.20%; P-AL - 5-6 ppm; K-AL – 130 ppm, at the amendable limit with $CaCO_3$;

- Alluvial mollisol, located in the Mures river plain, below the base of the terraces, with limited groundwater supply, pH 7.6 saturated in bases, V% > 90, humus - 2.68%, P-AL - 12-14 ppm, K-AL - 160 ppm. High fertility potential.

Experiments contained variants in different levels of applied elements:

- N - 0, 40, 80, 120, 160 kg a.i./ha - wheat;
- P_2O_5 - 0, 40, 80, 120, 160 kg a.i./ha - wheat, maize and soya;
- K_2O - 0, 40, 80, 120, 160 kg a.i./ha - wheat, maize, soya, on background:
    - N0P0; N80P60; N160P120 - on wheat, maize;
    - N0P0; N60P40; N120P80 - soybean;
    - N - 0, 50, 100, 150, 200 kg/ha - on maize.

Fertilization

Fertilizers were applied from:

- Ammonium nitrate, with 33.5% N;
- Superphosphate concentrate, with 42% P_2O_5;
- Potassium salt, with 40% K_2O.

The soil analyses carried out were aimed at the achievement of essential soil fertility indicators, with annual determinations at crop harvest: pH_{H2O}; organic-C/Schollenberger; P, K in AL (ammonium lactate acetate) solution, spectrophotometric (P) and photometric (K) determination; mobile-Al (Sokolov); SB, Ah – Kappen.

Results and Discussion

Changes in the reaction state (pH) of soils and other indicators of acidity

Stationary, fully continuous application of NP fertilization with ammonium nitrate and concentrated superphosphate causes soil acidification (more pronounced in acidic preluvosol and reduced in the alluvial mollisol, with relevant buffering capacity). The effect is due to the application of ammonium nitrate, which supports a process of elaboration and exchange of NH4 ions$^+$ (with H^+), resulting in increased acidity activity and solubilization of those specific to the acidic environment of Al^{3+}, depending on the dose of N a.i./ha and duration of fertilization (Table 1).

Table 1. Changes in acidity indices (pH, Al_{sch}, Al /S_{schB}·100) as a result of increasing NP (typical preluvosol fertilization) (alluvial mollisol)

Typical Preluvosol											
Crop/Fertilization NP		**Un-amended**				NP fertilization		**Amended**			
		pH	Alsch	Alsch/SB·100	V%			pH	Alsch	Alsch/SB·100	V%
Wheat											
P0	N0	5.7	0.18	1.0	76	P0	N0	6.0	0.11	0.6	84
	N80	5.5	0.17	1.2	77		N80	5.9	0.13	0.7	84
	N160	5.3	0.41	3.1	78		N160	5.6	0.16	0.9	92
P80	N0	5.5	0.10	0.7	78	P80	N0	5.9	0.15	0.8	85
	N80	5.5	0.15	1.0	77		N80	5.9	0.16	1.0	83
	N160	5.5	0.29	2.0	77		N160	5.9	0.18	1.9	78
Maize 0.15											
P0	N0	5.7	0.17	1.6	80	P0	N0	6.1	0.15	0.8	85
	N100	5.5	0.26	2.3	77		N100	5.9	0.13	0.7	85
	N200	5.3	0.54	3.3	74		N200	5.8	0.17	1.0	81
P80	N0	5.5	0.28	1.6	80	P80	N0	6.0	0.15	0.8	82
	N100	5.4	0.37	2.5	75		N100	5.9	0.15	0.9	80
	N200	5.5	0.55	3.1	74		N200	5.8	0.13	0.8	81

Alluvial mollisol						
Soya	N0	N30	N60	N90	N120	Average
P0	7.4	7.3	7.2	7.1	7.0	7.2
P40	7.3	7.2	7.1	7.0	6.9	7.1
P80	7.3	7.2	7.1	6.9	6.8	7.1
P120	7.2	7.1	7.0	6.9	6.8	7.0
P160	7.2	7.0	7.0	6.8	6.8	7.0

The data presented show a significant mobilization of mobile Al in the acidic environment but also in the acidified one by increasing the N doses a.i/ha and enhancing the representation of this ion compared to the representation of the basic cations, which also reveals the application of a calcium amendment (with $CaCO_3$) as necessary and optimal. This application is required in order to decrease the solubilization of aluminium and to prevent the phytotoxic effect from these ions in the precarious acidic environment created by long term fertilization. In conjunction with the effect of the calcium amendment in neutralizing the newly created acidity, it is found that the phosphate level achieved by the application of concentrated superphosphates also plays an ameliorating role, both through the contribution of this type of Ca^{2+} and through the active chemical form of monocalcium phosphate in these fertilizers, capable of inactivating the Al^{3+}, Fe^{2+}, Mn^{2+} ions that are responsible for the phytotoxic character of the acidity.

Additionally, yield data support the effect of amendment (with $CaCO_3$ – 5 t/ha/5 years), in positive interaction with mineral fertilization, showing an increased amendment effect, as additional acidity increases or sets in overtime due to increasing doses of N kg a.i./ha (Table 2).

The effect of liming on wheat and maize crops is determined by better valorisation of applied fertilizer (NP) due to the neutralization of natural and newly created acidity by liming.

Reduction of organic-C and humus content by long-term NP and NPK fertilization

There are known instances mentioned in previous studies that attest the reduction of organic-C and humus content in multiple agricultural technologies that can cause disturbances over time in multiple humus functions, considered as very complex and essential for fertility, but there are also many assessments that do not attest the occurrence of such changes (Ștefănescu, 1996; Hera, 2010; Kurtinecz *et al.*, 2023).

The acidifying effects are significant mainly in the mineral (NP) fertilization variant, due to the long-term effect of ammonium nitrate. In this particular case, the effect of amendment application is significantly higher in maize rather than wheat, which is determined by higher N doses and their acidifying potential (Johnston and Poulton, 2018; Kurtinecz and Rusu, 2007).

Table 2. Effect of $CaCO_3$ amendment on NP background (3 cycles - 5t/ha $CaCO_3$)

Maize						
N kg/ha	0	50	100	150	200	+ difference from un-amended
	479	451	510	514	733	
P_2O_5 kg/ha	0	40	80	120	160	+ difference from un-amended
	708	409	414	757	614	
Average	1187	860	924	1271	1347	+ 5589
Wheat						
N kg/ha	0	40	80	120	160	+ difference from un-amended
	103	555	457	310	391	
P2O5 kg/ha	0	40	80	120	160	+ difference from un-amended
	243	332	305	417	307	
Average	346	887	762	727	698	+ 3420

Table 3. Changes in humus content by long-term fertilization and limestone amendment (typical preluvosol, alluvial mollisol)

Typical Preluvosol							
Wheat							
Un-amended				Amended			
Doses N	Humus%	Doses P_2O_5	Humus %	Doses N	Humus%	Doses P_2O_5	Humus %
0	2.18	0	2.29	0	2.24	0	2.34
40	2.22	40	2.29	40	2.30	40	2.30
80	2.38	80	2.34	80	2.30	80	2.25
120	2.35	120	2.32	120	2.27	120	2.27
160	2.32	160	2.32	160	2.35	160	2.29
Average	**2.32**		**2.32**		**2.31**		**2.25**
Maize	Un-amended			Amended			
0	2.02	0	1.97	0	2.18	0	2.10
50	2.04	40	2.03	50	2.11	40	2.98
100	2.06	80	2.01	100	2.11	80	2.18
250	2.05	120	2.09	250	2.12	120	2.19
200	2.06	160	2.07	200	2.11	160	2.17
Average	**2.06**		**2.05**		**2.13**		**2.13**

Our observations converge towards the finding that under non-fertilized conditions, in wheat with preceding soybean crop for 20 years, NP fertilization contributes to maintaining organic-C and humus content at specific values, without any noticeable alteration of the organic matter regime (possibly also due to the effect of the preceding soybean plant). However, under amendment conditions there is a tendency to reduce these two indicators, caused more by P and less by N. On the other hand, the amendment stimulates microbiological activity and it is in this context that it can advance the phenomenon of organic content reduction through more intense mineralization.

It is noticeable in the case of maize that there are processes of humus content reduction (even regardless of fertilization) as an effect of tillage within a conventional system.

In alluvial mollisol, changes in organic-C and humus are imperceptible due to the high buffering capacity of the soil, the stability of the reaction and the good representation of cations in the working horizon. The humus content remains within the initial values (2.60-2.70%).

In conclusion, the reduction of the organic-C content (humus and its N, S, P compounds) require conclusions and measures for long-term modelling of the humus content, support of the humified organic matter content and the increase of the organic-C sequestration capacity in the soil (Jutta Rogasik *et al*., 2004; Kurtinecz and Rusu, 2007).

The phenomenon of organic-C content reduction, even in advance of its long-term onset, is partly prevented by introducing organo-mineral fertilization to one of the plants in the crop rotation system (usually maize), periodically, which supplements the soil's organic component reserves (Table 4).

Table 4. Favourable changes in agrochemical indicators of typical amended preluvosol (in the last 5 experimental years)

Fertilisation	pH	Humus %	S_B m.e./100 g soil	Ah m.e./100 g soil	T e.m./100 g soil	V%	T/Ah	P-AL ppm	K-AL ppm
Unfertilised	5.8	1.90	10.0	4.0	14.0	71	3,5	9	118
N50P50	5.70	1,89	10,5	4.6	15.1	69	3.30	36	129
Manure 20 t/ha	6.3	2.36	13.0	3.6	16.6	78	4.6	34	146
Manure 20 t/ha + N50P50	6.2	2.20	13.8	3.3	17.1	80	5.10	48	158

It is clear from the data presented that the periodic application of organic resources in long-term fertilisation maintains soil buffering capacity and improves the supply and bioavailability of the necessary elements.

Phosphate regime changes in multi-year fertilized soils

Phosphorus plays an essential role in the achievement of NP interaction, starting with soils with low phosphorus representation in the soil solution. In this respect, the optimization of its chemism (in terms of representation and mobility) is a determining condition in the production yields determined by these elements. Improving the chemistry and effect of phosphorus application in NP interaction is achieved by annual application of this element in concentrated superphosphate (with 42% $P2O_5$ a.i.). After the effect of "long term" application, in the two soils (preluvosol and alluvial mollisols) the evolution of mobile forms of phosphate are positive and decisive, with the transformation of the phosphate nutrient environment of the two soils from the poorly supplied to the very well supplied category (Table 5).

Table 5. Favourable evolution of concentrated superphosphate application in NP interaction

Wheat											
Preluvosol un-amended				**Preluvosol amended**				**Alluvial mollisol**			
N kg a.i./ha	P-AL ppm	P_2O_5 kg a.i./ha	P-AL ppm	N kg a.i./ha	P-AL ppm	P_2O_5 kg a.i./ha	P-AL ppm	N kg a.i./ha	P-AL ppm	P_2O_5 kg a.i./ha	P-AL ppm
0	39	0	5	0	34	0	6	0	46	0	12
40	39	40	20	40	34	40	17	40	48	40	28
80	35	80	33	80	38	80	31	80	47	80	49
120	33	120	59	120	35	120	63	120	46	120	66
160	32	160	61	160	37	160	63	160	39	160	71

Optimization of the phosphorus supply regime in the two soils depends primarily on the size of the P_2O_5 dose (a.i./ha) applied and the significant duration of fertilization (20 years), with the possibility of boosting phosphorus by applying annual doses that can exceed (or be at least equal) the consumption of this essential element by the representative crop in the soil.

Further investigation of phosphorus chemism under the given conditions has shown that the optimization of the phosphorus cycle starts in the soil with the evolution of the raw amount applied in the phosphate balance forms (P-Al, P-Fe, P-Ca) which actually feed the mobile forms accessible to plants (expressed in the previous table) (Table 6).

Table 6. Evolution of phosphorus applied as superphosphate with non-occluded mineral phosphates (P-AL, P-Fe, P-Ca)

Preluvosol un-amended (ppm)				
Fertilization	P-Al	P-Fe	P-Ca	Σ
P0N0-160	15	47	273	335
P80N0-160	60	94	306	460
Alluvial mollisol (ppm)				
P0N0-160	19	22	230	271
P80N0-160	70	75	292	427
Preluvosol amended (ppm)				
Fertilization	P-Al	P-Fe	P-Ca	Σ
P0N0-160	20	58	212	290
P80N0-160	61	111	260	432

Regardless of the chemical form of phosphate evolution applied, on an overall and in particular for each (P-Al, P-Fe, P-Ca) there is a total involvement in the quantitative and qualitative improvement of the soil phosphorus regime as a result of superphosphate fertilization.

It is thus concluded that long-term accumulation of mobile-P (P-AL) is a function dependent on the doses applied against plant consumption, fertilization duration and decisive factors for phosphorus retrogradation (Krishna, 2002; Borlan *et al*., 1994). The level of availability for plants of accumulated phosphorus remains as essential over the long-term (Johnston and Poulton, 2018).

Modifying the potassium regime in NPK fertilizer composition

In the long-term fertilization system with NPK experiments, potassium was applied at 3 levels of NP-0; 80-60; 160-120 supply in annual rates of 0-40-80-120-160 kg a.i. K_2O/ha.

Potassium application (from potassium salt 40% a.i. K_2O) on NP background, significantly changes the dynamics of soil K forms (exchangeable and non-exchangeable) and crop supply, including deciding on the effect of K application (Table 7).

Table 7. Synthetic representation of soil K dynamics

Soil/crop/fertilization	**N0P0**			**N80P60**			**N160P120**		
	K-AL (ppm)	$K_{nesch.}$ (ppm)	Report	K-AL (ppm)	$K_{nesch.}$ (ppm)	Report	K-AL (ppm)	$K_{nesch.}$ (ppm)	Report
Amended preluvosol/Maize									
K-0-40-80-120-160	131	759	5.8	141	781	5.6	143	744	5.2
Alluvial mollisol/Maize									
K-0-40-80-120-160	146	964	6.3	157	1047	6.7	148	993	6.7

The effect of K-l application is provided only on NP background, higher on high nitrogen-phosphorus application background and dependent on the regime of this cation in soils. On the acidic soil (preluvisol) for instance, the effect is due to mitigating measures of some negative effects of acidity in K nutrition. In the alluvial mollisol, with better supply of this element and with high humus content, the production is less dependent (with low significance) on this element. Alternatively, the supply of the soil solution with mobile amounts of K is due to the high amount of K in the unexchangeable form. The dynamics of K forms in the soil, with the assessment of the dependence of plant response to its application, is connected to the content (percentage) of clay and mostly the type of clayey minerals that provide a differentiated maintenance potassium representation and availability in the soil or applied to it (Römheld and Kirkby, 2010; Kurtinecz *et al.*, 2023).

Overall, our research confirms other similar approaches and long-term experiments in other areas, which note acidification effects due primarily to unilateral and excessive nitrogen application in the acidic luvisol class of soils, with the caveat that phosphorus applied as superphosphate $[Ca(H_2PO_4)2]$ at our sites can mitigate these observed effects (Kurtinecz *et al.*, 2023). The change in reaction occurs at 0.2-0.4 pH units at our sites, compared to albic luvosol acidifications of 0.6-0.8 pH units in 5-10 experimental year cycles, including amended variants. More significant reductions and control in organic C - content modeling is unanimously found and balanced mineral and organo-mineral treatments are proposed in such a way that these management decisions influence soil organic component dynamics (Miles and Brown, 2011; Nafziger Emerson *et al.*, 2011; Muneshwar Singh *et al.*, 2021). Thus, over time, the processes that lead to the optimization of soil organic C and humus content can be effectively controlled. Balancing organic-C dynamics through effective measures, rational supply of mineral elements in this agrochemically optimized framework determines a real and integrated management of the main nutrient elements (Jing *et al.*, 2018; Christensen Bent *et al.*, 2022; Azeez Musibau *et al.*, 2019; Chen *et al.*, 2020). Thus, soil protection, through organic supply and rational fertilization can model the long-term nutrient regime.

The effect of tillage (in the case of maize technologies) on the decline of organic-C levels, a phenomenon also proven in other alternatives of long-term stationary fertilization, remains essential in the thorough investigation of the agrochemical changes observed with long-term stationary fertilization (Leifeld *et al.*, 2003). Thus, there is sufficient data proving the positive effect of the reduction of mechanical tillage work, in a constantly productive cultivation system, in the conservation of the soil organic component, in some alternatives of positive modification of the organic-C content, including on the soil profile (Brown J.R., 1994). In the context of long-term modelling of soil organic-C content, it is also evident that in all situations of long-term experiments, constant input (through organic, plant residues) resulting either from cultivated plants or more effectively from organo-mineral fertilization technologies, maintain the organic-C constant and balanced, with positive effects of chemical, physical and through mass effects and activated microbial activity (Blair *et al.*, 1995; Darmody and Peck, 997; Eivazi *et al.*, 2003; Gregorich *et al.*, 1994; Islam and Weil, 2000).

The goal of modelling controlled organic-C content, with positive chemical, physical, biological outcomes effectively achieve and supports mineral nutrition, supports and enhances the nutritive roles of primary essential elements (N, P, K), increases the efficiency and productivity of soils and agricultural crops (Azeez *et al.*, 2019; Muneshwar Singh *et al.*, 2021). Under these conditions, an efficient chemistry and use of essential nutrients, their mobility and bioavailability in the soil-plant system is ensured. Their application and use in newly created systems have improved nutrient status and balance due to the optimization of soil organic carbon (SOC) optimizes their efficiency, while ensuring effective prevention of phenomena that may disturb their nutrient status. Under these controlled and improved conditions the agrochemical status of these elements is maintained in good availability for plants. Nitrogen can maintain a balance of the two ionic nutrient forms (NO^{3-} and NH$^{4+)}$ resulting from moderate multi-annual fertilisation considering the pH and phosphate regime under control. The nitrate balance can be judiciously and nutritionally apportioned, but also weighted to crop availability without extremes (Powlson and Addiscott, 2005; Addiscott *et al.*, 1991).

Within this framework there are variants that ensure the optimisation of nitrogen representation and cycling in the soil-plant system (Zhao *et al.*, 2011).

The multiannual application of phosphorus (under NP conditions) and also through organo-mineral resources creates an optimal phosphate substrate, which is stable. Through crop technologies this ensures a reuse of the reserves formed and as such an economical use of phosphate fertilisation (Barrow *et al.*, 2018; Huang *et al.*, 2011; Johnston *et al.*, 2014; Van der Bom *et al.*, 2017; 2019).

In deeply modified agrochemical conditions, with predominant NP application, in a physico-chemical substrate in which the dynamics of K forms in the soil do not function actively, it is the agrochemical optimization in NPK system that becomes essential. In this optimization process, potassium plays a balancing role in nutrition, qualitatively but also with predominant support of efficiency in the control of nitrogen application. From the multitude of long-term fertilization options, it is thus necessary to choose productive, efficient fertilization systems designed under fertility protection and environmental conditions.

Conclusions

NP complex fertilization is a fertilizing alternative for field crops in the wheat-maize-soybean rotation system, where nitrogen is the quantitative and qualitative determinant, dependent on the phosphorus supply and optimization over time (over a 'long term'). Annual NP fertilization may jeopardize (according to literature observations) the representation regime and organic-C and humus stability. In our experiments - on a preluvosol and alluvial mollisol, this fertilization represented a balanced nutrient context. In these soils, calcic amendment in the preluvosol (with three 5 t/ha cycles) and intensive tillage jeopardized humus stability. The optimization of the agrochemical regime in both soils was even more disturbed annually by the application and use of only ammonium nitrate as N source in NP formulations. This revealed that, in the "long regime", acidification can occur due to increased N doses and lower pH due to protonation of the soil solution and mobilization of Al ions from the soil. Through annual applications of superphosphate in the NP context, at increasing rates and within a long-term regime allows phosphate to significantly improve, both quantitatively and qualitatively, its chemism, as well as its soil solution and crop supply, at the expense of the non-occluded chemical formations resulting from this application (P-Al, P-Fe, P-Ca). Potassium, as an essential element, has significant effects on all crops in the wheat-maize-soybean soils in relation and dependence on the applied doses and the dynamics of this ion between the adsorbed forms with an exchange or the non-exchangeable ones to the adsorbent complex.

Authors' Contributions

The contributions of authors to the manuscript should be specified in this section; according to the type of contribution (choosing only the appropriate ones), the authors are mentioned by initials: Conceptualization MR and CT; Data curation CT and LM; Formal analysis MM, VM, MF, MR, and CT; Funding acquisition CT and LM; Investigation MR, CT; Methodology MR, CT, MF; Software CT, MM and VM; Writing - original draft MR, CT, MM, VM, MF and LM; Writing - review and editing MR, CT, MM, VM, MF and LM. All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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