The Bauxite Residue as Amendment for the Acidic Soils Rehabilitation in Romania

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Abstract

This paper is reporting the results of a multistage research program concerning the use of bauxite residue (BR) from Bayer alumina production process as alkaline amendment for rehabilitation the acidic soils from Romania. First stages cover the preliminary laboratory and glass house experiments with carefully selected soil compositions and plant species. The further experimental stages are regarding for open field experiments on maize, wheat and sunflower plants grown in acidic soils under carefully selected conditions. In all these stages, the remediation of acidic soils was assisted by some complementary adjuvant for raising the soil fertility close to a sustainable level. In all the open field experiments two property control adjuvant were used: the bauxite residue for pH control and the NPK mineral fertilizers as sources of macro and micronutrients. In both glass house and open field experiments the particular targets were: a) Set up meaningful experimental tests for demonstration of the BR efficiency as acidic soils remediation material; b) Monitoring the plants growth response to the BR; c) Monitoring the soil changes in compositions and properties before and after harvesting; d) Finding effective adjuvant formulations for the plants under experiments; e) Statistical validation of the results and comparing the original data with data in real agricultural practice; f) Better understanding of the BR rehabilitation effect on soil properties and composition after the rehabilitation program; g) Accumulating credible data about the crop outputs and the grains quality achieved in the best variants of acidic soils remediation and use them for a reasonable application at larger scale in Romania.

By amending the Albota luvosoil type acidic soils (Romania) with significant bauxite residue doses, under well managed fertilization, the surface reshaped layer of acidic soil acquired initially 1.0 - 1.3 units higher in pH. Also, the crop may rise with 30 to 60 %.

Keywords: Bauxite residue, Acidic soils, Remediation, Open field experiments, Glass house experiments.

1. Introduction

This paper concludes a cycle of investigations concerning the use of bauxite residue (BR) from the alumina and aluminum industry as an alkaline amendment for improving the quality of acidic soils. The preliminary tests were done on various plants at the laboratory scale, using various acidic soils conditioned with BR and with common fertilizers to ensure the plants chances for adaptation to continue the vegetative cycle until fruiting [1-4]. But, the first successful experiments were made later, when both the Albota acidic soil and BR coming from Sierra Leone bauxite was fully characterized and, on the basis of previous researches, it was decided that normal fertilizers doses should be applied in order to activate the neutralization effects of BR on the Albota soil acidity. With this conclusion, the next step of researches was the experiment in glass vegetation house [5,6]. The results obtained in the vegetation house confirmed the doses of bauxite residue proposed to control the acidity of the Albota soil and showed that the fertilizers used (NPK and fermented manure) can contribute to obtaining sustainable maize harvests. Moreover, this experiment demonstrated that the BR, coming from Sierra Leone bauxite processing, has a suitable mineralogy for the intended purpose and a stable chemical composition with limited possibilities of releasing heavy metals or toxic elements in soil. Also, two reports drawn up in 2011 and in 2017 confirmed the absence of radioactive elements in both bauxite and bauxite residue. The measurements were carried out by the Horia Hulubei National Institute for Research and Development in Nuclear Physics and Engineering (IFIN-HH) Bucharest.

With the new knowledge accumulated after conducting the experiments in the greenhouse, in 2018 were started the experiments in the open field: 2018 - maize, already published [5], 2019 – wheat, partially published [7] and 2020 sunflower, unpublished.

The purpose of this work is to present a review of the entire experimental material, accumulated in the period 2018-2020, regarding the testing of bauxite residue as an alkaline amendment in rehabilitation of the acidic luvosoil of Albota (Arges) Romania. The study refers to the optimization of the doses size and the frequency of application of the amendment in the crops of maize, wheat and sunflower.

2. Experimental

Experimental plants varieties were a) Maize grown in the open field experiment, 2018: Hybride DKC 4590; b) Wheat grown in the open field experiment, 2019: Hybride PG 102; c) Sunflower grown in the open field experiment, 2020: Hybride Puntasol CL. In all experiments the soil was fertilized with NPK 20.20.20 (urea) and Bio Enne with 12 % organic nitrogen, 23 % soluble sulphuric anhydride and 35 % organic carbon.

Location for carrying out all the experiments was the Agricultural Research and Development Station of Albota - Pitesti, Arges County, Romania. The entire research program was developed and supervised by National Research and Development Institute for Soil Science, Agro-chemistry and Environment–ICPA Bucharest, Romania. Also, the entire morphometric and chemical analysis programs were carried out according the National and European standards and methodology. The open field experiments set up for all above plants were organized on 13 variants (Table 1) with 3 repetitions laid in latin square, as in previous papers [5-7]. Each of the 13 variants lays in plots of 50 sqm size (10 x 5 m), all of them being included in a 2500 sqm non-irrigated area (Figure 1). Mainly, these arrangements help to understand the effects of bauxite residue on plants growth at different dosages.

Table 1. Variants in the open field experiment (maize, wheat and sunflower).

Vari-ants	**BR, t/ha-**	**NPK, Kg/ha**	**Organic, t/ha**	**Vari-ants**	**BR, t/ha-**	**NPK, Kg/ha**	**Organic, t/ha**
V1	0	0	0	V8	40	0	0
V2	10	0	0	V9	40	N_{120} P_{60} K_{40}	0
V3	10	N_{120} P_{60} K_{40}	0	V10	40	N_{120} P_{60} K_{40}	0.25
V4	10	N_{120} P_{60} K_{40}	0.25	V11	60	0	0
V5	20	0	0	V12	60	N_{120} P_{60} K_{40}	0
V6	20	N_{120} P_{60} K_{40}	0	V13	60	N_{120} P_{60} K_{40}	0.25
V7	20	N_{120} P_{60} K_{40}	0.25				

V1	**V2**	**V3**	**V4**	**V5**	**V6**	**V7**	**V8**	**V9**	**V10**	**V11**	**V12**	**V13**	**R1**
V5	**V6**	**V7**	**V8**	**V9**	**V10**	**V11**	**V12**	**V13**	**V1**	**V2**	**V3**	**V4**	**R2**
V11	**V12**	**V13**	**V1**	**V2**	**V3**	**V4**	**V8**	**V9**	**V10**	**V5**	**V6**	**V7**	**R3**

Figure 1. Experimental field layout design.

3. Materials and Methods

3.1 Bauxite Residue Characterization

The bauxite residue preserves in its structure the mineralogy of the lateritic Sierra Leone bauxite from which it originates. Thus, the major mineralogical phases with iron content from bauxite are present in BR with minor changes. Among these, the main mineralogical phase is the alumino-goethite, in which the atomic substitution of iron with aluminum is raising up to 22-25 %. Aluminous hematite is the second major phase in which the atomic substitution of iron with aluminum is 7-8 %. The alumino-goethite is mostly found as a fine and uniform crystallized product, having the crystallites size below 10 nm, which are accompanied by a small coarse fraction of irregular shape particles (20 and 50 nm). Crystalline phases are accompanied by amorphous phases (30-40 % of dry BR mass). These phases originate from wearing and decaying of the crystalline phases and are mostly found as small worn-down particles, uniformly dispersed into the bulk material. All above phases are non-reactive phases in Bayer process at the low temperature (LT) digestion conditions. The reactive phases did come out from Bayer alumina process as DSP. Other crystalline phases amounts are less than 10% from crystalline mass. The gibbsite is a minor phase in the bauxite residue composition, most of Al_2O_3 constituent is trapped into alumino-goethite and in the aluminous hematite. A leaching test of the BR, according to the standard SR EN 12457 – 2/2003, was made by INCD for Industrial Ecology, ECOIND Bucharest in 2018. In the Table 2 are given the data for liquid/solid ratio 10/1 Kg. The measured values for 15 elements are given in the Table 2. These values classified the BR in category of non-hazardous materials.

Table 2. Leaching test of bauxite residue. Leaching ratio 10 L/1 kg.

Nr crt	Elements	UM	Measured values	Maximum permited values, mg/kg dryed		
				Inert	Non hazardous	Hazardous
1	Arsenic	mg/kg s.u	0,025	0,5	2	25
2	Barium	mg/kg s.u	0,433	20	100	300
3	Cadmium	mg/kg s.u	<0,05	0,04	1	5
4	Chromium VI	mg/kg s.u	<0,05	-	-	-
5	Total Chrome	mg/kg s.u	9,56	0,5	10	70
6	Copper	mg/kg s.u	<0,03	2	50	100
7	Mercury	mg/kg s.u	<0,05	0,01	0,2	2
8	Molybdenum	mg/kg s.u	0,100	0,5	10	30
9	Nickel	mg/kg s.u	<0,03	0,4	10	40
10	Lead	mg/kg s.u	<0,05	0,5	10	50
11	Antimony	mg/kg s.u	<0,1	0,06	0,7	5
12	Selenium	mg/kg s.u	0,146	0,1	0,5	7
13	Zinc	mg/kg s.u	<0,03	4	50	200
14	Chlorides	mg/kg s.u	35,5	800	15000	25000
15	Sulphates	mg/kg s.u	679	1000	20000	50000

Radioactivity of bauxite residue was the subject of two reports. The first report on bauxite residue radioactivity measurements carried in 2012 confirmed some older suppositions on the very rare occurrence of radio-nuclides in the bauxite residue disposal site at Alum SA, Romania. The second report, carried in 2017, turned out that concentrations of gamma radiation of radio-nuclides in the bauxite residue are below the minimum detectable activity-AMD, according the ISO 11920/2010. Also, the total radioactivity measured on bauxite residue samples is below the soil natural radioactivity, which is about 40/Bq/kG. Both tests corroborate the conclusion that Sierra Leone bauxite used as raw materials in the production of alumina at Alum SA does not contain radio-nuclides [8]. Corrosiveness was also studied for acquirement of more safety data about BR. The tests of bauxite residue samples corrosiveness were carried out on skin and eye at a certified Military Medical Research Center in Bucharest, Romania. Samples with pH 11.2, 11.6 and 12.2 were prepared in the laboratories of Military Medical Research Center from the raw non-weathered bauxite residue, which was collected from the newest layers of disposed bauxite residue in 2011 at disposal site of Alum SA, Romania. According to the preliminary reports, it seems that corrosive threshold in the bauxite residue is located at pH 11.8. Below this threshold the bauxite residue has to be considered non - corrosive material for skin and eye. Repeated tests showed that acute conjunctiva irritation occurs with certainty at pH 11.8. Under this pH value, there was observed no-conjunctive irritation. The same threshold is valid also for acute dermal irritation [8]. Other of our studies concerning the bauxite residue as absorbent-adsorbent of chromium from fluids and concentrated or diluted suspensions containing residual chromium from different industries have been published in the last 12 years. In one of these studies [9], the experimental data have shown that the ion exchange capacity of BR may be raised up to 60-62 mg/g as far as the concentration of residual chromium ion in the treated waters ranges between 0.03 to 0.4 mg/L. Also, it was demonstrated that above ion exchange mechanism for entrapping chromium is valid only if chromium charged water is in contact with a given quantity of BR at a pH less than 7.0.

3.2 Albota Acidic Luvosoil Characterization

The Albota's albic luvosoil composition and its particular properties have been fully presented in our previous papers [5-8]. The Albota albic luvosoil is a typical acid soil with moderate pH, controlled by its low to medium bases saturation (VAh), specific for oligo-meso-basic soils. Chemical and agrochemical properties of the Albota acidic soil are presented in the Tables 3-5 toghether with the same parameters of the bauxite residue (BR).

Table 3. pH, organic carbon, macro in BR and in Albota acidic soil.

Main components	pH	C_{ORG}, %	N, %	P, %	K, %	Ca, %	Mg, %
Bauxite residue	11.08	0.626	0.02	0.092	0.12	2.610	0.009
Albota acidic soil	5.29	1.920	0.180	0.005	0.45	0.670	1.020

Table 4. Micronutrients and heavy metals in BR, and Albota acidic soil

Elements, mg/Kg	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
Bauxite residue	0	9.8	604	68.7	276481	206	15.1	49.0	24.0
Albota acidic soil	0.13	15	22.8	12.6	2.8	1370	15.6	-	66.8

Table 5. Agrochemical properties of the Albota albic luvosoil (Arges county) upper horizons.

D	pH (H_2O)	SB	A_h	V_{Ah}	N_t	$N\text{-}NO_3$	Humus	P_t	P_{AL}	K_{AL}
0-20	5.10	10.06	5.86	63.2	0.100	9.0	1.98	0.047	14.3	92
20-40	5.31	10.94	5.11	68.2	0.094	7.5	1.86	0.045	13.0	100

D - Soil layer depth, cm; SB - Total exchangeable bases, meq/100 g; A_h - Medium bases saturation, meq/100 g; V_{Ah} - Degree of saturation with bases, %; N_t – total nitrogen, %; $N\text{-}NO_3$ nitric nitrogen, %; Hum – Humus, %; P_t – Total phosphorus, % ;P_{AL}- Phosphorus ionic mobility, mg/kg; K_{AL}- Potassium ionic mobility, mg·kg.

Table 6. Agrochemical properties of the bauxite residue.

Parameter	pH (H_2O)	C_{ORG}, %	Total N_t, %	$N\text{-}NO_3$ mg/Kg	P(H_2O) mg/Kg	K(H_2O) mg//Kg
Bauxite residue	11.08	0.626	0.616	-	216.0	173

Table 7. Bauxite residue specific agrochemical properties.

Ionic mobility, mg/Kg		Ion exchange capacity, meq./100g		Total ion exchange capacity, meq./100g	
P_{AL}	196	Na at pH 7	128.63	T_{Na}	62.58
K_{AL}	287	Na in water	26.45	T_{NH4}	29.48
		Exchangeable Na	100.15	-	-

This soil medium hydrolytic acidity (Ah) and low trophic level are due to its poor content in exchangeable bases (SB), humus, total nitrogen (Nt), nitric nitrogen ($N\text{-}NO_3$), mobile phosphorus (PAL) and mobile potassium (KAL) (Table 3). All data are in good with the reference literature [10]. Due to its well-known particularities, the Albota albic luvosoil (Arges), Romania was considered a representative acid soil to be remediated, according to the present proposed technology. Bauxite residue, excepting the favorable changes in pH and some larger quantities of available phosphorus and potassium, does not bring too much help to alleviate the discrepancies in soil agrochemical properties. But, the real problem of bauxite residue conversion into an alkaline amendment for recovery acidic soils is the high level of both Na (1+) (5300 mg/kg) and

Ca (2+) (2800 mg/kg) ionic mobility [1, 2]. Only the ionic mobility of phosphorus (about 216 mg/kg) and potassium (about 173 mg/kg) (Table 6) seem to be appropriate values for sustaining the plant vegetative growth, as happens in the common soils. Solving this problem requires adequate fertilizers to alleviate salinity accumulation and to prevent the soil new damages. Due to low organic carbon in both Albota soil and bauxite residue, a couple of concentrated fertilizers were proposed for conducting these studies: NPK urea and organic Bio Enne Coactyl complex fertilizer.

3.3 Analytical Management Program

This activity encompassed the following type of analyses and determinations performed according to Romanian and EU standards and methodology: ionic and non-ionic elements in all materials and products. Full analysis program for the soil and composition and properties, full analysis program for the vegetative growth and crop quality, common heavy metals analysis for some materials and products. Statistical analysis of the collected data was done by variance analysis, Duncan test software SPSS 14.0. The details about these programs were given in our previous papers [2, 4-8].

4. Results and Discussion

4.1 Crop Production Growth

Figure 2 shows the groups of variants with the highest production values of the three cultivated plants. In the case of maize (red bars), V1 is the control, i.e. the soil not amended with BR, V11 is the variant with the soil only amended with 60t BR/ha, and V12 and V13 are the variants amended with 60t BR/ha and fertilized with NPK and, respectively, with NPK and organic fertilizer, according to the Table 1. According to Figure 2, the differences between the maize productions in the V1 and V11 variants and the productions in the V12 and V13 variants are the obvious effect of soil amendment with BR, respectively of improving the acidity of the Albota soil. Moreover, a slight difference between crop values in the variant V11 and V12 might suggest the contribution of the organic fertilizer in V13 is minimal or is missing. Apparently, similar situations are shown also, in the Figure 1 for wheat (yellow bars, year 2 since applying BR as alkaline amendment) and sunflower (blue bars, year 3 since applying BR as alkaline amendment). But the things are little different. In both cases, the maximum values of wheat and sunflower productions are placed at lower dosage of BR, 20 t/ha for wheat and 40 t/ha at sunflower. Also, according to Figure 1, the relative values of the increase in wheat production (year 2 after applying alkaline amendment with BR), V6 and V7 versus V1 and V5, and the relative values of sunflower production (year 3 after applying alkaline amendment with BR), V9 and V10 versus V1 and V8), seem to be visibly affected by the only factor that has changed significantly during plant vegetative growth – the partial depletion effect of soil amendment with BR in the first year of experimentation. Based on this information, it is logical to be accepted that an Albota soil amendment with BR once every two years is logical and recommended.

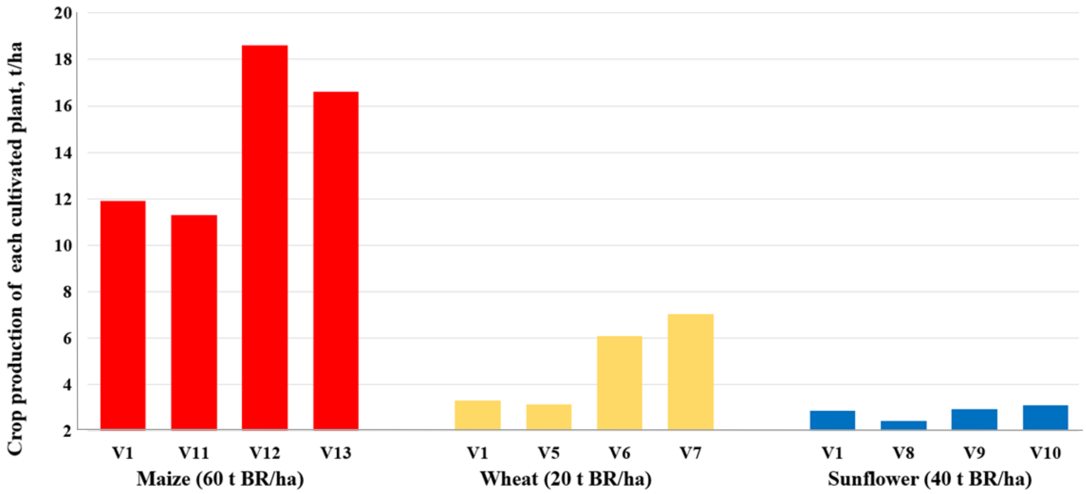

Figure 2. Crop production of each cultivated plant. Maize 2018; Wheat 2019; Sunflower 2020.

4.2 Soil pH in the Experimental Variants.

Figure 3 shows the experimental results regarding soil pH measurements at the end of each year of experimentation for the variants with the best results regarding the production of maize, wheat and respectively, sunflower.

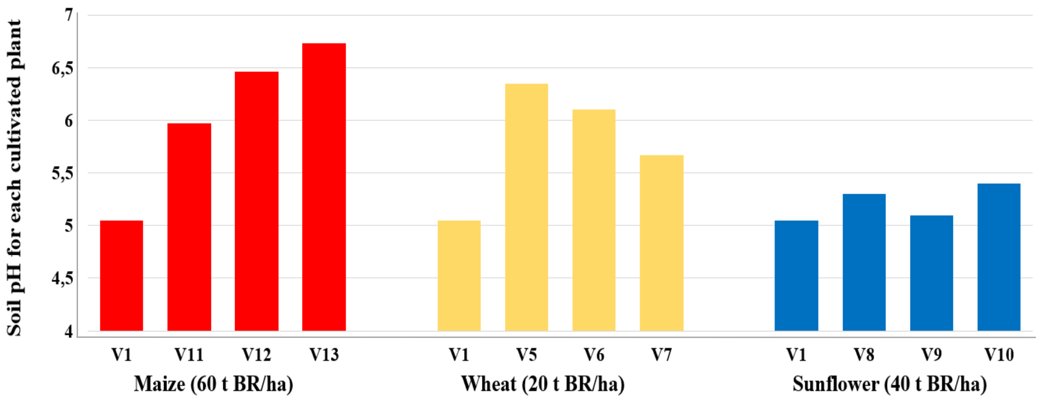

Figure 3. Soil pH for each cultivated plant. Maize 2018; Wheat 2019; Sunflower 2020.

The gradual increase in soil pH with the increase in the dose of BR used for soil amelioration is proof that the dose of 60 t/ha can furnish the soil with sufficient alkalinity to support the natural growth of the maize plant continuously for 1 year, without any doubt. In this figure, the V1 variant presents the natural pH of the Albota soil. The raise in pH in V11 variant was done exclusively by the BR amendment, which discharged its entire alkalinity on the land surface. The fertilizers bring in soil, also, their part of alkalinity, sustaining the vegetative growth of maize until the end of 2018 experiments. These assertions remain valid for all other variants under survey. Actually, in the next season 2019, the experimental field is starting the next crop vegetative growth (wheat, yellow bars) from well moderated soil pH values. Yellow bars in Figure 2 are describing the pH map after second season 2019 and after the cropping the wheat/ In spite of some distortions in the most productive variants, and preference of the cultivated Hybride PG 102 for lower pH (maximum crop at 20 t BR/Ha) the second season was successfully ended. Thus, the above data suggest that application of the BR, as alkaline amendment for control the pH of the acidic soils like Albota soil, should be made once at 2 years in dosages attested by the previous verification tests for each large scale cultivated plant. Returning to the third year, 2020, the experimental year started with a little reserve of alkalinity, which was quickly drained and soil pH did return to normal values. Beyond the above assertions about correlation between soil pH and the harvest sizes, there are some another important factors which have a large contribution to increase in harvest and harvest quality. It is about meteorological factors and the reserves of water available in soil. During the entire experiment, all these factors had continuous and significant positive contributions.

4.3 Plant Waists at Maturation: Maize 2018, Wheat 2019, Sunflower 2020.

In the Figure 4 is presented a simple remark about the evolution of the plants green mass growth during the 3 years experiment 2018 – 2020. The particular parameter that serves as an example was the plant waists at the stage of plant maturity. This parameter is important because it expresses the degree of development of the plants before fruiting stage.

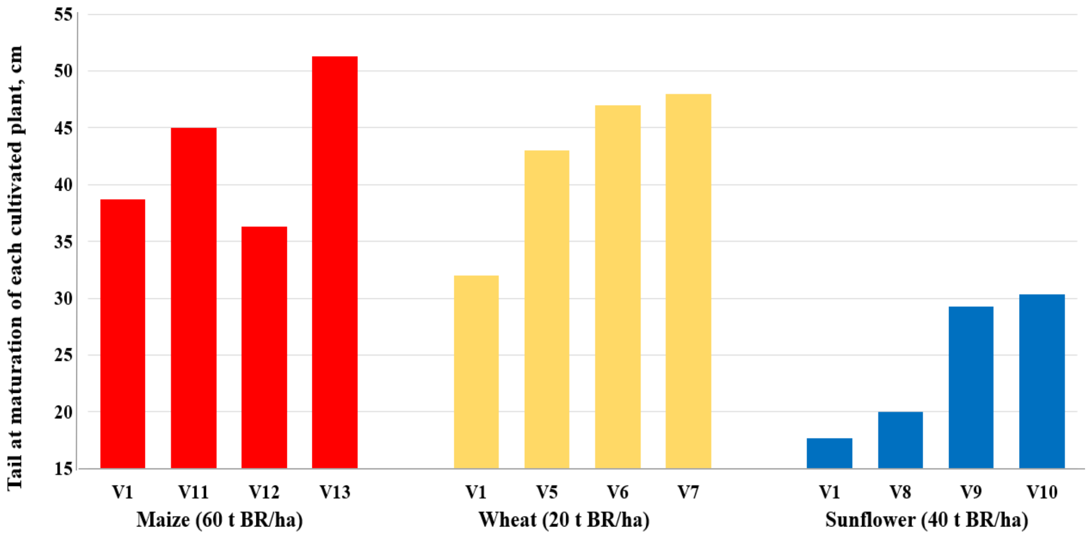

Figure 4. Plant waists at maturation

In Figure 4, only the variants that provided the highest production of grains and seeds were taken into consideration. From this figure, it can be seen a proportional increase in the waist of plants depending on the amount of BR added to the soil and respectively, on pH changes which differentiate by variants. Also, this figure suggests an independence between the vegetative growth and the growth in grains and seeds production, i.g. plants waists can grow, but not the production too.

4.4 Quality Parameters of Maize, Wheat and Sunflower Crops.

The common quality parameters of maize, wheat and sunflower crops are nitrogen, phosphorus and potassium (NPK) concentrations and heavy metal concentrations (Cu, Fe, Mn and Zn) in maize, wheat and sunflower seeds. Figures 5 and 6 show the quality parameters for all the experimental variants for which the maximum harvests were obtained.

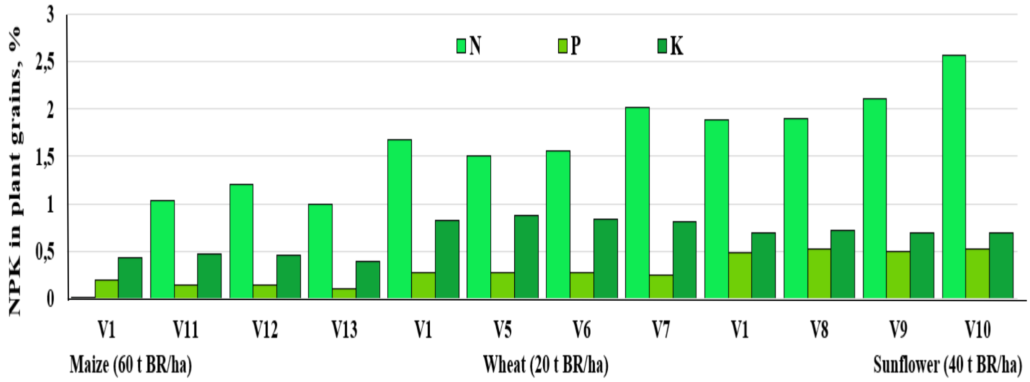

Figure 5. NPK in the maize and wheat grains and in the sunflower beans after experiments.

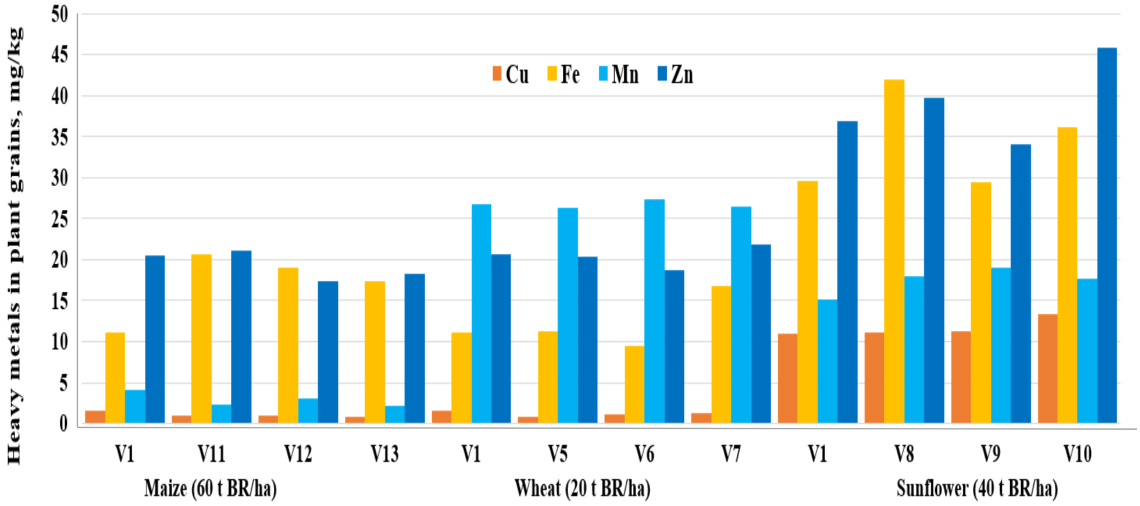

Figure 6. Heavy metals in the maize and wheat grains and sunflower beans after experiments.

Differences between the fertilized and non-fertilized variants are minimal for both groups of elements (NPK) and (Cu, Fe, Mn and Zn) and for all 3 cultivated plants. The results have no statistical relevance, but the values as they look like, exhibit NPK concentrations lower than in the same crops on other more fertile soils. The concentrations (Cu, Fe, Mn and Zn) are in accordance with the nature of the acidic soil of Albota. But, these data do not reveal any indication of possible releases of heavy metals locked in mineralogical phases of BR.

4.5 Statistical Analysis

For statistical analysis was applied Duncan's Multiple Range Test and, for mathematical processing data was used the program SPSS 14.0. All the experimental data from the entire analytical program, including all the reparations were introduced in the computing program. The test results are delivered in diagrams, as those from the Figures 6-8. The main factor in this test is the bauxite residue dose (0, 10,20,40 and 60 Mg/ha).

From interaction between BR, at different doses with both type of fertilizers (NPK urea and NPK organic) at constant doses, the crop yields might be significantly increased ($p \leq 0.05$) versus the control plots in each variant or could not be significantly increased ($p > 0.05$) (Figures 6-8). The significant differences between treatments were labeled with small letters, the ”a” symbol (in the Figure 7) representing the highest values, according to Duncan's Multiple Range Test. Actually, the sample V60-NPK was designed as reference for all samples concerning the crop production in maize. Samples V10-0 and V60-0, denoted by letter ”d” was also, designed as reference for the smallest maize crop production, Thus, in Figure 7 sample V60-NPK is fully different of samples V10-0 and V60-0. But, the samples V60-NPK-25, V-40NPK and V40MPK-25 and V20NPK. denoted with letters „ab” could be associated with V60-NPK as belonging to the same category of data significantly-insured from statistical point of view.

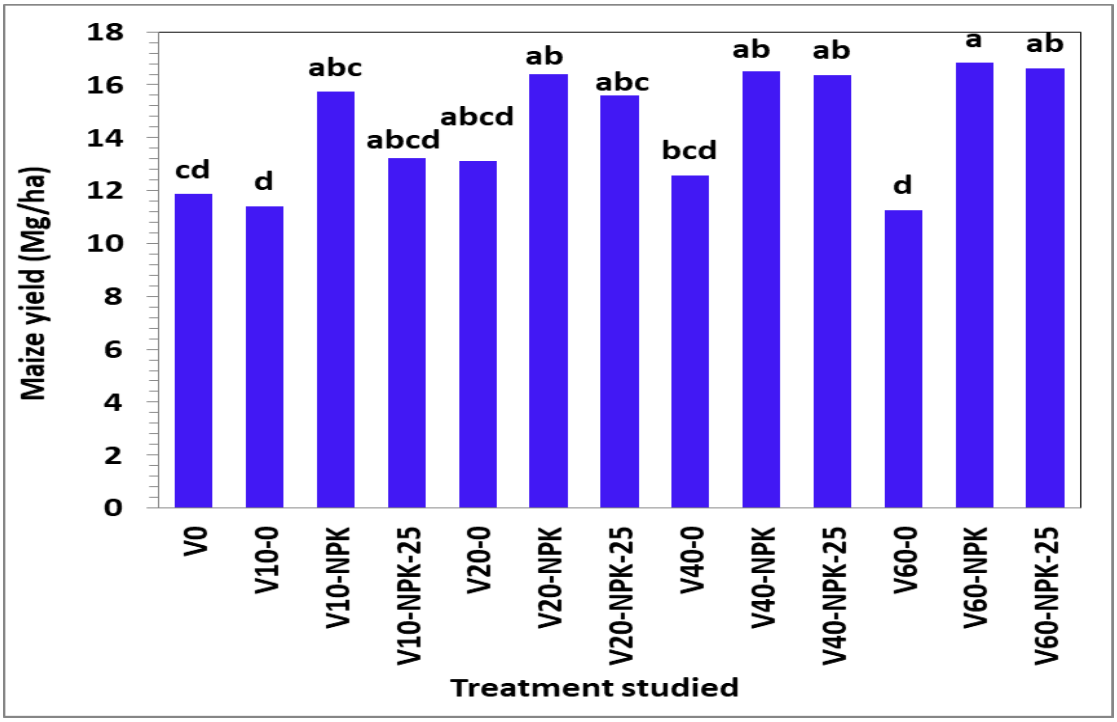

Figure 7. Maize crop yields.

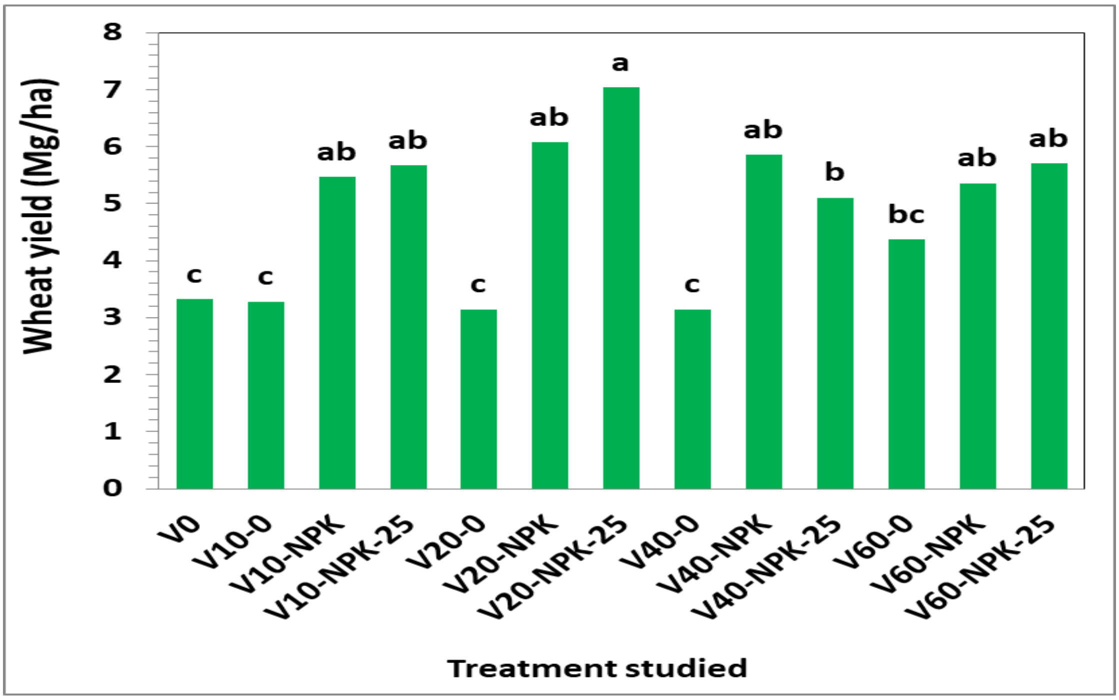

Figure 8. Wheat crop yields.

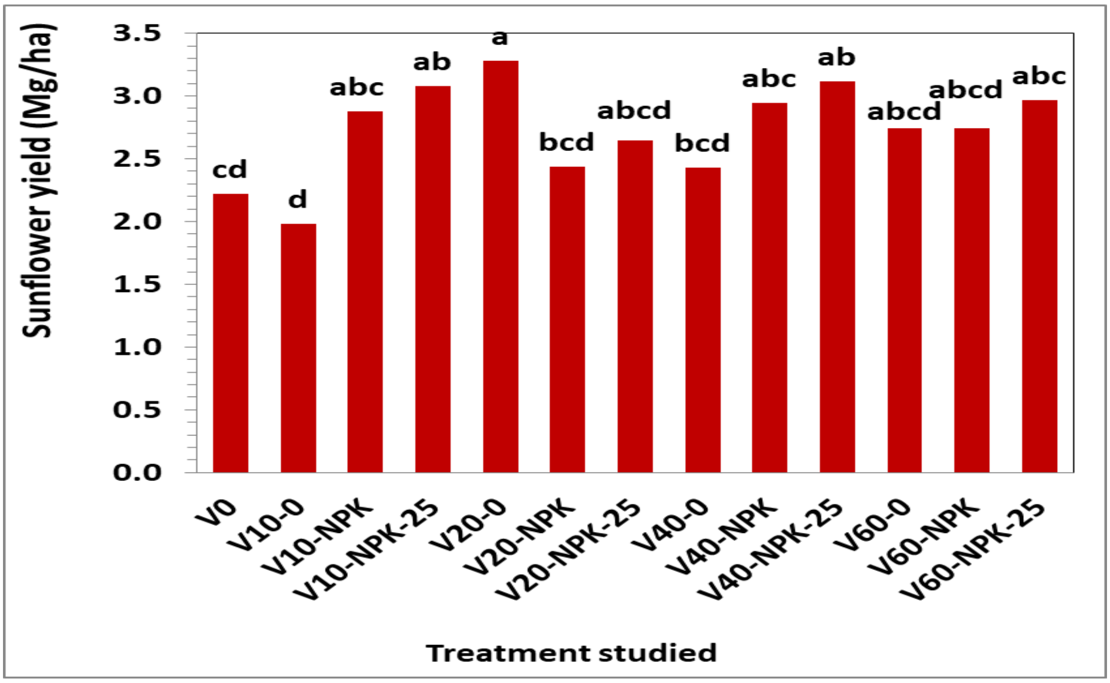

Figure 9. Snflower crop yields.

In the Figure 8 there are two samples which exhibit the larger crop yield. They are significantly-insured from statistical point of view. Is about samples V20-NPK-25, labeled ”a” and V40 NPK 25. They are completely different from samples V0, V10-0, V20-0 and V40-0 labeled ”c.”. In both cases presented above, the existence of variants delivering significantly-insured crop yields has to be appropriated by the fact that soil pH at the ends of two vegetative seasons is still 1.-1.5 unit above the standard Albota soil pH (Figure 3). In the Figure 9, the sunflower crop yields diagram is completely disrupted, without any parameter significantly insured from statistical point of view. Probably, this a clear sign of total alkalinity missing from soil (Figure 3). Statistical analysis was extended over the Albota soil chemical and agrochemical parameters (Tables 3-5) before set up the experiments with maize (2018) and after the end of the experiments with sunflower (2020), applying the same Duncan's Multiple Range Test. The collected data show no significantly insured differences between all the parameters measured before and after the three years of experiments.

5. Conclusions

The contribution of this work to the deeper knowledge of the effect of Albota soil rehabilitation by using BR as an alkaline amendment after a 3-year experimental program in an open field production regime can be summarized as follows: a) It has been shown that BR has a complex mineralogy with 50-60 % non-reactive phases, which ensures minor emissions of heavy and toxic metals in the rehabilitated soil. BR does not contain radionuclides and has an acceptable corrosiveness up to pH 11.8; b} It has been demonstrated that the interaction between BR and the acidic soil of Albota is reduced, mainly, to the change in pH, through simple mechanisms of adsorption - desorption, with a chemical reaction of the alkaline elements from BR. With a single application of BR, the neutralization effects extend over a limited period of time. This duration is approximately 2 years under the conditions of the application of intensive agricultural technologies; c) It has been demonstrated that the acidic soil of Albota is a soil poor in humus and organic carbon and, in addition, it lacks proper agrochemical properties, necessary for a fertile soil (SB - low total exchangeable bases, Ah - low medium bases saturation and VAh - hydrolytic acidity, which is high). Also, the soil of Albota has a low content of nitric nitrogen and moderate mobility of ions with phosphorus and potassium content; d) It was demonstrated that the simple application of BR on the soil of Albota does not have the expected effect, mainly due to the reported deficiencies. As a measure to increase the fertility of the Albota soil, alkalization with BR must be accompanied by a significant intake of NPK fertilizers and organic carbon fertilizers. In the conducted studies, two NPK fertilizers were used: urea and organic Bio Enne Coactyl complex fertilizer. Under these conditions, the profile of plant productions for all 3 cultivated plants (Figure 1) carries the profile of the pH of the soil in which the plants grew (Figure 2). e) All cultivated plants recorded exceptional crop yields with the beneficial contribution of meteorological factors and due to the valuable water reserves available in the soil, all during the three-year experiments.

6. References

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