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Use of recycled sand as a corrective material for soil acidity in soybean crops

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ABSTRACT

Acidity is one of the main factors capable of reducing the productive potential of Brazilian soils, as it promotes the release of toxic elements for plants and reduces the availability of nutrients. Recycled civil construction and demolition waste (R-CCW class A) is a major environmental problem in Brazilian cities, especially in terms of its illegitimate disposal, causing floods, clogging of galleries and silting of channels, in addition to the proliferation of vectors and pollution. The objective of this study was to evaluate the potential of recycled sand (R-CCW) as a corrective of soil acidity, through soybean cultivation, in an experiment installed in PVA1 yellow-reddish with sandy/medium texture, acid and of low fertility with doses of 10, 20 and 40% of R-CCW, by mass, in Fernandópolis/SP. Variables related to soil fertility and to plants that were subjected to analysis of variance by F and comparison of averages by the Skott-Knott test at 5% probability were evaluated. The results obtained allowed us to conclude that recycled sand from civil construction R-CCW class A has favorable effects in terms of its ability to neutralize H^+ ions in the soil solution and those adsorbed to negative soil charges, important effects as an acidity corrective, in addition to providing increases in the contents of Ca, Mg, SB, CEC and V%, greater development of soybean plants, which indicates that this use is an environmentally correct alternative for the disposal of these residues.

KEYWORDS: Recycled construction and demolition waste (R-CCW). Soil acidity corrective. Limestone.

1 INTRODUCTION

Soil reaction is the degree of acidity or alkalinity that it presents and is one of its most important characteristics since it affects both its chemical, physical and biological properties. It can be acidic, neutral, or alkaline. The appearance of one of these types of reaction is closely linked to atmospheric precipitation conditions in the region and the soil's original material (RONQUIM, 2010).

In general, when high atmospheric precipitation and high temperature occur in humid tropical regions, the soils present an acidic reaction. Besides the original material and the atmospheric precipitation conditions, the use and management of the soil also influence its reaction, and the soil can be more acidic or less acidic depending on what was or is done on the site (RONQUIM, 2010).

Soil acidity is one of the main factors capable of reducing the productive potential of Brazilian soils because it promotes the release of toxic elements for plants (Al^{3+}) and decreases the availability of nutrients for them (LOPES et al., 1991).

According to Lopes and Guilherme (2000), fertilizing a crop in acidic soil is a waste of fertilizer since the low pH of the soil hinders the assimilation of nutrients by plants, and this is one of the most critical factors related to the low efficiency of fertilization, lower yields and low profits for farmers, in numerous crops in Brazil. Thus, correcting soil acidity is one of the practices that contribute most to increasing the efficiency of fertilizers and, consequently, productivity and agricultural profitability (LOPES et al., 1991).

The primary materials used as soil acidity correctives are: virgin lime, hydrated or extinct lime, calcined limestone, silicates (steelworks slag), marine limestones (Sambaquis coral), and limestone (limestone rock), the latter being the most widely used (LOPES et al., 2002).

For decades, the civil construction process has used non-renewable raw materials (of natural origin), such as ceramic materials, aggregates for reinforced concrete, crushed stone, coarse sand, steel, water, and Portland cement aggregate. This raw material constitutes the structural elements of the buildings, which are transformed into solid waste from buildings under renovation, demolition, and the garbage that occurs in buildings under construction. Many cities do not have enough space for these wastes due to the agglomeration of people and the high valuation of physical space, which causes great environmental impact throughout the production chain of civil construction and complex and costly management to the municipality (OLIVEIRA, 2015).

Approximately 20 to 50% of natural resources are used by civil construction, and it is considered the most prominent waste generator of the whole society (SANTOS et al., 2011; SANTOS et al., 2012). According to Pinto (1999), in medium and large Brazilian cities, waste from construction and demolition represents 40 to 70% of all solid waste, whose incorrect destination brings economic, social, and environmental losses.

The civil construction industry is one of the most critical sectors of the Brazilian economy. It includes various features in its framework, which is demonstrated by the volume of labor of various specializations that it employs, generating income for workers and circulating wealth, being largely responsible for the country's development. Likewise, it is also one of the most impactful due to the large amount of waste it generates, accounting for about two-thirds of all solid material generated in Brazil (SCHERRER et al., 2014; REVISTA ENCONTRO, 2016).

The definition of civil construction waste (CDW), according to Resolution No. 307, of July 5, 2002, of the National Council of the Environment (CONAMA), is as follows:

> Civil construction waste is that which originates from construction, remodeling, repair, and demolition of civil construction works, and those resulting from the preparation and excavation of land, such as: bricks, ceramic blocks, concrete in general, soil, rocks, metals, resins, glues, paints, lumber and plywood, linings, mortar, plaster, tiles, asphalt, glass, plastics, pipes, electrical wiring, etc., commonly called construction debris, slag or rubble (BRASIL, 2002).

Recycled civil construction waste (R-CCW) is classified into four classes, according to the possibilities of recycling (A: reusable or recyclable as aggregates; B: recyclable for other destinations, such as plastics; and C: no economically feasible recycling technology; D: hazardous waste) (BRASIL, 2002).

Also, according to CONAMA's Resolution No. 307/2002, in its article 10, it is determined that the residues, according to the classification established in article 3, must have their destinations determined in the following order:

> I - Class A: they shall be reused or recycled in the form of aggregates or forwarded to civil construction waste landfill areas, being disposed of in such a way as to allow their future use or recycling;
> II - Class B: they shall be reused, recycled, or forwarded to temporary storage areas, being disposed of in a way to enable their future use or recycling;
> III - Class C: they must be stored, transported, and disposed of in conformity with the specific technical standards;
> IV - Class D: must be stored, transported, reused, and disposed of following the specific technical standards (BRASIL, 2002).

Thus, CONAMA Resolution 307/2002 becomes the main guideline for the public and private sectors and society. It establishes guidelines, criteria, and procedures for managing civil construction waste, regulating the necessary actions to minimize environmental impacts. It presents a management model in which responsibilities are defined for the agents involved: generators, transporters, destination areas, and municipalities, and, since its publication, the Resolution has undergone changes contemplating the improvements resulting from its implementation.

In turn, according to Mello Filho (2005), limestone is one of the main raw materials used in the manufacture of Portland cement and hydrated lime - products widely used in the preparation of concrete, mortars, and plasters in civil construction in Brazil. In the production of Portland cement, limestone contributes in the proportion of 85 to 95 %, to which clay is added. The limestone-clay mixture is ground, homogenized, and calcined at a temperature of 1.450°C in a rotary kiln, obtaining the clinker. Portland cement is finally obtained from the grinding of clinker with some additives, such as gypsum, finely ground limestone, pozzolan, and steel slag, in various proportions to regulate cement properties, such as hardening time strength and improving its workability and polishment.

Thus, it is expected that the R-CCW, also known as recycled sand, which is basically bricks, plaster, concrete, mortar, and others, by having elements minerals such as Ca, Mg, and others, have the potential for agricultural application as a soil conditioner or as a substrate for plants and seedlings.

In recent years, Brazilian agribusiness has been responsible for a large part of the country's economy, representing about 21% of the Gross Domestic Product (GDP) and for 49.7% of exports in the first five months of 2020, with the soybean complex being the first on the agenda (WALENDORFF, 2020).

Currently, there is great concern about the disposal of waste generated throughout the different production processes. In this sense, the civil construction sector faces serious problems since it produces large amounts of waste during the execution of the works or the dismantling of existing constructions. The inadequate disposal of this waste can cause severe environmental damage, such as degradation of springs and permanent protection areas silting up of rivers and streams, among others.

Jones et al. (2009), in a study on the use of mineral waste from quarries (basalt) associated with vegetable waste, cited R-CCW as a possible example of waste with potential application in agriculture. However, there is a considerable lack of studies related to the reuse of such waste, and its use in soil correction is one of the possibilities since most Brazilian soils are acidic. Acidity is represented basically by the presence of two components H^+ and Al^{+3} ions, which need to be neutralized by liming for the adequate development of plants, such as soybean, which is one of the most sensitive ones.

Liming has several benefits for plants, such as: eliminating soil acidity and providing a supply of calcium and magnesium; stimulating root growth through calcium, helping the plant to tolerate drought; increasing the availability of phosphorus; increasing the mineralization of organic matter with consequent greater availability of nutrients and favoring the biological fixation of nitrogen, all of those are important in soybean cultivation.

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Thus, the recycling of construction waste and its subsequent use in the neutralization of acidity in soil cultivated with soybeans is an economically and environmentally viable alternative, justifying the importance of conducting this research.

2 OBJECTIVE

The general objective of this work was to evaluate the effectiveness of using recycled sand (R-CCW class A) as an acidity corrective material for improving the chemical quality of soils, contributing to the environmentally correct disposal of this waste. Specifically, the objective was to evaluate the material's performance as a soil acidity corrective in pots, considering the correction of soil pH and the increase of productivity in soybean (*Glycine max* L.) culture.

3 METODOLOGY

The experiment was conducted from September/2020 to April/2021 in Universidade Brasil, Fernandópolis/SP campus, in the northwest of São Paulo State, located between latitudes 20°17'34.40" and 20°17'36.19" South and longitudes 50°16'44.90" and 50°16'48.67" West and at an altitude of 535 m.

The soil used in the experiment is from the PVA1 group; its characteristics are clayey yellow-reddish with a sandy/medium texture (OLIVEIRA et al., 1999). The results of the chemical analysis of its fertility are presented in Table 1.

Table 1: Chemical characteristics of the soil used for the implementation of the experiment. Fernandópolis/SP, 2020.

P res.	O.M.	pH	K	Ca	Mg	H+Al	SB	CEC	V
mg dm^{-3}	g dm^{-3}	$CaCl_2$	------------------------------mmol$_c$ dm^{-3}--------------------------						%
5	17	5,0	1,2	14	5	26	20,2	46,2	43,72

Source: Soil Fertility Laboratory of the Universidade Brasil, Fernandópolis/SP campus, 2020.

The recycled sand (R-CCW class A) was collected at the Debris Recycling Plant belonging to the company Mejan Ambiental in Votuporanga/SP (Figure 1).

Figure 1: The image on the left is from Mejan Ambiental's recycling material processing and on the right, collection of recycled sand - R-CCW, Votuporanga/SP, 2020.

Source: The authors, 2020.

Around 3 m^3 of soil was collected, previously sieved in a 2 mm mesh, and separated into six fractions. On 10/15/2020, three soil fractions were homogeneously mixed with doses of 10, 20, and 40% recycled sand, mass base; one was incorporated with limestone (PRNT = 93%) in order to elevate the base saturation (V) to 80%, according to the recommendation of Raij et al. (1997) and two were not mixed. The fractions were irrigated with the same amount of water three times a week, maintaining soil moisture near field capacity and avoiding percolation. After 65 days of soil incubation with recycled sand and limestone, 110 L plastic pots were filled.

The experimental design used was entirely randomized, with twenty-four experimental units of six treatments and four repetitions. The treatments evaluated were: (1) testem SA - witness without mineral fertilization at seeding and without corrective; (2) testem - witness with mineral fertilization at seeding and without corrective; (3) limestone; (4) sand 10% - 10% recycled sand; (5) sand 20% - 20% recycled sand and (6) sand 40% - 40% recycled sand, all on a mass basis.

On 12/22/2020 (65 days after incubation), all the pots, except for the testem SA, were fertilized with phosphorous (90 kg/ha) as simple superphosphate and potassium (60 kg/ha) as potassium chloride. The nutrient doses were calculated according to the soil analysis results (Table 1) as recommended by Raij et al. (1997) aiming for a soybean yield of 3.0 to 3.4 t ha^{-1}.

On the same day, the seeds of cultivar CZ37B43 IPRO were sown and inoculated with *Bradyrhizobium* (commercial product NitroGeo®) at a dose of 300 mL per 50 kg of seeds. Each pot was sown with 18 soybean seeds, irrigated with 5 L of water, and then covered with a shading screen to protect against bird predation for 15 days.

Throughout the experiment, the pots were irrigated to maintain soil moisture near 70% of field capacity. After 17 days (01/07/2021) and 37 days from sowing (01/28/2021), the pots were thinned, leaving 12 and 8 plants per unit, respectively. When necessary, the weeds were removed manually, as well as the pests (caterpillars) (Figure 2).

Figure 2: Image on the left, pot with eight plants and on the right, general view of the experiment, Fernandópolis/SP, 2021.

Source: The authors, 2020.

After 110 days after sowing (April 12, 2021), the plants were removed and evaluated for plant height (PH) (cm), first pod insertion height (IHFP) (cm), number of pods per plant (NPP), number of seeds per pod (NSP), seed weight per plant (SWP) (g), seed mass of 1000 seeds

(M1000) (g) and dry mass of aboveground plant (DMAP) (g). The PSP and M1000 values were corrected to 13% humidity (wet basis).

Subsequently, a soil sample was taken from each pot for fertility analysis, according to the methodology described by Raij et al. (2001), in which pH, K, Ca, Mg, H + Al, SB, CEC, and V% were determined.

The results of the variables related to soil fertility and plant biometry were submitted to analysis of variance by F test and when significant were compared by the Scott-Knott test at 5% probability using the statistical program SISVAR (FERREIRA, 2011).

4 RESULTS AND DISCUSSION

The results of soil analysis 110 days after sowing, that is, 175 days after soil incubation with recycled sand and lime, are presented in Table 2.

According to the values in Table 2, it can be inferred that all treatments using recycled sand were efficient in neutralizing soil acidity. The treatment with 40% sand was superior to the others, surpassing even the limestone, which indicates that this dose may even be excessive.

According to the limits of interpretation of acidity levels in $CaCl_2$ and base saturation (V%), available in Bulletin 100 (RAIJ et al., 1997), the controls presented acidity classified as medium (5.1), whose values should be between 5.1-5.5, that is, at the limit, since below 5.0 is considered high acidity. The treatments with lime and sand raised the pH to values above 6.0, which is considered very low acidity. The results obtained by Ramalho and Pires (1999) and Lasso (2011) also showed that the addition of these residues could raise the pH of the soil, indicating their potential use as a soil conditioner.

Table 2: Chemical characteristics of the soil after 175 days of reaction of the various treatments evaluated. Fernandópolis/SP, 2021.

Treatment	pH	O.M.	P res.	K	Ca	Mg	H+Al	SB	CEC	V
	$CaCl_2$	g dm^{-3}	mg dm^{-3}		----------------------mmol$_c$ dm^{-3}--------------------					%
Testem SA	5.1d	14.0b	4.5	0.95	9.75d	3.5d	30.75a	14.4d	44.95d	31.58d
Testem	5.1d	14.5b	5.25	1.02	10.5d	4.0d	29.75a	15.52d	45.27d	34.24d
Limestone	6.7b	15.0a	5.0	0.85	16.7c	5.25c	27.0b	22.85c	49.85b	45.83c
Sandy 10%	6.4c	15.5a	5.0	1.07	16.2c	4.75c	26.0b	22.07c	48.07c	45.90c
Sandy 20%	6.5c	15.75a	5.0	1.07	19.2b	6.25b	22.0c	26.57b	48.57c	54.69b
Sandy 40%	7.6a	15.5a	5.5	1.25	24.7a	7.5a	17.75d	33.5a	51.25a	65.36a
F test	**	*	ns	ns	**	**	**	**	**	**
Midium	6.3	15.04	5.04	1.03	16.2	5.21	25.54	22.45	47.99	46.27
CV (%)	2.03	5.37	12.15	12.7	8.06	11.31	6.41	8.62	0.97	8.15

Source: the authors, 2021.
Averages followed by the same letter in the column do not differ by the Scott-Knott test at 5% probability.
** significant at 1% level, * significant at 5% level; ns: not significant. CV: coefficient of variation.
Testem SA - witness without mineral fertilization at seeding; Testem - witness
O.M. - organic matter; SB - sum of exchangeable bases; CEC - cation exchange capacity, V% - base saturation

Recycled sand and limestone provided reductions in the potential acidity of the soil (H + Al), which agrees with Lasso (2011), who reported results of reduction of H + Al levels using construction and demolition waste (R-CCW). Again, 40% recycled sand treatment outperformed the others, while the 10% sand did not differ from the limestone.

The organic matter (O.M.) content of the treatments with sand and limestone outperformed the controls, while phosphorus and potassium values showed no significant changes. According to the limits of interpretation of phosphorus and potassium contents available in Bulletin 100 for annual crops (RAIJ et al., 1997), the phosphorus (P) and potassium in all treatments are considered low.

In turn, although the calcium (Ca) content in all treatments presented high values (> 7 $mmol_c\ dm^{-3}$) (RAIJ et al., 1997), the 40% recycled sand was higher than all treatments. The magnesium (Mg) content of the controls showed low values (< 4 $mmol_c\ dm^{-3}$) (RAIJ et al., 1997), while the other treatments raised Mg to medium contents (between 5 to 8 $mmol_c\ dm^{-3}$), again indicating the use efficiency of the recycled sand. For both Ca and Mg, the 10% recycled sand did not differ from the limestone.

The sum of bases (SB) with the use of sand and limestone showed increases that statistically outperformed the controls, with the 40% sand being higher than the others. According to the results of Ramalho and Pires (2009), R-CCW can be used as a source of nutrients, which was confirmed with a pot experiment, besides providing an increase in the cation exchange capacity (CEC) of the soil.

The CEC of the soil also suffered interference from the use of sand and limestone, with sand again being 40% higher than the others. According to Silva (1999), the addition of construction waste to agricultural soils increases the CEC, an important property that is related to the chemical attributes and fertility potentials of the soil, as well as to the reserve of nutrients for plants, enabling the reduction of cation losses by leaching and inactivation of toxic compounds. In turn, Lasso (2011), using R-CCW at a dose of 40% in mass in the soil, observed significant increases in the concentrations of Ca^{2+} and Mg^{2++} bases, increasing, therefore, the sum of bases (SB) and the CEC of the soil, greatly surpassing the action of conventional liming with limestone at the two levels used (60 and 80%).

The values of base saturation (V%) of the controls were low, between 26-50% according to Raij et al. (1997), being lower than the others, while the sand at 20 and 40% passed the average limit (51-70%), showing the efficiency of the use of recycled sand. For soybean, the recommended V% value is 60, which was achieved only with the use of 40% sand. Limestone applied at a dose of 1.1 t ha^{-1} after calculation based on soil fertility analysis (Table 1) did not increase V% as expected.

Table 3 presents the results of variables PH, IHFP, NPP, NSP, SWP, M1000, and DMAP per plant according to the treatment evaluated.

There was no significant effect of the treatments on the biometric variables evaluated, with the exception of DMAP.

In general, the biometric values were very low, probably due to the fact that the plants were grown in pots, combined with the stress resulting from high temperatures and low relative humidity throughout the experiment since sowing occurred at the end of December, an unfavorable and not recommended period for soybean cultivation in Fernandópolis/SP.

The soybean cultivar sown was CZ37B43 IPRO, belonging to maturity group 7.4, with an average cycle of 113 days, indeterminate growth habit, PH of 89 cm, IHFP of 15 cm, and the recommended population for its planting is 220-300 thousand plants ha-1 (IGA, 2019).

In this experiment, the averages of PH and IHFP were 34 cm and 12.5 cm, respectively, very low values that would make the mechanized harvest of soybean unfeasible. The values for NPP, NSP, SWP, M1000 were also very low.

Table 3 - Average values of plant height (PH), first pod insertion height (IHFP), number of pods per plant (NPP), number of seeds per pod (NSP), seed weight per plant (SWP), 1000 seed mass (M1000) and aboveground dry mass (DMAP.) per plant according to the treatment evaluated. Fernandópolis, SP. 2020/2021.

Treatment	PH (cm)	IHFP (cm)	NPP	NSP	SWP (g)	M1000 (g)	DMAP (g)
Testem SA	30.5	13.8	10.9	1.7	1.50	68.21	3.32 B
Testem	35.1	12.6	13.5	2.4	2.54	86.41	4.20 B
Limestone	31.6	11.6	16.8	2.3	2.44	63.20	5.98 A
R-CCW 10%	34.3	11.2	17.7	1.9	3.28	90.69	6.29 A
R-CCW 20%	36.6	13.2	15.2	1.7	2.22	71.78	5.17 A
R-CCW 40%	36.0	12.5	17.3	2.0	3.05	83.12	4.96 A
F test	ns	ns	ns	ns	ns	ns	**
Midium	34.0	12.5	15.2	2.0	2.5	77.23	4.99
CV (%)	12.2	22.1	29.1	23.4	47.2	31.2	17.1

Source: the authors, 2021.
Averages followed by the same letter in the column do not differ by the Scott-Knott test at 5% probability.
** significant at 1% level, ns: not significant. CV: coefficient of variation.
Testem SA - witness without mineral fertilization at sowing; Testem - witness

The control treatments were lower than the others with the use of recycled sand and lime in relation to DMAP, which indicates that the soil had its acidity corrected in order to increase fertility, favoring greater development of soy plants. In alfalfa, Lasso et al. (2013) in a pot experiment using R-CCW from concrete, mortar, and plaster (gray material) at doses higher than 24 t ha^{-1}, reported that the residue provided significant gains in productivity.

Thus, according to the results obtained, there is a possibility of using R-CCW in agriculture as a viable alternative to the use of lime as a corrective. And this may create a new market for the CDW recycling industry, contributing to the environmentally correct final destination of this waste, which is per Law 12.305/2010, which established the National Policy for Solid Waste (NPSW). This is one of the main guidelines, and it states that: "encourage the use of raw materials and inputs derived from recyclable and recycled materials" (BRASIL, 2010).

A major advantage of R-CCW in relation to limestone is that the former generation occurs in a distributed way in all municipalities. At the same time, the latter is produced only in limestone mining areas. In Brazil, the geographical distribution of limestone reserves is very irregular, with significant extensions in the central and coastal regions and only small outcrops in the country's extreme north and south regions (NERI, 2007). As freight costs have the most significant impact on the final cost of both R-CCW and limestone, the more distributed generation of the former tends to reduce, on average, its freight costs.

Although the results presented are favorable, another critical and necessary point is to incorporate an evaluation of heavy metals as a parameter for quality control of R-CCW produced in recycling plants since there is no regulation on its application in agriculture. According to Schaefer et al. (2007), the great heterogeneity of materials and the wide variety of CDW sources that give rise to recycled aggregates (R-CCW) leads to concern about the presence of contaminants that may present themselves in hazardous concentrations. In Florida, high levels of heavy metals have been found in CDM-R. These materials can cause environmental damage, such as soil and groundwater contamination (TOWNSEND et al., 2004).

Finally, there is a need for further research with materials from other regions of the country, a study of the effects on other soils and crops, evaluations as material for seedlings and pits, the development of processes to separate the inert part of the material (quartz), and add more detailed environmental impact assessments (LASSO et al., 2013).

5 CONCLUSION

The use of recycled sand (R-CCW class A) presents favorable effects regarding the ability to neutralize the H^+ ions in the soil solution and those adsorbed to the negative soil charges, important effects as an acidity corrective, besides increases in the Ca, Mg, SB, CEC and V% contents, providing a greater development of soybean plants and the environmentally correct destination of this waste.

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