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EXPERIMENTAL RESULTS ON ALTERNATIVE WAYS OF INCREASING THE pH OF ACID SOILS, USING CARBONATION MUD (DEFECATION LIME), THE WASTE FROM SUGAR BEET INDUSTRY

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Abstract

The waste precipitate from sugar technology contains $CaCO_3$ and aggregated or adsorbed non-sugars. This work is an attempt to investigate the possibility of using sugar beet waste-carbonation lime residue (sludge) as an amendment to correct the pH of acid soils, embracing and implementing the concept of circular energy crop. Research were carried out during three agricultural years (2020-2022), in the experimental field of the National Institute of Research and Development for Potato and Sugar Beet Brașov, Romania. A total number of 96 experimental sugar beet plots were analyzed, divided into six variants (variables), V1 - control, V2 - $CaCO_3$ (classic), V3-V6 different amounts of carbonation lime sludge (Factor A), using two methods of incorporating amendments into the soil and different amounts of fertilizers (4 experiments) (Factor B). The use of defecation lime had an impact on soil pH, yield production (very significant differences compared to the control), sugar production (very significant differences compared to the control), and less on sugar biological concentration (significant differences compared to the control). For evaluating the results, analysis of variance (ANOVA) and Duncan multiple range test were used.

***Key words**: amendment, carbonation sludge, sugar beet, pH.*

INTRODUCTION

The soil is a vital source for human food production. According to FAOSTAT, only 29% of the total global area is land, and out of this, only 6.4% is used as agricultural land. From this area, approximately 98% of food for the world's population is produced.

Currently, the state of soil fertility is continuously degrading. This degradation causes changes in the chemical properties of soils and includes nutrient loss, acidification, salinization, and alkalinization. Worldwide, in 62% of the area, soils have low or very low fertility, 27% have moderate fertility and only 11% have high fertility. Agricultural activity is the main cause of soil degradation on all continents (FAO, 2006).

In the context of the current efforts being made to protect the environment and maintain a natural biological and ecological balance in the soil favorable to the development of animal and plant life, the management of agricultural crops, through finding cost-effective alternative methods, acquires new values of maximum economic and scientific importance (Obaisi et. al., 2022).

Sugar beet (*Beta vulgaris* L. ssp. *vulgaris* var. *altissima)* is known in Romania and worldwide as one of the most valuable technical crops, from which the raw material needed for sugar factories and significant amounts of fodder for animal feed is mainly provided (Malmir et al., 2020).

Sugar beet is very demanding in terms of soil due to its deep root system, with a high absorption capacity and high consumption of nutrients and water. For this reason, it is not indicated to grow beets on compact soils that form a crust, because they prevent germination and normal development due to high physical-mechanical resistance, and the roots remain small and branch. Sugar beet prefers a neutral soil pH of 6.5-7. The highest root productions are obtained on lands with a deep arable layer, rich in nutrients, and well supplied with water throughout the growing season. Calcareous, too sandy, and heavy soils are not suitable for sugar beet cultivation. Also, compact, cold and impermeable soils, as well as too acidic or too

alkaline soils, are not suitable for sugar beet (Taus & Gherman, 2011).
Adjusting the pH by adding calcium is the first step if the soil is acidic or very acidic, because otherwise the plants cannot absorb the necessary nutrients and nutritional deficiencies can appear visible through the yellowing of the leaves or the lack of development of the plants.
The carbonation mud (technological sludge) is a residue resulting from the purification operations, by physico-chemical methods of the diffusion earth, in order to concentrate and crystallize the normal sucrose in the sugar factories (Gherman et al., 2022). The technological sludge is obtained through the process of classical purification in which calcium hydroxide and carbon dioxide are used for the removal of non-sugar in the following operations: pre-defecation and defecation, treatment with $Ca(OH)_2$ Ist saturation and treatment with CO_2 IInd saturation (Domșa, 1973).
Considering the large amount of $CaCO_3$ in the technological sludge (50-70%), it can be used with very good results to improve the acid reaction of soils. Before use, it must be dried in platforms, so that it has 10% moisture.
Technological sludge is a fast-acting amendment favoring production increases of 15-35% even in the first year after application. The ameliorative effect is combined with that of fertilizer because it contains 0.3-0.5% N; 0.8-1.5 P_2O; 0.15 K_2O and 10-15% organic substances (Rusu, 2005). The neutralizing power is 55-75%. The technological sludge can be used directly from the storage pits of the sugar factories or from the platforms where it is stored. Its physical condition is good after draining, being in the form of a semi-dry paste, easy to apply to the field in the following summer of the sugar processing campaign. From each sugar factory approximately 20-40 thousand tons of technological sludge result annually, depending on the amount of beet processed.
Currently, in our country, in the settling pits and storage platforms of the operating or closed sugar factories, there are very large amounts of technological sludge left over from the beet processing campaigns of recent years, which can be recovered free of charge in order to be used as an amendment (Gherman et al., 2022).
Land application of press sludge from cane sugar mills as an amendment has become a common practice in countries such as Pakistan and India.
Boeriu and Rusu (1972) used technological sludge (defecation foam) from the Luduș sugar factory as an amendment to correct the acidity of podzolic soils from Livada (Satu Mare county) in multi-year experiments on 11 crops. The average increase in production obtained on them was 36% compared to the control (unamended soil).
Lăpușan et al. (1980) tested at SCA Livada technological sludge as an amendment to correct soil acidity on a permanent meadow and a temporary meadow in a multi-year experience. The increase in green mass production obtained on average over 7 years on the permanent meadow was 111.6%, and on the temporary meadow, the increase in production was 129.4% compared to the unamended control.
In this context, this work aims to investigate the possibility of using sugar beet waste (carbonation lime residue -CLR) as an amendment to correct the pH of acid soils.

MATERIALS AND METHODS

The research was carried out during the 2020-2022 period in the experimental field of NIRDPSB Brașov on a cambic chernozimoid type soil with an average pH of 6.1 determined in the fall preceding the agricultural year. The main preceding crops were wheat (2020) and potato (2021, 2022).
Four experiences were established in the field:

- In the first two experiments, 800 kg/ha of complex NPK fertilizers (16:16:16) were applied in autumn before plowing.
- In the last two experiments, 1.000 kg/ha NPK complex fertilizers (20:20:0) were applied in autumn after plowing and incorporated into the soil with a tiller.

The experimental factors were the following:
Factor A - six variants with different doses of amendments ($CaCO_3$ and technological sludge)
V1 - Control (unamended soil);
V2 - 6 t/ha $CaCO_3$;
V3 - 7 t/ha/ technological sludge (TS);
V4 - 8 t/ha technological sludge;

V5 - 9 t/ha technological sludge;
V6 - 10 t/ha technological sludge.

Factor B - two methods of incorporating amendments into the soil:

- Under basic plowing
- Administration by plowing and incorporation into the soil with the tiller

The amendment doses in this study were calculated based on the formula developed by Borlan et al. (1982), incorporating indices of exchange capacity and neutralizing power of the amendment. Amulet, a monogerm beet hybrid was sown on March 26, 2020, and the sowing density was 1.2 GU/ha of pelleted seed treated with insecticides to safeguard young beet seedlings from diseases and pests during early vegetation stages (Figure 1). Precision seeding was carried out with a 6-row drill, with each repetition plot consisting of 6 rows, measuring 11.1 m in length and 2.7 m in width, totaling a surface area of 30 m^2.

Beet harvesting was carried out every year between October 15 - November 15. Manual harvesting involved knocking the beets to the ground, followed by scalping with a knife. The harvested beets were then counted and weighed to determine the production on each experimental plot.

Figure 1. Sugar beet (Amulet beet hybrid) during the growing season in the experimental field of NIRDPSB Brașov, 2021

For assessing beet technological quality, 20 beetroots from each of the 96 plots were taken for analysis. To calculate the yield, the roots of each variant with an area of 30 m^2 were weighed, after which it was reported to the area of one hectare.

After harvesting, soil samples were taken from each variant/repetition, and the pH of the soil samples was determined using the Test-Strip Quantofix Reader, with which the pH values before and after application could be compared amendments.

In the laboratory, the scalped beets were cleaned, and pasta samples were extracted separately using a milling cutter. The biological sugar content was determined with a polarimeter. The production of biological sugar (expressed in tons of sugar/ha) from each plot was calculated based on root production and beet sugar content.

For evaluating the results, analysis of variance and Duncan multiple range test were used, using the PoliFact program.

RESULTS AND DISCUSSIONS

Soil pH value

The initial pH soil value was 6.1, determined in the autumn of 2019.

The unamended variant (V1) kept its value of 6.1 after the 2020 harvest, while V2 (6 t/ha $CaCo_3$) improved its value, measuring 6.9 in experiences number 1 (E1), 2 (E2), 4 (E4), and 7.0, in the experience number 3 (E3). In Table 1 can be observed that variants V3, V4, V5, and V6, have improved their values, depending on the amount of amendment applied.

Table 1. Mean of pH values, determined on each experience 2020-2022

Year	Variant	E1	E2	E3	E4
2020	V1	6.1	6.1	6.1	6.1
	V2	6.9	6.9	7.0	6.9
	V3	6.6	6.6	6.6	6.7
	V4	6.8	6.7	6.7	6.8
	V5	6.9	6.8	6.9	6.9
	V6	7.0	6.9	7.0	6.9
2021	V1	6.0	6.1	6.0	5.9
	V2	6.9	7.0	6.8	6.9
	V3	6.6	6.7	6.5	6.6
	V4	6.8	6.7	6.7	6.7
	V5	6.8	6.8	6.8	6.8
	V6	6.9	6.9	6.8	6.8
2022	V1	5.9	5.9	5.9	5.9
	V2	6.8	6.7	6.8	6.7
	V3	6.6	6.5	6.5	6.5
	V4	6.7	6.7	6.7	6.6
	V5	6.7	6.7	6.7	6.7
	V6	6.8	6.7	6.8	6.7

In 2021 and 2022, the highest values were registered at V2 where 6 t of $CaCO_3$ were used (soil pH 6.8-7.0) and in V6, where 10 t/ha of technological sludge were used (soil pH 6.8-6.9) (Table1).

Root yield

In E1, where NPK (16.16.16) and amendments incorporated in the soil with rotary milling in autumn were applied, root yield (t/ha) varied between 79.66 t/ha (Control), and 92.26 t/ha (V6) (Table 2).

Table 2. Fertilization with NPK (16.16.16) and amendments incorporated in the soil with rotary milling in autumn - Root yield (t/ha) in the E1 experiment

Var	2020	2021	2022	Av.	%	Diff.	Sign.	DT
V1	87.4	81.55	70.03	79.66	100	0	-	A
V2	98.55	92.09	85.45	92.03	115.5	12.37	***	B
V3	91.65	86.43	81.46	86.51	108.6	6.85	***	B
V4	93.30	87.83	82.12	87.75	110.2	8.09	***	C
V5	97.68	91.43	84.50	91.20	114.5	11.54	***	C
V6	98.85	92.35	8559	92.26	115.8	12.60	***	C

LSD (p 5%)= 2.54 t/ha
LSD (p 1%)= 3.60 t/ha
LSD (0.1%)= 5.22 t/ha

All variants had very significant differences, compared to the control.

In E2 where NPK (16.16.16) and amendments incorporated in the soil under plowing in autumn were applied, root yield (t/ha) varied between 77.39 t/ha (Control), and 89.76 t/ha (V6).

All variants had very significant differences, compared to the control (Table 3).

Table 3. Fertilization with NPK (16.16.16) and amendments incorporated in the soil under plowing in autumn - Root yield (t/ha) in E2

Var.	2020	2021	2022	Av.	%	Diff.	Sign.	DT
V1	82.28	80.38	69.50	77.39	100	0	-	A
V2	95.35	89.90	82.58	89.28	115.4	11.89	***	B
V3	90.88	84.43	80.61	85.31	110.2	7.92	***	B
V4	91.63	85.62	81..46	86.24	111.4	8.85	***	BC
V5	92.40	88.70	82.33	87.81	113.5	10.42	***	C
V6	95.25	89.88	84.15	89.76	116	12.37	***	C

LSD (p 5%) = 2.48 t/ha
LSD (p 1%) = 3.53 t/ha
LSD (0.1%) = 5.11 t/ha

In E3 where NPK (20.20.0) amendments incorporated in the soil with the rotary milling in autumn were applied, the root yield (t/ha) varied between 78.80 t/ha (Control), and 89.50 t/ha (V6). The variants V2, V4, V5, and V6 had very significant differences, compared to the control (Table 4).

Table 4. Fertilization NPK (20.20.0) - amendments incorporated in the soil with the rotary milling in autumn - Root yield (t/ha) - E3

Var.	2020	2021	2022	Av.	%	Diff.	Sign.	DT
V1	88.03	79.10	69.26	78.80	100	0	-	A
V2	96.08	87.70	81.86	88.55	112.4	9.75	***	B
V3	91.35	84.23	80.12	85.23	108.2	6.44	**	BC
V4	92.33	85.83	82.49	86.88	110.3	8.09	***	BC
V5	96.07	86.43	83.34	88.61	112.5	9.82	***	BC
V6	96.30	87.58	84.63	89.50	113.6	10.71	***	C

LSD (p 5%) = 3.19 t/ha
LSD (p 1%) = 4.53 t/ha
LSD (0.1%) = 6.57 t/ha

In E4 where NPK (20.20.0) - amendments incorporated under plowing in autumn where applied, the root yield (t/ha) varied between 78.15 t/ha (in which variant?) and 88.71 t/ha (V6) (Table 5).

Table 5. Fertilization with NPK (20.20.0) - amendments incorporated under plowing in autumn - Root yield (t/ha) in E4

Var.	2020	2021	2022	Av.	%	Diff.	Sign.	DT
V1	87.48	78.45	68.52	78.15	100	0	-	A
V2	94.45	85.73	82.54	87.57	112.1	9.42	***	B
V3	90.18	82.60	79.57	84.12	107.6	5.97	**	BC
V4	92.35	84.08	82.60	86.34	110.5	8.19	***	BC
V5	94.40	85.15	84.07	87.87	112.4	9.72	***	BC
V6	94.50	85.60	86.04	88.71	113.5	10.56	***	C

LSD (p 5%) = 3.90 t/ha
LSD (p 1%) = 5.55 t/ha
LSD (0.1%) = 8.03 t/ha

Biological sugar content

Regarding the biological sugar content (°S), in E1, the values varied between 18.01°S (Control) and 18.70°S (V2). Variant V2 was followed by V6 with a sugar content of 18.66°S. The most significant results were obtained in V2 (0.69°S difference) and V6 (0.65°S difference) (Table 6).

Table 6. Biological sugar content (°S) in E1

Var.	2020	2021	2022	Av.	%	Diff.	Sign.	DT
V1	16.25	18.90	18.88	18.01	100	0	-	A
V2	16.58	19.80	19.73	18.70	103.8	0.69	***	AB
V3	16.26	19.20	18.95	18.14	100.7	0.13	-	BC
V4	16.50	19.53	19.20	18.41	102.2	0.40	**	C
V5	16.65	19.68	19.15	18.49	102.7	0.48	**	C
V6	16.60	19.78	19.60	18.66	103.6	0.65	***	C

LSD (p 5%) = 0.27°S
LSD (p 1%) = 0.39°S
LSD (0.1%) = 0.56°S

In E2 the average biological sugar content (°S) varied between 17.71°S (Control) and 18.64 °S (V6). Significant results were found in V2 (0,75°S difference from the control) and V5

(0.72°S difference), V6 (0.93°S difference) (Table 7).

Table 7. Biological sugar content (°S) in E2

Var.	2020	2021	2022	Av.	%	Diff.	Sign.	DT
V1	16.25	18.55	18.33	17.71	100	0	-	A
V2	16.48	19.53	19.38	18.46	104.3	0.75	**	AB
V3	16.30	19.10	18.40	17.93	101.3	0.22	-	ABC
V4	16.38	19.23	18.95	18.19	102.7	0.48	-	BC
V5	16.50	19.45	19.35	18.43	104.1	0.72	**	C
V6	16.53	19.50	19.88	18.64	105.5	0.93	**	C

LSD (5%) = 0.49°S
LSD (1%) = 0.70°S
LSD (0.1%) = 1.01°S

In E3 the average biological sugar content (°S) varied between 17.57°S (control) and 18.20°S (V2). The result obtained in V2 is very significant, 18.13°S (V6) - very significant (Table 8).

Table 8. Biological sugar content (°S) in E3

Var.	2020	2021	2022	Av.	%	Diff.	Sign.	DT
V1	16.23	18.20	18.27	17.57	100	0	-	A
V2	16.43	19.03	19.13	18.20	103.6	0.63	***	B
V3	16.20	18.58	18.68	17.82	101.4	0.25	*	BC
V4	16.42	18.75	18.78	17.98	102.4	0.42	**	BC
V5	16.48	18.83	18.85	18.05	102.8	0.49	**	C
V6	16.40	18.95	19.05	18.13	103.2	0.57	***	C

LSD (p 5%) = 0.24°S
LSD (p 1%) = 0.35°S
LSD (0.1%) = 0.50°S

In E4 - Average biological sugar content (°S) varied between 17.47°S (control) and 18.10°S (V2) - very significant, 18.05°S (V5) 18.10°S (V6) - very significant. The application of carbonation mud improved significantly the biological sugar content in V5 (0.59°S difference) and V6 (0.64°S difference from the control) (Table 9).

Table 9. Biological sugar content (°S) in E4

Var.	2020	2021	2022	Av.	%	Diff.	Sign.	DT
V1	16.08	18.10	18.22	17.47	100	0	-	A
V2	16.30	18.95	19.05	18.10	103.6	0.63	***	B
V3	16.23	18.55	18.58	17.79	101.8	0.32	*	BC
V4	16.35	18.68	18.68	17.90	102.5	0.44	**	C
V5	16.40	18.88	18.88	18.05	103.4	0.59	***	C
V6	16.33	19.00	18.98	18.10	103.6	0.64	***	C

LSD (p 5%) = 0.25°S
LSD (p 1%)= 0.36°S
LSD (0.1%)= 0.51°S

In E1, the average biological sugar yield (t/ha) varied between 14.28 t/ha (Control) and 17.14 t/ha (V2), 17.15 t/ha (V6).
All variants had very significant differences, compared to the control (Table 10).

Table 10. Biological sugar yield (t/ha) in E1

Var.	2020	2021	2022	Av.	%	Diff.	Sign.	DT
V1	14.20	15.41	13.22	14.28	100	0	-	A
V2	16.33	18.23	16.87	17.14	120.1	2.87	***	B
V3	14.85	16.59	15.44	15.63	109.5	1.35	***	B
V4	15.39	17.15	15.77	16.10	112.8	1.83	***	C
V5	16.26	17.99	16.18	16.81	117.7	2.53	***	C
V6	16.41	18.26	16.78	17.15	120.1	2.87	***	C

LSD (p 5%) = 0.56 t/ha
LSD (p 1%) = 0.79 t/ha
LSD (0.1%) = 1.14 t/ha

In E2, the average biological sugar yield (t/ha) varied between 13.47 t/ha (Control) and 16.43 t/ha (V2), 16.66 t/ha (V6). All variants had very significant differences, compared to the control (Table 11)

Table 11. Biological sugar yield (t/ha) in E2

Var.	2020	2021	2022	Av.	%	Diff.	Sign.	DT
V1	13.37	14.91	12.74	13.47	100	0	-	A
V2	15.71	17.55	16.02	16.43	120.1	2.75	***	B
V3	14.82	16.13	14.86	15.27	111.7	1.60	***	BC
V4	15.01	16.47	15.44	15.64	114.4	1.97	***	CD
V5	15.24	17.25	15.94	16.14	118.1	2.47	***	D
V6	15.74	17.52	16.71	16.66	121.8	2.98	***	D

LSD (p 5%) = 0.58 t/ha
LSD (p 1%) = 0.82 t/ha
LSD (0.1%) = 1.19 t/ha

In the Experience no. 3, the average biological sugar yield (t/ha) varied between 13,73 t/ha (Control) and 16.08 t/ha (V2), 16.26 t/ha (V6).
Variants V2, V4, V5, V6 v had very significant differences, compared to the control (Table 12).

Table 12. Biological sugar yield (t/ha) in E3

Var.	2020	2021	2022	Av.	%	Diff.	Sign.	DT
V1	14.28	14.40	12.52	13.73	100	0	-	A
V2	15.78	16.68	15.79	16.08	117.1	2.35	***	B
V3	14.80	15.64	14.86	15.10	110.0	1.37	**	BC
V4	15.16	16.09	15.51	15.59	113.5	1.85	***	C
V5	15.82	16.27	15.85	15.98	116.4	2.25	***	C
V6	15.79	16.60	16.39	16.26	118.4	2.53	***	C

LSD (p 5%) = 0.80 t/ha
LSD (p 1%) = 1.13 t/ha
LSD (0.1%) = 1.64 t/ha

In the E4, the average biological sugar yield (t/ha) varied between 13.58 t/ha (Control) and 15.79 t/ha (V2), 16.01 t/ha (V6) (Table 13).

Table 13. Biological sugar yield (t/ha) in E4

Var.	2020	2021	2022	Av.	%	Diff.	Sign.	DT
V1	14.06	14.20	12.47	13.58	100	0	-	A
V2	15.40	16.25	15.79	15.79	116.3	2.21	***	B
V3	14.63	15.32	14.91	14.91	109.8	1.33	***	BC
V4	15.10	15.70	15.41	15.41	113.5	1.83	***	C
V5	15.48	16.07	15.81	15.81	116.4	2.23	***	C
V6	15.43	16.27	16.01	16.01	117.9	2.43	***	C

LSD (p 5%) = 0.81 t/ha
LSD (p 1%) = 1.16 t/ha
LSD (0.1%) = 1.67 t/ha

Variants V2, V4, V5 and V6 had very significant differences, compared to the control.

CONCLUSIONS

The replacement of calcareous amendments purchased from fertilizer factories and used to improve the acid reaction of soils with technological sludge obtained free of charge from sugar factories presents advantages such as the reduction of the purchase of calcareous amendments and the efficiency of the transport of the technological sludge, because the trucks intended for the transport of sugar beet to the factory make only one round trip.

Compared to the unimpaired control over the course of the three-year testing period, increases in sugar beet yield between 10 and 13 t/ha were obtained in the 2020–2022 experiments conducted at The National Institute of Research and Development for Potato and Sugar Beet Brașov using technological sludge as an amendment to correct the acidity of a soil with an average pH of 5.9 (unamended) (Gherman et al., 2022).

Yield values per hectare and average biological sugar yield (t/ha) values from all four experiments exceeded the control variant, highlighting the fact that technological sludge can be an alternative to $CaCo_3$ (V2) currently used for soil amendment.

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