Chapter

The State of the Soil Organic Matter and Nutrients in the Long-Term Field Experiments with Application of Organic and Mineral Fertilizers in Different Soil-Climate Conditions in the View of Expecting Climate Change

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Abstract

Soil organic matter (SOM) plays an important role in the terrestrial ecosystems and agroecosystems. Changes in the agricultural sector in the countries of the Central and Eastern Europe (the Czech Republic, Slovakia, Poland, etc.) within the past 25 years have negatively affected the SOM and contributed to the soil degradation. The aim of this chapter is the evaluation of the long-term application of mineral fertilizers and farmyard manure: the Control (without fertilization), farmyard manure (FYM + 0), FYM accompanied with NPK (FYM + N_3PK), and FYM with mineral nitrogen FYM + N (FYM + N_2), on the essential chemical properties of the soil and yield of the fundamental arable crops in the long-term field experiments, established in different soil and climate conditions (black soils, brown soils, cambisols, altitude ranging from 260 to 650 m a.s.l.) of the Czech Republic in 1955, using the modern multi-criteria statistical methods (PCA, FA, CLU, etc.). The long-term and regular application of organic manure and organic manure with mineral fertilizers (FYM + N_3PK and FYM + N_2) optimize the soil characteristics, stabilize crop and feedstuff production, and increase the adaptation potential of the soil in the Czech Republic, which is supposed to be weakened due to the expected changes of the environmental conditions in the near future.

Keywords: soil organic matter, nutrients, long-term field experiments, different soil-climate conditions, multi-criterial evaluation, PCA, FA, CLU

1. Introduction

In the current world, facing the climate and demographic changes, agriculture plays an important role not only as the food producer, feeding the rapidly increasing world population, but also as a feedstuff producer and also an important factor affecting the world climate [1, 2]. The worldwide agricultural production has increased significantly over the last 50 years, but the future demand for cereals, feedstuff, and renewable energy sources will increase considerably as a result of the growing population [3–5]. On the other hand, however, the agricultural crop yields have declined globally over the past 20–30 years [6] due to global warming, and the results of the model studies suggest that climate change will further reduce the yield potential of food and feedstuff, including maize [7–12]. It is supposed that Europe is not going to be affected to such extent as other parts of the world [13] and the impact of climate change in Europe will not affect EU countries equally. It is assumed that the most affected crop in Europe will be maize [12].

Soil organic matter (SOM) plays an important role in terrestrial ecosystems and agroecosystems [14]. It is an important factor related to the three components of soil quality and fertility [15]. From the chemical point of view, SOM largely determines, together with clay minerals, the cation exchange (and anion retention) capacity of soil, pH buffering capacity, and the retention of inorganic and organic pollutants or toxic elements [16, 17]. From the physical point of view, SOM is crucial in determining the soil structure and thereby ultimately controlling soil erosion, water infiltration and holding capacity, and habitat provision for plant roots and soil organisms [18]. From the biological point of view, SOM is a primary source of energy for soil microorganisms and thus the whole soil food net, as well as a source of major nutrients, most notably nitrogen, phosphorus, and sulfur, for plants and the soil biota.

Current status and changes in soil organic carbon stock, in response to agronomic and climatic conditions, become extremely important today [19]. There is an effective strategy to mitigate global climate change by increasing carbon stock in soil [20, 21]. The level and balance of soil organic carbon and mineral nutrients are also the main criterion of agricultural sustainability [22, 23]. Sustainability depends on soil ability to maintain productive and other nonproductive functions (biodiversity, hygienic, environmental, etc.). Sustainable soil management systems require the proper choice of crop rotation system, agricultural practices, carbon stock, as well as a supply of nutrients to reach higher productivity [24].

The intensive use of soil is essential, but it must be associated with conservation practices [25]. One of the main consequences of agricultural land degradation is the C depletion in soils [26]. Loss of soil carbon degrades these services, decreasing crop yields and environmental and market value of the soil. Land management can also enhance soil carbon content by optimal crop rotation and fallow cover crops, organic matter application, optimized fertilization application, and tillage systems [15].

Deterioration of natural sources quality is leading to a negative influence on soil quality (degradation), which agricultural activity depends on. This is also evident in the Czech Republic during the past 25 years [27]. Soil quality deterioration is primarily caused by four major factors: (a) Changes in the structure of cultivated crops and crop rotations (reduction of the share of perennial fodder crops (alfalfa, clover [index 1990/2015: 35%]) and cereals [index 1990/2015: 84%] on behalf of market crops/rapeseed [index 1990/2015: 343%]). (b) Significant reduction of animal husbandry (cattle [index 1990/2015: 40%], pigs [index 1990/2015: 31%], and sheep [index 1990/2015: 50%]) with large differences between regions (large areas without animal husbandry). The average charge of the agricultural land is currently 0.37 LUs per 1 ha^{-1} [28]. (c) Low inputs of organic manures (farmyard manure, slurries, etc.) and, as a consequence, low inputs of organic matter to the soil (the average N, P, and K intake in manures [index 1990/2015: 50, 50, and 50%, respectively]). (d) Reduced application of mineral fertilizers (P, K) [index 1990/2015: 17; 15%] and increased use of mineral nitrogen [index 1990/2015: 101%], resulting in higher soil acidification [28]. Zhang et al. [29] and Ren et al. [30] quoted that decreasing application of manures and organic fertilizers influenced not only stable organic compounds but also soil microorganisms and nutrients regimes. From the soil quality point of view, organic matter (farmyard manure, slurries, and high-quality compost) play an irreplaceable role during the humification process, during the formation of stable humus fractions, and in the fertilization management [27, 31]. Thus, continuous application of balanced fertilizers is necessary for sustaining soil fertility and productivity of crops [32].

The aim of this study was to estimate the effect of long-term application of different organic manures and mineral fertilizers (Control, FYM + 0, FYM + N_3PK, and FYM + N_2) on soil properties in different soil-climate conditions in the Czech Republic. Three long-term field experiments were established in 1956. Basic soil reaction, carbon and nitrogen content, and available nutrient content were analyzed during 2012–2015 and evaluated using the modern multi-criteria statistical methods (PCA, FA, etc.).

2. Organic and mineral fertilizers

Organic fertilizers represent a wide group of materials derived from agricultural by-products, plants, and animal husbandry, such as manures and litters. Organic fertilizers are essential especially for soil microorganisms, which decompose fertilizer's matter to grow and release fertilizer's nutrients into the soil environment. The nutrients then can be utilized by arable crops and support theirs grow and development.

The first systematic use of organic fertilizers is connected with the Neolithic period in the area of the Fertile Crescent approximately 12, 500 years ago. During the Neolithic Revolution, human population and society started changing their habits from essentially hunters and gatherers to farmers and breeders. Together with the establishment of the first crop production, they also started with the domestication of goats, sheep, and later cattle. Waste pits became commonly used in the settlements approximately 6000 years ago to store biologically degradable wastes, stored for the use in the agriculture. So began the use of organic fertilizers by the human population, and to this day, the sense and principle have not changed. Organic manures and fertilizers have played and play several important roles in today's agriculture. They serve as a feedstuff for soil microorganism and significantly affect soil's biodiversity. The process of mineralization performed by the soil microorganisms release fertilizer's nutrients into the environment, allowing arable crops to grow and develop properly. The ratio of the profit significantly depends on the kind of organic fertilizer. While fertilizers with low C/N ratio (slurries) release theirs nutrients rapidly and in a relatively huge proportion during the first year, fertilizers with high C/N ratio (farmyard manure) release theirs nutrients slowly but for a longer time period [33, 34]. The process of mineralization also depends on the climate conditions, decreasing significantly with the occurrence of dry periods. The main contribution of organic fertilizers, however, lies in the addition of organic matter to the soil [35], influencing soil chemical, physical, and biological properties.

Application of organic manure to the soil was a traditional way to maintain soil's fertility in the Czech Republic, especially to the 1990s, when animal husbandry and crop production was extensive. The agriculture sector was a priority for the communist leaders, and this era was so characterized with intensive application of mineral fertilizers (**Figure 1**) and organic manure (no statistical data are available up to 2007). After the Velvet Revolution in 1989, a significant decrease of mineral fertilizer consumption can be recorded, and this development continues in the case of P and K fertilizers. Nowadays, same doses of P and K fertilizers are applied on the arable land like in the 1960s. Situation is different in the case of mineral N, which is

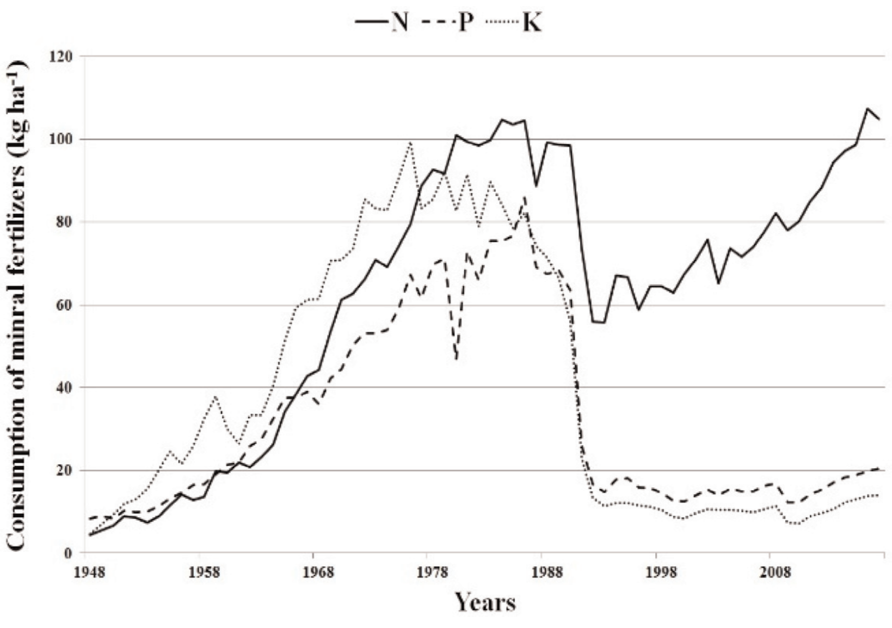

Figure 1.
Consumption of mineral N, P, and K (kg ha^{-1}) fertilizers in the Czech Republic from 1949 to 2017.

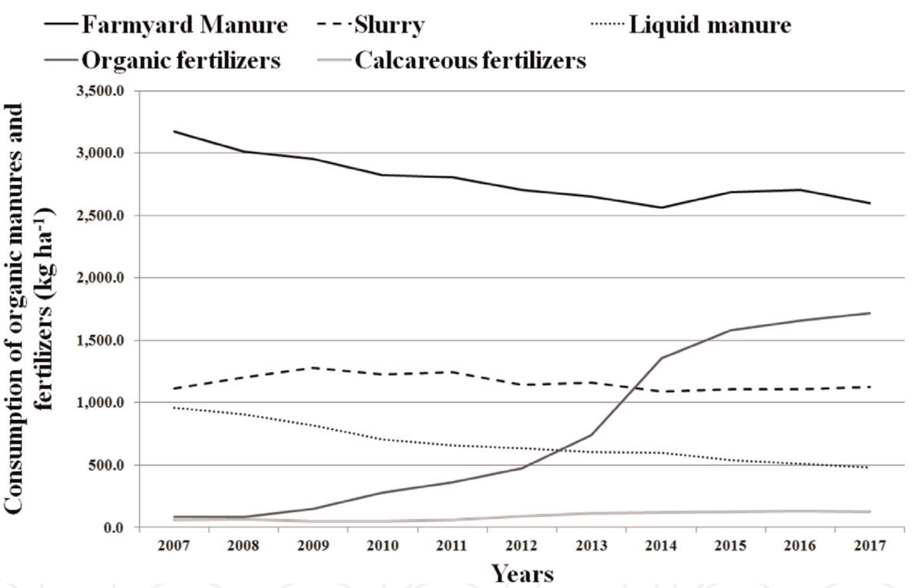

Figure 2.
Consumption of farmyard manure, slurry, liquid manure, organic fertilizers, and calcareous fertilizers in the Czech Republic from 2007 to 2017.

applied in approximately 100 kg ha^{-1}. Statistical data describing application of organic manure and fertilizers are available from 2007 (**Figure 2**). A long-term decrease trend can be observed in farmyard and liquid manure categories, which continues from the previous time era. A significant increase can be seen in the organic fertilizers category, which is connected with a huge boom of the biogas stations in the Czech Republic. However, digestates can serve as a source of nitrogen for the agriculture sector but cannot deal with the problem of organic matter in the soil.

The aforementioned information stand at the root of the problem of the present time when low doses of livestock manure (organic matter), together with reduced crop rotation, cause soil erosion and soil inability to support crops during extreme climate conditions, such as periods of droughts that will occur more frequently [36].

3. Materials and methods

3.1 Site description

In 1955, a series of three long-term crop rotation and fertilizer experiments was established on different soils (chernozems, cambisols) in the Czech Republic (**Figure 3**).

The most productive site is Ivanovice na Hané (ICRFE [37]); the intermediate is Čáslav (CCRFE [38]). The least productive is Lukavec (LCRFE [39]) crop rotation and fertilization experiment. Detailed descriptions of all experimental sites with climate description (precipitation and temperature, 2012–2015) are given in **Tables 1** and **2**.

Figure 3.
Ivanovice, Lukavec, and Čáslav experimental sites displayed on the map of the Czech Republic.

Parameter/locality	ICRFE	LCRFE	CCRFE
Altitude (m a.s.l.)	225	620	263
Soil type*	Chernozems leptic	Cambisols skeletic	Chernozems calcic (luvic)—degraded
Parent material	Loess, loess loam	Parabula metamorphosed	Loess, loess loam
Cropping area**	Sugar beet	Potato	Sugar beet
Thickness of the arable layer (cm)	40–45	25–30	30–35
Mean annual temperature (°C)***	9.1	7.4	8.3
Mean annual precipitation (mm)***	538.2	690.7	590.0

**WRB 2015.*
***According to the Czech national classification.*
****ICRFE weather station Ivanovice na Hané (1962–2012), LCRFE weather station Lukavec (1962–2012), CCRFE weather station Filipov (1982–2012).*

Table 1.
Basic description of Ivanovice (ICRFE), Čáslav (CCRFE), and Lukavec (LCRFE) crop rotation and fertilization experiments.

Locality	Year	Temperature (°C)		Precipitation (mm)	
		Mean annual	Mean annual in growing season	Annual	Annual in growing season
ICRFE*	2012	9.6	16.8	481.6	329.9
	2013	9.2	15.7	550.9	379.2
	2014	10.5	15.9	520.4	391.0
	2015	10.4	16.8	387.0	265.4
LCRFE**	2012	8.0	14.3	744.4	403.5
	2013	7.3	13.4	875.7	606.5
	2014	8.9	14.1	708.8	541.5
	2015	8.7	14.3	576.1	281.2
CCRFE***	2012	9.8	16.3	636.8	439.9
	2013	9.3	15.6	636.6	466.5
	2014	10.8	15.9	619.1	448.4
	2015	11.0	16.7	442.4	232.4

*ICRFE weather station Ivanovice na Hané.
**LCRFE weather station Lukavec.
***CCRFE weather station Filipov.

Table 2.
Basic description of weather conditions (2012–2015) in Ivanovice (ICRFE), Čáslav (CCRFE), and Lukavec (LCRFE) crop rotation and fertilization experiments.

3.2 Experimental design

All experiments were established in the same standardized design in four field strips because four crops were in rotation. In each field strip, 12 fertilizer treatments were established in four replications arranged in completely randomized block design (12 × 4 = 48 experimental plots per field strip). The size of each experimental plot was 8 × 8 m, but only the central area 5 × 5 m was used for yield determination and soil sample collection. In each strip, two complete randomized blocks of all treatments were located (**Figure 4**) (a list of fertilizer treatments used in the experiment is given in **Tables 3** and **4**).

In this paper, only four of the most contrasting fertilizer treatments were analyzed: the control (Control), without any fertilizer input; the farmyard manure

a		b		c		d	
11	12	21	22	15	16	23	24
13	14	23	24	11	12	25	26
15	16	25	26	13	14	21	22
25	26	15	16	21	22	13	14
21	22	11	12	23	24	15	16
23	24	13	14	25	26	11	12

Figure 4.
*Spatial arrangement of treatments in experimental strips; the same spatial arrangement was used in all four experimental strips. Letters (a–d) indicate complete randomized blocks, and Arabic numbers indicate individual treatments. Treatment numbers are given in **Tables 3 and 4**.*

Treatment	Nutrients applied by farmyard manure			Nutrients applied by mineral fertilizers			Total amount of applied nutrients			Distribution of N application
	N	P	K	N	P	K	N	P	K	
Control	0	0	0	0	0	0	0	0	0	
FYM + 0	8	4	12	0	0	0	8	4	12	
FYM + N_3PK	8	4	12	120	35	83	128	39	95	1, 2
FYM + N_2	8	4	12	80	0	0	88	4	12	1

Note: 1. Application of 80 kg N ha^{-1} in the spring before sowing; 2. application of 40 kg N ha^{-1} early in the spring (six leaves unfolded).

Table 3.
Nutrients applied directly to Zea mays *in kg ha^{-1} in all years of the experiment.*

Treatment	Nutrients applied by farmyard manure			Nutrients applied by mineral fertilizers			Total amount of applied nutrients		
	N	P	K	N	P	K	N	P	K
Control	0	0	0	0	0	0	0	0	0
FYM + 0	20	10	30	0	0	0	20	10	30
FYM + N_3PK	20	10	30	94	40	87	114	50	117
FYM + N_2	20	10	30	74	4	14	94	14	44

Table 4.
Mean annual application rates of nutrients (kg ha^{-1}) over all crops during the run of the experiment.

(FYM + 0) treatment; farmyard manure together with mineral N, P, and K, fertilizers (FYM + N_3PK); and farmyard manure together with mineral N (FYM + N_2).

Except for the Control, the FYM application was performed in the autumn before the preceding root crop planting. Mineral P and K fertilizers and FYM were plowed down immediately after application. The distribution of mineral N application within the year was the following: (1) application of 80 kg N ha^{-1} in the spring before sowing and (2) application of 40 kg N ha^{-1} early in the spring (six leaves unfolded) (**Table 3**). A 4-year crop rotation system was used during the run of the experiment: maize, spring barley, oilseed rape, and winter wheat. Straw of cereals and residues of other crops were removed from the experimental plots after the harvest of the main product. Pesticides have been applied if necessary, and growth regulators have never been used. Average yield (dry mass of silage maize) values of main products during the 2012–2015 are given in **Figure 5**.

3.3 Sampling and soil analysis

Sampling from the upper Ap horizon was done in the 2012–2015 period. Each treatment (in selected year) was sampled four times (n = 4), altogether 64 samples for the studied period. Soil reaction was determined by potentiometric method in 50 ml of 0.2 mol KCl (inoLab pH 730, WTW, Germany). The SOC (Corg) content was analyzed colorimetrically according to Sims and Haby [40] and also by oxidimetric titration, according to Nelson and Sommers [41]. Total nitrogen content was determined with concentrated sulfuric acid in a heating block (Tecator, Sweden), followed by the Kjeldahl method [42, 43]. Up to discovering the Mehlich III method [44], the concentrations of P, K, and Mg were analyzed by the Mehlich II and Mehlich I methods. Concentrations of P, K, and Mg were then analyzed by ICP-OES (Thermo Scientific iCAP 7400 Duo, Thermo Fisher Scientific, Cambridge, UK).

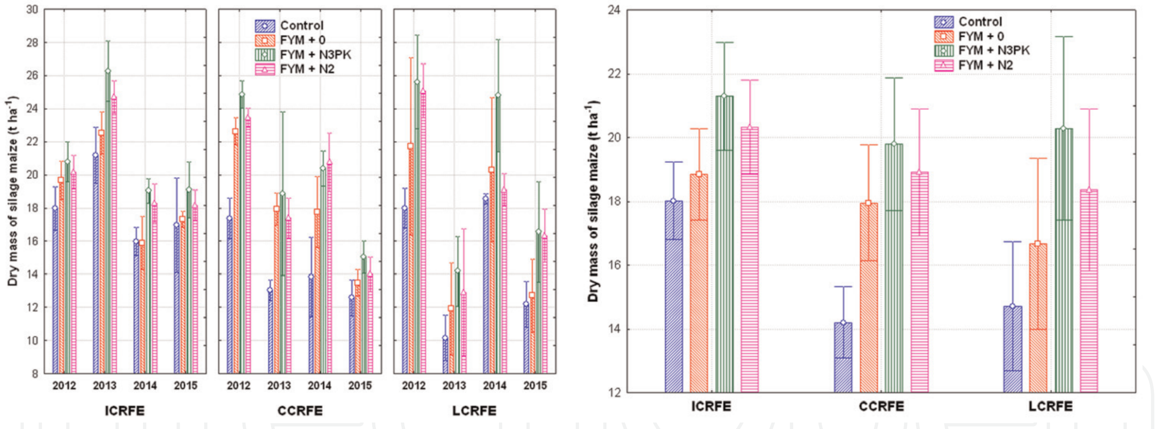

Figure 5.
The yield dry mass of silage maize and the average yield in period 2012–2015.

3.4 Data analysis

Statistical analysis, including graphical outputs, was carried out using Statistica 13 (TIBCO Software Inc., Palo Alto, USA, 2018). For the statistical data processing and evaluation we applied exploratory data analysis (EDA), analysis of variance (ANOVA), Tukey test (HSD test), Fisher's LSD test (LSD test), linear regression (LR), principal component analysis (PCA), factor analysis (FA), and cluster analysis (CLU). LR was calculated by the QC.Expert 3.3^{Pro} statistical program (TriloByte Statistical Software, Ltd., Pardubice, CZ, 2018). The linear regression diagnostics was solved with the aid of a technique called regression triplet [45]. PCA was used for interpreting the parameters of soil organic matter (C_{org}, C/N ratio, etc.) and physicochemical properties of soil (pH, content of nitrogen, phosphorus, calcium, potassium, magnesium, etc.). Selected measured characteristics were used as predictors (factors); they were chosen on the basis of an eigenvalue graph. Variables with the impaired assumption of normality were converted using logarithmic transformation. As a part of step 1, PCA was carried out with all the variables to calculate the most important variables. Step 2 involved selecting active and supplementary variables for better interpretation. In the case of a lower number of samples, this stepwise analysis significantly improves the outcome of the PCA. The PCA was used for calculating a component weight for the investigated variables. Based on correlations and contributions in convincing factors, each of the characteristics was subsequently assessed for relevance explaining the multidimensional dependencies (correlations) in the factorial plane. The factor analysis (FA) analyzed the internal contexts and relationships (correlations) and revealed the basic structure of the source data matrix. The FA also identified factors and then assigned to each factor a content meaning (physical or chemical) [45].

The CLU was used for classification of objects to the clusters. The CLU does not differentiate significant and insignificant markers but differentiate the significant clusters [45]. The CLU was performed by a complete linkage method. The statistical significance was assessed at a significance level of $p = 0.05$.

4. Results

4.1 Carbon, nitrogen, C/N ratio (SOM)

The SOC content (C_{org}) ranged in individual years (2012–2015) at all three sites from 1.05 to 2.38% (**Figure 6**). Higher SOC contents were recorded at ICRFE and

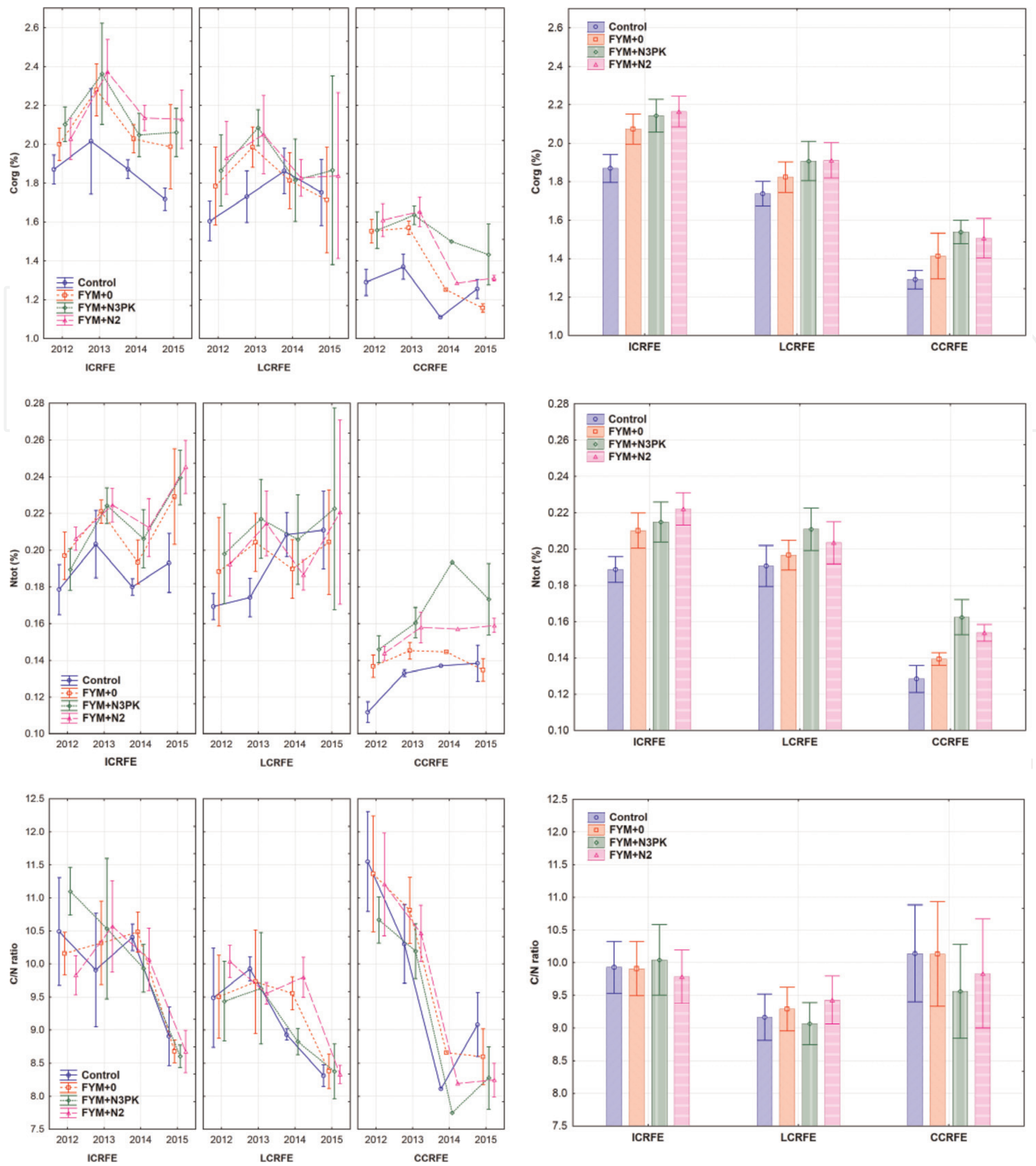

Figure 6.
Soil organic carbon (C_{org}) content, total nitrogen (N_{tot}), and C/N ratio as affected by fertilizer treatment and locality during studied period (2012–2015).

LCRFE, compared to CCRFE (degraded chernozem). Statistically higher SOC content (HSD test) in individual years and for the 2012–2015 period was recorded in FYM + N_3PK and FYM + N_2 treatments, compared to the Control treatment at all three sites and FYM + N_2 treatment (LCRFE and CCRFE). Similar results, including statistically significant differences (HSD test), were also recorded for the nitrogen content (N_{tot}) in individual years and in 2015–2015 period. The concentration of N_{tot} ranged from 0.11 to 0.25% (**Figure 6**). The average C/N ratio ranged from 9.5 to 10.1 at ICRFE (2012–2015, without significant differences between the treatments) and CCRFE (significantly lower C/N ratio in the FYM + N_3PK treatment). Lower C/N ratio was observed at LCRFE (without statistically significant difference between the treatments), where the ratio ranged from 9.0 to 9.5 (**Figure 6**). Statistically significant linear regression (data from all three sites) between the SOC and N_{tot} was recorded (equation parameters for N_{tot} (%): $y = 0.0293 + 0.0886 * C_{org}$; $R = 0.8139$; $p = 0.0000$; $R^2 = 0.6624$; mean quadratic error of prediction (MEP) = 0.0003; Akaike information criteria (AIC) = −4163.4912 (**Figure 7**)).

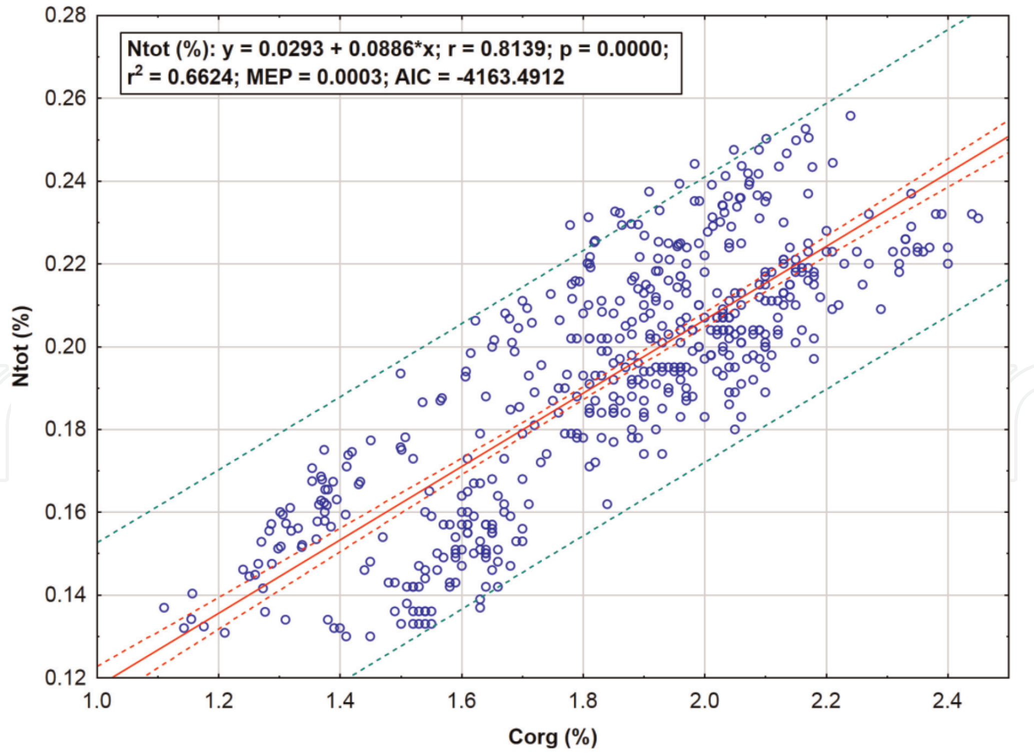

Figure 7.
The linear regression dependence of the N_{tot} on C_{org} during the studied period (2012–2015).

4.2 Soil reaction and nutrients

The value of pH at ICRFE and CCRFE (chernozems and degraded chernozems) ranged from 6.5 to 7.4 (**Figure 8**). The decrease of the pH was recorded at both localities and both treatments (FYM + N_3PK and FYM + N_2), without any statistically significant difference in particular years and during the whole 2012–2015 time period (**Figure 8**). The lower pH value was recorded at LCRFE (cambisol). At this site (LCRFE), a significantly lower pH value was recorded in the FYM + N_3PK treatment (2012–2015), compared to other fertilizer treatments.

The contents of plant available P and K at all three experimental sites and in all fertilizer treatments in individual years showed a similar trend (except of the FYM + N_3PK treatment at LCRFE, where a gradual decrease of P was recorded). The average P content ranged from 45 to 195 mg kg^{-1} (2012–2015). The highest content, at all sites, was recorded in the FYM + N_3PK treatment (significantly higher than in the Control and FYM + 0 treatments, **Figure 9**). Statistically

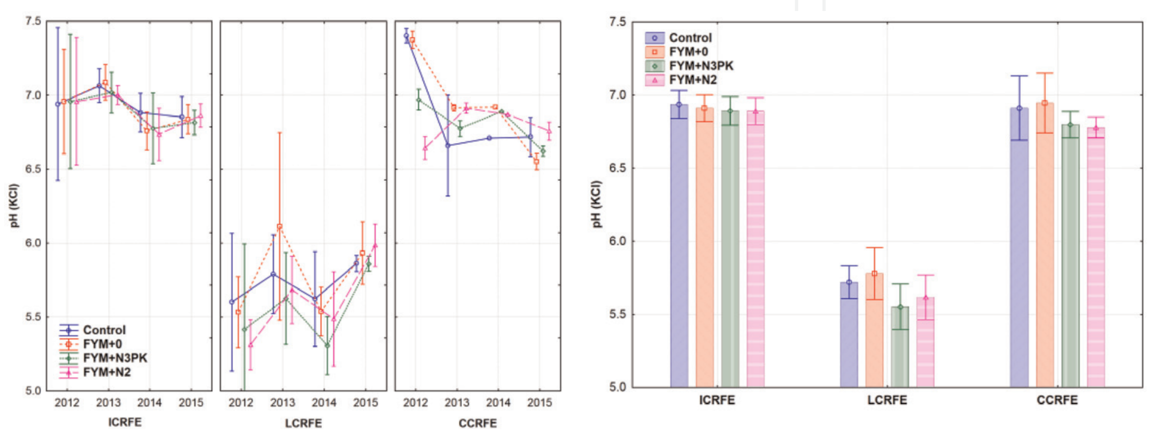

Figure 8.
The pH value (KCl) as affected by fertilizer treatment and locality during the studied period (2012–2015).

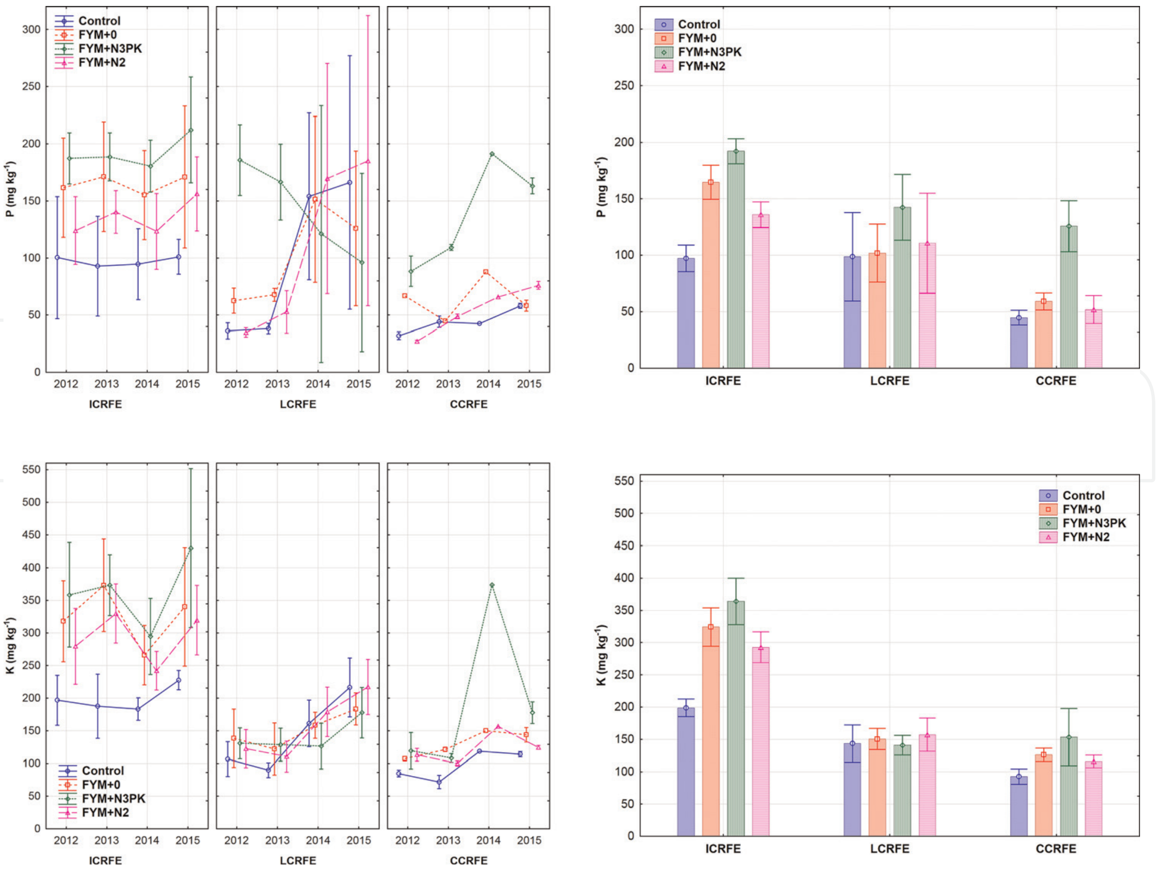

Figure 9.
Soil available macronutrients (P, K/mg kg^{-1}/) as affected by fertilizer treatment and locality during the studied period (2012–2015).

significant linear regression dependency (data from all three sites) between the K and P content was recorded (parameters of K equation: (mg kg^{-1}): $y = 69.8464 + 1.0883 * P$ (mg kg^{-1}); $R = 0.7331$; $p = 0.0000$; $R^2 = 0.5375$; MEP = 3154.2151; AIC = 3674.2704 (**Figure 10**)).

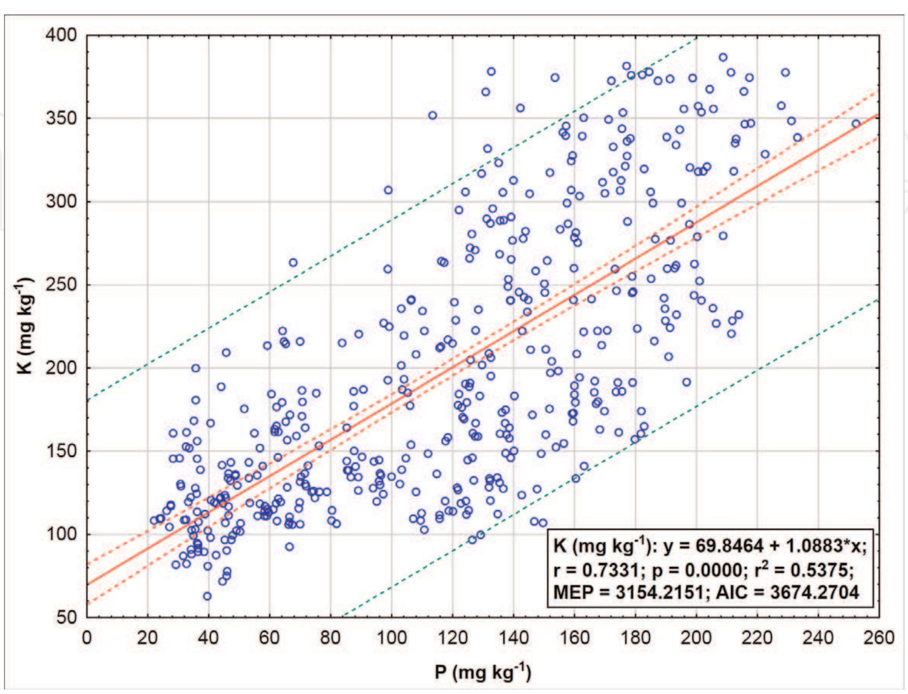

Figure 10.
The relationship between K (mg kg^{-1}) and P (mg kg^{-1}) contents during the studied period (2012–2015).

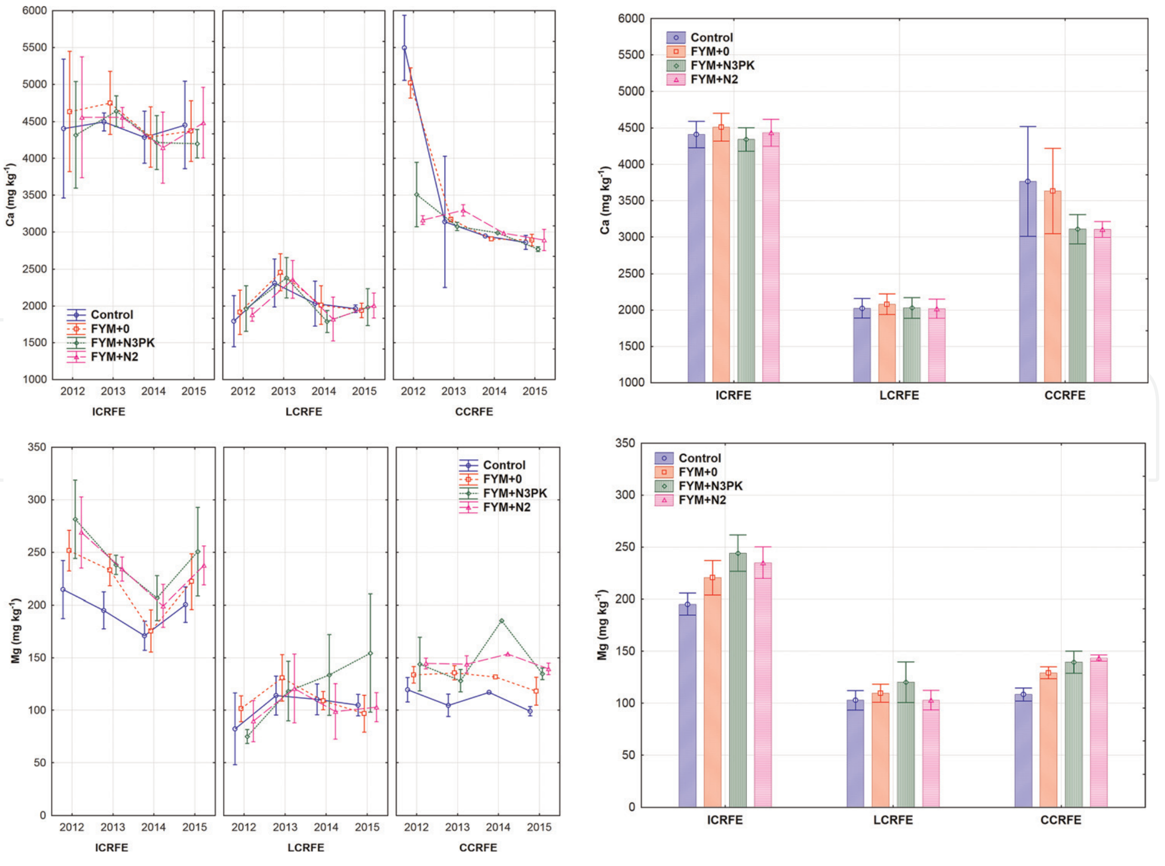

Figure 11.
Soil available macronutrients (Ca, Mg (mg kg⁻¹)) as affected by fertilizer treatment and locality during the studied period (2012–2015).

The contents of available Ca and K at all three sites and in all fertilizer treatments in individual years showed a similar trend (**Figure 11**). The Ca content at ICRFE and LCRFE sites is balanced and without significant differences between the treatments. At all three sites, higher levels were recorded in the Control and FYM + 0 treatments (significantly higher at CCRFE). The average Mg content for the 2012–2015 period ranged from 100 to 250 mg kg^{-1} (higher content at ICRFE, lower contents at LCRFE and CCRFE). The highest contents were recorded in the FYM + N_3PK treatment at all experimental sites (significantly higher compared to the Control and FYM + 0 treatments).

4.3 Multi-criteria evaluation of measured soil attributes and parameters

According to the eigenvalue results, the first two axes are significant on the PC1 and PC2 component figure (PCA), which together represent about 95% of the variability (2012–2015, **Figure 12**).

The PC1 axis in **Figure 12** (PC1 × PC2) represents the content of available nutrients (K, Mg, P) and the SOM (C_{org}). The K content is strongly and negatively correlated with this axis (r = −0.98). Similar correlations are in the case of Mg content (r = −0.91), C_{org} (r = −0.88), P (r = −0.88), P (r = −0.86), and N_{tot} (r = −0.77). The PC2 axis represents correlation with the pH value (r = 0.95) and Ca content (r = 0.78). According to the projection of the cases (**Figure 12**), the fertilizer treatments and localities are separated (clusters close together that behave similarly are correlated). According to the analysis, the Control treatment at ICRFE is significantly separated from other treatments. At LCRFE and CCRFE sites, two clusters are separated: (1) Control and FYM + 0 and (2) FYM + N_3PK with

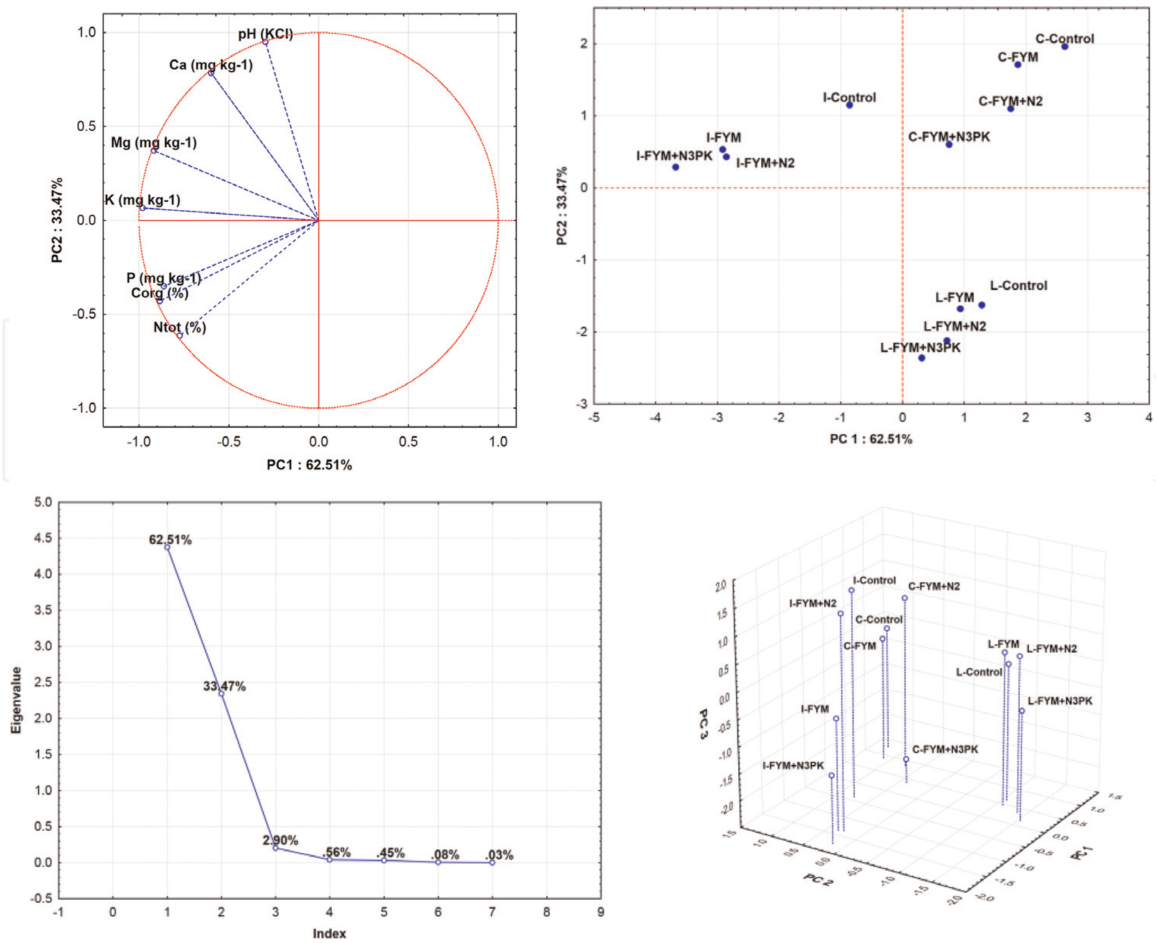

Figure 12.
The PCA of studied parameters of soil organic matter (C_{org}, N_{tot}), soil available macronutrients (P, K, Ca, Mg), and soil reaction (pH) during the studied period (2012–2015). Note: I, ICRFE; L, LCRFE; C, CCRFE.

FYM + N_2. Factor 1 in the FA (**Figure 13**) describes the properties from the point of view of the SOC (decomposition processes) and nutrient content. Factor 2 describes the soil from the point of view of pH value.

The communality represents the proportion of variability of attributes expressed by the factors involved. It is similar to R^2 value we get when explaining the original characters by regression of selected factors [45]. From the contribution of factors 1 and 2 to the communality, it's clear how communality acquires high values (more than 0.9), and thus, the values of attributes are precisely considered by the proposed factor model (**Table 5**).

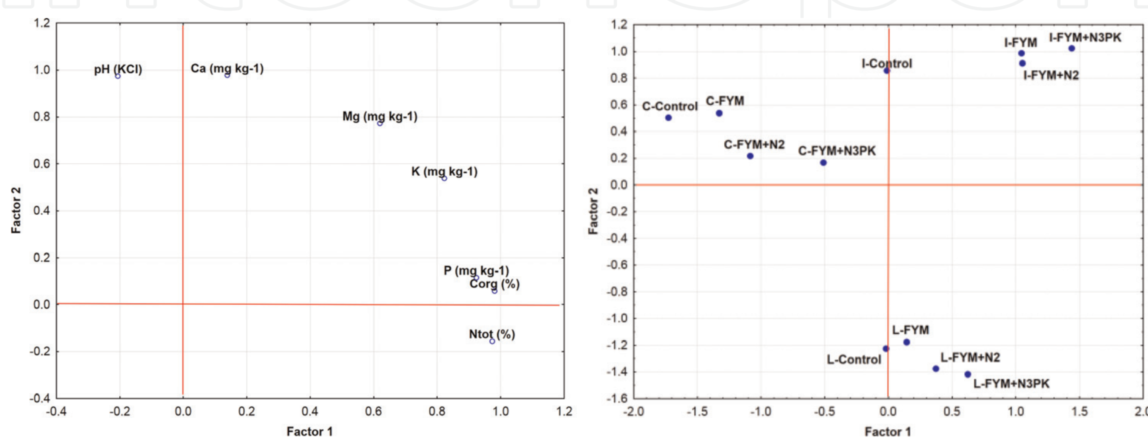

Figure 13.
The FA of studied parameters of soil organic matter (C_{org}, N_{tot}), soil available macronutrients (P, K, Ca, Mg), and soil reaction (pH) during the studied period (2012–2015). Note: I, ICRFE; L, LCRFE; C, CCRFE.

Parameter	Factor weights		Factors contribution		
	Factor 1	Factor 2	Factor 1	Factor 2	Communality
pH (KCl)	−0.2063	0.9737	0.0426	0.9906	0.9876
C_{org} (%)	0.9818	0.0578	0.9638	0.9672	0.9966
N_{tot} (%)	0.9736	−0.1564	0.9479	0.9724	0.9962
P (mg kg^{-1})	0.9241	0.1151	0.8540	0.8673	0.9126
K (mg kg^{-1})	0.8232	0.5375	0.6777	0.9665	0.9718
Ca (mg kg^{-1})	0.1389	0.9770	0.0193	0.9739	0.9630
Mg (mg kg^{-1})	0.6200	0.7721	0.3844	0.9806	0.9865

Table 5.
The factor weights and contributions of selected factors to the communality for each parameters in factor analysis (FA).

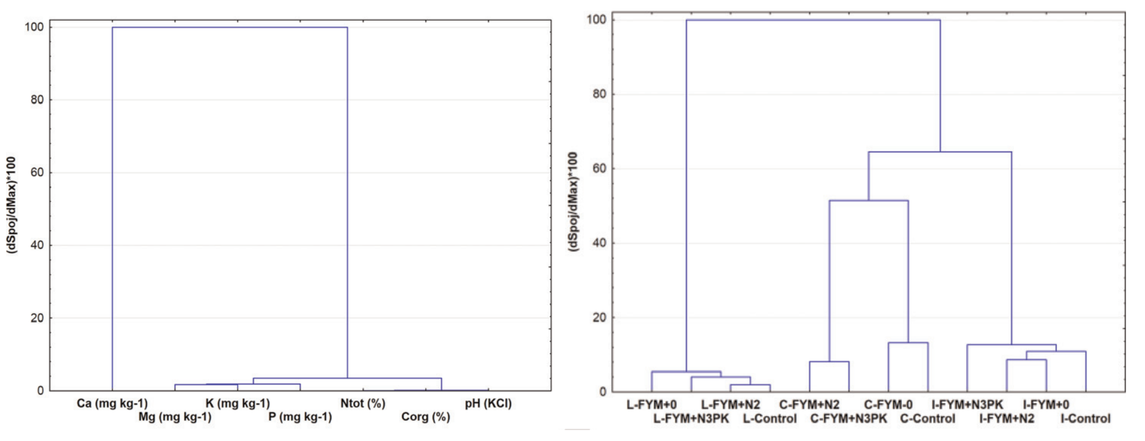

Figure 14.
CLU of studied parameters of soil organic matter (C_{ox}, N_{tot}), soil available macronutrients (P, K, Ca, Mg), and soil reaction (pH) during the studied period (2012–2015). Note: I, ICRFE; L, LCRFE; C, CCRFE.

The dendrograms (**Figure 14**) accomplished by complete linkage method prove separated clusters of the Control treatment and inosculated clusters of FYM + 0, FYM + N_3PK, and FYM + N_2 fertilizer treatments (ICRFE and LCRFE). Two clusters were recorded at CCRFE site—Control with FYM + 0 and FYM + N_3PK with FYM + N_2. Similarly, the CLU analysis also divided the soil properties—a cluster of nutrient content, SOM, and the pH value. The results of the CLU are consistent with the results of FA and PCA.

5. Discussion

The results (2012–2015) from the long-term fertilizer experiments, established in 1955 in different soil-climate conditions (Ivanovice na Hané, Lukavec, and Čáslav) in the Czech Republic (representation of soil types in the Czech Republic: chernoszems 11%, luvisols 12%, cambisols 46% [46]), proved that the application of the farmyard manure (FYM) increases the SOM (C_{org}) content in the soil (**Figure 1**). If we apply the FYM together with mineral fertilizers (NPK), the conditions of the soil and its quality are maintained at optimum quality (still increasing the C_{org} content in the soil (**Figure 6**)). These results are confirmed by the study of Zhao et al. [47], performed under similar conditions (the average annual air temperature and precipitation are in the range of 8–15°C and 500–950 mm) in the North China Plain. Benefits of the long-term application of organic manure and mineral fertilizers on SOC pools and sequestration also confirmed studies from Liu et al. [48] and Menšík et al. [14], who analyzed the effect of the long-term application of organic manures and NPK on soil quality parameters (brown soils) in the Czech Republic. The application of organic manures and slurries to the soil increases soil fertility and ensures stable production and food security for future generations, even under changing environmental conditions. On the other hand, application of mineral fertilizers without any inputs of organic matter leads to destabilization of soil environment and is connected with a significant decrease of soil fertility. This is confirmed by studies of Yang et al. [49] and Chen et al. [50], who published that application of mineral fertilizers is insufficient for maintaining the SOC under the conditions of conventional agriculture, where no plant residues or manures are returned to the soil.

Increasing C_{org} content is closely connected with increasing N_{tot} (see linear relationship between C_{org} and N_{tot} (**Figures 6** and 7)). The same results were published by Maltas et al. [51] from Switzerland, who analyzed the effect of the cattle manure and NPK in the long-term experiment, established in 1976, on calcaric cambisols.

Nitrogen fertilization has been reported to increase C sequestration [52, 53], but the effect differs between the studies [51, 54, 55]. The application of fertilizers to nutrient-deficient soils generally increases the SOC content because fertilizers increase the crop production and, thereby, the amount of plant residues released to the soil [56]. Thus, the strategy in soil nitrogen management is continuous incorporation of organic manure, to prevent acidification and maintain high soil productivity [57–59].

According to our results, application of mineral fertilizers and organic manures did not significantly influence phosphorus, potassium, and magnesium content during the studied period (2012–2015). Results from the Maltas et al. [51] also show that N fertilization significantly reduces the available Mg content in the soil, where nitrogen fertilization likely increased Mg extraction from the soil, due to higher crop yields [60]. This has not been proved in our study. On the contrary, the Mg content in the soil increased (**Figure 11**). The highest N, P, and K content in top soil was recorded in FYM + N_3PK treatments, while the lowest content was in the Control treatment. Our results are consistent with the study of Yang et al. [31]. He showed that application of organic manure in cultivated farmland significantly increased nitrogen accumulation rate, and this influence was greater in comparison with NPK application.

The multivariate exploratory techniques help us to determine the structure and interrelationships between objects and attributes by the technique of the reduction of the attributes on the latent variable [45]. The aim of the PCA is to simplify the description of a group of mutually dependent or correlated attributes [61], while the FA serves to examine relationships and correlations between a large number of original attributes by using a set of less latent variables, called factors [62]. The multivariate exploratory techniques (PCA, FA, and CLU) divided different techniques of ecosystems into two categories (**Figures 12–14**): (1) Control and FYM + 0: higher C_{org}, N_{tot}, and pH value. The contents of P, K, Ca, and Mg were comparable to the Control treatment (except of ICRFE, where chernozems are occurring). (2) FYM + N_3PK; FYM + N_2 treatments: higher C_{org} and N_{tot} content, higher content of plant available P, K, and Mg, especially in FYM + N_3PK treatment, and higher pH value (a decrease compared to the Control and FYM + 0 treatments —acidification due to mineral nitrogen application on soils with worse properties in LCRFE and CCRFE sites (**Figures 12** and **13**)).

6. Conclusion

More than 60 years of continuous fertilization with organic manures and mineral NPK fertilizers on different soil types (chernozems, degraded chernozems, and cambisols) and in different climatic conditions in the Czech Republic (the Central Europe) leads to a significant differentiation of soil properties in terms of soil quality. According to the multi-criterial evaluation (PCA, FA, CLU), we separated three different soil-climate localities (SOC and N_{tot} content, the C/N ratio, soil acidity and content of available nutrients) and different fertilizer treatments (Control, FYM + 0, FYM + N_3PK, and FYM + N_2) in each locality.

The Control and FYM + 0 treatments (the basic soil conditions) are characterized by a higher content of C_{org}, N_{tot}, and pH value. The P, K, Ca, and Mg content in the FYM + 0 treatments was comparable to the Control (except of chernozem soil type—ICRFE). The FYM + N_3PK and FYM + N treatments are characterized by a high content of C_{org} and N_{tot}; higher content of available nutrients (P, K, and Mg), especially in FYM + N_3PK treatment; and slight decrease of the pH value (compared to the Control and FYM + 0 treatments—acidification of the soil due to the application of N in mineral form, especially in wore conditions of LCRFE and CCRFE).

The long-term application of organic manures, and organic manures with mineral NPK (or N), maintains the soil in optimal quality (soil fertility), stabilizes the production in terms of quantity and quality of food and feedstuff, and increases the adaptive potential of current land to the changing environmental conditions.

The multivariate exploratory techniques, such as PCA, FA, and CLU, are very suitable methods for displaying, evaluating, and interpreting the data and results about the physicochemical soil properties.

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