Revista Ciência Agronômica, v. 55, e20228497, 2024
Centro de Ciências Agrárias - Universidade Federal do Ceará, Fortaleza, CE
www.ccarevista.ufc.br

Scientific Article
ISSN 1806-6690

Potential use of green coconut shell liquid in young dwarf coconut plants[1]

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ABSTRACT - The pressing of green coconut shell, aiming at the production of powder or fiber, used as raw material by the industry, generates large amounts of the green coconut shell liquid (GCSL), whose incorrect disposal results in environmental impacts. This study evaluated the potential use of GCSL as a source of potassium for young dwarf coconut plants. The experiment was carried out in pots, in a completely randomized design, applying seven treatments, comprising five doses of GCSL, which corresponded to 0% (G_0), 50% (G_{50}), 100% (G_{100}), 150% (G_{150}) and 200% (G_{200}) of the need for K_2O of the plants, a treatment with mineral fertilizer, corresponding to 100% of K_2O supplied as KCl (K_{100}), and another containing 50% of K_2O as KCl and 50% as GCSL (G_{50} + K_{50}), with five replicates. One hundred and twenty days after transplanting the seedlings, soil chemical attributes as well as growth and nutritional status of dwarf coconut plants were evaluated. Increase in GCSL doses altered soil fertility and reduced the percentage of live leaves of dwarf coconut. The G_{50} + K_{50} treatment did not differ from K_{100} for all variables of growth, except for % of live leaves, indicating the possibility of replacing 50% of the K_2O dose recommended for the first year of dwarf coconut cultivation with GCSL.

Key words: *Cocos nucifera* L. Potassium. Liquid residue.

DOI: 10.5935/1806-6690.20240020
Editor-in-Chief: Prof. Tiago Osório Ferreira - toferreira@usp.br
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Received for publication 31/05/2022; approved on 20/09/2023
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INTRODUCTION

Brazil has shown a considerable increase in the area planted with coconut (*Cocos nucifera* L.) in recent years, driven by consumer interest in healthier eating habits (RODRIGUES; MARTINS; BARROS, 2018), which resulted in increased demand for products and consumption of coconut water in large urban centers (SANTOS *et al*., 2020). With the growth of the Brazilian market of products from coconut farming, the generation of large quantities of coconut shell has become a problem for public management, due to the inadequate disposal of this residue in dumps, landfills and public areas, after processing or fresh consumption, generating costs and environmental and social impacts (ARAÚJO *et al*., 2017).

According to Leitão *et al*. (2010), the environmental impacts caused by the incorrect disposal of green coconut shell can be mitigated by its use as a raw material in the industry, after its transformation into fiber and coconut powder. However, during this transformation, each ton of processed coconut shell generates 500 liters of effluent, called green coconut shell liquid (GCSL), which has caused concern to the industrial sector and public policies, due to the need for adequate and sustainable disposal of this residue.

On the other hand, GCSL contains high concentration of potassium, a nutrient required in greater quantity in the dwarf coconut cultivation, due to the beneficial effects on growth and fruit production (PEREIRA *et al.*, 2017). Therefore, this residue has the potential to totally or partially replace the mineral fertilizer, potassium chloride, which is the source of K_2O most commonly used in coconut cultivation. However, its agricultural exploitation potential still needs to be elucidated. Thus, the objective was to evaluate the potential use of GCSL as a source of potassium in the cultivation of young dwarf coconut plants.

MATERIAL AND METHODS

The experiment was conducted in October 2019 and January 2020, in the open air, at Embrapa Tropical Agroindustry, located in the municipality of Fortaleza, CE, Brazil (3° 45' 10" S, 38° 34' 32" W and 21 m altitude). The predominant climate in the region, according to Köppen's classification (PEEL; FINLAYSON; MCMAHON, 2007), is Aw', that is, rainy tropical climate, with average annual temperature of 26.5 ºC.

The soil used in the experiment was classified as Arenic Haplustults, collected in the 0-20 cm layer, in the Experimental Field of Pacajus, municipality of Pacajus, CE (4° 11' 6" S, 38° 30' 6" W). Then, the soil was characterized for chemical attributes (SILVA *et al*., 2009b) and particle size (ALMEIDA *et al*., 2012): pH_{H2O} = 6.4; OM = 9 g kg^{-1}; P = 242 g dm^{-3}; K^+ = 1.5 $mmol_c$ dm^{-3}; Ca^{2+} = 27 $mmol_c$ dm^{-3}; Mg^{2+} = 8 $mmol_c$ dm^{-3}; Na^+ = 1,0 $mmol_c$ dm^{-3}; Al^{3+} = 0 $mmol_c$ dm^{-3}; H+Al = 9 $mmol_c$ dm^{-3}; Zn = 9.9 $mmol_c$ dm^{-3}; Cu = 0.7 $mmol_c$ dm^{-3}; Fe = 19 $mmol_c$ dm^{-3}; Mn = 47 $mmol_c$ dm^{-3}; CEC = 47 $mmol_c$ dm^{-3}; BS = 82%; sand = 924 g kg^{-1}; silt = 31 g kg^{-1}; and clay = 45 g kg^{-1}.

The green coconut shell liquid (GCSL) was obtained after crushing the green coconut shell and pressing it in a horizontal rotary press. After the pressing process, the liquid passed through a 1-mm-mesh sieve to remove suspended particles from the shell. GCSL was supplied by the Paraipaba Agroindustrial coconut water bottling company, located in the municipality of Paraipaba, CE (3° 27' 53" S, 39° 11' 58" W).

The experiment was conducted in a completely randomized design, consisting of five replicates and seven treatments (five doses of GCSL and two additional treatments). The five treatments related to GCSL doses corresponded to the application of: 0% (G_0), 50% (G_{50}), 100% (G_{100}), 150% (G_{150}) and 200% (G_{200}) of the need for K_2O in the form of GCSL. The additional treatments consisted of: additional 1 – 100% of the need for K_2O in the form of potassium chloride (K_{100}); additional 2 – 50% of the need for K_2O in the form of GCSL and 50% of the need for K_2O in the form of potassium chloride (G_{50} + K_{50}).

The K_2O dose applied was defined based on the results of soil analysis, on the recommendation of fertilization for young dwarf coconut plants, from 0 to 1 year of age, according to Sobral *et al*. (2009), and on the K content of the GCSL. The treatments were applied monthly for three months.

Table 1 shows the values of pH, electrical conductivity, nutrients and sodium of GCSL, collected before each monthly application, according to the methodology described in Miyazawa *et al.* (2009) and Brasil (2007).

To establish the C/N ratio, the total N content was initially determined according to Tedesco, Volkweiss and Bohnen (1985). Organic carbon content (C-org) was determined according to the methodology described in Brasil (2007).

Each experimental unit consisted of one young plant (0 to 1 year old) of dwarf coconut, approximately 124 ± 2.5 cm tall, which was transplanted to plastic pots with capacity of 100 L, filled with 75 L of soil.

Treatments G_{50}, G_{100}, G_{150}, G_{200} and G_{50} + K_{50} received in each application 8, 16, 24, 32 and 8 liters of GCSL per plant, respectively. GCSL and potassium chloride were applied over three months (three applications) once a month, considering the recommendation of 50 g of K_2O plant^{-1} month^{-1} (SOBRAL *et al*., 2009). Each application was compensated with water, so that all treatments received the same amount of liquids.

Based on soil analysis and on fertilization recommendations for the dwarf coconut crop (SOBRAL *et al*., 2009), there was no need for liming or addition of other nutrients, except for nitrogen fertilization, so 50 g of N plant^{-1} month^{-1} were applied in the form of urea.

Throughout the study, soil moisture was monitored by tensiometers installed in the pots, at 25 cm depth. Means of temperature, relative humidity and rainfall were collected in the experimental field weekly (Figure 1).

At 120 days after transplantation (DAT), that is, 30 days after the last GCSL application, soil samples were collected with a probe-type sampler, at five points in the pots to form a composite sample, in the 0-20 and 20-40 cm layers. The soil samples collected were placed in identified plastic bags and air dried. Subsequently, they were pounded to break up clods, homogenized and passed through a 2-mm-mesh sieve. Then, the samples were subjected to chemical analyses, according to procedures described in Silva *et al*. (2009b).

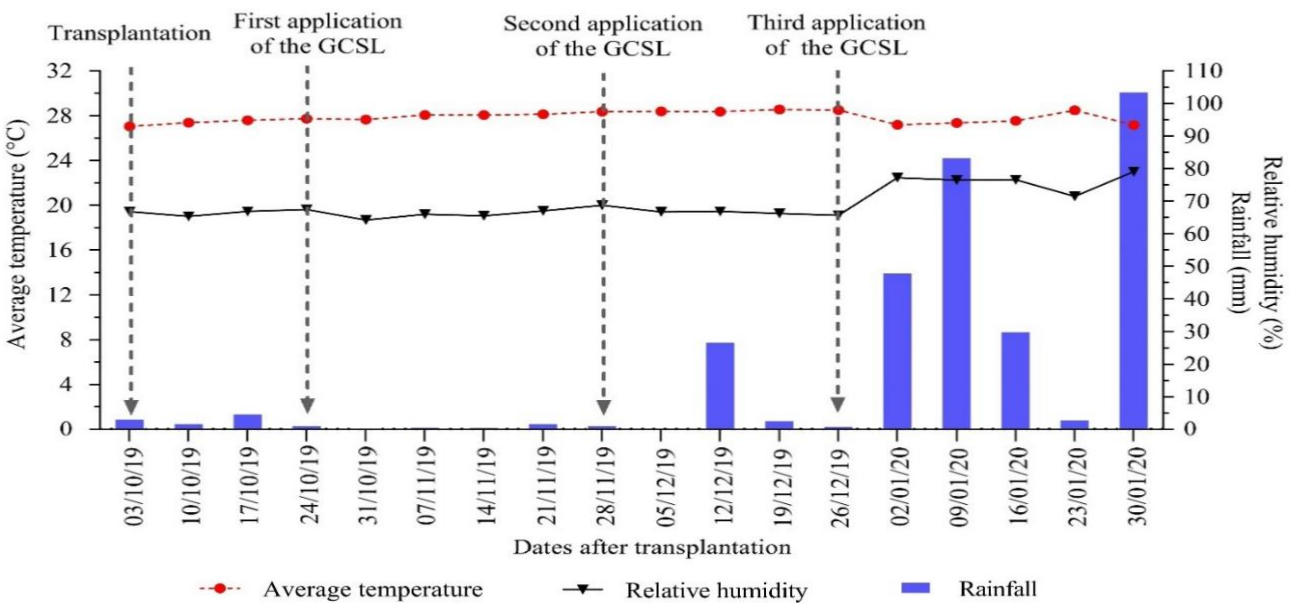
The analysis of the growth parameters of the young dwarf coconut plants was performed on the day of transplantation and at 120 DAT, by means of the following determinations: plant height (PH), measured with a measuring tape, considering the vertical distance between the soil surface and the apex of the plant; stem diameter (SD), determined with a digital caliper at 5 cm from the soil level; number of leaves (NL), counted to calculate the percentage of live leaves. The results of plant height and stem diameter were then used to calculate the relative and absolute growth rates of plant height and stem diameter (RGR-PH, RGR-SD, AGR-PH and AGR-SD, respectively) (BENINCASA, 2003).

Table 1 - Chemical characterization of green coconut shell liquid (GCSL) in each monthly application in dwarf coconut cultivation

GCSL applications	pH	EC	C/N	P	K	Ca	Mg	Na	Cu	Fe	Zn	Mn
		dS m^{-1}		mg L^{-1}								
1st	4.0	8.5	150/1	85	2174	87	192	263	0.3	7	2	1
2nd	5.2	7.9	150/1	89	1948	83	220	389	0.2	33	6	1
3rd	3.5	9.0	150/1	83	2229	89	177	212	0.2	25	3	1

pH: hydrogenionic potential; EC: electrical conductivity; C/N: carbon to nitrogen ratio; P: phosphorus; K: potassium; Ca: calcium; Mg: magnesium; Na: sodium; Cu: copper, Fe: iron, Zn: zinc and Mn: manganese

Figure 1 - Data of average temperature, relative humidity and rainfall during the experimental period in Fortaleza, Ceará, Brazil



The shoots of the dwarf coconut trees were separated into stem and leaves, washed with water, 3% hydrochloric acid (v:v) and deionized water, placed in paper bags and dried in a forced air circulation oven at 65 ºC until reaching constant mass. After drying, leaf dry mass (LDM), stem dry mass (SDM) and total shoot dry mass (TDM) were determined. Then, the leaf samples were ground in a Wiley mill and passed through 1-mm-mesh sieves for subsequent chemical analysis according to Miyazawa *et al*. (2009). Data were subjected to the Shapiro-Wilk test ($p < 0.05$) to check the normality of distribution. When the normality condition was not met, the data were transformed to $\log_{10}$. Subsequently, analysis of variance was performed and, when significant by the F test ($p < 0.05$), regression analysis was performed for GCSL doses.

Treatments K_{100} and $G_{50} + K_{50}$ were explored by orthogonal contrasts with the 100% GCSL dose, considering the equivalence of 100% of the K_2O recommendation. The designated constants were: G_{100} vs K_{100}; K_{100} vs $G_{50} + K_{50}$ and G_{100} vs $G_{50} + K_{50}$, with significant effect when $p < 0.05$. These statistical analyses were performed using SAS (Statistical Analysis System) software.

RESULTS AND DISCUSSION

The dwarf coconut plants showed dry leaf tips about fifteen days after the treatments began to be applied, including in the control that received only water (G_0), or in the treatments with potassium chloride (K_{100}), or GCSL associated with potassium chloride ($G_{50} + K_{50}$). Over time, the drying of the tips advanced to the central region until the leaves were completely dry. In treatments that did not receive GCSL, drying of leaves can be attributed to stress caused by the transplanting of dwarf coconut seedlings into the pots. For plants that received GCSL, drying of leaves can be explained not only by the stress caused by transplanting, but also by the application of the raw liquid.

Silva *et al*. (2016) found that dwarf coconut is able to establish in soil with electrical conductivity of up to 6.5 dS m^{-1}. For Lima *et al*. (2017), dwarf coconut seedlings in nursery phase are tolerant to irrigation water salinity of 5.2 dS m^{-1} and moderately tolerant to salinity of 10.1 dS m^{-1}. The GCSL had high electrical conductivity, on average 8.47 ± 0.32 dS m^{-1} (Table 1), which may have contributed to increasing the stress condition of the seedlings at the higher doses of GCSL. However, GCSL doses did not increase soil electrical conductivity (EC), determined in the saturation extract (Table 2), possibly due to the leaching of ions to the deepest layers caused by rains that occurred in January, after the third application of GCSL (Figure 1).

On the other hand, with the application of G_{100}, there were increments of 4 and 2.5 times the value of EC compared to the mineral form (K_{100}) and the association of sources ($G_{50} + K_{50}$), respectively (Table 3). Electrical conductivity represents the amount of soluble salts in the soil saturation extract, and this increase can be explained by the fact that GCSL is an effluent with high K concentration and with considerable amounts of Na, Mg and Ca. Increase in electrical conductivity was also observed after the use of cassava wastewater by Barreto *et al*. (2013).

As a consequence of these initial changes, only the percentage of live leaves was affected by the application of GCSL doses in the soil (Table 4). The percentage of live leaves decreased with the increase in GCSL doses (Figure 2).

Table 2 - Chemical attributes of the Arenic Haplustults, in the 0-20 cm layer, treated with GCSL doses and cultivated with young dwarf coconut plants

SV	pH_{H2O}	EC	OM	P	K^+	Ca^{2+}	Mg^{2+}	Na^+
GCSL	0.7^{ns}	1.9^{ns}	10.5**	5.0**	16.4**	31.7**	7.7**	3.2*
p-value	0.58	0.15	<0.01	<0.01	<0.01	<0.01	<0.01	0.03
CV (%)	9.7	23.8	22.0	20.4	35.3	15.4	13.8	30.5
SV	H + Al	SB	CEC	BS	Zn^{2+}	Cu^{2+}	Fe^{2+}	Mn^{2+}
GCSL	1.5^{ns}	2.3^{ns}	1.9^{ns}	0.3^{ns}	0.4^{ns}	8.1**	70.8**	16.8**
p-value	0.26	0.08	0.15	0.83	0.80	<0.01	<0.01	<0.01
CV (%)	43.6	14.6	23.8	19.2	16.3	13.3	10.9	40.8

^{ns}: not significant; ** and *: significant at 1% and 5% probability, respectively. pH: pH determined in water; EC: electrical conductivity; OM: organic matter; P: phosphorus; K^+: potassium; Ca^{2+}: calcium; Mg^{2+}: magnesium; Na^+: sodium; H + Al: potential acidity; SB: sum of bases; CEC: cation exchange capacity; BS: base saturation; Zn^{2+}: zinc; Cu^{2+}: copper; Fe^{2+}: iron; and Mn^{2+}: manganese. CV: coefficient of variation; SV: source of variation

Table 3 - Chemical attributes of the Arenic Haplustults, in the 0-20 cm layer, in response to the treatments G_{100}, K_{100} and $G_{50} + K_{50}$ applied in the cultivation of young dwarf coconut plants

	Treatments		p-value	Treatments		p-value	Treatments		p-value
	G_{100}	K_{100}		G_{100}	$G_{50} + K_{50}$		K_{100}	$G_{50} + K_{50}$	
pH	6.8 a	6.5 a	0.632	6.8 a	7.0 a	0.603	6.5 a	7.0 a	0.309
EC	1.86 a	0.47 b	0.003	1.86 a	0.75 b	0.022	0.47 a	0.75 a	0.526
P	134 a	144 a	0.732	134 a	115 a	0.607	144 a	115 a	0.379
K^+	13.1 a	2.7 b	<0.001	13.1 a	5.7 b	0.005	2.7 a	5.7 a	0.160
Ca^{2+}	11.3 b	17.4 a	<0.001	11.3 a	12.3 a	0.350	17.4 a	12.3 b	0.001
Mg^{2+}	11.5 a	5.9 b	<0.001	11.5 a	8.7 b	<0.001	5.9 b	8.7 a	<0.001
Na^+	4.4 a	2.7 b	0.012	4.4 a	3.8 a	0.526	2.7 a	3.8 a	0.553
Zn^{2+}	13.7 a	14.7 a	0.451	13.7 a	13.4 a	0.813	14.7 a	13.4 a	0.611
Cu^{2+}	1.1 a	1.2 a	0.502	1.1 a	1.1 a	0.133	1.2 a	1.1 a	0.209
Fe^{2+}	60 a	18 b	<0.001	60 a	38 b	0.001	18 b	38 a	0.001
Mn^{2+}	8 b	28 a	<0.001	8 b	14 a	0.025	28 a	14 b	0.001

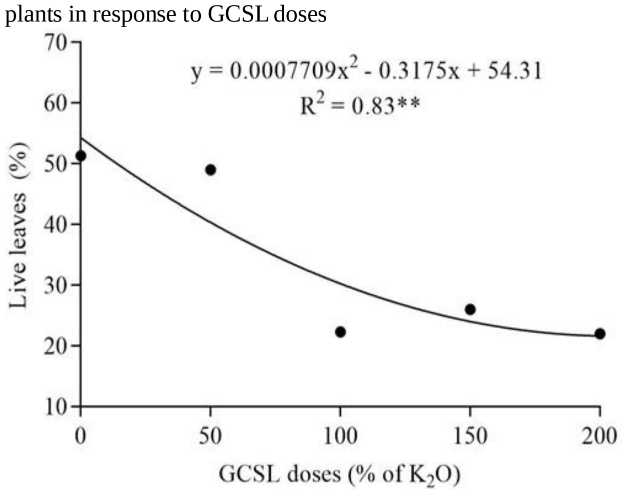
Means followed by the same letter on the line do not differ by Tukey's test ($p < 0.05$); G_{100}: 100% of the recommended K_2O requirement for coconut in the form of GCSL; K_{100}: 100% of the recommended K_2O requirement for coconut in the form of KCl; $G_{50} + K_{50}$: 50% of the recommended K_2O requirement for coconut in the form of GCSL and 50% in the form of KCl; pH: hydrogenionic potential; EC (dS m^{-1}): electrical conductivity; P (mg kg^{-1}): phosphorus; K^+ ($mmol_c$ dm^{-3}): potassium; Ca^{2+} ($mmol_c$ dm^{-3}): calcium; Mg^{2+} ($mmol_c$ dm^{-3}): magnesium; Na^+ ($mmol_c$ dm^{-3}): sodium; Zn^{2+} (mg dm^{-3}): zinc; Cu^{2+} (mg dm^{-3}): copper; Fe^{2+} (mg dm^{-3}): iron; and Mn^{2+} (mg dm^{-3}): manganese

Table 4 - Analysis of growth parameters of young dwarf coconut plants in response to GCSL doses

SV	NL	LL	PH	SD	AGR-PH	RGR-PH
GCSL	1.17^{ns}	7.80**	0.60^{ns}	1.13^{ns}	1.71^{ns}	1.84^{ns}
p-value	0.354	<0.01	0.668	0.369	0.251	0.226
CV (%)	13.71	34.58	12.75	10.11	20.61	9.17
SV	AGR-SD	RGR-SD	LDM	SDM	TDM	
GCSL	0.09^{ns}	0.07^{ns}	1.53^{ns}	0.73^{ns}	1.22^{ns}	
p-value	0.983	0.989	0.230	0.579	0.333	
CV (%)	26.85	15.78	33.58	30.72	30.58	

^{ns}: not significant; ** and *: significant at 1% and 5% probability, respectively. NL: number of leaves; LL: live leaves; PH: plant height; SD: stem diameter; AGR-PH: absolute growth rate of plant height; RGR-PH: relative growth rate of plant height; AGR-SD: absolute growth rate of stem diameter; RGR-SD: relative growth rate of stem diameter; LDM: leaves dry mass; SDM: stem dry mass; TDM: total dry mass. CV: coefficient of variation; SV: source of variation

Figure 2 - Percentage of live leaves of young dwarf coconut plants in response to GCSL doses



A comparison of the treatments with application of 100% of the K_2O recommendation in the form of GCSL (G_{100}) and with potassium chloride (K_{100}), as well as the association of the two sources of K ($G_{50} + K_{50}$), showed the negative effects of GCSL application not only on the percentage of live leaves, but also on the other parameters of initial growth of dwarf coconut (Table 5).

The G_{100} treatment caused a reduction in the percentage of live leaves when compared to the treatments K_{100} and $G_{50} + K_{50}$ (Table 5). The lower percentage of live leaves in the $GL_{50} + K_{50}$ treatment compared to K_{100} indicates that the GCSL applied raw, even at a dose equivalent to 50% of mineral fertilization replacement, affected the dwarf coconut plants. Excess salts in the soil limit the absorption of water by the plant and consequently induce adaptive morphological changes against stress

(KUSVURAN, 2012). The loss of leaves in dwarf coconut plants is related to defense mechanisms, due to the decrease in water absorption caused by stress.

The absolute (AGR) and relative (RGR) growth rates of stem diameter of dwarf coconut decreased with the application of G_{100} and increased with the application of K_{100} and G_{50}+K_{50} (Table 5). Decrease in stem diameter is an adaptive response to adverse conditions aimed at reducing energy expenditure (LIU; JIANG, 2015). Stress-related impacts compromise the physiological processes of cell elongation and differentiation (NASCIMENTO *et al*., 2011), directly influencing stem diameter. Leaf dry mass (LDM), stem dry mass (SDM) and total dry mass (TDM) were also influenced by the application of K_2O sources (Table 5). The treatments K_{100} and G_{50} + K_{50} did not differ from each other, unlike the G_{100}, which caused reduction in the biomass of dwarf coconut plants. This decrease was more pronounced in LDM, for which G_{100} showed reductions of 46.4 and 35.1% compared to the treatments K_{100} and G_{50} + K_{50}, respectively.

In coconut, one of the first responses to stress caused by high salt contents is stomatal closure, which leads to low CO_2 influx, affecting photosynthetic capacity and, consequently, the accumulation of leaf biomass in the plant.

In relation to SDM, Silva *et al*. (2016) observed that the decrease in this biomass can occur through the diversion of energy to maintain metabolic activities capable of adapting to stress, to the detriment of plant growth. This is consistent with the results obtained, since plants grown under the G_{100} treatment showed 41.2% less stem biomass than plants grown under K_{100}. As the LDM and SDM of dwarf coconut plants grown under the treatments K_{100} and G_{50} + K_{50} stood out from those of the G_{100} treatment, consequently, they also had higher accumulation of total dry mass (TDM), with 44.0% (K_{100}) and 30.8% (G_{50} + K_{50}).

The higher percentage of live leaves, higher stem diameter and increase of biomass in these treatments constitute a response to the nutritional status of dwarf coconut. When comparing the treatments in which the same amounts of K_2O were applied, but in the form of GCSL (G_{100}), potassium chloride (K_{100}) and the association of sources (G_{50} + K_{50}), plants that received the association of G_{50} + K_{50} differed from those that were fertilized with K_{100} only in the contents of S and Mn. On the other hand, plants that received G_{100} had lower N, P, K, S, Na and Mn contents and higher B content than those fertilized with K_{100} (Table 6).

There was also influence of GCSL doses on the nutritional status of dwarf coconut plants (Table 7), only for the leaf contents of N, K, Na and Mn (Figures 3A, 3B, 3C and 3D). Plants grown under K_{100} and G_{50}+K_{50} did not differ from each other and showed higher leaf N content compared

Table 5 - Analysis of growth parameters of young dwarf coconut plants in response to the treatments G_{100}, K_{100} and G_{50} + K_{50}

	Treatments		p-value	Treatments		p-value	Treatments		p-value
	G_{100}	K_{100}		G_{100}	G_{50} + K_{50}		K_{100}	G_{50} + K_{50}	
NL	4.6 a	5.2 a	0.696	4.6 a	4.8 a	1.00	5.2 a	4.8 a	0.4360
LL	22.3 b	62.3 a	<0.001	22.3 b	42.7 a	0.042	62.3 a	42.7 b	0.049
HP	121.4 a	131.0 a	0.336	121.4 a	131.6 a	0.307	131.0 a	131.6 a	0.951
SD	25.7 a	28.7 a	0.093	25.7 a	28.3 a	0.143	28.7 a	28.3 a	0.819
AGR-PH	4.4^{e-03} a	5.6^{e-02} a	0.247	4.4^{e-03} a	3.6^{e-02} a	0.478	5.6^{e-02} a	3.6^{e-02} a	0.647
RGR-PH	2.7^{e-05} a	3.9^{e-04} a	0.294	2.7^{e-05} a	2.7^{e-04} a	0.474	3.9^{e-04} a	2.7^{e-04} a	0.734
AGR-SD	-1.2^{e-02} b	3.1^{e-02} a	0.007	-1.2^{e-02} b	6.0^{e-03} a	0.230	3.1^{e-02} a	6.0^{e-03} a	0.108
RGR-SD	-4.3^{e-04} b	1.1^{e-03} a	0.008	-4.3^{e-04} b	2.2^{e-04} a	0.246	1.1^{e-03} a	2.2^{e-04} a	0.112
LDM	30.2 b	56.4 a	0.001	30.2 b	46.6 a	0.034	56.4 a	46.6 a	0.191
SDM	23.4 b	39.8 a	0.004	23.4 a	31.0 a	0.156	39.8 a	31.0 a	0.120
TDM	53.7 b	95.8 a	0.015	53.7 b	77.6 a	0.007	95.8 a	77.6 a	0.193

Means followed by the same letter on the line do not differ by Tukey's test ($p < 0.05$); G_{100}: 100% of the recommended K_2O requirement for coconut in the form of GCSL; K_{100}: 100% of the recommended K_2O requirement for coconut in the form of KCl; G_{50} + K_{50}: 50% of the recommended K_2O requirement for coconut in the form of GCSL and 50% in the form of KCl; NL: number of leaves; LL (%): live leaves; PH (cm): plant height; SD (mm): stem diameter; AGR-PH (cm day^{-1}): absolute growth rate of plant height; RGR-PH (cm day^{-1}): relative growth rate of plant height; AGR-SD (mm day^{-1}): absolute growth rate of stem diameter; RGR-SD (mm day^{-1}): relative growth rate of stem diameter; LDM (g $plant^{-1}$): leaves dry mass; SDM (g $plant^{-1}$): stem dry mass; and TDM (g $plant^{-1}$): total dry mass to the G_{100} treatment. The application of higher doses of GCSL also reduced the N content in the leaves, reaching 8.4 g kg^{-1} in the G_{200} treatment (Figure 3A).

Considering that urea was applied in the same amount in all treatments, possibly the inhibition of nitrogen absorption by plants results from the increase in soil Cl^- concentration that accompanied the GCSL doses, in addition to the high C/N ratio of GCSL. Crisóstomo and Aragão (2011) determined that, among the anions, Cl^- is found at higher concentration in the effluent, with 3681.6 mg L^{-1}, and that it can thus compromise the absorption of N, due to the competition between Cl^- and NO_3^- for the same anion transport sites (FERREIRA NETO *et al*., 2014). Regarding the C/N ratio, the increase in GCSL doses contributes to the significant increase in organic matter (OM) content in the soil. When the C:N ratio of the residue is high (>25:1), the active microbial biomass removes the nitrogen necessary for the decomposition of the residue by the soil or microorganisms, consequently the residue decomposition rate decreases (KRIAUCIUNIENE *et al*., 2018), and this can be attributed to the GCSL, which has high C:N ratio (Table 1).

There was no difference between the leaf contents of K in dwarf coconut plants cultivated under the treatments K_{100} and G_{50} + K_{50}; however, the G_{100} treatment showed lower leaf content of K, despite providing greater quantity of the element in the soil (Table 3). Excess salts reduce the potential gradient between the soil and the root, by increasing the osmotic potential of the soil, leading to a situation in which the plant does not have satisfactory force of suction to absorb water and nutrients even in moist soil (DUARTE; SOUZA, 2016; KUSVURAN, 2012; RAMEGOWDA; KUMAR, 2015).

Table 6 - Leaf contents of nutrients and sodium in young dwarf coconut plants in response to the treatments G_{100}, K_{100} and G_{50}+K_{50}

	Treatments		p- value	Treatments		p-value	Treatments		p-value
	G_{100}	K_{100}		G_{100}	G_{50} + K_{50}		K_{100}	G_{50} + K_{50}	
N	11.4 b	14.7 a	0.008	11.4 b	11.6 a	0.863	14.7 a	11.6 a	0.863
P	0.9 b	1.3 a	0.014	0.9 a	1.1 a	0.337	1.3 a	1.1 a	0.115
K	4.3 b	10.7 a	0.003	4.3 b	8.9 a	0.029	10.7 a	8.9 a	0.380
Ca	2.6 a	3.0 a	0.116	2.6 a	2.5 a	0.688	3.0 a	2.5 a	0.052
Mg	2.3 a	2.3 a	0.913	2.3 a	2.3 a	0.913	2.3 a	2.3 a	0.827
S	0.9 b	1.1 a	0.002	0.9 a	0.9 a	0.788	1.1 a	0.9 b	0.002
Na	0.8 b	2.2 a	0.001	0.8 b	1.8 a	0.015	2.2 a	1.8 a	0.388
Cu	7 a	6 a	0.165	7 a	5 b	0.024	6 a	5 a	0.350
Fe	238 a	169 a	0.059	238 a	202 a	0.313	169 a	202 a	0.355
Zn	16 a	14 a	0.538	16 a	16 a	0.905	14 a	16 a	0.579
Mn	48 b	95 a	<0.001	48 b	68 a	0.027	95 a	68 b	0.004
B	19 a	15 b	0.046	19 a	17 a	0.386	16 a	18 a	0.236

Means followed by the same letter on the line do not differ by Tukey's test ($p < 0.05$); G_{100}: 100% of the recommended K_2O requirement for coconut in the form of GCSL; K_{100}: 100% of the recommended K_2O requirement for coconut in the form of KCl; G_{50} + K_{50}: 50% of the recommended K_2O requirement for coconut in the form of GCSL and 50% in the form of KCl; N (g kg^{-1}): nitrogen; P (g kg^{-1}): phosphorus; K (g kg^{-1}): potassium; Ca (g kg^{-1}): calcium; Mg (g kg^{-1}): magnesium; S (g kg^{-1}): sulfur; Na (g kg^{-1}): sodium; Cu (mg kg^{-1}): copper; Fe (mg kg^{-1}): iron; Mn (mg kg^{-1}): manganese; and B (mg kg^{-1}): boron

Table 7 - Leaf contents of nutrients in young dwarf coconut plants in response to GCSL doses

SV	N	P	K	Ca	Mg	S
GCSL	5.65**	2.07^{ns}	12.06**	1.27^{ns}	1.68^{ns}	1.10^{ns}
p-value	<0.01	0.122	<0.01	0.315	0.194	0.385
CV (%)	14.79	33.49	41.67	15.73	12.95	14.28
SV	Na	Cu	Fe	Zn	Mn	B
GCSL	4.69**	0.64^{ns}	1.30^{ns}	1.72^{ns}	4.86**	0.51^{ns}
p-value	<0.01	0.641	0.304	0.184	<0.01	0.725
CV (%)	48.12	23.04	23.13	30.80	16.97	17.88

^{ns}: not significant; ** and *: significant by Tukey at 1% and 5% probability, respectively. N: nitrogen; P: phosphorus; K: potassium; Ca: calcium; Mg: magnesium; S: sulfur; Na: sodium; Cu: copper; Fe: iron; Mn: manganese; and B: boron. CV: coefficient of variation; SV: source of variation

This effect can also be attributed to the increase in the electrical conductivity of the soil (Table 3) because, when the plant is under stress condition, part of the energy used for nutrient absorption is diverted to adapt to the adverse environment to which it is subjected (TAIZ *et al*., 2017).

The absence of difference in leaf K content or its decrease in the G_{100} treatment can be explained by Silva *et al*. (2009a), who stated that the effects of reductions in K^+ content are much more intense in the roots than in the leaves, since they are directly exposed to salts.

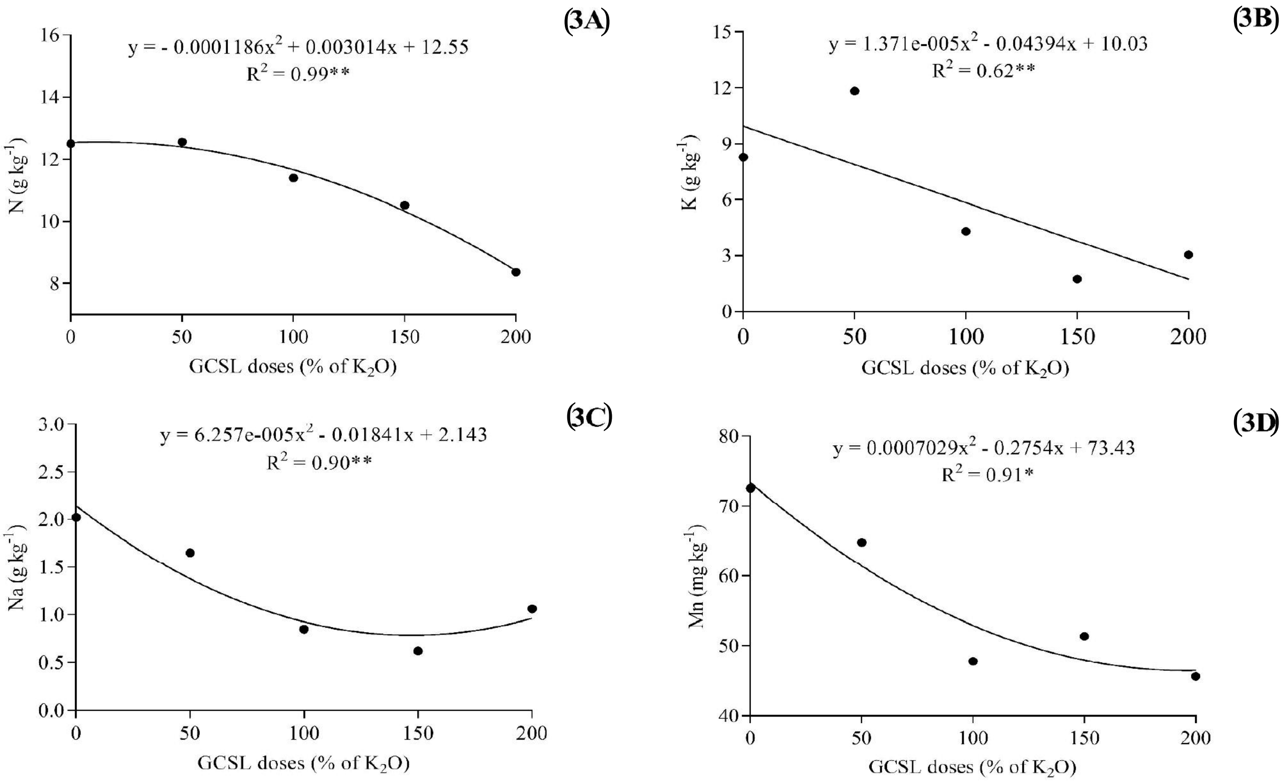
The increase in GCSL doses caused reduction in the K content in the leaves (Figure 3B), indicating that its absorption by the plant decreased, even with the greater availability of this nutrient in the soil (Figure 4A). The possibility of potassium dilution effect in the leaves was ruled out, since there was no difference in leaf dry mass production with the increase in GCSL doses (Table 4). Despite the low concentration of K^+ in the soil, plants of the G_0 treatment had leaf content higher than those of plants treated with the highest doses of GCSL.

Plants of the G_{100} treatment showed lower P content in the leaves compared to those under K_{100} (Table 6), but all treatments remained below the critical content of 1.5 g kg^{-1} established for adult dwarf coconut plants (SOBRAL *et al*., 2009). It should be pointed out that no symptoms of P deficiency were verified and, therefore, the lower values of the element can be explained by the difference in leaf sampling, since in the experiment all leaves of the young dwarf coconut plant were analyzed, while Sobral *et al*. (2009) recommend the collection of leaf 9 in adult plants.

As for the Ca and Mg contents in the leaves, there was no difference between the treatments, suggesting that the amounts found in the soil are considered adequate to nutritionally supply the dwarf coconut crop in this vegetative stage, despite the decrease in Ca^{2+} concentration in the soil (Figure 4B) and the increase in Mg^{2+} concentration (Figure 4C).

The increase in GCSL doses also reduced the absorption of Na by the dwarf coconut plants (Figure 3C); although the GCSL dose in which 116% of the K_2O recommendation was applied contributes to the highest Na concentration in the soil (Figure 4D), the highest doses of GCSL resulted in lower leaf contents of Na. The Na content in the leaves was higher in the treatments K_{100} and G_{50} + K_{50} than in G_{100} (Table 6). Sobral *et al.* (2009) found that the critical level of Na for the adult dwarf

Figure 3 - Leaf contents of nitrogen (3A), potassium (3B), sodium (3C) and manganese (3D), in response to GCSL doses applied in young dwarf coconut plants



coconut plant is 1.5 g kg^{-1}; therefore, only G_{50} + K_{50} and K_{100} would be adequately supplying the plant with this element. It is important to highlight that Na is an important element for palm trees, unlike other crops, as it stimulates production and development processes (FERNANDES; MATOS; CARVALHO, 2013). Lima *et al*. (2017), working with irrigation water salinity in dwarf coconut seedlings, verified that there was high accumulation of Na in the roots, while its content in the shoots remained low, even at the highest levels of salinity. The effect of salinity on coconut may be more harmful due to physical damage, such as the decrease in the amount of water available to plants, than due to direct damage caused by toxic effect on plants (SILVA *et al*., 2018).

Mn contents in the leaves differed between the treatments, with values 49.7 and 28.4% lower in the treatments G_{100} and G_{50} + K_{50}, respectively, compared to K_{100} (Table 6), hence also below the content found by Valicheski *et al.* (2011). This result was expected because the Mn^{2+} concentrations in the soil (Table 4) in the treatments G_{100} and G_{50} + K_{50} were 71.4 and 50.0%, respectively, lower than in K_{100}. Thus, there was also low availability of this nutrient in the soil, as a consequence of the application of GCSL at higher doses (Figure 5C), resulting in a decrease in its leaf content (Figure 3D). It is likely that the decrease in Mn^{2+} availability also occurred in response to the excess of Fe supplied to the soil (DECHEN *et al*., 2018). GCSL has average Fe and Mn concentrations of 22 and 1 mg L^{-1}, respectively (Table 1). Considering that, at the highest dose of GCSL, 32 L were applied per pot, in each application the supplies of Fe and Mn were 704 and 32 mg, respectively. Indeed, the application of GCSL doses promoted increases in Cu and Fe concentrations in the soil (Figures 5A and 5B).

The application of G_{100} increased the B content in the leaves compared to K_{100} (Table 6), which was even above the critical level (17 g kg^{-1}) proposed by Sobral *et al*. (2009) for adult plants. According to Babu *et al*. (2018), depending on the amount of K absorbed, there is a marked decrease of B in coconut leaves, due to a possible negative interaction between B and K, explained by the higher K content in the K_{100} treatment.

Based on the results, it was found that raw GCSL caused changes in soil fertility that resulted in lower development of young dwarf coconut plants. However, the application of GCSL associated with potassium chloride resulted in the growth of dwarf coconut plants similar

Figure 4 - Concentrations of potassium (A), calcium (B), magnesium (C) and sodium (D) in the Arenic Haplustults, in response to the GCSL doses applied in young dwarf coconut plants

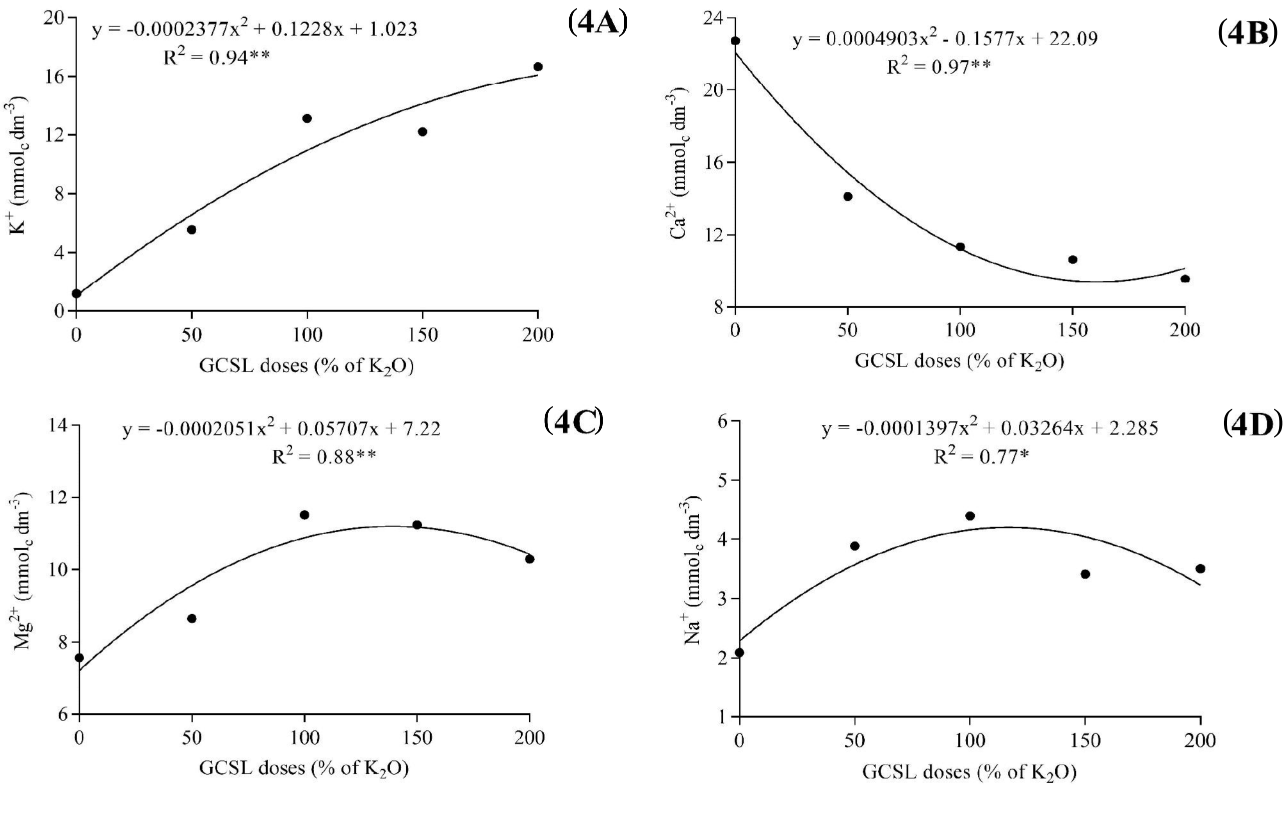
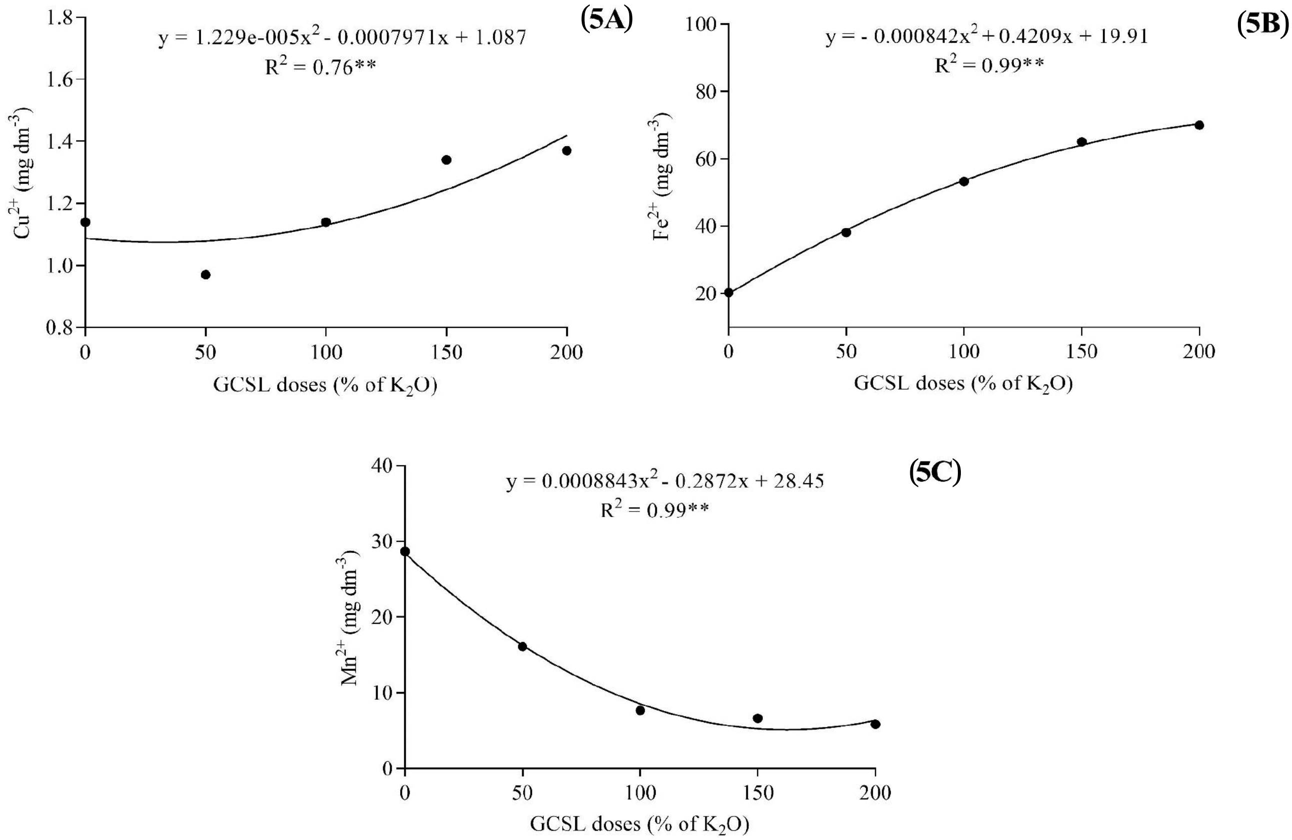


Figure 5 - Concentrations of copper (5A), iron (5B) and manganese (5C) in Arenic Haplustults, in response to GCSL doses applied in young dwarf coconut plants



to that promoted by mineral fertilizer. These results are important to support the production sector regarding the potential use of GCSL as a source of potassium in dwarf coconut cultivation, allowing the replacement of 50% of the mineral fertilizer with GCSL. Considering the large amount and diversity of residues generated in the processing of coconut shell, this study generated relevant information about the potential use of green coconut shell liquid as a source of potassium for the dwarf coconut crop. The use of green coconut shell liquid in agriculture can be a form of correct disposal of this effluent, provided that the applied dose is defined based on safe criteria, such as the potassium recommendation for the crop.

CONCLUSIONS

The use of raw green coconut shell liquid promotes changes in the availability of nutrients in the soil, affecting the development and nutritional status of young dwarf coconut plants. The combination of green coconut shell liquid with potassium chloride promotes the growth of dwarf coconut similar to that promoted by the single application of mineral fertilizer. Green coconut shell liquid can replace 50% of the K_2O dose recommended for the first year of dwarf coconut cultivation.

ACKNOWLEDGMENTS

The authors thank the Coordination for the Improvement of Higher Education Personnel (CAPES) for granting the scholarship to the first author. Thank to Embrapa Tropical Agroindustry for financial support and the infrastructure provided, and Paraipaba Agroindustrial for the supply of green coconut husk liquid, source of study.

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