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ADDITION OF BOILER CHARCOAL WASTE TO COMPOST FOR USE AS SUBSTRATE FOR VEGETABLE SEEDLINGS

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KEYWORDS

electrical conductivity, circular economy, easiness of removal of clod from tray, seedling quality index, salinity.

ABSTRACT

The recovery of waste from the broiler production chain (BPC) is consistent with the principles of a circular economy. Besides turning waste into organic compost, its use as substrate for the production of vegetable seedlings further increases its economic value. However, it is necessary to adapt its characteristics to enable its use as substrate. To this end, the addition of boiler remnant charcoal wastes (BCW), another type of waste generated in the BPC, to the organic compost resulting from the composting of BPC waste with different bulking agents (BAs) was studied. The addition of BCW to agro-industrial compost reduced the electrical conductivity (EC) of substrates. Multiple linear regression showed that, of the 13 variables (physical, chemical and physicochemical) studied, three (EC, pH and N content) are sufficient to explain the seedling quality index (SQI). Simple nonlinear regression showed that, in order to achieve higher SQIs and easier removal of clod from tray, an additional 30% in weight of BCW is required for compost, using urban tree pruning, wood sawdust and sugarcane bagasse BAs. The use of cotton and Napier grass waste as BAs is not recommended for BPC waste mixtures, as they cause a large increase in substrate EC.

INTRODUCTION

The use of waste generated at different stages of the broiler production chain, as in other industries, is connected to the principles of circular economy. According to Stahel (2016), a "circular economy" would turn goods that are at the end of their service life into resources for others, closing loops in industrial ecosystems and minimizing waste. It would change economic logic because it replaces production with sufficiency: reuse what you can, recycle what cannot be reused, repair what is broken, re-manufacture what cannot be repaired.

The recovery of agro-industrial waste from the broiler production chain (BPC) through composting has been reported in the national (Bernardi et al., 2018) and international literature (Costa et al., 2017). The organic compound produced, in turn, can be used as a soil conditioner for crops or as substrate for the production of vegetable seedlings. There are advantages and disadvantages in marketing both products. As a substrate for seedling production, the organic compound can reach a more attractive market value than organic fertilizers. On the other hand, its physical and chemical properties have to be more specific to achieve the expected results in the production of quality seedlings. Among these properties, electrical conductivity (EC), or salinity, is the characteristic that most affects the development of seedlings (Santos et al., 2015; Moraes et al., 2018), requiring the addition of inert materials such as rice hulls, vermiculite, perlite and sand to the organic compound to decrease salt concentration and thus enable its use as a substrate (Bilderback et al., 2005).

Another type of BPC waste that can contribute to the circular economy of this sector is agro-industrial boiler remnant charcoal wastes (BCW). This waste is generated by the incomplete burning of wood used in furnaces (*Eucalyptus* spp.) for the production of thermal energy. BCW does not deposit with firewood ashes, because it is aspirated from agro-industrial furnaces by multi-cyclones, having medium to fine grain size (Costa et al., 2017).

Currently, BCW joins other wastes generated in the BPC and is sent to specialized plants to undergo a

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composting process. The recovery of BCW to be used as a component in substrates for seedling production can contribute to improve the characteristics of organic compost and enhance BPC waste, generating a new product with higher market value: horticultural substrates. In addition, since it is a biomass subject to pyrolysis at temperatures that can reach between 300°C and 650°C, BCW may have similar properties to biochar, a material widely studied as a substrate component for seedlings (Méndez et al. 2015; Nieto et al., 2016; Kaudal et al., 2016). However, most references in which biochar is used as a substrate for seedling production are intended to evaluate its effect as a substitute for peat, a non-renewable natural resource widely used due to its excellent combination of chemical, physicochemical and physical properties, such as low pH, high CEC (Cation Exchange Capacity) and adequate porosity (Nieto et al., 2016).

When agro-industrial organic compost is used as substrate for seedling production, EC may be a limiting factor due to the high nutrient concentrations. Moreover, the controlled (*indoor*) conditions of the composting process promote the degradation of the organic material by microorganisms and considerably reduce windrow mass, increasing the concentration of salts in the organic compost. The more easily degradable the main carbon source of the compost mass, the higher the EC of the final compost (Costa et al., 2017).

Thus, the viability of using high EC organic compost as substrate for seedling production depends on the addition of inert materials to act as salinity diluents. Therefore, the objective of this work is to evaluate the use of different types of organic compost from the composting of agro-industrial BPC waste as substrates for lettuce seedlings production, through the addition of BCW.

MATERIAL AND METHODS

Compost provenance and Substrate preparation

Five types of organic compost were obtained from five BPC waste composting processes, plus a bulking agent (BA). Each BA was used exclusively in each windrow, and received different amounts of BPC waste in order to adjust the carbon nitrogen ratio to around thirty (C:N ≈ 30). Because of that, compost windrows ranged from 500 to 710 kg in terms of fresh matter, 270 to 330 kg in terms of dry matter, and were 2 to 7 m^3 in volume, depending on the BA used. The BA used and the percentages of waste added to each of the five windrows (A, P, S, B and N) are shown in Table 1. The entire composting process was conducted in an open compost yard, with cover and concrete floors. A detailed description of the composting process to obtain this composts is given by Costa et al. (2017). After obtaining the organic compost, it was ground in a waste crusher and sieved in a 5 mm mesh sieve.

TABLE 1. Characteristics and proportions of the wastes used in the five composting piles to obtain the organic composts.

Windrows	**A**	**P**	**S**	**B**	**N**
Bulking agent (%)	51	50	50	50	50
Sausage casings (%)	33	20	14	13	30
Reproductive poultry litter (%)	8	12	8	10	8
Hatchery waste (%)	4	12	14	13	8
Flotation sludge (%)	4	6	14	14	4
Initial volume (m^3)	3.9	3.8	1.9	7.0	3.2
Initial bulk density ($g.cm^{-3}$)	0.13	0.14	0.28	0.08	0.22

Bulking agent A: Cotton waste; P: urban tree pruning; S: Wood Sawdust; B: Sugarcane bagasse; N: Napier grass. Data expressed in percentage of dry matter.

For the preparation of the substrates, each of the five types of compost obtained (A, P, S, B and N) in the composting process was mixed with five doses (0, 15, 30, 45 and 60%) in dry matter of remnant charcoal waste from agro-industrial boilers (BCW), totaling 25 substrates. The main chemical, physical and physicochemical characteristics of BCW are presented in Table 2.

TABLE 2. Characterization of the boiler remnant charcoal waste used as a component in the preparation of substrates.

	pH	**EC** ($dS.m^{-1}$)	**C** (%)	**N** (%)	**P** ($g.kg^{-1}$)	**K** ($g.kg^{-1}$)	**C:N**	**HLIF index**	**BD** ($g.cm^{-3}$)	**WHP** (%)	**PS**
BCW	10.3	0.8	28.3	0.2	0.3	5.7	153	325	0.13	386.5	< 2mm

BCW: boiler remnant charcoal waste; EC: Electrical conductivity; N: Nitrogen; P: Total Phosphorus; K: Potassium; C:N: Carbon to nitrogen ratio; HLIF: humification index (Laser Induced Fluorescence); BD: Bulk density; WHP: water-holding porosity; PS: Particle size.

Conducting the Experiment

The experiment was conducted in a greenhouse with a 30% Aluminet® shade cloth covering. The 25 prepared substrates and the commercial substrate (CS) were placed in 200 cell expanded polystyrene trays. Considering four repetitions of each of the 25 substrates, plus 20 repetitions of the commercial substrate Tropstrato HT®, there were a total of 120 experimental plots. Each plot was randomized and consisted of 30 tray cells. Pelleted Lucy Brown lettuce seeds treated with 0.22% Thiram were used. Sowing was performed in trays with one seed per cell covered with the respective substrates. The daily watering of trays was performed manually using a watering can for vegetables. Trays were rotated inside the greenhouse every two days to avoid uneven light incidence. During the first 16 days after sowing, the number of emerged seeds was counted daily. After 30 days of cultivation, phytometric assessments were performed on 20 random plants of each substrate. For the assessment of clod properties, eight seedlings from each substrate were randomly chosen.

Analytical Methods

Analytical methods were the same for all substrates, including prepared mixtures, commercial substrate (CS) and BCW. The values of pH and EC were determined through an aqueous extract of the substrate (1:5 w/v) (Embrapa, 2009). Organic matter (OM) content was determined through volatile solids, after calcination in a muffle furnace at 550°C (Carmo & Silva, 2012). Nitrogen (N) content was determined through a Kjeldahl distiller (Malavolta et al., 1997). Phosphorus (P) and potassium (K) levels were determined after nitro-perchloric digestion (3:1). P reading was performed using a spectrophotometer (Malavolta et al., 1997) and K reading was conducted using a flame photometer (Embrapa, 2009). Laser Induced Fluorescence (LIF) was employed according to the methodology proposed by Milori et al. (2006). The determination of the humification index (HLIF) based on LIF spectroscopy was founded on the ratio between the area of the fluorescence emission spectrum (440-800 nm) and the total organic carbon concentration. The volumetric ring method, described by Tian et al. (2012), was used to determine bulk density (BD), total porosity (TP), aeration porosity (AP) and water-holding porosity (WHP) using the formulas: BD ($g.cm^{-3}$) = (W4 - W0)/V; TP (%) = (W2 - W4) /V×100; AP (%) = (W2 - W3) /V×100; and WHP (%) = TP - AP; where W0: set mass (ring + rubber band + cleaning cloth); W1: set mass + dry sample; W2: set mass + saturated sample; W3: drained set mass; W4: dry set mass at 65°C; V: ring volume. For total water-holding capacity (TWHC), the formula TWHC ($mL.L^{-1}$) = ((W3 - W4)/(W4 - W0))/(1/BD /1000) was used.

Emergence percentage (E) and emergence speed index (ESI) were determined according to Maguire et al. (1962). In order to determine E, the percentage of seeds emerged by the 15th day was calculated. During this period, ESI and mean emergence time (MET) were also determined, which were calculated according to the formulas: ESI = Σ (Pi/Di) and MET= Σ (Si*Di)/Nt; where: Si: number of seedlings emerged on the ith day of counting (not accumulated); Di: number of days in which seedlings emerged on the ith day; Nt: total number of seedlings emerged during the assessment period.

The phytometric parameters assessed were stem diameter (SD), shoot height (SH), root dry mass (RDM) and shoot dry mass (SDM). The Seedling Quality Index (SQI) was calculated according to Dickson et al. (1960), using the formula SQI = (SDM+ RDM)/((SDM/RDM) + (SH/SD)). Total chlorophyll was determined by the sum of chlorophylls a (633 nm) and b (645 nm), determined by a spectrophotometer (Arnon, 1949).

Clod quality properties after cultivation were determined by the easiness of removal of clod from tray (ERT) and clod stability (CSt), according to the adapted methodology for seedlings grown in tubes (Kratz & Wendling, 2013). ERT was scored from 0 to 10, based on the removal of seedling with clod from tray, where zero corresponded to maximum difficulty and seedling disruption, and ten to maximum easiness and clod integrity. As for CE, seedlings removed from tray were subjected to a one-meter-high free fall, which was scored from 0 to 10, where zero corresponded to a completely destroyed clod and ten to a totally intact one.

Statistical Analyses

Principal Component Analysis (PCA) was used to summarize and interpret the relationships between the effect of substrates (25 prepared + CS) on seedling development and quality, as well as on clod stability properties (7 parameters analyzed). Accumulated explanation percentages above 70% were used as selection criteria of components. In order to estimate the SQI explanation model, multiple linear regression (MLR) was used, categorizing SQI as a response (dependent) variable to the chemical, physicochemical and physical characteristics (13 explanatory variables) of the prepared substrates. In order to select the best MLR equation, the *Best Subsets Regression* tool was used. The combination of explanatory variables with the highest R^2, lowest standard error and Cp closest to the number of parameters was chosen. In order to validate the model, the assumptions of error randomness (Ɛ); Ɛ zero mean; Ɛ homoscedasticity (Goldfeld-Quandt test); Ɛ normality (Anderson-Darling); absence of serial autocorrelation (Durbin-Watson); absence of Xi measurement error; and absence of multicollinearity (variance inflation factor-VIF) were checked. For the detection of influential points, the following estimates were used: hii Element (leverage), Cook's Distance (Di) and Modified Cook's (DFit). Simple nonlinear regression (SNLR) was used to predict the ideal percentage of BCW required to achieve the maximum theoretical values of SQI and ERT.

RESULTS AND DISCUSSION

Effect of addition of boiler remnant charcoal waste (BCW) to organic compost

In general, the addition of increasing doses of BCW to the organic compost generated by the composting of BPC agro-industrial waste decreased OM, N, P, EC contents and the HLIF index, while increasing substrate pH (Table 3). This was due to the low C, N, P, EC and HLIF content of BCW (Table 2), as well as its alkaline character, which contributed, respectively, to a decrease in these variables and an increase in the pH of the prepared substrates.

TABLE 3. Percentage of boiler remnant charcoal waste (BCW) added to substrates and chemical and physicochemical properties of substrates.

Substrates	BCW (%)	OM (%)	N (%)	P (%)	K ($g.kg^{-1}$)	EC ($dS.m^{-1}$)	pH	HLIF index
IS^g		>80			0,15-0,25	0,75-2,0	5,3-6,5	
A0	0	58 a	3.5 a	3.4 a	13 a	18.3 a	7.4 d	1149 a
A15	15	55 b	2.9 b	3.0 b	12 ab	15.5 b	7.8 c	767 b
A30	30	55 b	2.5 c	2.6 c	12 ab	13.2 c	7.8 c	516 c
A45	45	54 bc	2.0 d	2.3 d	11 bc	7.9 d	8.2 b	407 d
A60	60	54 c	1.4 e	1.8 e	10 c	6.6 e	8.6 a	355 d
P0	0	65 a	2.5 a	2.7 a	6.9^{ns}	6.3 a	7.6 c	1647 a
P15	15	59 ab	2.3 b	2.5 b	7.3^{ns}	5.8 a	7.6 c	1054 b
P30	30	59 ab	1.8 c	2.4 b	7.2^{ns}	4.5 b	8.2 b	591 c
P45	45	58 b	1.2 d	2.0 c	7.6^{ns}	3.8 bc	8.8 a	414 d
P60	60	49 c	1.2 d	1.7 d	7.4^{ns}	3.4 c	8.9 a	382 d
S0	0	54 a	1.6 a	3.0 a	3.9 d	5.4 a	7.3 e	2960 a
S15	15	50 ab	1.4 b	2.6 b	4.6 c	5.0 b	7.4 d	1361 b
S30	30	48 bc	1.2 c	2.3 c	5.6 b	3.7 c	8.0 c	839 c
S45	45	46 bc	1.1 c	2.0 c	5.9 ab	3.2 d	8.4 b	526 d
S60	60	43 c	0.8 d	1.6 d	6.2 a	2.6 e	8.7 a	474 d
B0	0	53 a	1.9 a	3.0 a	5.4 c	10.4 a	6.9 d	1872 a
B15	15	47 b	1.8 ab	2.7 b	5.7 bc	8.5 b	6.9 d	1096 b
B30	30	47 b	1.8 b	2.8 b	6.1 b	6.8 bc	7.3 c	826 c
B45	45	45 b	1.5 c	2.1 c	6.8 a	5.7 c	7.7 b	723 d
B60	60	46 b	1.2 d	1.7 c	7.4 a	5.1 c	8.2 a	463 e
N0	0	66 a	2.6 a	2.3 a	11 a	11.7 a	7.6 c	1071 a
N15	15	62 a	2.1 b	2.3 a	10 b	9.8 ab	8.4 b	794 b
N30	30	56 b	1.7 c	2.2 ab	9.7 b	8.4 bc	8.3 b	623 c
N45	45	50 c	1.5 c	1.8 b	9.8 b	6.7 cd	8.7 a	493 d
N60	60	49 c	1.2 d	1.2 c	9.6 b	5.5 d	8.9 a	565 cd
CS	0	49	0.52	0.23	1.8	1.0	6.3	-

IS: Ideal Substrate, ^{g}Optimum or acceptable values for an ideal substrate according to Abad et al. (2004); BCW: boiler remnant charcoal waste; OM: Organic matter; N: Nitrogen; P: Total Phosphorus; K: Potassium; EC: Electrical conductivity; HLIF: humification index; CS: commercial substrate. Equal lowercase letters show no significant minimum difference (LSD) by the F test (α: 5%) among the BCW doses added in each agro-industrial compost.

All substrates presented OM levels below the ideal (>80%), including the substrates that did not receive BCW doses (A0, P0, S0, B0 and N0) and the commercial substrate. In an inventory of organic waste for use as substrates performed by Abad et al. (2001), it was found that almost half (46%) of the 63 organic materials studied presented suboptimal OM levels. OM levels below the recommended value (>80%) in composted substrates are expected, due to the microbiological degradation of organic fractions and consequent release of C as CO_2 (Costa et al., 2016, 2017; Lorin et al., 2016). As a result, a concentration of macro and micronutrients can be observed (Costa et al.,2017; Gavilanes-Terán et al., 2017) (Table 3).

The significant decrease ($p<0.05$) in substrate OM, N, P and EC levels due to the increasing addition of BCW doses (15, 30, 45 and 60%) showed that this component acts as a diluent for agro-industrial compost. Pearson's linear correlation showed that BCW percentage and EC are strong (0.9), negative, and significant ($p <0.05$) for each agro-industrial compound. That is, the higher the BCW dose added to the organic compound, the lower the substrates' EC. Increased EC due to higher amounts of organic compost in substrates has also been reported in other studies (Bustamante et al., 2008; Gavilanes-Terán et al., 2017). Despite a decrease in soluble salt concentration caused by the addition of BCW, all 25 prepared substrates presented EC and pH above the range considered ideal by Abad et al. (2001) (Table 3).

The addition of BCW doses to agro-industrial compost increased ($p<0.05$) substrate alkalinity. For all types of compost (A, P, S, B and N), it was found that the highest pH values were obtained in the substrates with the highest percentages of added BCW (Table 3). Since BCW has a pH of 10.3 (Table 2), it contributed to substrate alkalinity. Research in which biochar, a component with characteristics similar to BCW, was added to growth media, also found a rise in substrate pH Steiner & Harttung, 2014; Kaudal et al.,2016).

The increasing addition of BCW to agro-industrial compost decreased the HLIF aromaticity index in all substrates (Table 3). This index reflects the degree of humification of substrate organic matter, being able to identify fluorescent groups, such as aromatic rings and quinones (Milori et al., 2006). Higher HLIF index values indicate a higher concentration of fluorescent groups compared to total organic carbon in the substrate, that is, a higher degree of humification. When embedded into substrates, BCW's low aromaticity (HLIF index) (Table 2) generated a dilution effect on the concentration of aromatic compounds present in the agro-industrial compost, decreasing the degree of substrate humification with the addition of increasing doses of BCW.

BCW's low bulk density (BD) (Table 2) caused a significant decrease in BD in all substrates as BCW doses increased (15, 30, 45 and 60%) (Table 4). Research has found that higher proportions of agro-industrial compost added to substrates lead to increased BD (Bustamante et al., 2008; Gavilanes-Terán et al.,2017). Substrates A0, P0 and B0, prepared without the addition of BCW (100% agro-industrial compost), presented above-optimal BD values (≤ 0.4 g.cm^{-3}) (Abad et al., 2001). The addition of 15% BCW or more to these substrates allowed them to reach optimal BD values (Table 4).

TABLE 4. Bulk density (BD), Total porosity (TP), Aeration Porosity (AP), water-holding porosity (WHP) and total water-holding capacity (TWHC), of 25 substrates and commercial substrate (CS).

Substrates	BCW %	BD (g.cm^{-3})	TP %	AP %	WHP %	TWHC (mL.L^{-1})
IS^g		≤ 0,40	> 85	20-30		600-1000
A0	0	0.43 a	71 b	2.5 b	68 a	684 b
A15	15	0.36 b	78 a	4.5 a	74 a	737 a
A30	30	0.33 b	77 a	3.2 ab	74 a	741 a
A45	45	0.29 c	77 a	4.1 ab	73 a	733 ab
A60	60	0.23 c	75 ab	4.1 ab	71 a	711 b
P0	0	0.41 a	62 c	7.6 a	55 c	547 c
P15	15	0.33 b	78 a	4.7 b	73 a	731 a
P30	30	0.30 c	79 a	4.6 b	75 a	747 a
P45	45	0.26 d	76 a	3.4 b	73 a	727 a
P60	60	0.25 d	71 b	3.8 b	67 b	674 b
S0	0	0.42 a	79 ab	1.5 b	78 a	778 a
S15	15	0.33 b	77 b	1.8 b	75 ab	752 ab
S30	30	0.29 c	81 a	2.8 a	79 a	786 a
S45	45	0.25 d	75 bc	3.2 a	72 bc	720 bc
S60	60	0.26 d	71 c	3.3 a	68 c	680 c
B0	0	0.31 a	68 c	7.2 a	61 c	607 c
B15	15	0.28 b	71 bc	6.0 ab	65 b	653 b
B30	30	0.26 c	75 a	3.3 c	72 a	717 a
B45	45	0.24 d	75 ab	3.9 bc	71 a	707 a
B60	60	0.23 d	74 b	3.5 c	71 a	705 ab
N0	0	0.33 a	82 ab	7.3 a	75 a	746 ab
N15	15	0.31 b	84 a	6.3 a	77 a	772 a
N30	30	0.28 c	84 a	6.6 a	78 a	777 a
N45	45	0.24 d	79 b	4.4 b	75 a	748 ab
N60	60	0.22 e	74 c	4.4 b	70 a	700 b
CS	0	0.38	72	6.5	66	659

BCW: boiler remnant charcoal waste; ^{g}Optimum or acceptable values for an ideal substrate according to Abad et al. (2004); Equal lowercase letters show no significant minimum difference (LSD) by the F test (α: 5%) among the BCW doses added in each agro-industrial compost.

Overall, the relationship between TP and the increment of BCW in substrates did not have a linear behavior. That is, the addition of BCW to the compost did not lead to higher TP (Table 4). The highest TPs were found in substrates with doses between 15 and 45% BCW. However, none of the 26 substrates (25 prepared + CS) reached TP> 85%, considered optimal (Abad et al., 2001). The addition of BCW favored an increase in AP, especially in substrates with fine grain size (cotton and wood sawdust). The larger volume of particles size > 1mm favored clod formation by root folding (Bustamante et al., 2008). Regarding WHP, treatments in which cotton and Napier grass were used as the main carbon sources during composting were not significantly affected by the addition of BCW. Among the other treatments, the most pronounced effects occurred when tree pruning and sugarcane bagasse were used in the process. The grain size of these materials, when used as BAs, allowed BCW addition to improve substrate texture for water holding, as shown in TWHC (Table 4), which did not occur for other BAs (A, S and N).

Effect of substrates on lettuce seedling development and quality

The diluent effect of the increasing addition of BCW (15, 30, 45 and 60%) on the EC of the agro-industrial compost increased the percentage of E and ESI. As a result, the number of days required for seeds to emerge (MET) decreased ($p<0.05$). That is, the higher the BCW dose in the preparation of the 25 substrates, the lower the MET and the higher the E and ESI of lettuce seedlings (Table 5). In this sense, the decrease in EC caused both by the addition of BCW (Table 3) and salt leaching during the experiment (Menezes Júnior et al., 2000) favors the results of E, ESI and MET.

However, this effect of higher BCW percentages leading to better development of seedlings did not occur for seedling quality (SQI) after 30 days of cultivation. That is, SQI showed that seedlings do not present higher quality due only to a greater reduction of substrate EC. With the exception of substrates prepared with A and N which had the highest EC values (Table 3), the highest ($p<0.05$) SQI values were found in substrates prepared with 15 to 45% BCW (Table 5), which did not have the lowest EC values (Table 3).

TABLE 5. Emergence, development and quality of lettuce seedlings and clod properties after 30-days culture of tray.

Substrates	BCW (%)	E (%)	ESI	MET (days)	SQI	TChl	ERT	CSt
A0	0	10 d	0.5 d	7.1 a	0.0001 c ^{M}	ND	ND	ND
A15	15	28 c	1.3 d	7.5 a	0.0027 b ^{L}	0.42 ^{ns}	6.0 c	7.1 a
A30	30	58 b	2.8 c	7.0 a	0.0031 b ^{L}	0.41 ^{ns}	8.0 a	7.1 a
A45	45	69 b	4.2 b	5.2 b	0.0080 a ^{J}	0.39 ^{ns}	6.8 b	6.4 ab
A60	60	87 a	5.9 a	4.6 b	0.0089 a ^{IJ}	0.40 ^{ns}	5.1 d	4.8 b
P0	0	77 b	4.1 c	6.1 a	0.0122 b ^{FG}	0.19 b	7.1 b	5.9 ab
P15	15	77 b	4.1 c	6.1 a	0.0148 a ^{AB}	0.31 a	7.8 a	6.5 a
P30	30	84 ab	5.6 b	4.8 b	0.0153 a ^{A}	0.25 ab	7.9 a	6.3 ab
P45	45	97 a	7.1 a	4.3 b	0.0139 ab ^{BCD}	0.29 a	7.1 b	5.5 bc
P60	60	94 a	6.8 ab	4.3 b	0.0127 b ^{EF}	0.26 ab	5.4 c	4.9 c
S0	0	70 c	3.8 c	5.7 a	0.0124 b ^{FG}	0.27 ^{ns}	4.6 d	5.0 d
S15	15	84 b	5.6 b	4.7 b	0.0133 ab ^{CDEF}	0.36 ^{ns}	8.0 ab	7.0 b
S30	30	97 a	7.1 a	4.2 c	0.0138 a ^{BCD}	0.32 ^{ns}	8.6 a	7.4 ab
S45	45	98 a	7.5 a	4.1 c	0.0114 c ^{G}	0.35 ^{ns}	7.4 bc	8.0 a
S60	60	93 a	7.4 a	4.0 c	0.0101 d ^{H}	0.33 ^{ns}	6.8 c	6.1 c
B0	0	82 c	4.3 c	6.0 a	0.0082 d ^{J}	0.28 ^{ns}	7.1 ab	7.6 ab
B15	15	86 bc	4.8 bc	5.8 a	0.0129 c ^{DEF}	0.33 ^{ns}	8.0 a	8.0 a
B30	30	91 ab	6.0 ab	4.8 b	0.0144 a ^{ABC}	0.31 ^{ns}	8.5 a	8.6 a
B45	45	96 a	6.9 a	4.4 bc	0.0138 ab ^{BCDE}	0.33 ^{ns}	7.9 a	8.1 a
B60	60	98 a	7.5 a	4.0 c	0.0132 bc ^{DEF}	0.36 ^{ns}	6.4 b	6.6 b
N0	0	3.3 c	0.1 c	10.3 ab	0.0000 d ^{M}	ND	ND	ND
N15	15	3.3 c	0.1 c	11.1 a	0.0009 cd ^{M}	0.30 ^{ns}	5.5 b	6.0 ^{ns}
N30	30	9.2 c	0.4 c	8.3 b	0.0024 c ^{L}	0.29 ^{ns}	7.5 a	6.4 ^{ns}
N45	45	29 b	1.7 b	5.8 c	0.0046 b ^{K}	0.26 ^{ns}	7.0 a	6.1 ^{ns}
N60	60	48 a	3.3 a	4.6 c	0.0096 a ^{HI}	0.27 ^{ns}	6.3 b	6.0 ^{ns}
CS	0	96	7.7	3.9	0.0085 ^{IJ}	0.21	7.6	6.6

CS: commercial substrate; E: Emergence percentage; ESI: emergence speed index; MET: mean emergence time; SQI: seedling quality index; TChl: Total chlorophyll; ERT: easiness of removal of clod from tray; CSt: clod stability; ND: Not determined; ns: no significance. Equal lowercase letters do not show a significant minimum difference (LSD) by the F test (α: 5%) among the BCW doses added in each agro-industrial compost, and the equal uppercase superscript letters do not differ compared to all substrates.

Percentages lower than 60% BCW in compost types A and N generated seedlings with lower SQI values ($p<0.05$) compared to the CS. Only A60, N60 and B0 produced seedlings equivalent ($p<0.05$) to the CS, while all the other 22 prepared substrates produced seedlings with higher SQIs ($p>0.05$), although none of the prepared substrates presented EC values within the optimal range for the production of vegetable seedlings (0.75 - 2.0$^{\mathrm{dS.m^{-1}}}$) (Table 3).

There was practically no significant difference in total chlorophyll (TChl) among lettuce seedlings (Table 5). Therefore, BCW added to agro-industrial compost has no effect on the chlorophyll concentration of seedlings. However, BCW percentages significantly changed clod properties (ERT and CE) after cultivation (Table 5). In general, the BCW doses that facilitated clod removal from tray the most (highest ERT), were the ones between 15 and 45%. Doses above or below this interval presented lower CE and greater removal difficulty (clod stuck to tray or broken when removed).

In short, the interpretation of seedling quality and development and clod stability properties (Table 5) can be summarized by PCA, expressed in two main components (CP1 and CP2). Together, these components explained 87.6% of the total variance of substrate data. The biplots (A and B) generated with CP1 and CP2 are shown in Figure 1.

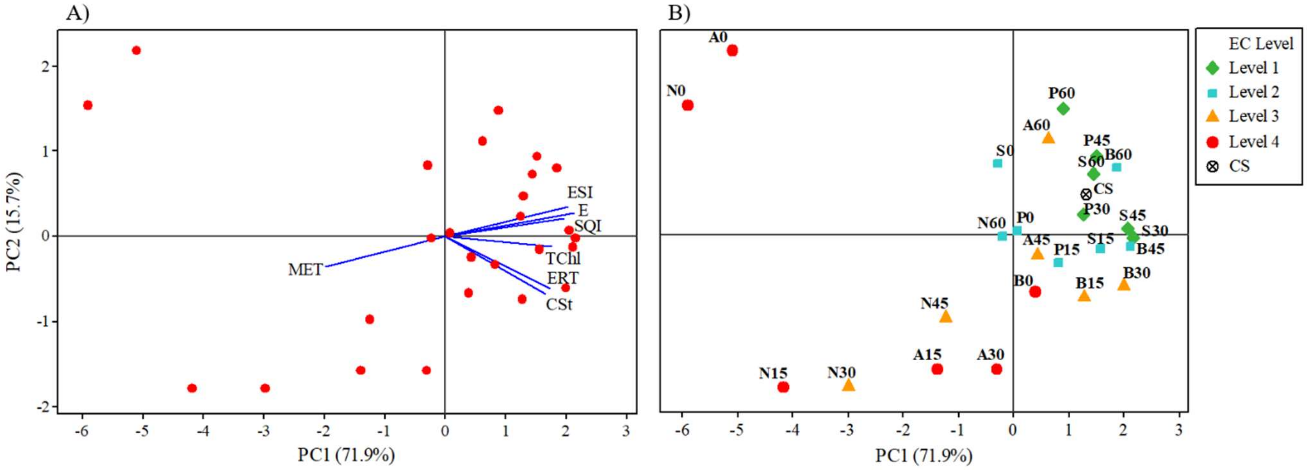

FIGURE 1. Biplot graphics generated from the PCA with the two main components (PC1 and PC2). A) Loadings Plot of the seven variables used. B) Score Plot of the 26 substrates (25 elaborated + CS), categorized according to the level of electrical conductivity (EC).

CP1, with 71.9% of accumulated explanation percentage, was positively correlated with all variables except MET, with which it correlated negatively (Figure 1A). Thus, substrate positions further to the left along the CP1 axis indicate slower emergence (higher MET), with poor development (lower E and ESI) and lower quality (low SQI).

The Score Plot in Figure 1B shows the position of the 26 substrates and their categorization into four EC levels. These levels were divided into Level 1 (2 > 5 dS.m^{-1}), level 2 (5 ≥ 6.5 dS.m^{-1}), level 3 (6.5 > 9 dS.m^{-1}) and level 4 (9 ≥ 18 dS.m^{-1}). In this case, substrates N0, N15, N30, N45, A0, A15 and A30 (located in the left area of the CP1 axis) provided the lowest E, ESI and SQI values, as well as the highest MET. All these substrates are classified as level 3 or 4, the highest salinity levels (6.5 ≥ 18 mS.m^{-1}). According to Gavilanes-Terán et al. (2017) when substrates present high initial EC, phytotoxic components inhibit seed emergence. In this sense, agro-industrial compost in which Napier grass (N) and cotton (C) were used as structuring agents proved to be not viable for Lucy Brown lettuce production, presenting poor development (E and ESI) and low seedling quality (SQI) (Table 5). The excess of nutrients contained in these types of compost caused a phytotoxic effect on lettuce seedlings (Santos et al., 2015).

The variables ERT and CE are explained partly by CP1 and partly by CP2 (15.7%). The substrates that presented the highest values for these variables were those prepared with the compost in which tree pruning (P), wood sawdust (S) and sugarcane bagasse (B) were used as structuring agents in the composting process. The lowest ERT and CE values were found in the treatments in which Napier grass (N) and cotton (C) were used, disqualifying them as satisfactory substrates for seedling production. ERT and CE are important variables for the assessment of seedling production, since they both influence post-cultivation stages such as transport, transplanting and permanent planting (Kratz et al., 2015).

Relevance of substrate characteristics to seedling quality

Among the 13 chemical, physical and physicochemical variables analyzed in the substrates, the three most relevant (N, EC and pH) can significantly explain 81% of the quality of lettuce seedlings (SQI). This proportion of mean SQI explanation is given by the estimated model of multiple linear regression (MLR) (Equation 1). With this model, and based on the data of N, EC and pH of substrates prepared with BPC agro-industrial compost and BCW doses, it is possible to predict seedling quality (SQI) after 30 days of cultivation even before sowing.

The MLR model was estimated with 48 observations and is significant at 1% ($p<0.01$) of probability and F value of 64.4, according to the analysis of variance. Its coefficient of determination R^2 was 81.4% and the adjusted R^2 was 80.9%. This MLR model (Eq. 1) revealed that for each 1% increase in the nitrogen (N) content of substrates, SQI increases by 0.00233 when other variables remain constant. Therefore, there will also be an equivalent decrease in SQI for each 1% decrease in the concentration of N in the substrates.

The EC coefficient of the estimated model (Equation 1) had a negative sign, that is, an increase in EC leads to a decrease in seedling quality. It can be inferred that for each reduction of 1 dS.m^{-1} in substrate EC, there is an increase in SQI of 0.00153. In this case, the model confirms the detrimental effects of high salinity on seedling development (Spiassi et al., 2015; Gavilanes-Terán et al., 2017). Regarding the pH, the model demonstrated that for each unit of pH reduced, seedling quality (SQI) increases by 0.00335. Due to the pH range (6.9 to 8.9) of the prepared substrates (Table 3), the pH coefficient was negative, demonstrating that in order to increase SQI, substrate pH must decrease, approaching the optimal range (5.3 to 6.5). Alkaline pH impairs substrates' cation exchange capacity, decreasing nutrient absorption (Abad et al., 2001) and consequently gaining less mass, which can be verified by lower SQIs (Table 5). Increased SQIs correspond to the ability of substrates to generate plants with better mass distributions (Meng et al., 2018).

Substrate preparation for maximum quality and easier removal from tray

The ideal BCW dose required for seedlings to reach maximum quality (SQI$_{max}$) and maximum easiness of removal from tray (ERT$_{max}$) for each agro-industrial compound studied (A, P, S, B and N), was determined by extracting the maximum point of the quadratic functions of the estimated models. Optimal BCW doses to achieve theoretical SQI$_{max}$ are presented in Table 6.

TABLE 6. Ideal dose of boiler remnant charcoal waste (BCW) percentage to be added in each agro-industrial compost to reach the maximum theoretical SQI.

Substrate	Ideal BCW (%)	SQI$_{máx}$	Quadratic model	p-value	R^2 adjust.
A	≥ 60	0.0091	$SQI\ A = 0.00013 + 0.000131(BCW) + 0.000000(BCW)^2$	0.707	ns
P	33.0	0.0152	$SQI\ P = 0.01239 + 0.000183(BCW) - 0.000003(BCW)^2$	0.002	70%
S	24.0	0.0136	$SQI\ S = 0.01247 + 0.000096(BCW) - 0.000002(BCW)^2$	0.003	82%
B	39.6	0.0147	$SQI\ B = 0.00846 + 0.000317(BCW) - 0.000004(BCW)^2$	0.000	93%
N	≥ 60	0.0081	$SQI\ N = 0.00020 - 0.000017(BCW) + 0.000003(BCW)^2$	0.305	ns

The quadratic model was not significant only for mixtures derived from organic compost using waste from cotton (C) and Napier grass (N) shredding as carbon sources in the composting process. This was due to the chemical characteristics of these two organic compounds, especially the high salinity (Table 3), level 3 and 4 ($6.5 \geq 18$ mS.m^{-1}) (Figure 1B). Although the addition of BCW causes a decrease in EC values, optimal conditions for seedling development were not reached, even with the addition of 60% BCW to substrate composition, which disqualifies both for use as substrate. For these two sources, the more BCW was added, the higher the SQI, demonstrating a linear behavior, not a quadratic function (not significant) (Table 6). Thus, it can be said that reaching the theoretical SQI$_{max}$ for A and N would require BCW doses greater than or equal to 60% (≥60%).

Regarding the other three substrates, prepared with organic compost in which tree pruning (P), wood sawdust (S) and sugarcane bagasse (B) were used, regression models showed that for lettuce seedlings to reach SQI$_{max}$, the BCW doses that need to be added are 33, 24 and 39.6%, respectively. Azevedo et al. (2010) affirm that SQI is a good indicator of seedling quality, because it takes into account the robustness and balance of the biomass distribution within the seedling for its calculation.

For maximum easiness of clod removal from tray (ERT$_{max}$) optimal BCW doses were found for each compound (A, P, S, B and N) and are summarized in Table 7.

TABLE 7. Ideal dose of boiler remnant charcoal waste (BCW) percentage to be added in each agro-industrial compost to reach the maximum theoretical ERT.

Substrate	Ideal BCW (%)	ERT$_{máx}$	Quadratic model	p-value	R^2 adjust.
A	34.5	7.7	$ERT\ A = 2.906 + 0.276(BCW) - 0.00403(BCW)^2$	0.002	85%
P	23.0	8.0	$ERT\ P = 7.016 + 0.083(BCW) - 0.00182(BCW)^2$	0.000	98%
S	34.2	8.6	$ERT\ S = 4.939 + 0.212(BCW) - 0.00313(BCW)^2$	0.001	81%
B	26.6	8.4	$ERT\ B = 7.061 + 0.101(BCW) - 0.00186(BCW)^2$	0.002	72%
N	38.8	7.4	$ERT\ N = 2.688 + 0.241(BCW) - 0.00306(BCW)^2$	0.002	85%

ERT is an important parameter, as clod aggregation will give the seedling better survival conditions in the field after transplanting. Boene et al. (2013) assessed the easiness of removal of seedlings from tubes and root adherence to substrates. The authors found that substrate components such as carbonized rice husks and coconut fibers were very loose materials, making it difficult for roots to adhere to clods and, consequently, remove tubes without damaging seedlings.

In this study, it was found that the substrates that received the highest scores in the ERT assessment (> 8.0) were the ones that used tree pruning (P), wood sawdust (S) and sugarcane bagasse (B) as structuring agents in the composting process. Thus, it can be inferred that seedlings originating from these substrates will have a better development and greater survival capacity in the field (Kratz et al., 2015). The BCW doses, in dry mass, required for substrates prepared with P, S and B to reach the theoretical ERT_{max} are 23, 34.2 and 26.6%, respectively. The averages of the optimal BCW doses for SQI_{max} and ERT_{max} of these substrates are 28, 29 and 33%, respectively. Therefore, for the preparation of substrates originating from BPC agro-industrial compost and BCW with maximum quality and easiest removal from tray, the recommended BCW percentage is approximately 30% in dry mass.

CONCLUSIONS

The addition of boiler remnant charcoal waste (BCW) to organic compost reduces the electrical conductivity of the mixture (substrates). Among the chemical, physical and physicochemical variables of the substrates, total nitrogen content, electrical conductivity and pH are the most important variables to explain seedling quality index (SQI). The percentage of BCW added to substrates directly influences the easiness of removal of clod from tray.

Cotton and Napier grass shredding waste, when used as a structuring agent and carbon source for the BPC waste composting process, generates an organic compost with high EC, which is not suitable for the preparation of horticultural substrates.

The use of more sturdy carbon sources in the BPC waste composting process, such as urban tree pruning, wood sawdust or crushed sugarcane bagasse, generates compost that is more suitable for the purpose of producing vegetable substrates. The addition of 30% in dry matter of boiler remnant charcoal to this compost is recommended to obtain maximum quality seedlings, which are superior to commercial substrate and easy to remove from tray.

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