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Full Length Research Paper

Effect of gypsum application on agro-energy performance of sugarcane varieties cultivated in a semi-arid environment

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Brazilian semi-arid soils can be dystrophic and often occur in areas with high agricultural potential. Gypsum application improves chemical and physical soil conditions, favoring root system development of plants and can improve sugarcane production for energy production, as a strategy for sustainable development, avoiding native vegetation destruction in semi-arid regions. This study aimed to analyze the impact of gypsum application on the agro-energy potential of three sugarcane varieties, through MS production, moisture, neutral detergent fiber (NDF), acid detergent fiber (ADF), lignin, ash and gross calorific value (GCV). The experimental design consisted of 3 (varieties) x 2 (with and without gypsum) over two sugarcane growing periods in a completely randomized block design with four replications. The application of gypsum did not affect the tested agro-energy variables. GCV ranged around 17 MJ kg^{-1}, confirming the suitability of the varieties for bioenergy use in semi-arid regions, but there were no significant differences between sugarcane varieties.

Key words: Bioenergy, *Saccharum* spp, gross calorific value, oxisoils; soil amendments.

INTRODUCTION

The search for more efficient, sustainable and renewable energy production has led to global interest in energy from biomass (Katinas et al., 2007; Liu et al., 2013; Scarlat et al., 2013; Sajdak et al., 2014; Pérez et al., 2014). Fossil fuels are being replaced because they are finite sources and civilization needs to decrease greenhouse gases to reduce climate change impact (Sheng et al., 2005; Shuit et al., 2009; Shen et al., 2010).

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Brazil stands out as a major producer of renewable energy sources, mainly ethanol production from sugarcane, eucalyptus charcoal, electricity cogeneration from sugarcane bagasse, biomass in pulp and paper industry, waste from trees and second-generation ethanol (Goldemberg and Lucon, 2007). However, growth of economic activity is causing natural vegetation devastation and environmental degradation, as in the "Caatinga" biome, due to the use of extracted wood as an energy source for industries.

To minimize effects of this devastation, studies have been performed to improve the production of biomass for energy generation, to assure the survival and volume of exotic and native species (Barros et al., 2010) and increase volumetric efficiency and energy of eucalyptus clones (Gadelha et al., 2012). However, the material used has to have high biomass production capacity and suitable characteristics for power generation. Confirmation of the suitability of material for the production of biomass energy depends on the study of fiber, lignin and moisture content and calorific value (Vale et al., 2000), whose levels can vary within species, age, part of plant and/or interferences caused by cultivation practices (Decruyenaere et al., 2009).

Sugarcane stands out for its high dry matter production (Santos et al., 2012). However, its exploitation occurs mainly in more humid regions or in irrigated areas. The "Chapada do Araripe" area (Araripina, Pernambuco, Brazil), although in semi-arid region, is an exception, having deep soils with better water storage capacity and more suitable topography to grow sugarcane and other grasses to replace natural vegetation (Santos et al., 2012). However, the soils in this region are poor due to base leaching, high acidity and high aluminum saturation (Ribeiro-Silva et al., 2012). Limitations caused by subsoil acidity limit agricultural productivity, particularly root system growth, with direct effects on water and nutrient absorption (Miguel et al., 2010).

In the "Chapada do Araripe" area, the Araripe sedimentary basin stands out as the producer of most of Brazil's gypsum, which has many industrial and agriculture applications (Rocha et al., 2008). Gypsum application adds calcium to soil, can reduce aluminum saturation in depth, and promotes root development so plants can access water and nutrients in deeper soil profiles (Ernani et al., 2001; Rocha et al., 2008; Carvalho et al., 2013). With improvement of root development, sugarcane can produce more biomass (Silva et al., 2011) and, consequently, improve its potential for power generation, because an increase in dry matter production leads to an increase in gross calorific value (Liu et al., 2013).

This study aimed to analyze the impact of gypsum application on agro-energy potential of three sugarcane varieties, through production of dry matter, neutral detergent fiber, acid detergent fiber, lignin and ash as well as moisture content and gross calorific value.

Table 1. Chemical and physical characteristics of Oxisol.

Soil Attributes	Depth (m)	
	0.0 – 0.2	**0.2 – 0.4**
pH [(1)]	4.85	4.54
Ca^{2+} ($cmol_c\ dm^{-3}$) [(2)]	0.95	0.30
Mg^{2+} ($cmol_c\ dm^{-3}$) [(2)]	0.68	0.38
K^{+} ($cmol_c\ dm^{-3}$) [(4)]	0.14	0.09
Na^{+} ($cmol_c\ dm^{-3}$) [(5)]	0.23	0.24
P ($mg\ dm^{-3}$) [(6)]	4.00	1.00
Al^{3+} ($cmol_c\ dm^{-3}$) [(7)]	0.37	0.70
(H + Al) ($cmol_c\ dm^{-3}$) [(8)]	3.74	3.27
TOC ($g\ kg^{-1}$) [(9)]	8.1	5.2
$S\text{-}SO_4^{-2}$ ($mg\ dm^{-3}$) [(10)]	1.83	0.69
Argila ($g\ kg^{-1}$) [(11)]	136.38	133.97
Ds ($kg\ dm^{-3}$) [(12)]	1.43	1.41
K_0 ($mm\ h^{-1}$) [(13)]	65.24	92.83

[1]Water (1:2.5); [2.3.7]KCl 1 mol L-1; [4.5.6]Mehlich-1; [8]$Ca(OAc)_2$ 0.5 mol L^{-1} pH 7; [9]Total organic carbon - $K_2Cr_2O_7$ 0.167 mol $^{L-1}$; [10]Alvarez et al. (2001); [12]Soil density – Ruiz (2004); [13]Saturated hydraulic conductivity – Embrapa (1997).

MATERIALS AND METHODS

Environmental particulars

The experiment was carried out under field conditions during February 2010 to April 2012, in Araripina (latitude: 07° 27'37 "S, longitude: 40° 24'36"W; altitude: 831 m) Pernambuco, Brazil. The predominant vegetation is classified as hyperxerophilic "Caatinga" with deciduous forest stretches. Climate is 'Bshw' type in the Köppen classification (Peel et al., 2007). The soil used was classified as an Oxisol (Table 1).

Plant material and experimental characteristics

Three varieties of sugarcane (RB867515, RB92579 and RB962962) were grown with (495 kg ha^{-1}) and without (0 kg ha^{-1}) gypsum ($CaSO_4\ 2H_2O$), applied within the furrows on the depth of 0.3m. Calculation was based on lime requirement for 0.2 to 0.4 m depth according to exchangeable aluminum neutralization, considering the high percentage of aluminum saturation in this layer, with values greater than 30% (Alvarez et al., 1999). The experiment used a completely randomized block design with four replications in 3 x 2 factorial split plots. The experimental plot consisted of 7 rows with 6 m length and 1 m spacing, totaling 42 m^2. The area used was 6 m^2 in the center of each plot. RB867515, RB92579 and RB962962 varieties were selected because they are considered to have high fiber content, and RB962962 is recommended for areas with scarce water (RIDESA, 2010).

Along with soil analysis, correction and fertilization was performed, with application of 550 kg ha^{-1} of dolomitic limestone, incorporated with a disc harrow in the layer from 0.0 to 0.2 m (IPA, 2008), along with 300 kg ha^{-1} of ammonium sulfate, 286 kg ha^{-1} of triple superphosphate and 150 kg ha^{-1} of potassium chloride. The triple superphosphate was applied at planting, while ammonium sulfate and potassium chloride were split (1/3 at planting and 2/3 seventy days afterwards). Planting was done eight days after gypsum application (IPA, 2008).

The experiment covered two growing seasons (14 months after planting and 12 months after the first harvest). In the second growing period, fertilization was not performed. Rainfall in the first and second seasons was 899.7 mm and 412.9 mm, respectively. Samples were obtained of 10 whole plants (stem + leaves + tips) in each plot. The number of tillers in each area was counted and then weighed for fresh matter (mg ha^{-1}). After that, the samples were crushed and 1 kg was removed to dry at 65°C until constant weight.

Measurement of variables

The variables analyzed were: moisture, production of dry matter, neutral detergent fiber (NDF), acid detergent fiber (ADF), lignin and ash and gross calorific value (GCV). Dry matter production and moisture were obtained after drying samples. NDF, ADF and lignin determinations were according to Silva and Queiroz (2002).

Insoluble ash was determined in lignin samples after lignin determination. Weighed samples were placed in dried and weighed porcelain crucibles, which were in turn placed inside a muffle furnace at 500°C for 3 h. Ash quantification was performed at room temperature by weight difference before and after combustion (Rech, 2010; Silva and Queiroz, 2002). GCV was determined according to the NBR 8633/84 standard from the Brazilian Association of Technical Standards (ABNT). The determination was performed with 0.5 g of dried and ground sample, placed in a porcelain crucible in a combustion chamber (IKA calorimeter, model C2000). Reading was in MJ kg^{-1} of released energy by each variety.

Statistical analysis

Statistical analyses, including analysis of variance (ANOVA), were performed using the SISVAR 3.01 software (Ferreira, 2011). Based on the significance of the F-test, the Tukey test was applied for a comparison of the means at $P < 0.05$ significance level.

RESULTS AND DISCUSSION

Moisture and dry matter production

Gypsum application did not affect the moisture and dry matter production of sugarcane varieties for the two harvests (Table 2). However, there was more moisture in RB962962 variety than in others during the second harvest (Table 2). This difference is probably due to genetic factors, morphological characteristics that can influence conversion of solar radiation into dry matter and/or water availability and temperature conditions (Bonnett et al., 2006).

Rainfall during the second growing season was lower than in the first. RB962962 has better ability to maintain water content in tissue, with is recommended for drought areas (RIDESA, 2010). However, biomass energy efficiency is related negatively with moisture (Furtado et al., 2012; Sajdak et al., 2014).

The need for evaporation of extra water present in biomass will consume part of total energy released upon combustion and reduce plant material calorific value, with consequent reduction in agro-energy performance (Quirino et al., 2005).

Neutral detergent fiber (NDF), acid detergent fiber (ADF) and lignin

Gypsum application did not affect the content of NDF, ADF and lignin for the two harvests (Table 3). The only differences between varieties were: NDF content in RB92579 was greater than in RB962962 in the second harvest; ADF content in RB867515 was greater than in RB92579 in the first harvest; and FDA content was lower for RB92579 in the second harvest. Lignin content remained the same among varieties (Table 3).

Similar results were described by Oliveira et al. (2012), when analyzing NDF, ADF and lignin contents in four sugarcane varieties (RB72454, RB867515, RB855536 and IAC86-2480). The values were not statistically different and average levels were similar to this experiment. ADF is basically made up of lignocellulosic material, where the pulp accounts for the largest fraction (Santos et al., 2012). The ADF concentrations quantified were above the 52% threshold suggested by Samson et al. (2005) for material used as an energy source. However, lignin contents were below the 10% indicated by McKendry al. (2002). Despite having high production and adequate fiber levels (RIDESA, 2010), the three varieties tested are mainly recommended for sugar production, as opposed to fibrous varieties from Cuba.

Lignin is the component richest in carbon, making sugarcane stems the best part for energy production (Samson et al., 2005; Moore et al, 2013). However, during field experimentation after full stem growth, water stress acted to reduce the lignin content of the three varieties.

Ash content and gross calorific value (GCV)

Ash and GCV were not changed by gypsum application in the two harvests (Table 4). Ash contents also did not vary between varieties, but GCV changed in both growth periods. In the first, RB92579 showed greater GCV than RB962962, while in the second, the GCV of RB962962 was greater than RB867515 (Table 4).

According to Flowers et al. (2012), the average ash content found in stems and leaves of elephant grass genotypes developed for energy purposes are between 6.9 and 5.8% in stems and 9.84 and 9.84% in leaves. The values in the three sugarcane varieties were between 2.01 and 2.49% (Table 4). However, low ash content is a positive feature for use of sugarcane biomass for energy purposes. The most important parameter to characterize a material's combustion is GCV, and this is inversely proportional to ash content (Liu et al., 2013) and moisture (Furtado et al., 2012; Sajdak et al., 2014).

Combustion conditions, variety, nutrition, soil and climatic conditions and grinding efficiency for sugarcane can influence ash concentration and other characteristics

Table 2. Moisture and shoot dry matter production (SDM) of three varieties of sugarcane in the presence and absence of gypsum in first and second harvests.

Factor	Moisture		Average	SDM		Averege
	With Gypsum	No Gipsum		With Gypsum	No Gipsum	
Varieties			*1º harvest*			
RB867515	78.04	72.79	75.42a	15.76	16.72	16.24a
RB92579	72.73	71.03	71.88a	20.92	21.75	21.34a
RB962962	74.87	73.17	74.02a	24.78	29.33	27.06a
Average	75.21A	72.33A		20.49A	22.60A	
		F			*F*	
Varieties		0.98 [ns]			4.05 [ns]	
Gypsum		1.93 [ns]			1.51 [ns]	
*Varieties*Gypsum*		0.32 [ns]			0.50 [ns]	
C.V. Portion (%)		6.88			35.30	
Subplot C.V. (%)		6.90			9.57	
Varieties			*2º harvest*			
RB867515	69.31	70.75	70.03b	12.51	8.31	10.41a
RB92579	66.68	67.39	67.03b	6.97	5.95	6.46a
RB962962	76.21	75.67	75.94a	10.79	9.25	10.02a
Average	70.73A	71.27A		10.09A	7.84A	
		F			F	
Varieties		36.04 *			3.56 [ns]	
Gypsum		0.48 [ns]			4.33 [ns]	
*Varieties*Gypsum*		0.56 [ns]			0.83 [ns]	
C.V. Portion (%)		3.01			36.41	
Subplot C.V. (%)		2.66			29.56	

Means followed by the same lowercase letter in each sub-column and capital letters in the same row for each plant harvest are not significant at 5% probability according to the Tukey test. *Significant; [NS]Not significant.

(Turn, 2003). According to Liu et al. (2013), differences in ash content can occur due to mineral composition of plant material and this change GCV. Results for GCV in sugarcane stems noted in previous studies were 18.87 MJ kg^{-1} found by Ripoli et al. (1991) and ranged from 14 to 22 MJ kg^{-1} as described by Quirino et al. (2005) for species appropriate for energy production. In addition, the values found in this study are very close to those found in studies of other species used for energy purposes (Queno et al., 2011; Flores et al., 2012).

Calorific value is the most important parameter for biomass production and hence for energy purposes (Liu et al., 2013), but it needs to be combined with high DM production. The varieties tested did not differ in SDM production (Table 2) and in response to gypsum application, although this application affected cation percolation and improved the root environment (Ernani et al., 2001; Carvalho et al., 2013). Gypsum application also did not affect sugarcane productivity. However, there was a change in GCV between varieties (Table 4), showing that other studies should be conducted to select adequate varieties for use as biomass for energy production, because combustion, variety, nutrition conditions, soil, climate and grinding may have influenced the varieties' response.

Conclusion

The three varieties tested are viable for bioenergy use in semi-arid conditions, due to NDF, ADF, lignin and GCV values found. Appropriate GCV values, around 17 MJ kg^{-1}, and high fiber content, mean these varieties can be used for energy production in semi-arid environment instead of natural vegetation. However, gypsum application was not an effective practice and did not contribute to improvement of the evaluated parameters, probably due to low rainfall recorded in the trial period.

Table 3. Neutral detergent fiber (NDF). acid detergent fiber (ADF) and lignin of three varieties of sugarcane in the presence and absence of gypsum in first and second harvests.

Factor	NDF		Average	ADF		Average	Lignin		Average
	With Gypsum	No Gipsum		With Gypsum	No Gipsum		With Gypsum	No Gipsum	
	....	....	....	....	%	....	....	....	....
Varieties					1º Harvest				
RB867515	67.21	66.01	66.61^{ab}	58.24	58.30	58.27^{a}	4.02	3.88	3.95^{a}
RB92579	70.95	69.81	70.38^{a}	56.08	56.12	56.10^{b}	3.48	3.39	3.44^{a}
RB962962	65.53	64.60	65.07^{b}	57.76^{a}	57.92	57.84^{ab}	4.87	4.13	4.50^{a}
Average	67.90^{A}	66.81^{A}		57.36^{A}	57.45^{A}		4.12^{A}	3.80^{A}	
		F			F			F	
Varieties		5.41*			7.96 *			3.87 ^{ns}	
Gypsum		0.37 ^{ns}			0.05 ^{ns}			1.07 ^{ns}	
*Varieties*Gypsum*		0.002 ^{ns}			0.008 ^{ns}			0.45 ^{ns}	
C.V. Portion (%)		4.94			2.01			19.43	
Su plot C.V. (%)		6.54			1.77			19.40	
Varieties					2º H^{a}rvest				
RB867515	75.75	68.38	72.07^{a}	55.32	54.09	54.71^{a}	3.17	1.96	2.57^{a}
RB92579	76.40	76.92	76.66^{a}	52.65	53.51	53.08^{b}	3.01	3.45	3.23^{a}
RB962962	72.41	72.56	72.49^{a}	54.55	55.17	54.86^{a}	3.01	3.79	3.40^{a}
Average	74.85^{A}	72.62^{A}		54.17^{A}	54.26^{A}		3.06^{A}	3.07^{A}	
		F			F			F	
Varieties		3.65 ^{ns}			15.77 *			0.97 ^{ns}	
Gypsum		2.12 ^{ns}			0.03 ^{ns}			0.00 ^{ns}	
*Varieties*Gypsum*		2.81 ^{ns}			1.98 ^{ns}			0.98 ^{ns}	
C.V. Portion (%)		5.10			1.30			41.31	
Subplot C.V. (%)		5.09			2.12			49.51	

Means followed by the same lowercase letter in each sub-column and capital letters in the same row for each harvest are not significant at 5% probability according to the Tukey test. *Significant; ^{NS} Not significant.

Table 4. Ash and gross calorific value (GCV) of three varieties of sugarcane in the presence and absence of gypsum in first and second harvests

Factor	Ash		Average	GVC		Average
	With Gypsum	No Gipsum		With Gypsum	No Gipsum	
	dag kg^{-1}			MJ kg^{-1}		
Varieties			*1º harvest*			
RB867515	2.01	2.46	2.24^{a}	17.75	17.13	17.44^{ab}
RB92579	2.37	2.18	2.28^{a}	17.37	18.41	17.89^{a}
RB962962	2.30	2.17	2.24^{a}	16.99	16.89	16.94^{b}
Average	2.23^{A}	2.27^{A}		17.37^{A}	17.48^{A}	
		F			*F*	
Varieties		1.00^{ns}			9.58 *	
Gypsum		0.91 ^{ns}			0.11 ^{ns}	
*Varieties*Gypsum*		0.60 ^{ns}			2.38 ^{ns}	

Table 4. Contd.

C.V. Portion (%)		50.49			2.48	
Subplot C.V. (%)		31.16			4.43	
Varieties				*2º harvest*		
RB867515	2.41	2.45	2.45^{a}	17.43	17.08	17.26^{b}
RB92579	2.29	2.29	2.31^{a}	17.35	17.52	17.44^{ab}
RB962962	2.28	2.38	2.33^{a}	18.46	17.37	17.92^{a}
Average	2.36	2.36		17.75^{A}	17.32^{A}	
		F			F	
Varieties		0.79^{ns}			7.36 *	
Gypsum		0.99^{ns}			4.12^{ns}	
*Varieties*Gypsum*		0.29^{ns}			3.12^{ns}	
C.V. Portion (%)		7.81			2.30	
Subplot C.V. (%)		12.24			2.49	

Means followed by the same lowercase letter in each sub-column and capital letters in the same row for each harvest are not significant at 5% probability according to the Tukey test. * Significant; ns Not significant.

Conflict of Interests

The authors have not declared any conflict of interests.

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Gas exchange in castor bean cultivars in response to foliar application of potassium silicate

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Since silicon and potassium are nutrients that influence plant physiological and biochemical aspects, the combined use of these minerals in the fertilization of cultivated plants has been increasingly investigated. This study aimed to evaluate the gas exchanges (Net photosynthesis, Stomatal conductance, Transpiration, Water use efficiency, Carboxylation efficiency, Internal carbon concentration, Chlorophyll *a*, *b*, total, Carotenoids and the Chlorophyll *a/b* ratio) of three castor bean cultivars in response to the foliar application of potassium silicate (PS). The assay in design of randomized blocks, was conducted in a factorial 5 × 3, five doses of potassium silicate (0; 222; 444; 665 and 836 mg L^{-1}) and three varieties of castor bean (BRS Energia, BRS 149 Nordestina and BRS 188 Paraguaçu), with three replications and 45 plants per. The promising effects of foliar fertilization using PS in castor bean plants depend on the genotype. Foliar application of PS increases photosynthetic capacity, stomatal conductance, water use efficiency, chlorophyll *a*, *b*, total, carotenoids and the chlorophyll *a/b* ratio, besides reducing water losses through transpiration.

Key words: Foliar spraying, Photosynthesis, *Ricinus communis* L., Silicate fertilization

INTRODUCTION

The area planted with castor bean (*Ricinus communis* L.) has increased over time due to its importance both for industry and for the biofuel production. Currently, it has emerged as an alternative for the production of energy, representing an excellent possibility for the reduction in the use of non-renewable energy sources.

In this context, in the 2013/2014 season, the production estimate reached 64.4 thousand tons to be harvested in

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an area of 105.9 thousand hectares, with a mean yield of 608 kg ha^{-1} (Conab, 2014). The stimulating prices, combined with good climatic conditions in most of the producing states, justify this increase.

Castor bean fertilization is a practice that, in the last crop seasons, has attracted a lot of interest, due to the increasing prices of fertilizers, because it is considered a nutrient-demanding crop (Brito Neto et al., 2014), which requires high amounts of fertilizers in order to obtain high yields. In this sense, the search for more efficient, low-cost alternatives, especially regarding the acquisition of fertilizers, has attracted the attention of research agencies, farmers and the scientific community.

As an alternative to improve plant nutritional status and its entire physiological apparatus, the use of silicon-based products has been considered, since this mineral is able to increase plant resistance against attacks of pests (Meena et al., 2014), nematodes (Marafon and Endes, 2013), bacteria and fungi (Guerra et al., 2014), minimizing production costs caused by the demand of pesticides. In addition, fertilization with potassium silicate can also influence some aspects of photosynthetic efficiency (Xie et al., 2014) and increase crop yield (Yogendra et al., 2014), among other factors.

According to the literature (Souza et al., 2010; Lalithya et al., 2014; Sarto et al., 2014), the beneficial effects of potassium silicate can be attributed to the joint action of Si and K on plant nutrition and production. According to Amaral et al. (2008) and Pinto et al. (2012), foliar application of potassium silicate in coffee and cocoa plants promoted greater covering of the leaf tissue because of Si precipitation and polymerization close to leaf cuticle, ensuring lower incidence of diseases and higher production and quality of the final product. For not being in the composition of organic compounds and not developing any structural function in plants (Hussein et al., 2014), K participates in the activation of enzymes such as synthetases, oxidoreductases, dehydrogenases, transferases, kinases, aldolases and rubisco (Catuchi et al., 2012), a key enzyme in the photosynthetic process.

This study aimed to evaluate the gas exchanges (net photosynthesis, stomatal conductance, transpiration, water use efficiency, carboxylation efficiency, Internal carbon concentration, chlorophyll *a*, *b*, total, carotenoids and the chlorophyll *a*/*b* ratio) of three castor bean cultivars in response to the foliar application of potassium silicate.

MATERIALS AND METHODS

The experiment was carried out under field conditions from June 2011 to December 2011, at the National Center for Research on Cotton of the Brazilian Agricultural Research Corporation (Embrapa - Cotton), located in Campina Grande, Paraíba, Brazil (7°13'1" S; 35°52'31" W; 551 m). According to Köppen climate classification, the climate of the study area is As, hot and humid with rains during autumn and winter. The rainy period occurs from April to July and the average annual rainfall is 800 mm (1974-2004). The maximum and minimum average annual temperatures are around 28.7 and 19.8°C, with small variation throughout the year (Coelho and Soncin, 1982).

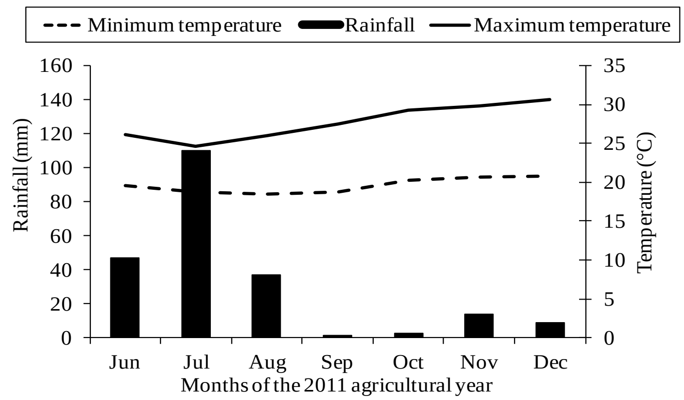

Figure 1. Maximum and minimum temperatures (°C) and rainfall (%) recorded during the conduction of the experiment, Embrapa Cotton, Campina Grande, PB.

During the conduction of the experiment, maximum and minimum temperatures and the rainfall of the studied area were daily recorded by a weather station (Figure 1).

The soil in the area is classified as dystrophic Regolithic Neosol, of sandy-loam texture (Embrapa, 2006). Soil samples were collected for the analysis of chemical attributes in the layer of 0-20 cm, under the canopy projection (Table 1). The samples were homogenized and analyzed in the Laboratory of Water and Soils of the Embrapa Cotton.

Crop fertilization followed the recommendations of the Laboratory of Soil Analysis of Embrapa Cotton, which indicated the application of 20 kg ha^{-1} of N and 30 kg ha^{-1} of P_2O_5, as urea and single superphosphate, respectively. Basal and topdressing fertilizations were performed 15 days after the emergence of the seedlings (DAE), by applying phosphate fertilizer directly into 30-cm depth in semicircular furrows. Nitrogen fertilization was divided into three doses; the first topdressing at 15 DAE and the second and the third applications at 30 and 45 DAE, respectively.

The experiment was set in a randomized block design and the treatments were distributed in a 5 × 3 factorial scheme, represented by five doses of potassium silicate (PS) (0, 222, 444, 665 and 836 mg L^{-1}) and three castor bean cultivars (BRS Energia, BRS 149 Nordestina and BRS 188 Paraguaçu), in three replicates. A spacing of 0.5 m between plants and 1.0 m between rows was used, totaling 45 plants per plot. Only the central rows were considered for the analysis, disregarding border rows.

The Si source was the commercial product Sifol®, with the following characteristics: Si = 12%; K (K_2O) = 15%; Saline index = 26; Electrical conductivity = 1.93 dS m^{-1}; Density = 1.40 g L^{-1}; pH = 10.96; Physical nature = Fluid. Si concentrations were obtained through the dilution of PS (Sifol®) in distilled water. Treatments were applied at 25 DAE, when plant height was 24.8 cm and leaf area 14.63 cm^2, on an average. PS application was performed through foliar sprayings directed on the abaxial and adaxial surfaces of the leaves. For a better absorption efficiency of PS on leaf surface, a surfactant was used in the spray solution (Sávio et al., 2011). For the application, a pre-compressed manual sprayer with a 3-L tank, made of high-molecular-weight polyethylene and a piston pump with beak diameter of 34 mm were used.

Plants were daily irrigated according to crop water demand, estimated by the difference between the applied and the drained volumes. The control of weed and possible fungal diseases, such

Table 1. Soil chemical characteristics in the layer of 0-20 cm, Campina Grande, PB.

pH	Ca^{2+}	Mg^{2+}	Na^+	K^+	S	H + Al	T	V	P	O.M.
1:2.5	Exchange Complex (mmol$_c$ dm^{-3})							%	mg dm^{-3}	g kg^{-1}
7.5	51.6	6.9	0.9	2.9	62.3	0.0	62.3	100	126.2	15.3

pH in H_2O; S – sum of bases; T: cation exchange capacity; V: base saturation; O.M.: organic matter.

as *Fusarium oxysporum* f. sp. Ricini, Branch rot (*Lasiodiplodia theobromae*) and Gray mold (*Amphobotrys ricini*), were performed through manual weeding and the application of fungicides based on carbendazim and tebuconazole, recommended for castor bean. Local water supply of good quality classified as C_2S_1, which was stored in a reservoir (cistern) located at the National Center for Research on Cotton, was used for the irrigation. According to the results obtained by the Laboratory of Water and Soil Analysis of the Embrapa Cotton, the water shows the following characteristics: alkaline pH (mean value of 7.7), moderate Cl content (266.25 mg L^{-1}), high $CaCO_3$ content (92.50 mg L^{-1}), soluble Ca^{2+} 29 mg L^{-1}, Mg^{2+} equivalent to 30.60 mg L^{-1} and low Na content (98.90 mg L^{-1}). Also, it has a moderate salinity level (EC=730 µS cm^{-1}) and low concentration of Na (SAR=3 mmol L^{-1})$^{0.5}$.

The following physiological parameters in response to PS treatments were evaluated at 90 DAE, during the fruiting stage: net photosynthesis (A) (µmol m^{-2} s^{-1}), transpiration (E) (mmol H_2O m^{-2} s^{-1}), stomatal conductance (gs) (mol m^{-2} s^{-1}), water use efficiency (WUE) (A/E) [(µmol m^{-2} s^{-1}) (mmol H_2O m^{-2} s^{-1})$^{-1}$] and carboxylation efficiency (CE) (A/Ci) [(µmol m^{-2} s^{-1}) (µmol mol^{-1})$^{-1}$]. Analyses were performed with infrared analyzer aid of gas (IRGA – *Infra Red Gas Analyzer*) (LI-6400; LICOR®, Inc., Lincoln, NE, USA) in the schedules (9am to 11am) using the third leaf fully expanded, told from the main branch of the apex (Melo et al., 2008).

Besides these variables, the photosynthetic pigments chlorophyll *a* (CLA), *b* (CLB), total chlorophyll (CLT), chlorophyll *a*/*b* ratio and carotenoids (CAR) in the leaves were also evaluated. For this, the leaves were collected and immediately placed in aluminum envelopes, stored in boxes with thermal insulation containing dry ice and transported to the laboratory. Then from the middle part circular fractions were taken without the midrib of the leaf tissue with size of 113 mm^2. Fractions were macerated and tissue were placed in test tubes coated with aluminum foil, to which 5 mL of dimethylsulfoxide (DMSO) was added. The tubes were left in a dark environment at room temperature of 25 °C for a period of 48 h. After this time the solution containing DMSO + fraction of the plant tissue was filtered through a "filter paper" during the 5 min period. With the solution extracted absorbance readings were performed in a spectrophotometer (Biomate® tm3) at respective wavelengths of 480, 649 and 665 nm (Wellburn, 1994).

For quantification of photosynthetic pigments the following equations were used according to the proposed by Wellburn (1994):

Chlorophyll *a* (µm mL^{-1}) = 12,19 × A665 – 3,45 × A649
Chlorophyll *b* (µm mL^{-1}) = 21,99 × A649 – 5,32 × A665
Total chlorophyll (µm mL^{-1}) = chlorophyll *a* + chlorophyll *b*
Carotenoids (µm mL^{-1}) = (1000 × A480 – 2,14 × chlorophyll *a* – 70,16 × chlorophyll *b*)/220

The data were subjected to the analysis of variance, and regression, using the statistical software SISVAR (Ferreira, 2011).

RESULTS AND DISCUSSION

In general, foliar application of PS in castor bean plants promoted isolated effects only on internal carbon concentration (Ci). For the factor cultivar, there were significant effects for the variables net photosynthesis (A), stomatal conductance (gs), transpiration (E) and internal carbon concentration (Table 2), indicating that plant response to the application of PS depends more on the genotype than on the applied dose. For the interactions between PS doses and cultivars, the effects were more pronounced for the physiological variables transpiration (E), water use efficiency (WUE) and internal carbon concentration (Ci), suggesting that the effects of PS application on plants can vary widely as a function of the genotype. Possibly, these results point to the development of new studies focusing not only on the definition of doses and responsive genotypes, but also on plant age, form of application, conditions of temperature and rainfall, and crop phenological stage.

The foliar application of PS doses on the canopy of the castor bean cultivars BRS Energia, BRS 188 Paraguaçu and BRS 149 Nordestina promoted significant increases in net photosynthesis (A) and stomatal conductance (gs), and the best response was observed when using the cultivar BRS 149 Nordestina as the indicator plant (Figure 2A and B).

Although the cultural practices were identical for all the studied cultivars, as well as the form of fertilizer application, it is possible to infer that the response to fertilizer application, regardless of the dose, is dependent on the genotype. According to Ferraz et al. (2014), one of the explanations for these results is associated to the capacity of the cultivar to absorb and use the fertilizer. In addition, the genetic load of the cultivar is a characteristic that defines its degree of response to fertilization. In general, the cultivar BRS 149 Nordestina showed the highest mean values of net photosynthesis (19.41 µmol CO_2 m^{-2} s^{-1}), stomatal conductance (0.49 mol CO_2 m^{-2} s^{-1}) (Figure 2A and 2B). On the other hand, the cultivars BRS Energia and BRS 188 Paraguaçu showed similar responses and the lowest mean values of net photosynthesis (17.77 µmol CO_2 m^{-2} s^{-1}) and stomatal conductance (0.35 mol CO_2 m^{-2} s^{-1}) (Figure 2A and 2B).

Although only a few research results claim that the use of PS-based foliar fertilizer is an excellent alternative to increase plant photosynthetic capacity, promote conditions to activate enzymes such as synthetases, oxidoreductase, dehydrogenase, transferases, kinases, aldolases and rubisco, a key enzyme in the photosynthetic process (Marschner et al., 2002), this mineral is of great importance for the metabolism,

Table 2. Summary of the analysis of variance (mean squares) for the variables: net photosynthesis (A), stomatal conductance (gs), transpiration (E), water use efficiency (WUE) (A/E), carboxylation efficiency (CE) (A/Ci) and internal carbon concentration (Ci) in the castor bean cultivars BRS Energia, BRS 188 Paraguaçu and BRS 149 Nordestina, in response to the application of different doses of potassium silicate (PS), at 90 DAE, Campina Grande, PB.

Source of variation	DF	A	Gs	E	WUE	CE	Ci
Potassium Silicate (PS)	4	1.3^{ns}	0.05^{ns}	6.9^{ns}	0.52^{ns}	0.000180^{ns}	1985.27*
Cultivars (C)	2	13.0*	0.08^{*}	15.1*	0.32^{ns}	0.000039^{ns}	1419.52*
Blocks	2	17.4*	0.01^{ns}	1.4^{ns}	0.03^{ns}	0.000247*	168.47^{ns}
C x PS	8	3.9^{ns}	0.04^{ns}	11.3*	0.51*	0.000052^{ns}	1191.99*
Residue	28	3.2	0.02	4.3	0.17	0.000063	429.06
CV (%)	-	9.8	31.4	23.0	19.27	11.94	7.57

*Significant at 0.05 of probability by F test; ** significant at 0.01 of probability, ns- not significant.

growth and yield of the cultivated species (Amaral et al., 2008). However, research results addressing the promising effects of the use of PS on the physiological aspects of castor bean plants are still scarce. Ferraz et al. (2014), evaluating the viability of foliar fertilization with PS in different cotton cultivars (BRS Topázio, BRS Safira and BRS Rubi) evidence that the response of this oil plant to PS fertilization is also dependent on the genotype. It is possible to infer, in part, that the extent of the response to the applied fertilizer depends on the capacity of the cultivar to absorb and metabolize the fertilizer. On the other hand, factors like irrigation, soil type, temperature, irrigation management, as well as the use of pesticides containing micronutrients, also influence the type of response of the genotype to a certain substance.

The transpiration (Figure 2C), water use efficiency (Figure 2D) and internal carbon concentration (Figure 2E) of the studied castor bean cultivars adjusted to quadratic and linear models in response to foliar fertilization with PS. According to Figure 2C, inside the interaction, the cultivars BRS Energia and BRS 149 Nordestina showed a similar quadratic adjustment, with reductions of up to 20.89 and 22.28% in transpiration (E), and critical values of 8.90 and 8.72 mmol H_2O m^{-2} s^{-1} estimated with PS applications of 485 and 500 mg L^{-1}, in response to the foliar sprayings. On the other hand, the transpiration showed linear adjustment for the interaction between PS doses and the cultivar BRS 188 Paraguaçu, with a tendency of stabilization between the applied doses.

The transpiration of the cultivar BRS 188 Paraguaçu was not affected by the foliar fertilizer. Possibly, these results can be explained by the fact that Si minimizes water losses due to its deposition on the leaf cuticles of the plants. Studies conducted by Zanão Júnior et al. (2013) on roses also evidenced that plant transpiration is reduced with the increments in PS doses. Si might have improved water use efficiency, considerably reducing losses by transpiration, since it acts directly on water use efficiency.

The highest values of photosynthetic rate (A) and stomatal conductance (gs) were observed when the indicator plant was the cultivar BRS Nordestina, followed by BRS Energia and BRS Paraguaçu. On the other hand, water use efficiency (WUE), a variable that relates the amount of carbon fixed per unit of water lost in the transpiration process, showed the best response when the genotypes BRS Energia and BRS Paraguaçu were used, evidencing higher carbon assimilation per mole of transpired water in these genotypes.

In general, the differences between the highest and the lowest PS doses were small, evidencing that the use of high, intermediate or low doses of this fertilizer little influenced the WUE of the studied genotypes. On the other hand, PS application promoted a quadratic response of the cultivar BRS Energia, indicating that WUE is compromised from the dose of 500 mg L^{-1} onwards.

According to the literature (Marschner et al., 2002), Si is a mineral that associates with the cellulose from the epidermal walls, forming a film, thus reducing the movement of water through the wall, promoting higher water economy due to the decrease in the transpiration rate, as observed in Figure 2A. Therefore, plants sprayed with the PS dose of 836 mg L^{-1} show higher WUE compared with the control treatment, for the cultivar BRS 188 Paraguaçu. On the other hand, for the cultivar BRS 149 Nordestina, the treatment corresponding to the highest PS dose (836 mg L^{-1}) promoted significant reduction in WUE, partially agreeing with the increase in the transpiration rate. According to the literature (Pinto et al., 2012), stomatal opening is directly related to the photosynthetic rates and transpiration, since plants lose water as they absorb CO_2. In addition, the highest values of net photosynthesis (A) and stomatal conductance (gs) observed in this study allow higher availability of photoassimilates for plant growth and also for the defensive metabolic pathways, since this genotype is precocious and can be used in dense cultivation systems. According to Amaral (2008), knowing the stomatal dynamics of a certain crop is a very useful tool for the understanding of physiological processes, since stomata

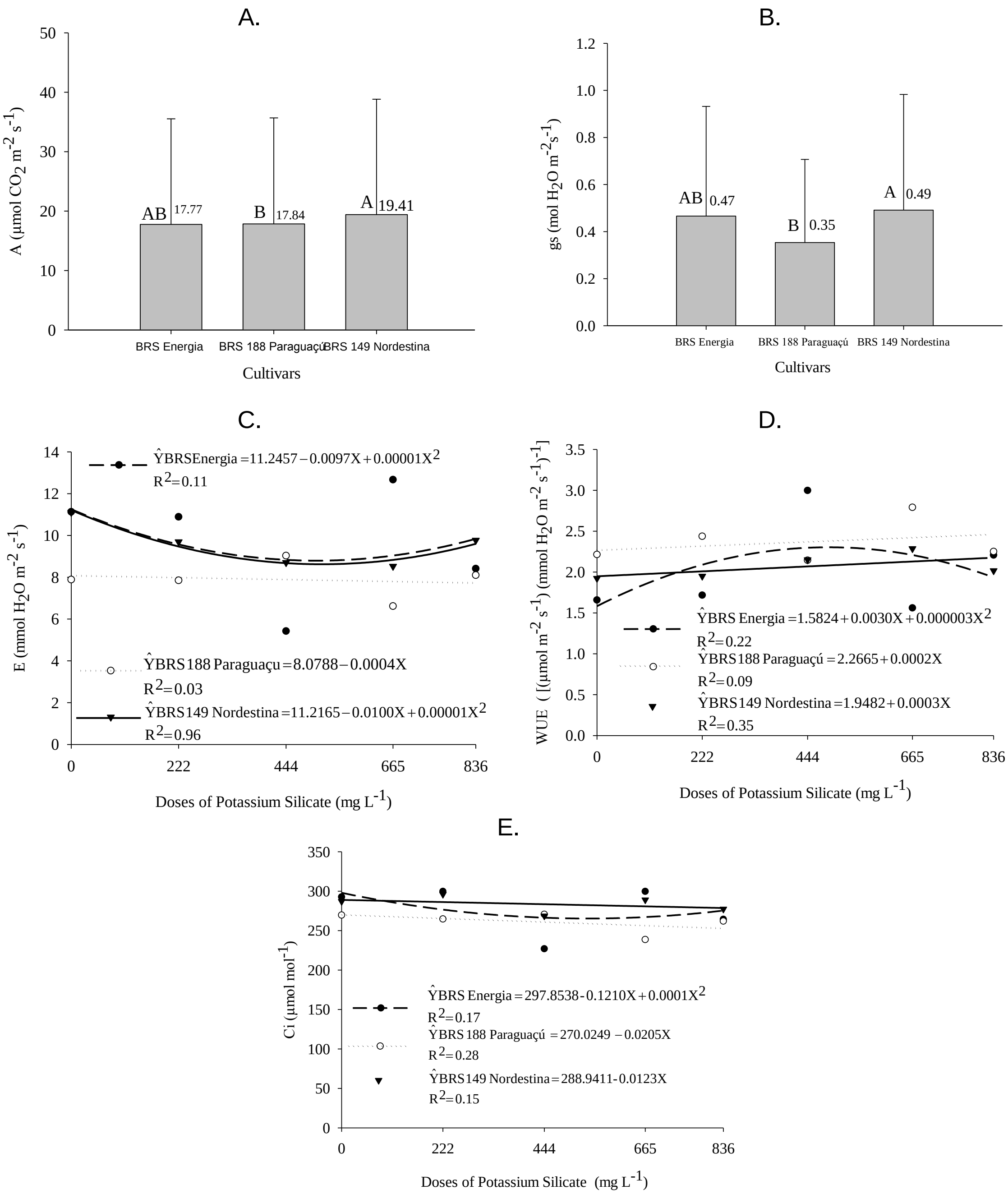

Figure 2. Net photosynthesis (A), stomatal conductance (B), transpiration (C), water use efficiency (D) and internal carbon concentration (E) in the castor bean cultivars BRS Energia, BRS 188 Paraguaçu and BRS 149 Nordestina in response to the application of potassium silicate (PS), evaluated at 90 DAE, Campina Grande, PB.

are the main pathways for the gas exchanges occurring between the atmosphere and the interior of the plant photosynthetic apparatus. According to the results obtained in this study, the internal carbon concentration (Figure 2E) was also influenced by the foliar application of PS, with linear adjustments in the response of the cultivars BRS 188 Paraguaçu and BRS 149 Nordestina. On the other hand, the cultivar BRS Energia responded quadratically, with an abrupt decrease in the internal carbon concentration from the dose of 665 mg L^{-1} onward. According to Shimazaki et al. (2007), the reduction in the internal CO_2 levels can be partially attributed to the decrease in carbon assimilation rates, since there is water loss during the processes of gas

Table 3. Summary of the analysis of variance (mean squares) for the variables: chlorophyll a (CLA), chlorophyll b (CLB), total chlorophyll (CLT), carotenoids (CAR) and the chlorophyll a/b ratio (CL a/b) in the castor bean cultivars BRS Energia, BRS 188 Paraguaçu and BRS 149 Nordestina, in response to the application of different doses of potassium silicate (PS) at 90 DAE, Campina Grande, PB.

Source of variation	DF	CLA	CLB	CLT	CAR	CLa/b
Silicon (Si)	4	3701.5^{ns}	1235.8^{ns}	2004.7^{ns}	792.1^{ns}	7.4^{**}
Cultivars (C)	2	4417.9^{ns}	254.2^{ns}	3919.9^{ns}	1579.5^{ns}	4.2^{**}
Blocks	2	75.2^{ns}	88.9^{ns}	28.6^{ns}	315.4^{ns}	0.1^{ns}
C x Si	8	5900.2^{*}	2311.1^{*}	12144.6^{*}	5520.4^{*}	5.3^{**}
Residue	28	2425.0	881.1	4778.8	2002.8	0.7
CV	-	19.6	35.6	20.6	23.0	24.04

*Significant at 0.05 of probability by F test; ** significant at 0.01 of probability, ns - not significant.

exchange and CO_2 absorption. In order to avoid water loss, the plant usually closes its stomata, resulting in lower rates of carbon assimilation and consequently lower internal carbon concentration. On the other hand, Taiz and Zeiger (2013) emphasize that the internal carbon concentration depends on climatic conditions and on the nutritional supply provided by pre-planting and post-planting fertilizations. In addition, for these authors, the genetic load of each cultivar weights the differences regarding the level of response to certain factor, in particular the internal carbon concentrations.

The Internal carbon concentration remained stable and did not show significant differences, regardless of the genotype and the applied PS dose. For herbaceous cotton cultivars (BRS Topázio, BRS Safira and BRS Rubi), Ferraz et al. (2014) observed that foliar application of PS increased the Internal carbon concentration, unlike the results found in this study, and that plant response to this fertilizer also depends on the genetic load of the plant, particularly of the cultivar.

PS application promoted significant interactive effects on the contents of the photosynthetic pigments chlorophyll *a* (CLA), chlorophyll *b* (CLB), total chlorophyll (CLT), carotenoid (CAR) and the chlorophyll *a*/*b* ratio (CL*a*/*b*). On the other hand, isolated effects for the PS doses and the cultivar were only observed for the chlorophyll *a*/*b* ratio (Table 3).

According to Epstein (2006), Si usually increases chlorophyll leaf content and plant tolerance to biotic and abiotic stress. For Taiz and Zeiger (2013), chlorophylls are responsible for the absorption of light to stimulate photosynthesis. In this context, chlorophyll *a* is the pigment used for photochemistry, while the other ones help the absorption of light and the transfer of radiant energy to reaction centers, and are referred to as accessory pigments, which include other types of chlorophyll, such as *a*, *b*, *c* and *d.* On the other hand, carotenoids are also accessory pigments responsible for light reception and transfer to reaction centers, besides protecting chloroplasts against excessive heat. The determination of chlorophyll contents in the leaves is essential because plant photosynthetic activity partially depends on the leaf capacity to absorb light (Emrich et al., 2011).

The foliar application of PS in different castor bean cultivars promoted significant effects on the contents of chlorophylls and carotenoids. According to the Figure 3A, PS application promoted a quadratic response, regardless of the cultivar. On the other hand, the cultivars BRS 188 Paraguaçu and BRS 149 Nordestina showed the same tendency, with a slight decrease in the chlorophyll *a* contents, as the PS doses increased until 480.4 and 325.1 mg L^{-1}. Both cultivars showed an increasing tendency, showing that chlorophyll *a* contents increased significantly for both cultivars from that dose onward. The cultivar BRS Energia showed the opposite behavior; as the PS doses increased, chlorophyll *a* contents increased until the maximum at the dose of 325 mg L^{-1}, then reducing with the subsequent increments. Thus, the chlorophyll content was also affected by the application of the fertilizer. However, the level of response to the applied treatment was depended on the genotype.

All the studied cultivars showed a quadratic response for the chlorophyll *b* contents (Figure 3B) in response to the foliar application of PS. However, the cultivars BRS Energia and BRS 149 Nordestina showed the same tendency, decreasing as the doses increased until the maximum limit of 416.7 and 552 mg L^{-1}. Then, the contents of chlorophyll *b* increased until the maximum dose of 836 mg L^{-1} determined in this study. Chlorophyll *b* contents in the cultivar BRS 188 Paraguaçu were little affected by the foliar application of PS.

In general, chlorophyll *b* is considered an accessory pigment that helps the absorption of light and the transfer of radiant energy to reaction centers, which are located in the membranes of the thylakoids (Taiz and Zieger, 2013). Possibly, the increase in the contents of chlorophyll *b* has been favored by the action of the Si in plant tissues, since this mineral usually increases chlorophyll contents (Epstein, 2006). For Mebrahtu and Havolver (1991), the increment of chlorophyll *b* contents can be a

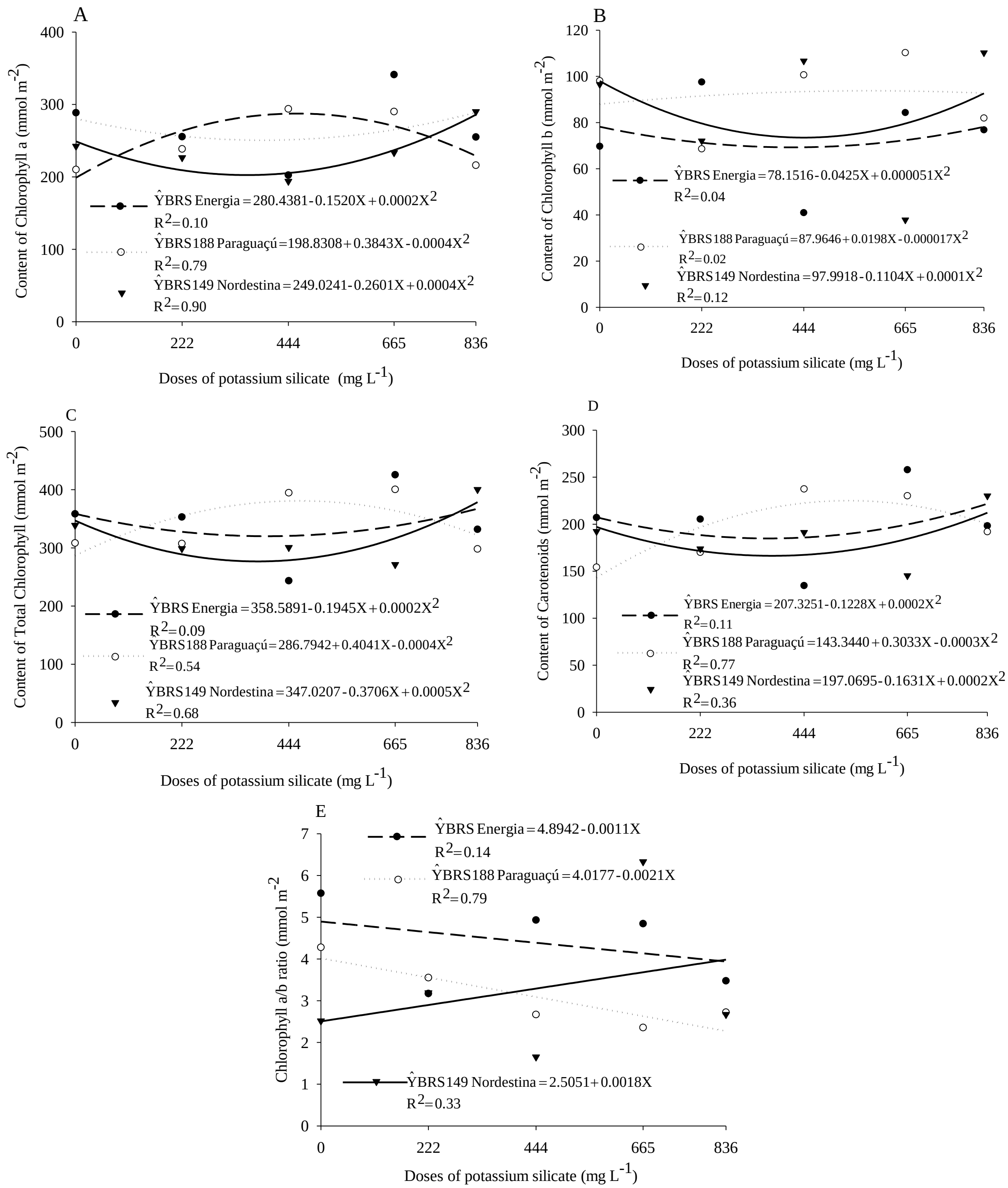

Figure 3. Contents of chlorophyll *a* (A), chlorophyll *b* (B), total chlorophyll (C), carotenoids (D) and the chlorophyll *a/b* ratio (E) in the castor bean cultivars BRS Energia, BRS 188 Paraguaçu and BRS 149 Nordestina, in response to the application of doses of potassium silicate (PS), at 90 DAE, Campina Grande, PB.

consequence of the increase in the proportion of the light-harvesting chlorophyll *a/b*-protein complex, in relation to the P700-chlorophyll *a*-protein complex. Another important factor that must be taken into consideration is the better development of the "grana" structure in the chloroplasts, where the chlorophyll *a/b*-protein complex is found (Mebrahtu and Havolver, 1991).

According to Figure 3C, together with the increment of the contents of chlorophyll *a* and *b*, observed for the cultivar BRS 149 Nordestina, there was an increase in the content of total chlorophyll of the plants, which represents the sum of the contents of chlorophyll *a* and *b*. The total chlorophyll for this cultivar decreased initially, with a subsequent tendency of increase as the fertilizer doses increased. One of the possible explanations is the fact that the contents of chlorophyll *a* and *b* were directly correlated to the PS doses.

On the other hand, the contents of total chlorophyll for the cultivars BRS 188 Paraguaçu and BRS Energia showed opposite responses, that is, while total chlorophyll contents of the former increased in response to the increment in PS doses, for the latter they initially decreased and then increased for the subsequent doses (Figure 3C). In general, the studied castor bean cultivars showed different behaviors with respect to the contents of chlorophyll *a*, *b* and total chlorophyll, and only the cultivar BRS 149 Nordestina showed the same tendency for these variables.

Carotenoids are essential for plants, since they play a significant role in the protection of the photosynthetic apparatus against photodegradation of the photosystems, through the interconversions between the xanthophyll molecules (Cardoso, 1997). As for the content of carotenoids (Figure 3D) observed in this study, PS foliar sprayings promoted favorable effects for the cultivar BRS 149 Paraguaçu; as the doses increased, the content of carotenoids increased until the inflection point of 505.5 mg L^{-1}. On the other hand, PS foliar application promoted similar responses for the cultivars BRS Energia and BRS 149 Nordestina for this pigment. In general, the increment in PS doses initially reduced the carotenoid contents until the level of 307 and 407.75 mg L^{-1}. From this dose onward, the contents of this pigment started recovering slowly. Although the cultivars BRS Energia and BRS 149 Nordestina exhibit a decreasing tendency in the carotenoid contents in their tissues when sprayed with PS, the increments in this pigment were maintained. Thus, studies clarifying more precisely the response of different castor bean genotypes to PS application should be performed in order to provide farmers with efficient doses and the most adequate cultivars to be fertilized with PS-based products.

Chlorophyll *a/b* ratio was influenced by PS doses (Figure 3E), with different behaviors for the studied cultivars. However, chlorophyll *a/b* ratio decreased as the fertilizer doses increased, especially when the cultivars BRS Energia and BRS 188 Paraguaçu were used as indicator plants. On the other hand, the cultivar BRS 149 Nordestina showed a direct relation between chlorophyll *a/b* ratio and PS doses. The observed differences regarding the magnitude of response for this variable can be partially correlated with the increase in the content of chlorophyll *b*, which was directly proportional to the fertilizer doses, in relation to the content of chlorophyll *a*. On the other hand, an opposite response was observed for the cultivar BRS 149 Nordestina, in which the chlorophyll *a/b* ratio was favored by the increment of PS doses, despite the initial reductions in chlorophyll *a* contents, showing a recovery for the highest doses and significant reductions in the contents of chlorophyll *b* as the PS doses increased, with a tendency of increase in response to the application of higher doses. However, this is an atypical behavior with respect to the response of castor bean cultivars to the tested fertilizer, which suggests the conduction of new experimental studies under field conditions in order to confirm these results or present a new response to PS foliar fertilization.

Conclusions

1) The promising effects of foliar fertilization with potassium silicate in castor bean plants depend on the genotype;
2) The foliar application of potassium silicate increases photosynthetic capacity, stomatal conductance, water use efficiency, contents of chlorophyll *a*, *b*, total chlorophyll, carotenoids and the chlorophyll *a*/*b* ratio, besides reducing water losses by transpiration.

Conflict of Interests

The authors have not declared any conflict of interests.

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Full Length Research Paper

Vermicompost of tannery sludge and sewage as conditioners soil with grown tomato#

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The objective was to evaluate the effect of tannery sludge vermicompost in the chemical properties of soil cultivated with tomato and irrigated with wastewater. The experimental design was completely randomized in a factorial 6 × 2, totaling twelve treatments with three replications. The treatments were: four tannery sludge vermicompost (25% Sludge tannery(LC) + manure - T1, 25% Sludge tannery(LC) + rice husk - T2; 50% Sludge tannery(LC) + manure - T3 and 50% Sludge tannery(LC) + cane gray - T4), conventional fertilization (T5) and control (without fertilization - T6) and two types of irrigation water (domestic sewage and class 2 water). The physico-chemical characteristics and chemical soil and vermicompost (fertilizers) were determined before the culture of the installation vessels and after ninety days of driving the tomato crop. The data were submitted to analysis of variance by F test and comparisons between treatment means were performed by 5% Tukey test. In general, concentrations of chemical parameters in the soil after addition of vermicompost have increased, particularly in the addition of T2 = 25% LC + 75% of rice husk and T4 = 50% LC + 50% cane gray. The treated soil demonstrated pH, CEC, organic matter and saturation enhanced base increased, sodium and potential acidity decreased. Thus it can be concluded that vermicompost used can be added to soil conditioners changing the soil chemical attributes positively.

Key words: vermicomposting, chemical attributes, reuse.

INTRODUCTION

The soil conditioners may also cause changes in the pH of the soil, converting the metals in forms not readily available to plants and microorganisms (Hamon et al., 2002). Studies related to the use of conditioners in contaminated soils by heavy metals were mostly developed for temperate soils. In tropical soils, which

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mostly exhibit pH values ≤ 5 and low levels of organic matter and nutrients, especially P, and high content of iron oxides, soil conditioners response with regard to mobility and availability of heavy metals can be distinguished. In Latosols, for example, oxides and Fe hydroxides influence the characteristics of adsorptive soils and consequently the retention of metals (Silveira et al., 2002).The soil salinity levels should be checked, given that sodium is one of the parameters that most interfere in the soil salt content and so it is interesting to ascertain the content of this and other nutrients in the irrigation water as well as on the ground. Under moderate salinity reduction in the yield of tomatoes due to the reduction in the average fruit weight (Cuartero and Munoz, 1999), where as in conditions of high salinity reduction in productivity is a result of the lower number of fruits per plant; the number of bunches per plant decreases only when the irrigation water has a high salt concentration and under long exposure periods. The use of waste (as tannery sludge) by monitoring and management, aims to reduce the environmental impacts, which proposed an agro industrial system and treatment of final waste, as vermicomposting, they may be suggested. The correct management of waste generated can turn waste from one activity to another input, such as tannery sludge to be used in this study. Therefore, it is important to reuse waste for growing vegetables in general such as tomatoes, enabling responsible for production, quality and committed to the concept of sustainable development (Factor et al., 2008), given the importance of adding substances to soil improving growing conditions.

When the final destination is the exposure to soil, this must be done carefully so that there is contamination of the environment. Thus, as arises vermicomposting disposed biotechnology and may result in vermicomposts with high nutritional content. Corroborating the proper disposal of waste that can be reused (such as waste-water), the provision of water in the soil for agronomic purposes, it is a technique that has been used in different countries (Metcalf and Eddy, 1991). This technique has some advantages such as conservation of water, with its wide availability and its ability to enable the intake and nutrient cycling (thus reducing the need for commercial fertilizers), and contribute to the environmental preservation (Hespanhol, 2002), which together with the use of vermicomposts can assist soil conditioners as providing nutrients. It is known that vermicomposting stands out as biotechnology and/or process of bioremediation interesting for the reuse of solid and liquid wastes able to generate material with high agricultural potential, with high potential for reuse is possible. Above all, their use in the processing of tannery waste is still little known, needing therefore assessments that leverages the processing of such waste more noble products from the agricultural point of view as well as a soil conditioner. As the disposal of waste a viable environmental issue that needs more attention, the vermicomposting process combined with the reuse of wastewaters emerge as biotechnology that may have high potential for use and nutritional value for tomato cultivation in Goiás. In this sense, the objective of the experiment was to evaluate the effect of tannery sludge vermicompost in the chemical properties of soil irrigated with waster water and cultivated with tomato.

MATERIALS AND METHODS

The study was conducted between April and July 2015, in a protected environment, experimental area belonging to the Federal Institute Goiano - Campus Urutaí, altitude of 812 m. According to Köppen, Urutaí (GO) is Aw climate with warm climatic conditions, humid to semi-arid, and tropical climate with average annual rainfall of 1402 mm and an average temperature of 23.4°C. The soil used in the experiment was collected in IF-Goiano Urutaí. This is considered in accordance with the classification of EMBRAPA (2006), as Hapludox clay soils. The physico-chemical characteristics and chemical soil and vermicompost (fertilizers) were determined (Tedesco et al., 1995) before the culture of the installation vessels through chemical analysis. The data were interpreted and corrected as 5th approach (Comissão de Fertilidade de Solos de Goiás, 1988). In addition, the data were compared with the technical criteria for organic fertilizer compound, to define the four best vermicomposts (V1, V2, V3 and V4). The initial chemical characterization of the soil and the vermicompost used in the experiment are shown in Table 1.The vermicomposts employed in this study were obtained from the tannery sludge mixture (primary sludge - LC) with the following substrates: V1 = 25% + LC 75% manure; V2 = 25% LC + 75% rice husk; V3 = 50% LC + 50% manure; and V4 = 50% LC + 50% cane gray. The vermicomposting process lasted for a period of 75 days after inoculation of adult individuals of the species *Eisenia foetida*, as described in Cunha et al. (2015).

The water from sewage was obtained from stabilization pond located at the Federal Institute Goiano Campus Urutaí from domestic sewage treatment. The water supply was obtained from water treatment own campus, also located on the premises of the institution. The qualitative analyzes of water were performed at the Laboratory of Inorganic chemistry of the state university of Goiás, Campus Anapolis. The methods of analysis followed the recommendations of the American Public Health Association (2012) and described in Borges et al. (2015). The samples were taken three times during the growing season of the tomato and the results are shown in Table 2. Some of the supply water analysis was used as the results described in Malafaia, (2015).The irrigation scheduling was performed in accordance with Salomão (2012), from mini tank Class A circular in shape, inner diameter 52 cm and height (internal) of 24 cm mounted on a wooden pallet and installed inside the room protected where it was developed this experiment. Irrigated volume daily to keep the water retention capacity of the soil by 70% (243 ml kg^{-1}) during the experiment was based on the vessel area to be irrigated (0.03 m^2) and crop evapotranspiration (ETc), as described in Malafaia (2015). It is noteworthy that the restored water volume was measured in a graduated cylinder. The experimental design was completely randomized (DIC) in a factorial 6 × 2, resulting twelve treatments, with three replicates, totaling thirty-six installments. Each plot consisted of a vase of eight liters and useful volume of six liters, with each pot plant. The soil was placed in the pots and the treatments were added as described in Table 3. The treatments consisted of six substrates (the top four vermicomposts classified according to the fertility parameters V1, V2, V3 and V4, conventional fertilizer - NPK and without fertilization

Table 1. Main characteristics of soil and vermicompost used in grown *Lycopersicum sculentum* (cv. Santa Cruz Kada). Urutaí, GO. Brazil. 2015.

Atributtes	Soil	V1	V2	V3	V4
pH (H_2O)	5.40	8.70	7.17	8.40	8.45
P (dag kg^{-1})	17.00	1.25	0.44	1.31	1.28
K (dag kg^{-1})	0.31	1.40	0.42	1.09	1.60
Ca (dag kg^{-1})	3.30	5.40	4.22	9.26	8.30
Mg (dag kg^{-1})	0.80	0.50	0.15	0.36	0.48
S (dag kg^{-1})	6.00	0.02	0.27	0.42	0.37
B (dag kg^{-1})	0.60	3.50	3.50	39.00	48.50
Cu (dag kg^{-1})	1.40	84.00	18.00	61.00	63.00
Fe (mg kg^{-1})	34.00	112.50	7921.67	124.60	300.00
Mn (mg kg^{-1})	32.00	318.67	492.00	287.33	779.00
Zn (mg kg^{-1})	5.20	124.90	55.63	105.30	35.00
Organic matter (%)	1.60	15.10	29.23	17.60	11.27
Clay (%)	34	-	-	-	-
Silt (%)	19	-	-	-	-
Sand (%)	47	-	-	-	-
V (%)	68.00	-	-	-	-
Na (dag kg^{-1})	50.00	-	-	-	-
H+Al (dag kg^{-1})	2.10	-	-	-	-
CEC (dag kg^{-1})	6.50	-	-	-	-

Legend: (-): parameter not evaluated. The available macro and micronutrient concentrations were evaluated. CEC: cation exchange capacity; Base saturation (V%). V1 = 25% de LC+75% manure; V2 = 25% de LC+75% rice husk; V3 = 50% de LC+50% manure; e V4 = 50% de LC+50% cane gray.

Table 2. Values of qualitative analysis, quantitative and standard deviation domestic sewage and class 2 water, used in the experiment. (Urutaí, GO. Brazil. 2015).

Parameter analyzed	Medium values of water 1/ standard deviation*	Medium values of water 2/ standard deviation*
pH	6.89±0.07	6.74±0.33
Cu (mg L^{-1})	2.49±0.50	1.00[1]
Fe (mg L^{-1})	0.91±0.27	0.68[1]
Na (mg L^{-1})	5.40±0.52	5.25[1]
Mn (mg L^{-1})	1.14±0.31	1.20[1]

Water 1: domestic sewage. Water 2: water class 2. *Values for three replicates for each parameter analyzed. 1Fonte: Malafaia (2015).

- control) and two waters (A1 = wastewater and A2 = class 2 irrigation water). They were randomly distributed and constituted by the combination of the substrate with water, as described in Table 3.

The dose of NPK used in treatments "soil + NPK" (Table 3) was calculated based on the nutritional needs of the crop, the nutrient concentrations in the soil and yield expectation of culture 200 t ha^{-1} as Filgueira (2003). NPK sources were urea, superphosphate and potassium chloride, respectively. The vermicompost doses added to the cultivation soil were calculated based on the concentration of K present in them highly demanded by the tomato crop element being supplied as a single dose 100 kg ha^{-1}. Thus, the following doses of vermicompost were established: Dose A: 18 Mg ha^{-1}; Dose B: 46 Mg ha^{-1}; C Dose: 21 mg h^{-1}; Dose D: 23 Mg ha-1. It is noteworthy that this work top dressing was performed (200 kg ha-1 N split in doses of 50 kg ha-1 at 20, 40, 60 and 80 days after transplanting).

The tomato cultivation was conducted for ninety days and after this period were collected homogeneous three samples with about 300 g of each vessel for subsequent analysis of chemical properties. The data were submitted to analysis of variance by F test and comparisons between treatment means were performed by 5% Tukey test. All statistical analyzes were performed with the aid of SISVAR software (Ferreira, 2011).

RESULTS AND DISCUSSION

The pH levels observed in Table 4 demonstrate increase of this parameter after addition of humates soil (Table 1),

Table 3. Experimental Units established for grown *Lycopersicum sculentum* (cv. Santa Cruz Kada) irrigated with wastewater and treated with tannery sludge. Urutaí, GO. Brazil. 2015.

Tratamentos	Tipos de água	
	Residuária	**Abastecimento**
Soil + V1 (dose A) = T1	x	
Soil + V2 (dose B) = T2	x	
Soil + V3 (dose C) = T3	x	
Soil + V4 (dose D) = T4	x	
Soil + NPK = T5	x	
Soil (control) = T6	x	
Soil + V1 (dose A) = T1		x
Soil + V2 (dose B) = T2		x
Soil + V3 (dose C) = T3		x
Soil + V4 (dose D) = T4		x
Soil + NPK = T5		x
Soil (control)= T6		x

Legend: Dose A: 18 Mg ha^{-1}; Dose B: 46 Mg ha^{-1}; Dose C: 21 Mg ha^{-1}; Dose D: 23 Mg ha^{-1}; Concentration of urea: 300 kg ha^{-1}; Concentration of superphosphate: 300 kg ha^{-1}; Concentration of potassium chloride: 100 kg ha^{-1}.

Table 4. Concentrations of pH, CTC, potencial acidity (H+Al), sodium (Na), organic matter (M.O.) e base saturation (V) soil analyses for diferente treatments and types of water. Urutaí, GO. Brazil. 2015.

Types of water	Treatments					
	T1	**T2**	**T3**	**T4**	**T5**	**T6**
pH						
A1	5.60^{Cb}	6.06^{Bb}	6.30^{Aa}	6.46^{Aa}	6.00^{Bb}	6.06^{Bb}
A2	6.26^{Ba}	6.33^{ABa}	6.43^{ABa}	6.53^{Aa}	6.43^{ABa}	6.23^{Ba}
CTC (dag kg^{-1})						
A1	8.45^{Ca}	10.10^{Aa}	9.20^{Bb}	7.92^{Da}	6.86^{Ea}	6.11^{Fa}
A2	7.43^{Cb}	9.47^{Bb}	9.66^{Aa}	7.52^{Cb}	6.43^{Db}	5.31^{Eb}
H+Al (dag kg^{-1})						
A1	1.53^{Aa}	0.90^{Ca}	1.05^{BCa}	0.46^{Da}	1.06^{Ba}	1.13^{Ba}
A2	0.56^{Bb}	0.43^{BCb}	0.41^{BCb}	0.40^{Ca}	0.86^{Ab}	0.90^{Ab}
Na (dag kg-1)						
A1	4.50^{ABa}	6.00^{Aa}	4.00^{Ba}	4.66^{ABa}	4.66^{ABa}	4.00^{Ba}
A2	4.00^{Ba}	4.16^{ABb}	4.33^{ABa}	5.66^{Aa}	4.66^{ABa}	5.00^{Aba}
M.O. (%)						
A1	2.23^{Ca}	2.96^{Ab}	2.13^{Cb}	2.63^{Cb}	2.03^{Cb}	1.56^{Da}
A2	2.10^{Ca}	3.56^{Aa}	3.53^{Aa}	2.63^{Ba}	2.33^{Ca}	1.60^{Da}
V (%)						
A1	80.33^{Db}	90.66^{Bb}	88.33^{Cb}	93.66^{Ab}	80.66^{Db}	80.66^{Db}
A2	91.33^{Ba}	94.33^{Aa}	95.66^{Aa}	95.00^{Aa}	85.66^{Ca}	84.33^{Ca}

Means followed by the different upper case letter in line and lower case in column differ to each other at 5% probability by Tukey test. T1: 25% Sludge Tannery (LC) + 75% manure; T2: 25% LC + 75% rice husk; T3: 50% LC + 50% manure; T4: 50% LC + 50% cane gray; T5: NPK; T6: control; A1: domestic sewage; A2: class 2 water.

which was classified as moderately acid (less than 5,50) as Comissão de Fertilidade de Solos de Goiás, (1988) and after the tomato crop could still be reused for new cultivation of tomatoes because, as highlighted by Primavesi (2002), the pH range interferes with the absorption of nutrients. Thus, the problem is not the correct pH, but the balanced supply of nutrients. The availability of nutrients is influenced by soil pH, which in this experiment showed a value of 5,40 (solo). Nitrogen (N) is better used by the plant in soil with a pH above 5,50 (achieved in the other treatments, Table 1). The maximum availability occurs at soil pH between 6,00 and 6,50 and then decrease. The tomato crop requires an optimum range of soil pH is between 5,50 and 6,80 (Primavesi, 2002).The supply of wastewater may have influenced the drop in pH values, because all values were (except T2 and T5) lower for this type of water when compared to the A2. Even with the decrease in pH (Table 4) after the beginning of cultivation of tomato (Table 1), the range is acceptable for a new culture cycle. Any pH as the base saturation and exchange capacity are influenced by soil use and can be modified by managements correct as adding soil conditioners, which involves the application of material which favorably modify the chemical properties (Bernardi et al., 2005), reducing the soil acidity and increasing the CTC.As noted the CTC values increased after the addition of vermicompost to the soil, so that the witnesses had the lowest values compared to other treatments (for different types of water). In general the A1 treatments were favored by irrigation of wastewaters that with the large amount of dissolved salts, mainly of urban origin (Metcalf and Eddy, 1991), may have promoted the exchange of cations. CTC evidence the soil's ability to retain and exchange positively charged ions in the colloid surface, perhaps one of the most important physical and chemical properties of the system. His determination can be made saturating the soil with a cation index, which is then translocated and determined, or adding to the exchangeable bases with the potential acidity (Camargo et al., 2009). This property presents the release of chemical elements as N, P, K, Ca and Mg, which leave the organic medium, said immobilized, to pass through the medium of nutrients for the plants (Camargo et al., 2009), which facilitates exchangeable forms.

The potential acidity (Table 4) was identified only for the contents H^+ for the results to aluminum saturation was zero. T1 demonstrated as higher value, that is, which may have been favored by the ratio of the manure (75%), which differs from T3, which has a smaller percentage thereof in the humus (50%), which can be checked dag the values 1,53 dag kg^{-1} and 1,05 dag kg^{-1}, respectively. In general, the potential acidity was decreased in all treatments, since the initial value (Table 1) was 2,10 dag kg^{-1}. This fact is justified in studies on the use of vermicompost (Landgraf et al., 2005; Steffen et al., 2010) on decreasing the acidity of the soil. The potential acidity, preferred term to others as titratable acidity, hydrolytic etc., is measured by the amount of strong base required to raise the pH to a particular value, often to 7,00 in our midst. This introduce the total acid present between the starting level (soil pH) and final (7,00) pH (Camargo et al., 2009).The sodium values (Table 4) for T2 in the wastewater was higher than the control, different from T4 in the class 2 water. The values between different types of water did not show statistical differences, except for T2 in the A2, which showed a lower value in the wastewater. Sodium is one of the parameters that most affects the salt content of the soil and so it is interesting to check the content thereof in irrigation water as well as in soil. Under moderate salinity reduction in the yield of tomatoes due to the reduction in the average fruit weight (Cuartero and Munoz, 1999), whereas in conditions of high salinity reduction in productivity is a result of the lower number of fruits per plant; the number of bunches per plant decreases only when the irrigation water has a high salt concentration and under long exposure periods. Opposed results were observed in this study, since the electrical conductivity was considered low usage restriction (Ayers and Westcost, 1999) and in addition, the salinity increases the incidence of blossom-end rot (Martinez et al., 1987; Filgueira, 2003) making the fruit unusable both for consumption and for the industry, which was not observed in this study.

The amounts of organic matter were increased (Table 4) as compared to the initial value of this parameter the soil (1.60%) to be added to the soil, which highlights the importance of humus and soil conditioning. In wastewater the T2 showed higher and A2 the T2 and T3 showed higher values. The figures presented by the control approached the initial values of the soil, which shows that treatments consisting of vermicomposts contrasting to the conventional treatment (T5 + A1 and T5 + A2). According to Santos et al. (2010), the use of organic wastes produced by activity animal as a source of plant nutrients and soil conditioner has become a viable alternative in terms of environmental protection, significantly reducing the use of chemical fertilizers and minimizing o environmental contamination. Furthermore, the supply of raw material into a long-term and low cost is guaranteed mainly by providing this in the surface layer of the soil. Thus, as found by Pina et al. (2015), the use of organic waste increased content of nutrients and organic matter in the soil, promoting greater root growth when assessing the influence of different organic waste associated with chemical fertilizers on sugarcane, sugar-rooting and yield in soil classified as Typic Quartzarênicos in Campo Grande, MS, Brazil. The initial base saturation value (68%) has been ranked as high (Comissão de Fertilidade de Solos de Goiás, 1988) and remained in this classification with values between 80 and 95% (Table 4), which shows that increased after the addition of vermicompost, and the lowest values were identified in the controls (80.66 and 84.33%).

The wastewater not favored treatments for base saturation when compared to treatments with A2, although the treatments were highlighted by vermicomposts increase, which were higher than conventional treatment, a fact verified by alternative studies application unconventional sources in the cultivation of vegetables (Cunha et al., 2014), aiming at savings of fertilizers and irrigation water front to environmental preservation.

Conclusion

Based on the results and according to the experimental conditions can be concluded that:

1). The added and cultivated soils with tomato had pH, CTC, organic matter and base saturation levels were incremented based mainly on the addition of T2 = 25% LC + 75% of rice husk and T4 = 50% LC + 50% cane gray, which favors use thereof as soil conditioners;
2). The levels of sodium and potential acidity were decreased after the addition of vermicompost and tomato crops, beneficial result for the use of this by changing the chemical characteristics of the soil;
3). The addition of vermicompost added to domestic wastewater irrigation convert an important technique applicable soil conditioners.

Conflict of Interests

The authors have not declared any conflict of interests.

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Full Length Research Paper

Water use efficiency and growth variables of *Operculina macrocarpa* L. Urban grown in tropical environment

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Most of the population in developing countries still uses medicinal plants as the main source to meet their medical needs. Field experiments were carried out at tropical environment in Brazil in order to determine the main characteristics of 'batata-de-purga' (*Operculina macrocarpa* L. Urban), cultivated under 5 different levels of irrigation. The crop was cultivated with and without shading, using a plastic cover. The irrigation treatments were based on reference evapotranspiration (ET_o): T1 = 25% ET_o; T2 = 50% ET_o; T3 = 75% ET_o; T4 = 100% ET_o; and T5= 125% ET_o. Irrigation was performed in interval of three days and the applied water volume was based on treatment T4. The daily values of ET_o were determined according to the method of Penman-Monteith. The results indicated that the growth variables of 'batata-de-purga' production components were strongly influenced by both the applied water levels and the cultivation conditions.

Key words: Evapotranspiration, irrigation water use efficiency, yield.

INTRODUCTION

The products of the Brazilian flora have aroused the curiosity and economic and scientific interest since the period of the New World colonization. Such national richness is revealed especially in the Amazon flora and in the Caatinga biome of the Brazilian semiarid region, which is the most biodiverse of the world, where there are plants with dyeing, odoriferous, stimulant, condimental, hallucinogenic and resinous, and balsamic properties.

There is an increasing interest in the practice of biomedicine and ethnoveterinary worldwide, particularly,

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when it relates the use of medicinal plants to treat various diseases (Bizimenyera et al., 2006). The phytotherapy can be used to contribute to the cure of infectious diseases, especially in small ruminants, because the isolated or associated use of natural substances generate products with less residues and more valued in the market, besides not causing environmental pollution and reducing the problem of waste (Krecek and Waller, 2006; Cenci et al., 2007).

In the context outlined earlier, goat/sheep farming is one of the most performed activities in the Brazilian semiarid region, notably due to the capacity of resistance of these animals to adverse climatic conditions, besides a social and economic function as source of nutrition and income. In the tropics and subtropics, nematode-caused diseases are among the most common and economically important infectious diseases of these small ruminants (Hoste et al., 2005). The epizootic outbreaks of haemonchosis and strongyloides that occur in the northeastern semiarid region increases goat morbidity and mortality (Rodrigues et al., 2007). ‘Batata-de-purga’ (*Operculina macrocarpa* L. Urban) is widely used by the population of the Brazilian semiarid region, due to its laxative, purgative and purifying action against skin diseases and in the treatment of leukorrhea in goat/sheep farming.

Operculina macrocarpa L. Urban has its therapeutic value recognized by the science and its use in the treatment against skin diseases and leucorrhea has gradually increased. This wild species, popularly known as ‘batata-de-purga’ or ‘jalapa’ (Convolvulaceae), has been the target of many studies on its chemical-taxonomical characteristics in the control of gastrointestinal helminth diseases of naturally infected goats (Michelin et al., 2010). In the last ten years, the interest in higher plants, especially in phytotherapeutic agents, has expressively increased, not only in developing countries, but also in industrialized countries. Despite the richness of the Brazilian flora and the wide use of medicinal plants by the population, scientific studies on the subject are insufficient. In addition, despite many studies on crop coefficient and water use efficiency of various species cultivated in the Brazilian semiarid region (Campos et al., 2008), none of them focuses on ‘batata-de-purga’. Therefore, considering the importance of goat/sheep farming for the semiarid regions, as well as the absence of any study on the addressed subject, this study aimed to determine water use efficiency and analyze the growth variables of ‘batata-de-purga’ cultivated in shaded environments and exposed to natural environmental conditions under various irrigation levels.

MATERIALS AND METHODS

Study area and field experiment

This study was carried out in a community that produces exclusively organic food, called ‘Grupo Ribeiro’, which is located in the municipality of Alagoa Nova-PB, Brazil. This community belongs to the ‘Brejo Paraibano’ Microregion and its climate is humid with rains distributed from January to September (Silva et al., 2010). The experimental design of the field study with ‘batata-de-purga’ was a randomized block, in a factorial scheme with 30 plots, containing 3 plants each and the factors were irrigation depths and shading conditions. The treatments with shading and without shading were used for assessing the luminescent effect on crop yield. Five irrigation levels, with and without shading and three replicates were used in the experiment. Plants were cultivated at spacing of 1.5 × 1.5 m, to facilitate experimental management and follow the contour line of the terrain. Irrigation treatments were applied from 30 to 210 days after sowing (DAS), during the period of November 2012 to July 2013 and replicated from December 2013 to August 2014.

Irrigation management and growth variables

The treatment corresponded to irrigated cultivation according to the atmospheric demand to evaluate the behavior of the plants. Irrigation depths were determined based on reference evapotranspiration (ET_o): T1 = 25% ET_o; T2 = 50% ET_o; T3 = 75% ET_o; T4 = 100% ET_o; and T5 = 125% ET_o. Reference evapotranspiration was determined by Penman-Monteith method (Allen et al., 1998). The data for ET_o determination were obtained from the automatic weather station close to the experimental area. Irrigation water was collected directly from a local supply damn and stored in a 1000-L tank, to be later used by the system. Irrigations were performed using a localized system (perforated hose-type), with flow rate of 1 L ha^{-1}. Irrigation interval was equal to three days and based on treatment T4.

Stem diameter was determined every 10 days, 5 cm high from the base of the plant, using a digital caliper. ‘Batata de purga’ seeds and tubers were collected and dried in the shade for 3 days, in order to obtain the number of seeds and tuber weight. The other crop production components, such as tuber size, tuber diameter, number of seeds and number of climbing stems in both cultivation conditions were also analyzed. Water use efficiency (WUE) was expressed by the relationship of ‘batata-de-purga’ yield expressed in grams of seed, number of seeds and number of climbing stems per liter of water consumed, according to each irrigation treatment, for cultivation conditions with and without plastic cover (Figure 1). Polycarbonate sheets were used for reducing the luminescent effect on plants.

Before and after the experimental period, soil samples were collected in the layer of 0 to 20 cm for analyses at the Laboratory of Irrigation and Salinity of the Federal University of Campina Grande, to evaluate the effects of ‘batata-de-purga’ on the soil. The samples were air-dried and sieved through a 2-mm mesh.

The contents of calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), aluminum (Al), carbon (C), organic carbon (OC), nitrogen (N), organic matter (OM), phosphorus (P) and the values of pH and electrical conductivity of the saturation extract (ECse) were determined, as shown in Table 1. The growth variables data were subjected to an analysis of variance at the 5% level of significance using the F test. All analyses were performed based on three samples and after repetition with the same physical-sample drawing number. Ion activity was determined using the potentiometric method.

RESULTS

Soil and crop growth

Soil chemical properties in the experimental area were

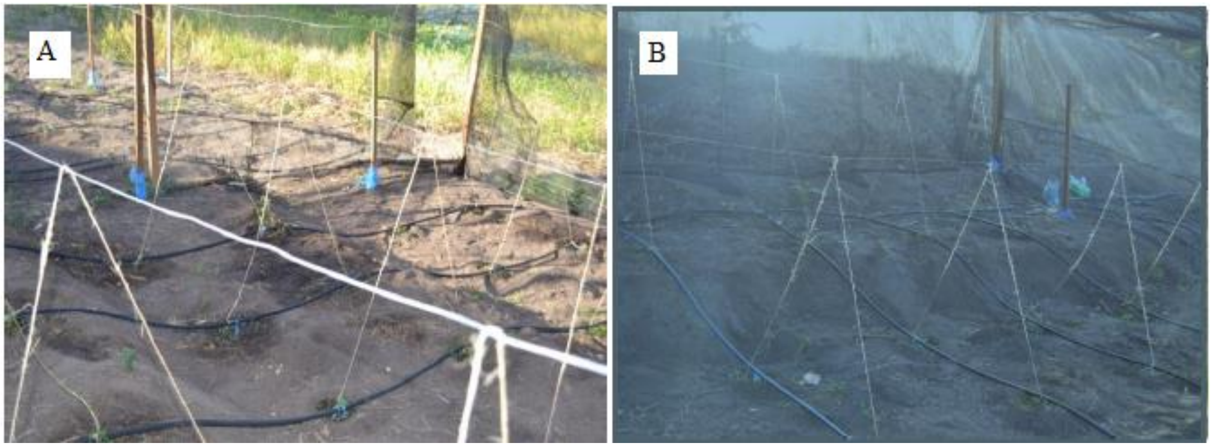

Figure 1. Experimental plots without plastic cover (A) and with plastic cover (B).

Table 1. Analysis of soil chemical properties of the experimental area in Lagoa Nova-PB, Brazil, before and after sowing of 'batata-de-purga'.

Chemical characteristics	Before	After
Calcium (Meg/100 g of soil)	0.67	1.46
Magnesium (Meg/100 g of soil)	1.19	1.21
Sodium (Meg/100 g of soil)	0.03	0.20
Potassium (Meg/100 g of soil)	1.07	1.14
Aluminum (Meg/100 g of soil)	0.80	0.00
Carbon (%)	1.10	1.48
Organic matter (%)	2.19	1.83
Nitrogen (%)	0.09	0.10
Phosphorus (mg/100 g)	0.10	3.52
pH H_2O	5.20	6.80
Electrical conductivity (mmhos/cm)	0.10	0.16

modified after the experiment; some contents increased and others decreased (Table 1). Some aspects of these properties are relevant; for example, according to the soil conditions before and after planting 'batata-de-purga', the increases in the contents of Ca, Na and P were above 100%, while the Al content decreased after the experiment.

Planting density may promote changes in soil physical and chemical properties. While physical characteristics are modified by the root system of the species, besides the type and amount of plastic cover deposited, chemical characteristics are affected by the dynamics of 'nutrients in the soil, due to the absorption by plants, and by the organic matter. Seed weight values under both cultivation conditions are equal in the treatment T1 and then vary linearly as a function of the increase in irrigation depth, always with higher values in the cultivation without cover, in comparison to that with cover (Figure 2A). The mean seed weight of all irrigation treatments for the planting condition without cover was only 3.2 g higher than that in the planting condition with plastic cover.

The tuber weight for plants cultivated under cover increased linearly by 0.7 kg between the treatments T1 and T2; however, in the plot without cover, the increase in irrigation depth caused a slight reduction of only 0.2 kg in tuber weight (Figure 2B). As observed for previous production components, in both cultivation conditions, the number of seeds increased linearly with the increment in irrigation, generating high coefficients of correlation that are statistically significant at 0.01 probability level by the Student's t-test (Figure 2E). In the treatment T1, plants produced 114 and 180 seeds for cultivation with and without cover, respectively, with a difference of 66 seeds.

The smallest difference in the number of seeds between the cultivation conditions occurred in the treatment T4, with only 16 seeds. The mean values of number of seeds for all irrigation treatments under planting conditions without and with cover were 209 and 166 seeds, respectively. The evolution in the number of climbing stems of 'batata-de-purga' cultivated without

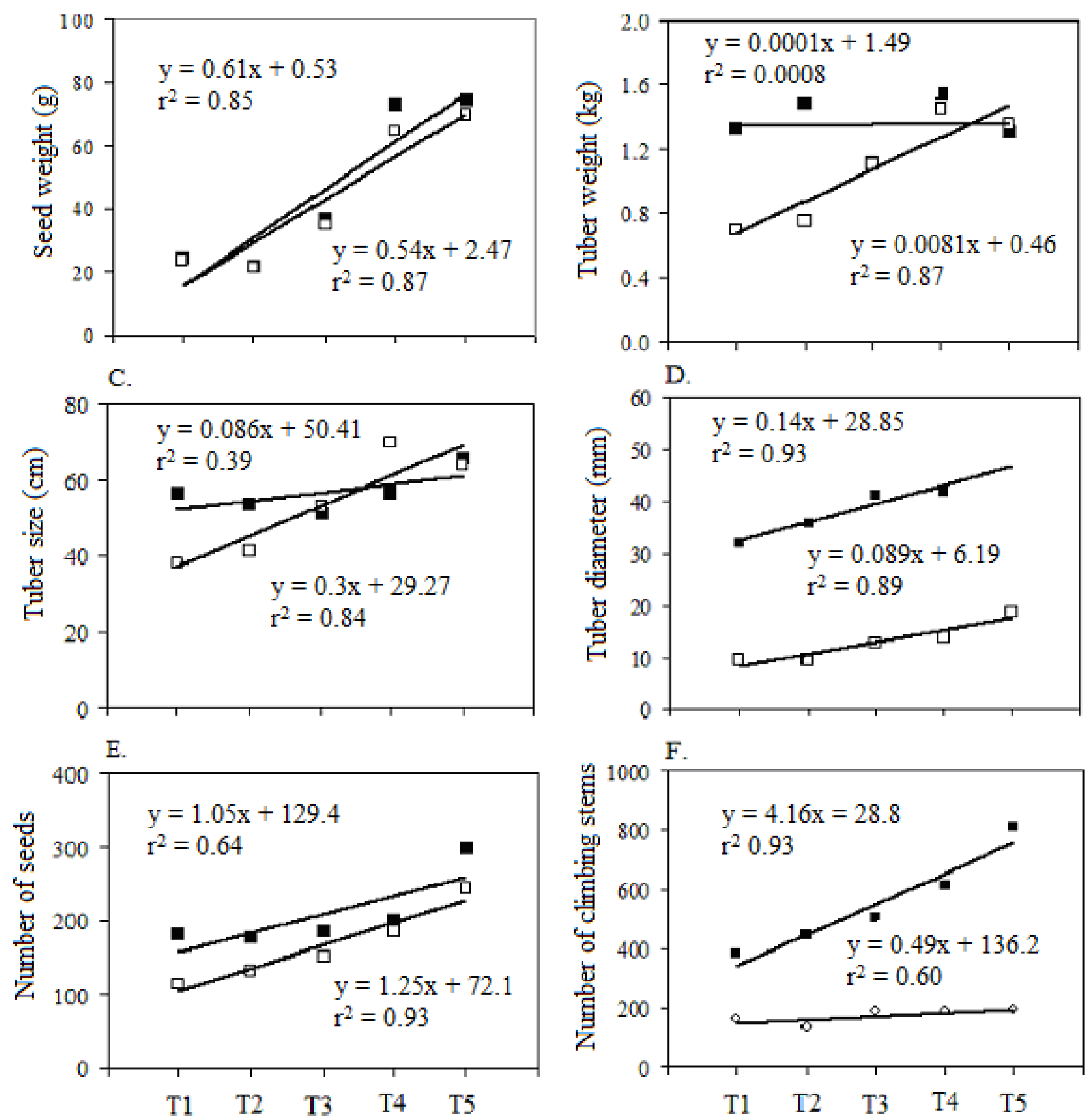

Figure 2. Evolution of seed weight (A), tuber weight (B), tuber size (C), tuber diameter (D), number of seeds (E) and number of climbing stems (F) of 'batata-de-purga' as a function of irrigation depths T1 (25% ET_o), T2 (50% ET_o), T3 (75% ET_o), T4 (100% ET_o) and T5 (125% ET_o). Black data points = without plastic cover and white data points = with plastic cover.

cover increased linearly as a function of irrigation depth, with high coefficient of correlation, which was statistically significant at 0.01 probability level by the Student's t-test. However, the number of climbing stems in the condition with cover was virtually constant, that is, it was little influenced by irrigation and highly affected by the plastic cover, although it did not show a coefficient of determination that is statistically significant at 0.05 probability level by the Student's t-test. This is confirmed by the fact that, for this cultivation condition, the difference between the highest and the lowest irrigation depths led to a difference of only 34 climbing stems, while in the condition without cover such difference was equal to 434.2 climbing stems.

Water consumption

Water consumption increased with plant growth until 140 DAS and then decreased until 210 DAS in both treatments and in areas with and without plastic cover (Table 2). This is associated with the variability of atmospheric conditions along the experiment, because in periods of high atmospheric demand, water consumption is higher than in periods with high nebulosity and rain events. Under cultivation conditions without plastic cover,

Table 2. Irrigation depth (liters) in the 'batata-de-purga' crop for the treatments T1 (25% ET_o), T2 (50% ET_o), T3 (75% ET_o), T4 (100% ET_o) and T5 (125% ET_o), under cultivation with and without plastic cover as a function of number of days after sowing (DAS).

DAS	T1	T2	T3	T4	T5
Without plastic cover					
30 DAS	19.5	39	58.6	78.0	97.5
60 DAS	51	102.4	153	204.3	255.0
90 DAS	71.25	142.5	213.5	285.3	356.6
120 DAS	58.5	127.1	175.7	234.3	292.8
150 DAS	29.2	58.5	87.5	117.0	146.3
Total	229.45	469.5	688.3	918.9	1148.2
With plastic cover					
30 DAS	19.5	39	58.5	78.0	97.5
60 DAS	44.3	88.6	132.9	177.3	221.6
90 DAS	52.2	104.5	156.7	209.0	261.2
120 DAS	47.1	94.2	141.3	188.5	235.6
150 DAS	50.1	100.2	150.3	200.4	250.5
Total	213.2	426.5	639.7	853.2	1066.4

crop water consumption was higher at 90 DAS, while the lowest consumption occurred at the end of the cycle (120 DAS). This result is directly related to the competition between plants and atmospheric demand.

The difference in crop water consumption between the treatments T1 and T5 was equal to 918.7 L for cultivation without cover and to 853.1 L for cultivation with cover. Additionally, the water consumption of 'batata-de-purga' cultivated without cover was on average 6.6% higher than in the condition with plastic cover. This difference in water consumption may be associated with the increase in crop yield, such as tuber weight, number of seeds, tuber diameter and tuber size, caused by the increase in luminosity. All the growth variables increased with the increase in the irrigation level. WUE values of 'batata-de-purga' in all irrigation treatments and under the cultivation conditions with and without plastic cover are expressed in the present study in terms of weight of seeds, number of seeds and number of climbing stems per volume of water applied to the crop (Table 3).

The irrigation depth of 25% ET_o (T1) in the area with cover showed an increase of 17% in WUE in terms of gram of seeds/liter of water in relation to the area without cover. For the treatment T2, WUE was higher in the area without cover, with a difference of 22%, WUE values, expressed in terms of grams of seed/liter of water, were higher in the cultivation without cover in the treatments T2 and T4. In terms of number of seeds/liter of water, the highest values of WUE were observed in T1 and T2. However, in terms of number of climbing stems/liter of water, WUE values were consistently higher in the cultivation without cover in all treatments in comparison to the cultivation with cover. The growth variables related to tuber increases with increases in irrigation depth. Tube is the unique part of the plant with medicinal effect and commercial value.

Statistical analysis

The analysis of variation of 'batata-de-purga' stem diameter as a function of irrigation treatments, in statistical terms, indicates that all irrigation levels led to difference between tuber diameters for the conditions with and without plastic cover, which was statistically significant at 0.05 probability level by F test (Table 4). Different uppercase letters in the same row indicate significant difference between tuber diameters and equal letters indicate no significant difference between tuber diameters for cultivation with and without cover.

In addition, for the conditions with and without cover, the diameter of 'batata-de-purga' was altered, also significantly at 0.05 probability level by F test, in all irrigation treatments from 30 to 120 DAS. Under both cultivation conditions, crop diameter was significantly altered by the irrigation level from 120 to 150 DAS.

This result suggests that the increase in 'batata-de-purga' diameter is little influenced at the end of the cycle by the increase in soil moisture, for both planting conditions, with and without plastic cover.

DISCUSSION

Agricultural systems with 'batata-de-purga' improved soil chemical conditions, increasing the contents of primary micronutrients and decreasing the contents of Al. Similar results were obtained by Portugal et al. (2010), who

Table 3. Water use efficiency (WUE) in the 'batata-de-purga' crop for the treatments T1 (25% ET_o), T2 (50% ET_o), T3 (75% ET_o), T4 (100% ET_o) and T5 (125% ET_o) under cultivation with and without plastic cover in terms of weight of seeds, number of seeds and number of climbing stems per volume of water

Treatments	Without plastic cover	With plastic cover
WUE (grams seed/liter of water)		
T1	0.41	0.58
T2	0.51	0.29
T3	0.43	0.58
T4	0.70	0.65
T5	0.53	0.62
WUE (Number of seeds/liter of water)		
T1	0.31	0.28
T2	0.41	0.18
T3	0.22	0.26
T4	0.19	0.19
T5	0.22	0.22
WUE (Number of climbing stem/liter of water)		
T1	0.65	0.39
T2	1.03	0.18
T3	0.59	0.31
T4	0.58	0.19
T5	0.58	0.17

Table 4. Variation of 'batata-de-purga' stem diameter as a function of irrigation treatments (T1 = 25%; T2 = 50%; T3 = 75%; T4 = 100%; and T5 = 125% of reference evapotranspiration – ET_o) and days after sowing (DAS) under planting conditions with and without plastic cover.

DAS	With plastic cover	Without plastic cover
Treatment T1 = 25% ET_o		
30	0.5617^{Aa}	1.8733^{Ba}
60	1.4333^{Ab}	3.1767^{Bb}
90	2.2100^{Ac}	5.0167^{Bc}
120	2.4650^{Ad}	6.2133^{Bd}
150	2.7183^{Ad}	6.3000^{Bd}
Treatment T2 = 50% ET_o		
30	1.1733^{Aa}	2.2717^{Ba}
60	2.2600^{Ab}	3.5167^{Bb}
90	3.6283^{Ac}	5.4983^{Bc}
120	3.9017^{Ad}	6.2050^{Bd}
150	4.0900^{Ad}	6.8383^{Bd}
Treatment T3 = 75% ET_o		
30	1.0117^{Aa}	2.2550^{Ba}
60	2.5000^{Ab}	3.2450^{Bb}
90	3.9183^{Ac}	5.4883^{Bc}
120	4.7500^{Ad}	6.8283^{Bd}
150	5.0733^{Ad}	7.0283^{Bd}

Table 4. Contd.

Treatment T4 = 100% ET_o		
30	1.1767^{Aa}	2.2717^{Ba}
60	2.2117^{Ab}	3.3500^{Bb}
90	3.8400^{Ac}	5.2883^{Bc}
120	4.5183^{Ad}	5.8733^{Bd}
150	4.9783^{Ad}	6.3350^{Bd}
Treatment T5 = 125% ET_o		
30	1.5333^{Aa}	2.6783^{Ba}
60	2.6000^{Ab}	3.6300^{Bb}
90	4.1000^{Ac}	5.8383^{Bc}
120	4.7833^{Ad}	6.7683^{Bd}
150	5.2000^{Ad}	7.0833^{Bd}

Means followed by the same lower case letters in a column and capital letters on the lines do not differ significantly by the F test ($p < 0.05$).

analyzed physical and chemical properties of a Latosol under different agricultural systems in the Zona da Mata region, in Minas Gerais. These authors observed that the agricultural systems with orange orchard and sugarcane plantation improved soil chemical conditions, increasing the contents of nutrients and decreasing the Al^{3+} of the exchange complex, but showed reduction in the contents of soil organic matter and intermediate levels of physical degradation. The lowest difference in seed weight between the cultivation conditions occurred in the treatment T1 (only 0.19 g), while the greatest difference occurred in the treatment T4 (8.9 g); then, it decreased to 4.4 g in T5. In this context, Bisognin et al. (2008) emphasize that the development of tubers is a critical period that determines crop yield and is one of the main stages directly influenced by solar radiation and amount of water.

The evolution of tuber weight with the increase in irrigation depth, for the cultivation with plastic cover, showed coefficient of determination (r^2) statistically significant at 0.05 probability level by the Student's t-test, while the reduction in the treatment without cover did not show r^2 statistically significant at 0.01 and 0.05 probability levels. The difference between minimal and maximal irrigation depths applied in the experiment was more than double in covered conditions (20.2 mm). However, the difference between the treatments T1 and T2 was only 3.6 mm and between T4 and T5, under these conditions, 9.3 mm. The smallest difference was observed between the treatments T3 and T4, which was equal to only 0.7 mm and below those under covered conditions. This occurs because solar radiation has direct relationship with crop yield, since air temperature and solar radiation affect the processes of plant growth and development (Tazzo et al., 2008).

The effects of luminosity on the production components of a crop are evident, since the presence of light causes a reduction in CO_2 concentration in the mesophyll, due to the photosynthesis, increasing the pH of the environment, which becomes alkaline and favorable to the production of enzymes involved in starch degradation and, therefore, increasing the concentration of glucose in the mesophyll (Michelin et al., 2010). Thus, plants cultivated without plastic cover consumed a greater amount of water due to the high temperatures occurring along the experimental period, in order not to be under stress and cause lower development of tubers. On the other hand, in the area with artificial shading, there was a lower water demand, which directly reflected in all production components of the tuber. Since 'batata-de-purga' is a plant adapted to low technological level systems, it is commonly found in small family-farming farms. Another great advantage from the perspective of family-farming cultivation is that harvest can be scheduled, anticipated or delayed, because the commercial parts are tuberous roots, which form along the crop cycle without a specific moment for harvest.

Conclusions

The results of the present study demonstrate that all growth variables of 'batata-de-purga' were strongly influenced by both soil moisture and cultivation conditions and irrigation depth. The optimum water and cultivation conditions for best plant growth are under 100% ETo and without plastic cover, respectively. The growth variables related to tuber (weight, size and diameter) increases linearly with increases in irrigation depth. Effectively, tube is the unique part of the plant with medicinal effect and commercial value. Irrigation has little influence on the cultivation of the crop exposed to the environmental conditions, while production is substantially increased under controlled conditions of luminosity. Results suggest that the weight of seeds showed higher values of water use efficiency for the cultivation with plastic cover, while the number of seeds and number of climbing stems showed higher water use efficiency for the cultivation without plastic cover. Except for the weight of seeds, which showed higher water use efficiency in the treatment of 100% $ET_{o,}$ the number of seeds and the number of climbing stems proved to be more efficient in the use of water in the treatments with smaller irrigation depths.

Conflict of Interests

The authors have not declared any conflict of interests.

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Water content and soil nutrient in consortium of native fruit trees with cover crops

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The use of cover crops in intercropping is an important strategy for soil management and conservation, the improvement of edaphic conditions, and the optimization of cultivation of intercropped plants of commercial interest. The goal of the present study was to evaluate the water content and soil nutrient as well as initial growth of some fruit trees native to the Cerrado, Brazil. That is, *Eugenia dysenterica* Mart. ex DC., *Dipteryx alata* Vogel and *Caryocar brasiliense* Camb., when intercropped with *Arachis pintoi* L., *Crotalaria spectabilis* Roth., *Dolichos lablab* L., and *Urochloa decumbens* Stapf., with nitrogen (81 kg N ha^{-1}) and *Urochloa decumbens* without nitrogen (*Urochloa decumbens* Stapf.) treatments. Fruit tree nutrient uptake, the biomass production of the cover crops, and the effects of the cover crops on soil moisture were evaluated. It was noted that *C. spectabilis* and *D. lablab* were less effective at maintaining soil moisture, but resulted in the highest nitrogen concentrations in *E. dysenterica* and *D. alata* leaves SO, these cover plants are recommended for these native species. The highest nitrogen concentrations in *C. brasiliense* were measured in response to N fertilizer. *A. pintoi* produced less biomass than the remaining cover crops tested, but resulted in the lowest soil moisture losses, justifying its use for soil moisture conservation.

Key words: Cerrado fruits, green fertilization, biomass, soil moisture, growth.

INTRODUCTION

The current situation in the Cerrado biome is of concern due to high deforestation rates and neglect of the soil grown and the addition of inputs to increase their fertility. Factors such as urban growth and agricultural exploitation, in 50 years have promoted the reduction of vegetation to less than half of the natural area. These human activities are responsible for several species which enter the group of plants at risk of disappearing, endangering the biodiversity and the ecosystem, and contribute to environmental change.

The native cerrado plants among plant species are the most promising for reforestation and restoration of altered soils. The ability to develop lush roots that reach deeper than other species, and already are adapted to the

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natural conditions of the region. The extinction of several species indicates the need for changes in the use of natural resources (Scalon and Jeromine, 2013). The plants constituting the Cerrado's vegetation mosaic are medicinal resources and sources of food, wood, plant dyes, and ornamental plants.

There are over 50 species of fruit trees that are native to the Cerrado, of which many have agricultural potential (Ribeiro and Rodrigues, 2006). However, their cultivation, production and handling have scarcely been studied.

Species such as *E. dysenterica*, *D. alata*, and *C. brasiliense* yield high-quality fruits with high nutrient concentrations; these fruits may be consumed fresh or processed in different ways (Fernandes et al., 2010; Sousa et al., 2011). These plants have potential for honey and wood production and medicinal uses and may be used in orchards and reforestation (Martinotto et al., 2007). Therefore, these species should be studied.

During cultivation of large amounts of fertilizers and lime, as well as pesticides, contaminate soil and water are used. The traffic of machines in farming and animal trampling in the grasslands, causes compression, changing the soil structure (Martins et al., 2015). Low infiltration of rainfall, drought and soil hardens quickly, the water that flows over the surface transports fertilizers and pesticides, causing erosions. The strong relationship between soil and native vegetation is clear, and the need for changes in the forms of use of natural resources (Scalon and Jeromine, 2013; Schwenk et al., 2013), the integration of plants that provide benefits to the farming system and recover the altered soil properties.

Although they are adapted to the conditions in the Cerrado, plants native to this biome suffer as a result of edaphoclimatic conditions such as acid soil, low nutrient concentrations, irregular rainfall and high temperatures (Guecker et al., 2009). Another important factor is the rapid decomposition of plant residues deposited on the soil surface. Crop handling methods are therefore needed to protect the soil against direct exposure to factors that cause its degradation, such as rain, insolation and drought (Guareschi et al., 2012).

The use of cover crops is an important strategy for soil management and conservation and may improve soil conditions and thereby increase the growth of plants of commercial interest when used in intercropping. The decomposition of cover crops releases nutrients, organic acids, amino acids and phytohormones, which may be beneficial for intercropped plants (Buzinaro et al., 2009).

Nitrogen is an essential nutrient for plants, and its deficiency causes low plant metabolism and development. Cover crops from the family Fabaceae should be highlighted because they establish associations with microorganisms that can perform biological nitrogen fixation (BNF) in large quantities, with economical benefits to producers (Perin et al., 2007).

The use of cover crops may improve soil characteristics by decreasing erosion, increasing soil nitrogen through BNF, improving nutrient cycling and moisture maintenance, decreasing the soil temperature range, and promoting the activity of beneficial microorganisms in the soil (Almeida et al., 2014, 2015). However, cover crops should be carefully selected. The growth time and habit of cover crops should be in agreement with fruit tree management, and other effects of coexistence should be considered to minimize competition (Perin et al., 2009).

The goal of the present study was to evaluate the water content and soil nutrient as well as initial growth of some fruit trees native to the Cerrado in an intercropped system with cover crops.

MATERIALS AND METHODS

Local

The experiment was performed between December 2013 and December 2014, at the Federal Institute of Goiás (Instituto Federal Goiano), Rio Verde Campus, located in the southwest state of Goiás, a region with Cerrado vegetation. The experimental area was located at 17º 48’ 46" S and 50º 54’ 02” W, at an altitude of 693 m, and consisted of *Urochloa decumbens* Stapf. pasture. The soil was classified as a dystrophic Red Latosol. The climate of this region is Aw according to the Köppen climate classification, that is, tropical, with rainfall concentrated in summer and a well-defined dry period in winter.

Experimental design

The experimental design was completely randomized, with a 3 x 5 factorial scheme (three native fruit trees, *E. dysenterica*, *D. alata* and *C. brasiliense,* and five cover crops, *A. pintoi*, *C. spectabilis*, *D. lablab*, *U. decumbens* + N and *Urochloa decumbens* without nitrogen), with four replicates. The *Urochloa decumbens* was a treatment with *U. decumbens* and no nitrogen as the cover crop.

Site preparation

The experiment began with the sowing of the cover crops in December 2013 (Figure 1b). The experimental area was prepared two months before the beginning of the experiment, with pasture desiccation (960 g kg^{-1} glyphosate), and mechanized soil preparation, with subsoiling, harrowing and leveling (Figure 1a). Soil samples were collected from depths of 0-10, 10-20 and 20-40 cm and used for determination of soil chemical properties and particle size (Table 1).

The cover crops *A. pintoi*, *C. spectabilis* and *D. lablab* were sown manually in furrows spaced 50 cm apart. *U. decumbens* grew spontaneously because it was the previous pasture. Holes measuring 40×40×40 cm were dug between the planted rows; these holes were spaced 5×5 m apart (Figure 1c). Fertilizer was applied during the filling of the holes, that is, the equivalent of 27 kg ha^{-1} P_2O_5, based on recommendations for soil in this region. The substrate was left to settle in the hole for thirty days, after which the native fruit tree seedlings were planted.

Biometric monitoring

Biometric monitoring of *E. dysenterica, D. alata* and *C. brasiliense* seedlings during cultivation was performed by measuring height

Figure 1. Intercropping of fruit trees native to the Cerrado with different cover crops. (A) Preparation of the experimental area, that is, harrowing. Scale bar = 1.5 m. (B) Sowing of *A. pintoi.* Scale bar = 1 m. (C) Planting of fruit trees. Scale bar = 0.5 m. (D) Top-dressing fertilization. Scale bar = 0.3 m. (E) Measurements of height and stem diameter. Scale bar = 0.2 m. (F) Growth of cover crops at 150 DAS. Scale bar = 0.2 m. (G) Grubbing of cover crops. Bar = 1.5 m. (H) Collection of leaves for analysis of nutrient concentration. Scale bar = 0.3 m. (I) Collection of leaves for foliar analysis. Scale bar = 0.3 m.

Table 1. Chemical and physical properties of soil collected from different soil depths and analyzed for the cultivation of seedlings of fruit trees native to the Cerrado, grown in intercropping systems with cover crops.

Depth	pH	P	Ca	Mg	K	Al	H+Al	Clay	Silt	Sand
	$CaCl_2$	mg dm^{-3}	cmol$_c$ dm^{-3}					g kg^{-1}		
00 - 10	5.3	4	0.32	0.15	0.41	0.00	0.19	270	170	560
10 - 20	5.3	2	0.33	0.14	0.31	0.00	0.20	310	220	470
20 - 40	5.3	2	0.34	0.14	0.29	0.00	0.18	370	230	400

(cm) and stem diameter (mm) at 0, 180 and 365 days after transplanting (DAT). The average height and stem diameter at 0 DAT were, respectively, 16.82 cm and 29.02 mm for *E. dysenterica*, 21.20 cm and 3.09 mm for *D. alata*, and 6.31 cm and 5.97 mm for *C. brasiliense* (Figure 1e). Four plants located in the center of each plot were identified and measured. Height was measured from the ground to the highest tip of the plant, using a measuring tape. Stem diameter was measured at a height of two cm above the ground, using a digital pachymeter.

Tree crowning to a 0.50 m radius and weed and ant *Urochloa decumbens* were performed in the experimental area as needed. Top-dressing fertilization was performed for treatment *U. decumbens* + mineral N, send 81 kg ha^{-1} de urea. The equivalent of 36.45 kg N ha^{-1} was applied to the crowns of the fruit trees in three stages, that is, February, April and November 2014 (Figure 1d). This amount of urea is an approximate average nitrogen fixation capacity by cover crops and the influences that they suffer (Alcântara et al., 2000; Andrade Neto et al., 2010; PERIN et al., 2004).

Cover crop management was performed 150 days after sowing (Figure 1f), by cutting the plants at ground level (Figure 1g). Biomass production was measured using a 1-m² quadrat that was placed in the center of each plot, and all plant mass within the quadrat was collected. The samples were weighed fresh and placed in a convection oven at 65°C for a minimum of 72 h, and the dry weight was measured. Fully expanded leaves from the fruit trees were also collected (Figure 1h), washed with distilled water (Figure 1i), dried in an oven as described for the cover crops, ground using a Wiley mill (2-mm sieve), and analyzed according to Malavolta et al. (1997).

Following sampling, grubbing of the cover crops, except *A. pintoi* due to its low height, was performed using a grubber. Part of the

Table 2. Nitrogen (N), phosphorus (P) and potassium (K) contents (g kg^{-1} dry matter) on Cerrado fruit trees at 180 days after transplanting (DAT) under different cover crops.

Plant roof	Fruit plants of the cerrado								
	E. dysenterica			***D. alata***			***C. brasiliense***		
	g kg^{-1}			g kg^{-1}			g kg^{-1}		
	N	P	K	N	P	K	N	P	K
A. pintoi	19.0	1.2	4.0	19.0	1.6	8.8	16.0	1.2	4.8
C. spectabilis	24.0	1.0	4.0	24.0	1.8	7.2	16.0	1.6	5.6
D. lablab	17.0	1.2	4.0	22.0	1.6	5.6	16.0	1.4	4.8
U. decumbens+ N	22.0	1.2	3.2	24.0	1.8	4.8	19.0	1.4	4.0
U. decumbens	17.0	1.6	4.8	19.00	1.8	10.4	16.0	1.4	5.6

straw was placed under the fruit trees to maintain moisture, *Urochloa decumbens* weeds, and enrich the soil with organic matter and nutrients resulting from its decomposition. Soil moisture measurements were conducted on soil samples collected at a depth of 0 to 10 cm, from all treatments except the *U. decumbens*, using a hoe according to Embrapa (2007).

For the nutrients contents on leaves of these plants, one individual was considered, since there was not enough plant material for this analysis. The growth characteristics of native fruit and fresh and dry mass of cover crops were also evaluated.

Analysis of variance was performed, followed by a Tukey test when needed, at a significance level of $p \le 0.05$.

RESULTS AND DISCUSSION

With respect to nutrients contents, N content on *E. dysenterica* in different cover crops ranged from 17 to 24 g kg^{-1}. The P content ranged from 1.0 to 1.6 g kg^{-1}, while for K values were between 3.2 and 4.8 g kg^{-1}. The foliar N observed in *D. alata* plants ranged from 19.0 to 24.0 g kg^{-1}, while the P levels were 1.6 and 1.8 and K 4.8 to 10 4 g kg^{-1}. In *C. brasiliense* plants, N concentration ranged from 16.0 to 19.0 g kg^{-1} while the P levels ranged from 1.2 to 1.6 g kg^{-1}. For the K were observed levels of 4.0 to 5.6 g kg^{-1}. These are important data because of the scarce number of works in this area, and the fact of characterize macronutrient contents of native plants intercropped with different cover crops (Table 2).

E. dysenterica presented low nutrient requirements for its initial growth. This species is very well adapted to different soil environments, nutrient availabilities, moisture levels and low pH (Naves et al., 2002), and this hardiness results in slow and somewhat uneven growth. In addition, this species is characterized by a greater initial investment into root growth (Venturoli et al., 2013). This is in accordance with the average *E. dysenterica* heights observed in the present study, which ranged from 22.57 cm at 180 DAT to 30.71 cm at 365 DAT across all intercropping systems.

The low nutrient requirements of *E. dysenterica* indicate its potential use in degraded areas of the Cerrado (Oliveira et al., 2015). The few existing reports regarding fertilization indicate that native Cerrado species are tolerant to low nutrient availabilities, and their low leaf nutrient concentrations reflect the low soil nutrient availability. In addition, *E. dysenterica* has been reported to be well adapted to low nutrient availability, high soil acidity and high aluminum in the soil (Naves et al., 2002), and to be resistant to drought).

Souza et al. (2013) studied the initial fruit production of cultivated *E. dysenterica* and observed that plant growth was slow and uneven. These authors suggested some strategies for the improvement of these factors, such as irrigation during drought periods and mulching. These characteristics of *E. dysenterica* have been attributed to its adaptation to environmental factors and to its high genetic variability (Aguiar et al., 2009).

D. alata usually exhibits greater growth than other Cerrado plant species, such as *E. dysenterica* and *Hancornia speciosa* Gomes. Studies on *D. alata* populations in natural and exploited environments show that although this species can become established in poor soils, it grows better with medium fertility levels (Ribeiro and Rodrigues, 2006), which is in agreement with the present results. Correa et al. (2008) studied the physical parameters of the fruits and seeds of Cerrado plant species and also assumed that *D. alata* prefers more fertile soils.

C. brasiliense has been observed to occur in different soil types, including those with low nutrient concentrations and different textures, ranging from sandy to clayey, and with the presence of gravel and boulders. However, this species has a high light demand, preferring areas with vegetation of small size and density (Santana and Naves, 2003). It was verified that the leaf contents corroborate Santana and Naves (2003), with a slight increase on this content, since this plants are located in different regions, climate, soil and genetics. Moreover, these results can be justified due to previous fertilizations carried out in the area of this study.

A. pintoi presented the lowest fresh ($p \le 0.05$) and dry weights for the cover crops (Figure 2). This is because *A. pintoi* is a perennial plant that has a low height and presents slow initial growth compared with annual plants.

Cover crops have beneficial effects on soil

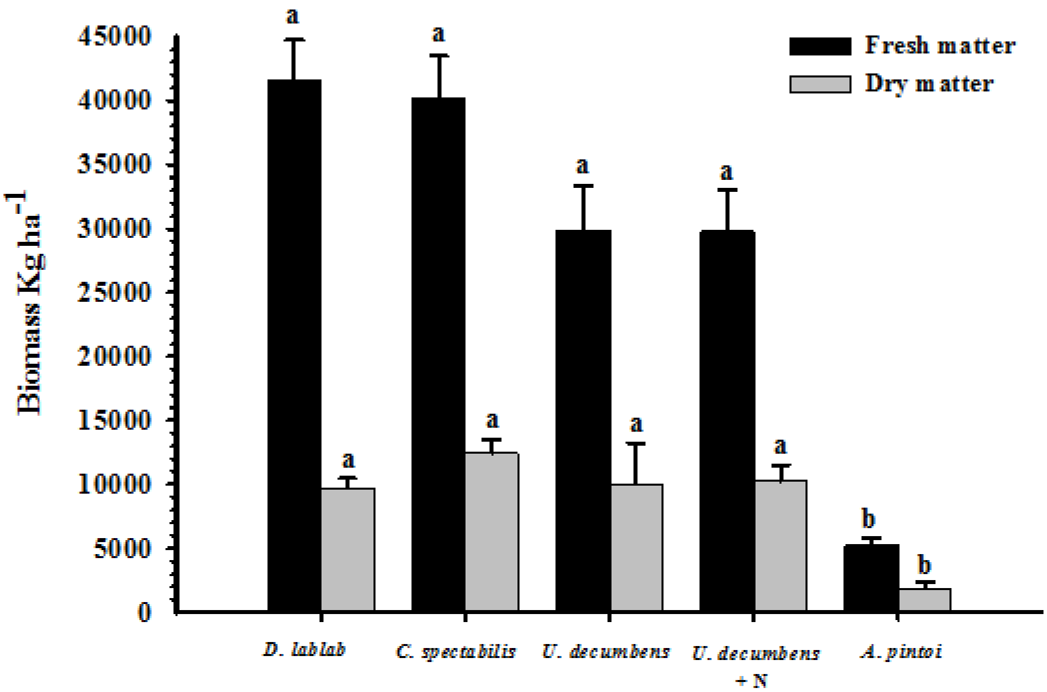

Figure 2. Fresh and dry weight of cover crops intercropped with fruit trees native to the Cerrado, 180 days following sowing.

characteristics and consequently on the plants of interest. These beneficial effects occur as a result of increased soil fertility through BNF and nutrient recovery from deeper soil layers and protection of the soil against erosion due to climate factors (Perin et al., 2009; Silva et al., 2008). Moreover, cover crops may improve the physical structure of the soil, increase soil organic matter concentrations, facilitate the maintenance of soil moisture levels and temperature, help to *U. decumbens* weeds, and decrease the load of agrochemicals in the soil. For these reasons, the use of cover crops is strategic in the cultivation of several crops of interest. This is in agreement with Vilela et al. (2011), who observed that deposition of plant mass close to *Coffea arabica* L. plants resulted in increased nutrient concentrations, plant growth, and soil pH.

Except for *A. pintoi*, the tested cover crops exhibited rapid growth and a strong potential for soil cover. Consequently, thinning the area where the fruit tree crown was located was necessary during the vegetative cycle of the cover crops to prevent choking and lodging of the fruit trees. The rapid growth and performance of *D. lablab* and *C. spectabilis* were beneficial for fruit trees, especially in terms of biomass production. This is in accordance with Carneiro et al. (2008), who observed increases in microbial biomass carbon. Pereira et al. (2012) reported that *C. spectabilis* was the cover crop with the highest mass production, which is in agreement with the results from the present study. *A. pintoi* had the lowest mass production among the cover crops tested. Teodoro et al. (2011b) also observed slow initial growth of *A. pintoi*, up to 90 days. However, this species provided efficient soil covers and weed inhibition following this period.

Regarding the effect of cover crops on soil moisture, *U. decumbens* and *D. lablab* resulted in better maintenance of soil moisture at the beginning of the experimental period, followed by *C. spectabilis* and *A. pintoi* (Figure 3). This pattern may be related to the amount of plant biomass produced and the extent of the soil cover, which protects the soil from sun exposure and results in higher moisture retention. In comparison to the remaining cover crops tested, *D. lablab* exhibited senescence. This may have been important for its effects on *D. alata* growth because this resulted in the maintenance of soil moisture and constant nutrient recycling, as reported by Teodoro et al. (2011a).

Soil moisture is one of the most important factors that affect plant growth. Zhu et al. (2012), observed a positive correlation between soil moisture and photosynthesis in tomato plants. Photosynthesis was low in soil with 55% field capacity and increased with increasing soil moisture. Soil moisture was considered to have greater effects than fertilization on fruit production, plant biomass and the root/shoot ratio.

In the present study, the most pronounced decrease in soil moisture may be associated with the annual life cycle of *D. lablab* and *C. spectabilis*. *U. decumbens* and *A. pintoi* are perennial plants with resprouting ability, and these species presented the greatest capacity for soil

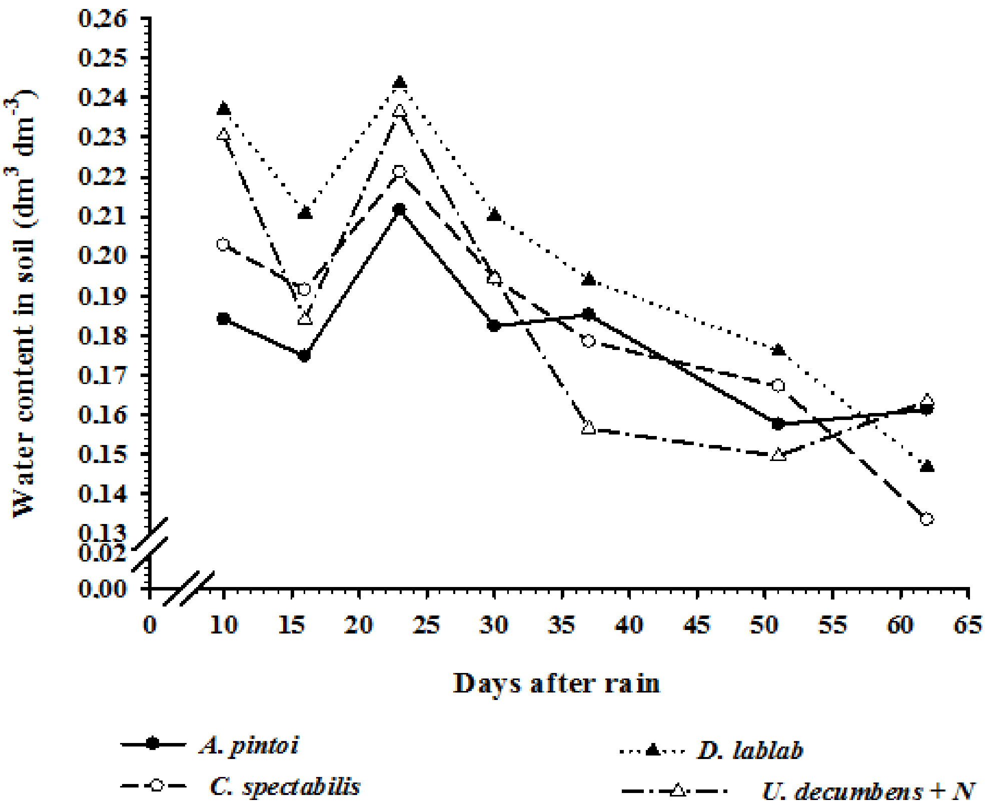

Figure 3. Variation in the soil water content of a dystrophic Red Latosol cultivated with different cover crops (evaluation period: 21/05/2014 to 22/07/14).

cover and soil moisture maintenance. The decrease in soil moisture may also be attributed to the low C/N ratio of *C. spectabilis* and *D. lablab*, which resulted in faster biomass decomposition. Intercropping of legumes with cruciferous plants and grasses has been observed to result in higher plant biomass and lower residue decomposition compared with monocropped legumes (Doneda et al., 2012).

The drought period following the cutting of cover crops resulted in decreased soil moisture throughout the experimental area. However, at the end of the experimental period, this decrease was more pronounced with *D. lablab* and *C. spectabilis* (38 and 34%, respectively) than with *A. pintoi* and *U. decumbens*, which presented similar soil moisture values (Figure 4).

For height and stem diameter, interaction was significant. Thus, no differences in plant height were observed for *E. dysenterica* intercropped with different cover crops ($p>0.05$). *D. alata* plants were taller at 180 DAT when intercropped with *U. decumbens*+N and at 365 DAT when intercropped with *U. decumbens*+N and *D. lablab*. *C. brasiliense* height at 180 DAT was the lowest when intercropped with *C. spectabilis*, whereas *U. decumbens*+N and the *Urochloa decumbens* treatment yielded the greatest heights at 365 DAT (Table 2).

D. alata presented greater growth compared with the remaining fruit trees up to 180 DAT, for all intercropping systems tested. *C. brasiliense* presented similar growth to *D. alata*, except when intercropped with *C. spectabilis* and at 365 DAT when intercropped with *C. spectabilis* and *D. lablab*. Within the *U. decumbens* treatment, no differences ($p>0.05$) were observed in the growth of the fruit trees until 180 DAT. At 365 DAT, *C. brasiliense* was significantly taller than *E. dysenterica* (Table 3).

The higher growth observed for *D. alata* than for the remaining fruit tree species is in agreement with Vieira et al. (2006), who studied fruits native to the central-western region of Brazil and observed the occurrence of *D. alata* in soils with medium fertility.

The growth of *C. brasiliense* intercropped with the *U. decumbens* and the *U. decumbens*+N treatment indicated the ability of this species to adapt to different environments and nutrient concentrations. This may be explained by several factors, such as the adaptation of this species to the soil of the region, that is, with low fertility and moisture, the accumulation of nutrient reserves in the seeds, investment in root growth, and high genetic variability (Martins et al., 2015).

No stem diameter differences were observed when *E. dysenterica* was intercropped with various cover crops ($p>0.05$), at both evaluation times (Table 4). *D. alata* had a lower stem diameter at 180 DAT when intercropped

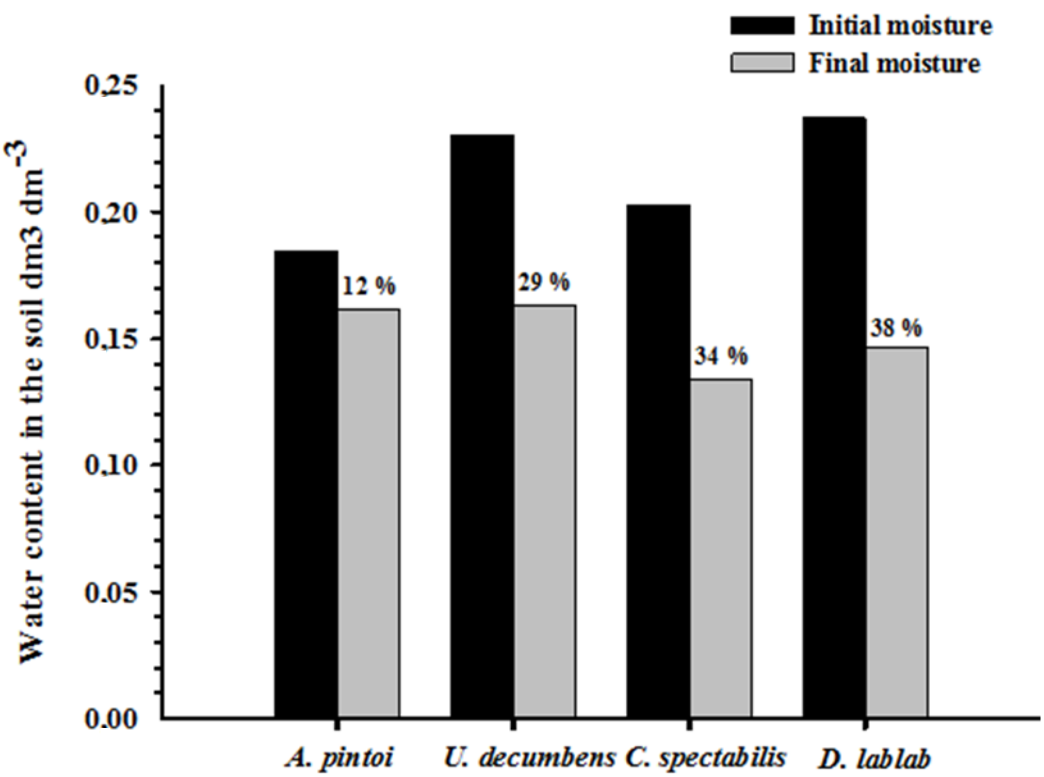

Figure 4. Water storage in a Latosol cultivated with different cover crops (evaluation period: 21/05/2014 to 22/07/14). *Values are the relative water loss during the evaluation period.

Table 3. Height (cm) of fruit trees native to the Cerrado grown in intercropping systems with different cover crops, 180 and 365 days after transplantation.

Fruit tree	Cover crops				
	A. pintoi	***C. spectabilis***	***D. lablab***	***U. decumbens*+N**	***U. decumbens***
			180 DAT		
E. dysenterica	23.00^{Abz}	21.57^{Ab}	16.50^{Ab}	24.50^{Ac}	27.00^{Aa}
D. alata	29.12^{Bab}	38.12^{Ba}	39.25^{Ba}	56.87^{Aa}	36.37^{Ba}
C. brasiliense	29.62^{ABab}	23.00^{Bb}	33.75^{ABa}	44.87^{Aab}	41.25^{Aa}
			365 DAT		
E. dysenterica	29.00^{1Ab}	32.00^{Aab}	20.50^{Ab}	44.25^{Ab}	27.80^{Ab}
D. alata	58.50^{Bab}	60.00^{Ba}	66.00^{ABa}	95.00^{Aa}	46.00^{Bab}
C. brasiliense	67.50^{BCa}	26.00^{Db}	36.00^{CDb}	106.00^{Aa}	77.25^{ABa}

[z]Values followed by the same upper case letter within a line, and lower case letter within a column are not significantly different at $p<0.05$ according to the Tukey test.

with *C. spectabilis* and *D. lablab* and at 365 DAT when intercropped with the *U. decumbens*. The highest *C. brasiliense* stem diameter (*p≤0.05*) was measured in the *A. pintoi*, *U. decumbens*+N and *U. decumbens* intercropping systems at 180 DAT and in the *U. decumbens*+N and *Urochloa decumbens* intercropping systems at 365 DAT. *D. alata* and *C. brasiliense* had greater stem diameters than *E. dysenterica*, regardless of cover crop (Table 4).

D. alata and *C. brasiliense* had similar or higher initial stem diameters than *E. dysenterica* in all intercropping systems tested. *D. alata* and *C. brasiliense* presented faster growth than *E. dysenterica.*

The taller height and greater stem diameter of *D. alata* and *C. brasiliense* in all intercropping systems are in agreement with Oliveira et al. (2015), who observed similar responses for *D. alata* and *C. brasiliense* compared with *E. dysenterica* in monocropped systems.

Table 4. Stem diameter (mm) of fruit trees native to the Cerrado grown in intercropping systems with different cover crops, 180 and 365 days after transplantation.

Fruit tree	Cover crops				
	A. pintoi	***C. spectabilis***	***D. lablab***	***U. decumbens* + N**	**U. decumbens**
			180 DAT		
E. dysenterica	4.13^{Ac1}	4.23^{Ab}	3.00^{Ab}	4.06^{Ab}	3.60^{Ac}
D. alata	9.48^{ABab}	8.60^{Ba}	8.58^{Ba}	12.41^{Aa}	8.94^{ABab}
C. brasiliense	12.06^{Aa}	7.05^{Cab}	7.91^{BCa}	12.88^{Aa}	10.95^{ABa}
			365 DAT		
E. dysenterica	5.53^{Ab1}	5.44^{Ab}	4.34^{Ab}	5.66^{Ab}	4.21^{Ac}
D. alata	14.21^{ABa}	15.05^{ABa}	14.84^{ABa}	19.35^{Aa}	12.85^{Bb}
C. brasiliense	17.01^{Ba}	8.04^{Cb}	9.80^{Ca}	24.85^{Aa}	23.91^{Aa}

[1]Values followed by the same upper case letter within a row, and lower case letter within a column are not significantly different at $p<0.05$ according to the Tukey test.

Conclusions

1. For the nutrient content, independently of the consortium used, high levels of nitrogen, phosphorus and potassium presented in the leaves of native plants, highlights the importance of consortium with cover crops, especially with perennials, *A. pintoi* and *U. decumbens* which promoted higher soil water storage.
2. For the water content was observed that the *Arachis pintoi* was the cover plant that produced the smallest amount of biomass, however provided the lowest soil moisture loss.
3. For the initial growth success of native plants (*E. dysenterica, C. brasiliense, D. alata*) was observed that the intercropping with cover crops (*D. lablab, A. pintoi, U. decumbens, C. spectabilis*) can be better than chemical fertilization.

Conflict of Interests

The authors have not declared any conflict of interests.

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Full Length Research Paper

Characterizing commercial cattle farms in Namibia: Risk, management, and sustainability

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Commercial cattle farming in semi-arid regions is subject to high rainfall risk. At the same time, it is prone to rangeland degradation. Theoretical works suggest that rainfall risk management by means of financial instruments may stabilize farming-derived income over the short-term, but provides little incentives for conservative rangeland management. Thus, the use of financial strategies of income stabilization may accelerate rangeland degradation over the long term, as opposed to production or organization strategies which may alternatively be used to stabilize farming incomes. In this paper, we provide an empirical characterization of Namibian commercial cattle farming and explore the link between risk, management, and sustainability by examining structural farm patterns with a cluster analysis. Our data comes from a large-scale survey across the Namibian commercial cattle farming area, to which 398 farmers responded. Our results show that the most distinct of the three identified clusters is characterized by high sustainability and low financial risk management, and that it does not differ from the remaining two clusters with respect to income. This suggests an inverse relationship between financial risk management and sustainability, and thus supports theoretical insights.

Key words: Cattle farming, semi-arid rangelands, Namibia, empirical survey, rainfall risk, risk management, sustainability.

INTRODUCTION

A defining characteristic of semi-arid areas is low and highly variable rainfall. Roughly 50% of the land in these areas is used as rangeland for extensive livestock farming (MEA, 2005), as this type of land use offers sufficient flexibility to adapt to the challenging rainfall conditions. However, even though livestock farming is intended to deal with the variable rainfall conditions, it is frequently unsustainable with 10–20% of semi-arid areas being degraded (MEA, 2005: 637, 640). One reason is that livestock farming is often practiced as *communal,* common-property farming systems where it may be rational for farmers to “produce outcomes that are not in

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anyone's long-term interest" (Ostrom, 1999: 279).

However, degradation is also observed in *commercial* farming systems where property-owning farmers exclusively manage rangeland and may do so for decades (de Klerk, 2004; Smit et al., 2015). One reason for degradation in commercial systems is the use of inadequate management strategies (Fynn and O'Connor, 2000; de Klerk, 2004; Wiegand, 2010; Kgosikoma et al., 2012). More specifically, theoretical analyses suggest that financial management strategies may stabilize farming-derived income, but that farmers who apply these strategies refrain from periodically resting their rangeland and thereby ultimately overstock their land (Quaas et al., 2007; Quaas and Baumgärtner, 2008, 2012; Baumgärtner and Quaas, 2009a; Müller et al., 2011). Essentially, financial strategies thus trade-off the short-term reduction of income risk against the system's long-term sustainability. The precise link between risk, management and sustainability in commercial farming systems is, however, poorly understood, not least of all because comprehensive empirical data is lacking.

In this paper, we empirically characterize risk, management and sustainability for commercial livestock farming in semi-arid rangelands. Our case study is commercial cattle farming in Namibia which constitutes an economically important sector that contributes directly 1–2% to Namibia's GDP (MAWF, 2009) and provides employment for approximately 40,000 farmers and farm workers (NTA, 2013: 15).[1] Like other semi-arid areas, Namibian rangelands are subject to high rainfall risk (Sweet, 1998) as well as to degradation in the form of bush encroachment (de Klerk, 2004; Smit et al., 2015).

In August 2008, we conducted a large-scale survey among 2,119 commercial cattle farmers through a mail-in questionnaire (Olbrich et al., 2012).[2] We collected information on 1) perceived rainfall risk, 2) risk management strategies, 3) the farm's sustainability, 4) individual risk and time preferences and normative views of sustainability, and 5) personal, farm and environmental features. 398 farmers responded to the survey, corresponding to a response rate of 19%. Here, we analyse these data by providing descriptive statistics and also by exploring structural farm patterns in a cluster analysis for a subset of 108 farmers. We hypothesize that risk, management and sustainability are intricately linked for our case study along the lines of earlier theoretical results described above.

The paper is organized as follows: First is a brief description of commercial cattle farming in Namibia, followed by a description of the data collection and the analytical procedures. Thereafter the descriptive statistics and results for the cluster analysis is presented, discussed and the research concluded.

SUSTAINABILITY AND THE TRADE-OFF WITH RISK MANAGEMENT

One prominent notion of sustainability is strong sustainability: critical natural and economic components of a system – such as rangeland condition or farm income – have to be conserved at or above specified thresholds, and have to be conserved independently of each other (Pearce et al., 1989; Ekins et al., 2003). Specifying sustainability thresholds is a normative decision and may, like all normative decisions, occur at the level of the individual or at the level of the society (Schwartz, 1977; Stern, 2000; Baumgärtner and Quaas, 2009b; Young and Burke, 2010; Olbrich et al. 2014).

Once thresholds are specified, achieving sustainability depends on choosing and applying adequate management strategies (or, more generally, measures) in order to comply with the thresholds (Baumgärtner and Quaas, 2009b).

The management strategies that are ultimately adequate may not be obvious at first, as different strategies may all have beneficial effects over the short-term. However, some strategies may ultimately be detrimental for the system and lead to an unsustainable development, which may become only obvious over the long term.

In a series of theoretical studies, Quaas and Baumgärtner (2008), Baumgärtner and Quaas (2009a) and Müller et al. (2011) showed for Namibian rangelands that conservative rangeland management that employ resting strategies particularly adapted to variable rainfall may provide a form of natural insurance, as it buffers the negative effects of low rainfall events. Such strategies that are aimed at the production process / farm organisational levels and financial strategies are substitute for reducing income risk – and thus for stabilizing income – over the short term. Over the long-term, however, financial strategies can be unsustainable: farmers no longer have an incentive to use natural insurance by means of conservative rangeland management. Instead, they overstock their farms. This slowly degrades their rangeland and eventually also leads to considerably lower farm income.

System description of commercial cattle farming in Namibia

Commercial cattle farming is an extensive farming system and economically the dominant livestock system in Namibia: it contributes by far the largest share of total agricultural output and approximately 1–2% directly to GPD (MAWF, 2009: 7, 9).[3] An estimated 2,250 commercial cattle farmers (Olbrich et al., 2012) keep an

[1] This amounts to 5.7% of total employment in Namibia (NSA, 2015: 6).
[2] Although dating from 2008, our survey is (to our knowledge) still the most recent and comprehensive of its kind in Namibia.

[3] All subsequent figures from MAWF (2009) are calculated as averages over the period 2000–2007.

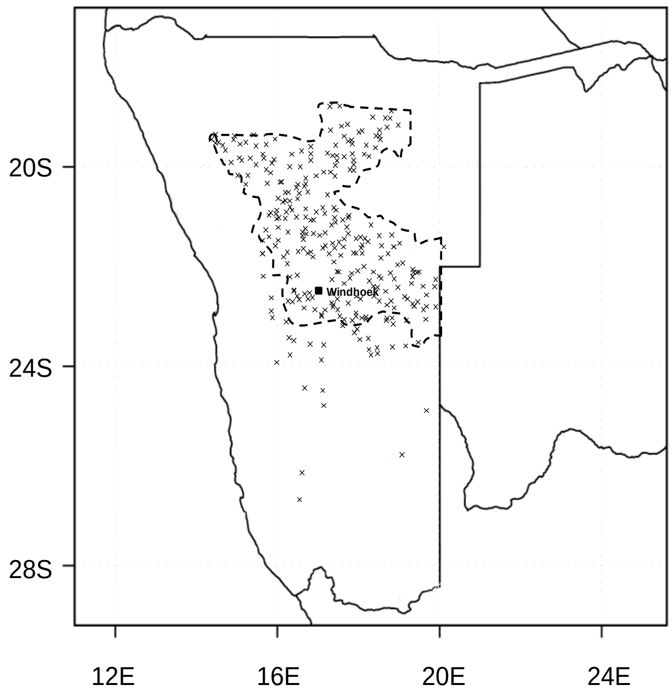

Figure 1. Commercial cattle farms in Namibia. The dashed line delimits what is considered the commercial cattle farming area (Mendelsohn, 2006). Crosses denote the position of all 299 farms which were identified in our mail-in questionnaire.

average of 840,000 cattle (MAWF, 2009: 13). Of the 298,961 cattle that are on average marketed each year, roughly half (49%) are sold as live cattle (almost exclusively as weaners) whereas the other half (51%, almost exclusively oxen) are sold as beef (MAWF, 2009: 14). Almost all weaners are exported as live cattle to feed lots in South Africa (Schutz, 2010). Beef is primarily sold to South Africa (45%), overseas (37%) and other markets (3%) with only a small fraction consumed domestically (15%) (MAWF, 2009: 14, 15). The commercial cattle farming area in Namibia covers approximately 14.5 million hectares (ha) (Mendelsohn, 2006: 42) of rangeland in the northern half of Namibia (Figure 1). It is confined at its southern and western fringes by areas too dry for farming and at its northern and eastern fringes by communal lands. On average, the commercial cattle farming area receives an annual rainfall of only 374 mm, with 95% (352 mm) of rainfall falling during the rainy season from November to April (NMS, unpublished).[4]

Rainfall is low on average and varies considerably, both across rainy seasons (NMS, unpublished)[5] and across individual farms (Ward et al., 2004). The rangeland's production is rainfall-limited and strongly co-varies with rainfall (Ward and Ngairorue, 2000; du Plessis, 2001; Atlas of Namibia Project, 2002: Figure 2).

As such, precipitation risk directly transforms into rangeland production risk. Since commercial cattle farming in Namibia is extensive farming, the rangeland production risk in turn translates into cattle production and ultimately income risk.

Beyond being subject to low and highly variable rainfall, rangelands of the commercial cattle farming area are in an unsustainable state. They suffer from degradation due to bush encroachment, i.e. they have come to be dominated by woody vegetation (de Klerk, 2004; Joubert et al., 2008; Kgosikoma et al., 2012; Smit et al., 2015). Bush encroachment entails a reduction in the rangeland's overall production which is equivalent to a reduction in grazing capacity. A reduction in grazing capacity, in turn, diminishes farm income (de Klerk, 2004; Lukomska et al., 2014) since grazing capacity directly relates to the amount of cattle that may be supported by the rangeland. Bush encroachment across the commercial cattle farming region is illustrated by grazing capacity being nowadays much worse than the historic value of above 0.1 Large Stock Unit per hectare (LSU/ha) that was encountered on average across Namibia until the mid 1960s (de Klerk, 2004: 21).

Risk management strategies in cattle farming

As previously mentioned, farmers' income is highly risky since it is related to the high rainfall risk via rangeland production and cattle production. Income may thus change dramatically from year to year if no risk management is conducted.

A farmer may manage the risk through a number of risk management strategies. These strategies either adjust the organization or production processes of the farm ("on-farm strategies") or makes use of financial products or off-farm assets ("financial strategies"). The main on-farm strategies are:

i) Increasing the rangeland size ("rangeland size increase"),
ii) Resting part of the rangeland to provide feed throughout the year ("resting rangeland"),
iii) Providing cattle with purchased hay and licks ("additional feed"),
iv) Choosing cattle breeds adapted to local environmental conditions ("breed adaptation"),
v) Choosing a production system, such as weaner or ox production, that is adapted to local environmental conditions ("production system adaptation");
and the main financial strategies are:

[4] We refer here to the meteorological year, which is commonly defined from July to June in southern Africa (e.g. Unganai, 1996; Burke, 1997). We define the rainy season as the period 01st of November until 30th of April.

[5] For example, the coefficient of variation for total annual rainfall shows a value of 0.35 (NMS, unpublished). For comparison: the corresponding coefficient of variation is between 0.1 and 0.2 for countries in central and northern Europe (Chapman, 2010: Map 2).

i) agreeing on advances on livestock sales ("advances on livestock sales"),
ii) keeping a checking account as a financial buffer ("checking account as buffer"),
iii) taking up loans for covering operating losses ("loans for covering operating losses"),
iv) obtaining income from off-farm sources ("off-farm income"), and
v) investing into agricultural derivatives ("investment into agricultural derivatives").

DATA AND METHODOLOGY

Data sources

Here, we briefly describe the process and the questionnaire that we used for the data collection. A detailed description of the data collection can be found in Olbrich (2012) which also includes a copy of the questionnaire.

Description of data collection

In August 2008, we sent out mail-in questionnaires to commercial cattle farmers in Namibia in order to elicit 1) perceived rainfall risks, 2) risk management strategies, 3) the farm's sustainability, 4) individual risk and time preferences and normative views of sustainability, and 5) personal, farm and environmental features. Questionnaires were sent to a group of 2,119 farmers which consisted of members of the Namibia Agricultural Union (NAU) and of farmers that deliver cattle to MeatCo, the largest slaughterhouse in Namibia. This group essentially is the whole population of commercial cattle farmers in Namibia (Olbrich et al., 2012). We mailed out questionnaires for the first time in the period 19th – 21st of August 2008, and a second time as a follow up on the 15th of September 2008.

398 questionnaires were returned, equaling a return rate of 19%.[6] An optional question for identification of the farm was answered by 299 (75.1%) of questionnaire participants.

Elicitation of rainfall risk, management and sustainability

We elicited rainfall risk by asking farmer to rate this risk on a six-item Likert-scale ranging from "no risk at all" to "very high risk".We elicited risk management by asking farmers for each on-farm risk management strategy (that is, *rangeland size increase*, *resting rangeland*, *additional feed*, *breed adaptation* and *production system adaptation*) and financial risk management strategy (that is, *advances on livestock sales*, *checking account as buffer*, *loans for covering operating losses*, *off-farm income* and *investment into agricultural derivatives*) to self-report the importance they ascribe to each strategy. Importance was recorded on a six-item Likert-scale ranging from "not at all important" to "very important".

We measured sustainability by the grazing capacity in the unit LSU/ha, in line with our depiction of the rangeland system. Note that we explicitly asked farmers to report the grazing capacity of their rangeland (and that we did not simply calculate the stocking rate).[7]

Elicitation of risk and time preferences and normative views of sustainability

We elicited risk and time preferences by hypothetical choice experiments in the questionnaire using a multiple-price-list format (Olbrich et al., 2012). Based on this elicitation, we construct indices for risk and time preference out of the raw responses in the experiments. The *risk* preference index hereby is a discrete variable with values in {1, 2, …, 7} where low values denote high risk aversion and high values denote risk attraction. For the *time* preference index we construct a discrete variable with values in {1, 2, …, 6} where low values denotes patience and high values denote impatience.[8]

In accordance with the definition of strong sustainability in Section 2.1, we pre-selected ecosystem condition of the rangeland, measured as grazing capacity in the unit LSU/ha, as one critical component for conservation; and we selected income, measured as net annual income in the unit N$, as an additional critical economic component. We then elicited the threshold level at or above which ecosystem condition (income) should be conserved.
In addition, we elicited two further normative views of sustainability which are tied closely to the notion of strong sustainability.[9] Firstly, the acceptable risk that the conservation of ecosystem condition (income) fails in a given year, measured as a probability, and secondly the time horizon for conservation of ecosystem condition and income, measured in the generations.[10]

Elicitation of personal, farm and environmental features

In addition to the aforementioned variables, we elicited a variety of personal, farm and environmental features. A list of all elicited variables along with their summary statistics is given in Table 1.

Statistics analysis

In a first step, we analyze data through the use of descriptive statistics. Results are presented in the form of a summary table.

[6] To our knowledge, there exists no other comprehensive survey of commercial cattle farmers in Namibia. We thus cannot validate the representativeness of our sample by comparison with independently collected data sets. However, we statistically compared independent subpopulations within the sample and found only negligible differences at the 5% significance level (Olbrich et al., 2009: Table 3).

[7] We can easily calculate the stocking rate from the questionnaire. Grazing capacity and stocking rate are only moderately correlated (Pearson correlation: r=0.49, p-Value<0.01, N=340), indicating that farmers indeed reported two separate concepts.

[8] As Olbrich et al. (2011b) detail, we encountered irregularities for some farmers in the risk experiments, which we treated as artifacts and excluded in our further analyses. Similar irregularities were encountered in the time experiments and the respective observations were likewise excluded.

[9] As these aspects are not central to this paper, we have for simplicity not detailed the underlying conceptual framework in Section 2.1. This is explained in detail in Baumgärtner and Quaas (2009b). To briefly summarize the main point of that publication, we here point out that the notion of strong sustainability as introduced in Section 2.1 assumes a deterministic system. In such a system the effect of human measures (such as management strategies) on the system's development is fully known. However, many systems such as cattle farming in Namibia are stochastic where unpredictable events (such as stochastic rainfall) may occur and negatively impact on the system. This may preclude the achievement of sustainability despite the best intentions for setting sustainability thresholds and taking measures. Thus, in order to consider sustainability in such systems, one also has to define 1) which risk that conservation fails due to unpredictable events is still acceptable, and 2) the time horizon over which the system should be conserved.

[10] Altogether, more demanding views of sustainability are thus reflected in *higher* values for the threshold level of ecosystem condition (income) and for the time horizon, and in *lower* values for the acceptable risk that conservation of ecosystem condition (income) fails.

Table 1. Summary statistics for 1) rainfall risk, 2) risks management strategies, 3) the farm's sustainability, 4) risk and time preferences and normative views of sustainability, and 5) personal, farm and environmental features.

Characteristics	Mean	Median	Std. dev.	Min	Max
1) Rainfall risk					
Rainfall *[1=no risk, 6=very high risk]*	4.6	5.0	1.2	1.0	6.0
2) Risk management strategies *[1=not at all important, 6=very important]*					
On-farm management strategies					
Additional feed	4.7	5.0	1.5	1.0	6.0
Production system adaptation	4.4	5.0	1.4	1.0	6.0
Breed adaptation	4.5	5.0	1.3	1.0	6.0
Resting rangeland	4.7	5.0	1.5	1.0	6.0
Rangeland size increase	3.3	3.0	1.7	1.0	6.0
Financial management strategies					
Advances on livestock sales	3.1	3.0	1.8	1.0	6.0
Checking account as buffer	4.7	5.0	1.4	1.0	6.0
Loans for covering operating losses	3.0	3.0	1.7	1.0	6.0
Off-farm income	4.0	4.0	1.7	1.0	6.0
Investment into agricultural derivatives	2.4	2.0	1.6	1.0	6.0
3) Sustainability indicators					
Grazing capacity *[LSU/ha]*	0.080	0.077	0.040	0.012	0.500
4) Preferences and normative views					
Risk preference index *[1=very risk averse, 5=risk neutrality, 7=very risk attracted]*	4.8	5.0	1.1	1.0	7.0
Time preference index *[1=very patient, 6=very impatient]*	3.2	3.0	1.1	1.0	6.0
Sustainable annual net income *[N$]*	275,791	240,000	206,896	4,000	2,000,000
Sustainable ecosystem condition *[LSU/ha]*	0.082	0.077	0.045	0.013	0.05
Acceptable income risk *[probability]*	0.6	0.6	0.2	0.0	1.0
Acceptable ecosystem condition risk *[probability]*	0.6	0.6	0.2	0.0	1.0
Time horizon *[generations]*	3.3	2.0	3.2	0	10
5) Personal, farm and environmental features					
Personal features					
Household size *[number of members]*	3.3	3.0	1.8	1.0	14.0
Age *[years]*	55.4	55.0	11.9	27.0	90.0
Afrikaans *[%]*	50.4	100.0	50.1	0	100.0
Education level *[1=no high school graduation, 6=Doctorate]*	3.4	4.0	1.2	1	6
Farm features					
Rangeland *[hectare]*	7,949	6,765	5,512	0	44,244
Land net rented [a] *[hectare]*	1,149	0	2,897	-5,017	14,000
Single owners *[%]*	70.7	100.0	46.0	0.0	100.0
Oxen production *[%]*	47.7	50.0	40.3	0.0	100.0
Annual net income *[1= <N$50,000, 5= >N$350,000]*	2.9	3.0	1.4	1.0	5.0
Weekend farmer *[%]*	20.0	0.0	40.0	0.0	100.0
Environmental features					
Average rainy season assessment (2004–2008) *[1=very poor, 6=very good]*	4.0	4.0	0.7	1.0	6.0
Land quality *[1=very poor quality, 6=very good quality]*	4.3	4.0	1.0	1.0	6.0
Actual bush cover *[1=0%, 6=81 to 100%]*	3.5	3.0	1.1	1.0	6.0
Optimal bush cover *[%]*	25.1	20.0	16.0	0.0	81.0

Displayed are mean, median, standard deviation, minimum and maximum for all continuous and Likert-scale measured.

We then analyze characteristics jointly through a cluster analysis to explore whether we may classify farms into similar groups. Specifically, we conduct a hierarchical cluster analysis. We use Ward's method for agglomeration over an N x N dissimilarity matrix, where N is the number of observations (Ward, 1963). The matrix contains as elements the Gower dissimilarity measure between observations which is designed to accommodate both continuous and binary characteristics (Gower, 1971). It is defined as

$$D_{ij} = \frac{\sum_k w_{ijk} d_{ijk}}{\sum_k w_{ijk}}$$

where D_{ij} is the dissimilarity between observation i and j as the sum of the dissimilarities d_{ijk} between observation i and j with respect to each characteristic $k = \{1, \ldots, K\}$ (StataCorp, 2007; Everitt et al., 2011). w_{ijk} is a binary indicator that takes on the value 1 if observations i and j have non-missing entries for characteristic k and is 0 otherwise. We only include observations that have non-missing entries for all K characteristics since all D_{ij} are then calculated over the same set of characteristics. Thus, w_{ijk} always takes on the value 1, and the denominator equals K. Only including observations with non-missing entries has the side effect of reducing the sampling set to 108 observations, since not all farmers responded to all questions.

The specification of d_{ijk} differs between binary and continuous characteristics. For binary characteristics,

$$d_{ijk} = \begin{cases} 0 & if \ x_{ik} = x_{jk} \\ 1 & otherwise \end{cases},$$

where x_{ik} and x_{jk} are the values that characteristic k takes on for observations i and j, respectively. For continuous characteristics,

$$d_{ijk} = \frac{|x_{ik} - x_{jk}|}{\max(x_k) - \min(x_k)},$$

which standardizes the absolute distance between x_{ik} and x_{jk} by the range of values that characteristic k takes on over all observations.

When calculating the Gower dissimilarity measure, highly correlated characteristics may bias results as the impact of these characteristics on the measure is overemphasized with respect to the remaining characteristics (Backhaus et al., 2006: 550). However, none of the 528 unique characteristics pairs (based on 33 characteristics over which we conduct the cluster analysis) display a correlation coefficient above 0.6 and only 11 a correlation coefficient above 0.4.

We chose the number of clusters by calculating the pseudo F index (Calinski and Harabasz, 1974), where large values indicate a good number of clusters, and the pseudo T squared Je(2)/Je(1) index ("pseudo T squared index") (Duda and Hart, 1973), where low values indicated a good number of clusters, and by subsequently identifying local maxima and minima, respectively. As a robustness check we require that both indices display local optima at the same number of clusters.

Subsequent to the cluster analysis, we examine in regards to which characteristics the clusters differ significantly overall and exactly which clusters are responsible for the significant difference. For continuous characteristics, we thereto conduct one-way analyses of variance (ANOVA) followed by pair-wise, Bonferroni-corrected t-tests. For binary characteristics, we conduct Chi-square tests followed by pair-wise, Bonferroni-corrected Chi-square tests. All analyses are performed using the Stata/SE 10.1 statistical software package.

RESULTS

Descriptive statistics

A comprehensive overview of descriptive statistics is given in Table 1. Here we briefly discuss these statistics, beginning with rainfall risk, risk management and sustainability, and closing with farmers' preferences, normative views and personal, farm and environmental features.

Rainfall risk

The rainfall risk is rated above average with a value of 4.6 (out of 6.0) on the Likert scale. The risk is heterogeneous across farmers as indicated by a standard deviation of 1.2.

Risk management strategies

In terms of risk management, farmers predominantly consider on-farm management strategies to be important in the management of risky rangeland production. Especially those on-farm strategies where the decision process is in the hand of farmers are rated high, that is, *resting rangeland* (4.7 on a six-item Likert-scale), *additional feed* (4.7), *breed adaptation* (4.5) and *production system adaptation* (4.4). In contrast, the remaining on-farm strategy, *rangeland size increase* is rated considerably lower (3.3), potentially because the application of this strategy depends on third parties offering land for sale or renting.

Financial risk management strategies are of less importance. *Checking accounts as buffer* (4.7) and *off-farm income* (4.0) are rated relatively high. In contrast, farmers seem to be skeptical towards the remaining financial management strategies: *advances on livestock sales* (3.1), *loans for covering operating losses* (3.0) and *investment into agricultural derivatives* (2.4) are among the lowest rated strategies.

Heterogeneity in ratings across farmers is considerable for most risk management strategies (standard deviations of 1.6 to 1.8).

This finding is in accordance with our aforementioned statement that strategies may (in part) be substitutes with respect to risk management, which allows for considerable leeway in whether individuals farmers apply a specific strategy or not.

Sustainability

Average grazing capacity is 0.080 LSU/ha and is lower than the historic 0.1 LSU/ha that was found on average prior to the mid 1960s (de Klerk, 2004: 21). The rangeland thus (on average) has not been managed sustainably. However, grazing capacity is, with a standard deviation of 0.040 LSU/ha, highly variable across farms, suggesting large differences in sustainability of individual farms.

Risk and time preferences

Farmers are on average risk averse, as indicated by a value of 4.8 (out of 7.0) for the risk preference index. In another study on the same database, the authors calculate for the average farmer a point estimate for the coefficient of relative risk aversion (CRRA) of 0.78 which likewise indicates risk aversion (Olbrich 2012).[11] The estimate is slightly higher than the value of 0.54 reported for a field study of semi-subsistence farmers in Ethiopia, India and Uganda by Harrison et al. (2010), but in range with the value of 0.79 provided for the Danish population by Andersen et al. (2006).

Farmers are of intermediate impatience as exemplified by a value of 3.2 (out of 6.0) for the time preference index. Calculating point estimates of discount rates – to mirror the aforementioned point estimates of risk aversion – has not yet been done by the authors in a separate publication, and is beyond the scope of this publication.

Normative views of sustainability

Farmers believe that ecosystem condition should be sustained at or above a threshold of 0.082 LSU/ha and annual net income at or above a threshold of N$ 275,791.[12]

Heterogeneity for both the normative view on ecosystem condition and income is high with standard deviations of 0.045 LSU/ha and N$ 206, 97, respectively.

In regards to the time horizon for sustaining ecosystem condition and income we find that 8.7% of farmers do not care about the future beyond their own generation, whereas 16.1% of farmers have a very long outlook, i.e. ten generations or more. On average, farmers indicated that ecosystem condition and income ought to be sustained for the 3.3 generations following their own generation, that is, for the generations of their children, grandchildren, and great-grandchildren. This is the timeframe that most farmers are expected to experience in their lifetime.[13]

Acceptable ecosystem condition risk and acceptable income risk are both centred at an intermediate probability value of 0.6, that is, a probability of 60% that grazing capacity (income) falls below the specified threshold is still acceptable. Distributions of both probability thresholds are, however, spread out over the whole range of possible values, as exemplified a standard deviation of 0.2 for both characteristics, revealing large heterogeneity across the farmers' population.

Personal, farm and environmental features

Farmers are very heterogeneous in age and the distribution is centred within the advanced age: average age of farmers is 55.4 years with a standard deviation of 11.9 years. The majority of farmers (50.4%) are of Afrikaans decent, with the remaining farmers being predominantly of German descent. Education is of high importance among farmers with a median of 4.0, indicating that half of the farmers have a university degree (bachelor, master or doctorate). Household size is on average 3.3 members.

Farms are typically large with an average area of rangeland of 7,949 ha, but individual farms are very heterogeneous in size as indicated by a standard variation of 6,765 ha. On average, farmers rent 1,149 ha of farmland in addition to the land they own. Farms are typically operated by a single owner (70.7%) as opposed to forms of joint ownership (e.g. corporations, partnerships or cooperatives). The most common production system is oxen production (pursued by 47.7% of farmers), while other production systems such as weaner production or speculation production are of less importance. Farmers earn a considerable higher income than other Namibians: median income among farmers is N$ 150,001 to N$ 250,000 which is much greater than the 2009/2010 Namibian median household income of N$ 40,744. [14] Not all farmers earn this income primarily from their farm: 20% of farmers are weekend farmers that operate the farm only on the weekend (as a hobby or secondary occupation) while earning their livelihood primarily in a different occupation.

Farmers assess the previous five rainy seasons as above average as indicated by a value of 4.0 (out of 6.0). Land quality (e.g. soil conditions) is likewise assessed to be above average with a value of 4.3 (out of 6.0). Almost half of the farms (48.2%) have actual bush cover that is intermediate or higher (that is, 41% or more of the farm covered by bushes). Finally, the bush cover that farmers

[11] In Olbrich (2012), as well as in the subsequently cited papers, a positive value of the CRRA indicates risk aversion, a negative value risk attraction and a value of zero risk neutrality.

[12] For comparison: median annual income for the Namibian population was N$ 29,361 in 2003–2004. See also Footnote 12.

[13] Namibian farmers typically have their children at a young age (personal observation), and life expectancy is high (see for comparison our findings on farmers' age in below in this section).

[14] The latest available national income data was elicited in 2009/10 by Namibia Statistics Agency (NSA, 2012, 2010: 15). In order to properly compare our 2008 farm data to the 2009/10 national data, we have to adjust for inflation which amounted to 9.1% in Namibia in 2008 (Statista, 2016). Adjusted median farmer income can then be interpolated to N$ 164,651 to N$ 272,750 in 2009 prices, and is thus still considerably higher than the N$ 40,744 median household income.

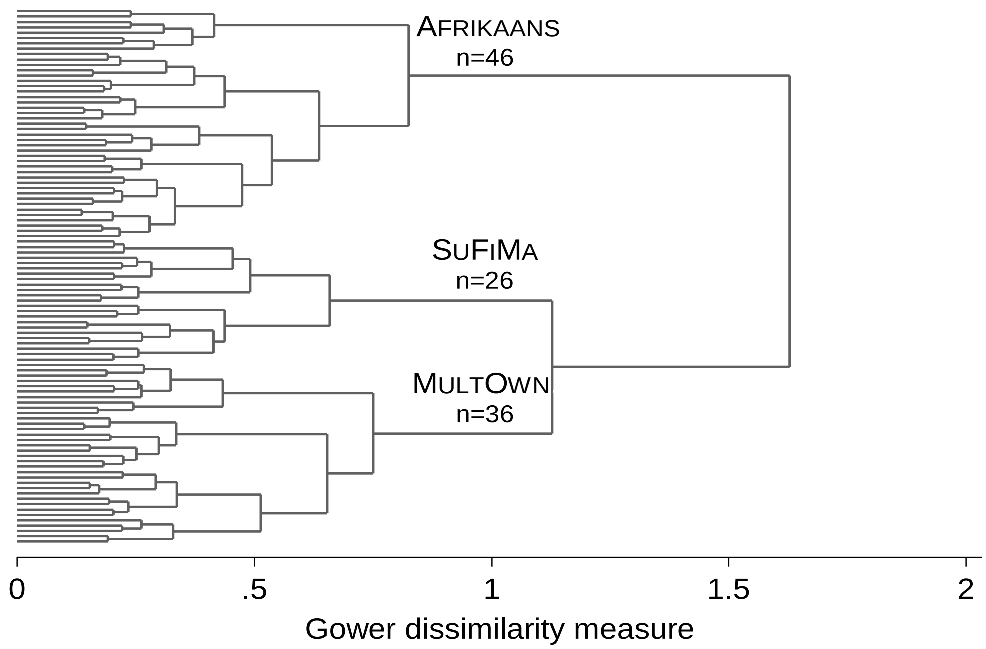

Figure 2. Dendrogram for three cluster solution. Cluster labels and observations per cluster are indicated above the respective branch. Clusters are MULTOWN (multiple owners), SUFIMA (high sustainability / low financial risk management) and AFRIKAANS (Afrikaans farmers). N=108.

consider optimal on their farms is a low to medium cover (an average of 25% of the farm being covered by bush) and thus lower than actual bush cover.

Table 2. Results for pseudo F- and pseudo T square-indices for different numbers of clusters. Good number of clusters are indicated by high values for pseudo F-index and by low values for pseudo T-square index.

Number of clusters	pseudo F	pseudo T square
1		0.30
2	0.30	0.98
3	0.57	0.00
4	0.38	0.99
5	0.53	1.26
6	0.59	1.48
7	0.79	3.07
8	1.22	2.43
9	1.59	0.15
10	1.41	1.44
11	1.43	0.35
12	1.31	0.07
13	1.20	0.02
14	1.09	1.56
15	1.03	0.17

Cluster analysis

In reporting results for the cluster analysis, we make three terminological simplifications for convenience: firstly, we say “characteristics of clusters” when we, of course, actually refer to characteristics of the farmers or farms included in the respective clusters; secondly, the values we report are cluster-averaged values, but we do not explicitly refer to them as “averaged”; thirdly, when we state that a cluster is “different” we always mean, unless otherwise noted, that the discussed clusters differ significantly from *all* other clusters.

As previously mentioned, we excluded in the cluster analysis all observations which had a missing entry in any of the analyze characteristics. As a consequence, only 108 observations (out of 398) were used in the cluster analysis.

Choice of cluster number

Both the pseudo F- and the pseudo T-index have optima jointly at a number of three and nine clusters (Figure 2, Table 2). At three clusters the pseudo T-index has a global minimum while the pseudo F-index has only a local maximum. Conversely, at nine clusters the pseudo F-index has a global maximum and the pseudo T-index’ only a local minimum. Examining both indices thus does

so large that individual clusters are distinct in only very few characteristics; secondly, under this solution we encounter clusters with fewer than 7 observations, making the validity of the analysis doubtful due to the low not give a unique solution to the optimal number of clusters. Nonetheless, we report the three cluster solution as the nine cluster solutions has two disadvantages: firstly, it is not very insightful as the number of clusters is number of observations.

Cluster SuFiMa

This cluster is best described by high sustainability and low financial risk management ("SuFiMa"). It is the smallest in that it contains 26 out of the 108 analyzed farms (Table 3). It is also the most distinct cluster, differing significantly from each of the two other clusters in 10 out of the 33 analyzed characteristics.

The cluster has the highest grazing capacity (0.089 LSU/ha; $p<0.05$) and thus the highest sustainability. In regards to risk management, it has the lowest ratings of the three clusters for *all* financial risk management strategies, albeit the differences are significant only for the strategies *advances on livestock sales* (1.4 on a six-item Likert-scale; $p<0.05$) and *loans for covering operating losses* (1.5; $p<0.01$). In contrast, it does not have the lowest ratings for all on-farm strategies, but only for three of these strategies: for *rangeland size increase* (2.7; $p<0.1$), albeit at only the 10% significance level; and for *production system adaptation* and *breed adaptation* (both 3.9; $p<0.05$), albeit differing in both strategies only from one other cluster. Finally, it also has the lowest rating of rainfall risk (4.4 on a six-item Likert-scale; $p<0.1$), but differs in the latter only at the significance level of 10% and only from one other cluster. Thus, of the aforementioned characteristics it is sustainability (via the proxy grazing capacity) and financial risk management that make this cluster distinct.

Cluster SuFiMa also has the most demanding normative views pertaining to acceptable grazing capacity risk (probability threshold of 0.7; $p<0.05$), possibly because farmers in this cluster experience low risk and can thus "afford" this more demanding normative view. Other normative views are not significantly different.

Finally, the cluster is distinct in two characteristics which are not obviously related to sustainability and management: it has the lowest number of household members (2.7 members; $p<0.1$) and it is the most patient (2.6 out of 6.0, $p<0.1$), albeit it is again significantly distinct in the latter characteristics from only one other cluster.

The cluster does not differ significantly in any other personal, farm and environmental features or in risk preferences. We especially note that it does not differ in income, and that it also does not differ in weekend farming (a criterion which, in Namibian everyday use, is typically employed to characterize farmers).

Cluster MultOwn

Based on the distinct characteristics of cluster SuFiMa, the remaining two clusters are accordingly characterized by low sustainability and high financial risk management. Beyond this distinction, however, they also have their own distinct characteristics.

The next larger cluster with 36 farms is significantly distinct in five such characteristics and best characterized by multiple ownership ("MultOwn") as it has the highest proportion of multiple ownership (41.7% of single owners, corresponding to 58.3% multiple owners; $p<0.01$). It also has the highest area of (net) rented land (2,587 ha, $p<0.05$) and the highest area of rangeland, although the difference in the latter variable is not significant. We may interpret this as a tenuous indication that multiple owners have the means to operate altogether larger farms.

This cluster also differs from the other clusters in characteristics that are less obviously associated with multiple ownership: it has the highest rating of the strategy *advances on livestock sales* (3.6; $p<0.05$), the lowest rating of the strategy *resting rangeland* (4.1; $p<0.05$) and the youngest farmers (46.9 years; $p<0.01$), albeit it significantly differs in latter two characteristics from only one other cluster.

Cluster Afrikaans

The largest cluster with 46 farms is distinct in four characteristics. It is difficult to describe this cluster as we see no obvious connection between these characteristics; we opt to describe it as Afrikaans farmers ("Afrikaans") as it exclusively consists of farmers of this ethnicity ($p<0.01$). Beyond this distinction, it has an intermediate rating of the strategy *advances on livestock sales* (2.6; $p<0.05$) and, differing significantly from one other cluster, has the lowest proportion of oxen production (42.3%; $p<0.01$) and the lowest education level (3.4 index points; $p<0.05$).

Summary of cluster analysis results

Altogether, we thus also observe heterogeneity of cattle farms when classifying them, albeit only one cluster of farms (namely SuFiMa) is very distinct. In accordance with the key distinct characteristics of this cluster, classification is predominantly driven by sustainability and financial risk management. To a lesser extent, classification is driven by organizational structure or ethnicity, the defining characteristics of the remaining two clusters. Rainfall risk, risk and time preferences as well as normative views play only a marginal role for classification. Finally, we especially note again that income does not drive classification at all.

DISCUSSION

In this paper we characterize commercial cattle farms in

Table 3. Cluster-averaged values of characteristics for clusters MULTOWN (multiple owners), SUFIMA (favorable environment / low financial risk management) and AFRIKAANS (Afrikaans farmers).

Characteristics	MULTOWN	SUFIMA	AFRIKAANS	p-value
1) Rainfall risk *[1=no risk, 6=very high risk]*				
Rainfall	4.9	4.4*	5.0	0.067
2) Risk management strategies *[1=not at all important, 6=very important]*				
On-farm management strategies				
Additional feed	4.3	4.8	4.5	0.371
Production system adaptation	4.9	3.9**	4.5	0.039
Breed adaptation	4.8	3.9**	4.6	0.032
Resting rangeland	4.1**	4.7	5.0	0.025
Rangeland size increase	4.1	2.7***	3.3	0.004
Financial management strategies				
Advances on livestock sales	3.6**	1.4**	2.6**	0.000
Checking account as buffer	4.8	4.3	4.8	0.327
Loans for covering operating losses	3.0	1.5***	3.4	0.000
Off-farm income	3.9	3.6	3.8	0.803
Investment into agricultural derivatives	2.4	1.9	2.0	0.392
3) Sustainability indicators				
Grazing capacity *[LSU/ha]*	0.071	0.089**	0.074	0.016
4) Preferences and normative views				
Risk preference index *[1=very risk averse, 5=risk neutrality, 7=very risk attracted]*	4.6	5.0	4.7	0.416
Time preference index *[1=very patient, 6=very impatient]*	3.1	2.6*	3.2	0.069
Sustainable annual net income *[N$]*	292,806	251,539	294,000	0.567
Sustainable ecosystem condition *[LSU/ha]*	0.074	0.086	0.076	0.217
Acceptable income risk *[probability]*	0.6	0.5	0.6	0.801
Acceptable ecosystem condition risk *[probability]*	0.6	0.7**	0.6	0.009
Time horizon *[generations]*	3.3	4.1	3.5	0.671
5) Personal, farm and environmental features				
Personal features				
Household size *[number of members]*	3.6	2.7*	3.6	0.036
Age *[years]*	46.9***	55.5	51.4	0.010
Afrikaans *[%]*	19.4	7.7	95.7***	0.000
Education level *[1=no high school graduation, 6=Doctorate]*	3.8	4.0	3.4**	0.035
Farm features				
Rangeland *[hectare]*	9,448	7,980	8,181	0.483
Land net rented *[hectare]*	2,587**	512	919	0.010
Single owners *[%]*	41.7***	84.6	89.1	0.000
Oxen production *[%]*	68.3	60.5	42.3***	0.008
Annual net income *[1= <N$50,000, 5= >N$350,000]*	2.9	3.4	3.2	0.358
Weekend farmer *[%]*	83.3	80.8	87.0	0.773
Environmental features				
Average rainy season assessment (2004–2008) *[1=very poor, 6=very good]*	3.9	4.1	3.9	0.328
Land quality *[1=very poor quality, 6=very good quality]*	4.0	4.2	4.4	0.342
Actual bush cover *[1=0%, 6=81 to 100%]*	3.7	3.3	3.6	0.392
Optimal bush cover *[%]*	23.8	19.3	26.5	0.115

p-values for cluster differences calculated for each characteristic by one-way ANOVA for continuous and Chi-square test for binary characteristics. Shading indicates cluster responsible for differences as calculated by Bonferroni-corrected t-tests for continuous and pair-wise Chi-square test for binary characteristics, with the significance levels: *** p<0.01, ** p<0.05, * p<0.1. Dark shading denotes that cluster differs from both other clusters, light grey shading that it differs from only one other cluster (the one most different in averaged values). N=108.

Namibia, a prime case of livestock farming in semi-arid rangelands, according to 1) perceived rainfall risk, 2) risk management, 3) the farm's sustainability, 4) risk and time preferences and normative views of sustainability, and 5) personal, farm and environmental features. We find that cattle farms are highly heterogeneous in a wide range of characteristics.

When classifying farms in a cluster analysis, we also find heterogeneity as exemplified by the identification of three separate clusters ("SUFIMA", "MULTOWN" and "AFRIKAANS"). More specifically, results from the cluster analysis show that cattle farms are classified mainly by their sustainability and the farmer's financial risk management, but not by the farmer's income: the most distinct of the three identified clusters is characterized by high grazing capacity (a proxy for high sustainability) and low financial risk management, but not by high or low income. In other words, our results suggest that sustainability and financial risk management are inversely related while income levels appear to be unaffected by the choice of risk management technique. One possible explanation, is that financial risk management may provide income risk reduction to a similar extent than on-farm management over the short term; however, it may simultaneously reduce long-term sustainability since farmers neglect the adequate on-farm management of their rangeland. Such a link has already been proposed in theoretical work (Quaas et al., 2007; Quaas and Baumgärtner, 2008, 2012; Baumgärtner and Quaas, 2009a; Müller et al., 2011), and our empirical results thus nicely conform to these theoretical findings.

It is also interesting to note which other characteristics (apart from income) are *not* driving farm classification. Firstly, risk and time preferences as well as normative views of sustainability are only marginally important for classification. Based on the observed differences in management, one might hypothesize that preferences and normative views, which are key behavioural determinants, are not related to management behaviour in Namibian cattle farming. Regarding preferences, this is controversial and we do not expect that such a hypothesis will be upheld under more in-depth scrutiny than can be achieved through a cluster analysis. Regarding normative views, however, we indeed find no evidence that they impact on farm management in an in-depth analysis (Olbrich et al., 2014). Secondly, weekend farming, a characteristic typically employed by Namibian farmers and decision makers for characterization of farms, also does not drive our classification. It thus seems that it is only of minor importance for characterization in comparison to other characteristics.

Having provided these observations, we note the limitations of the cluster analysis: it cannot be used to make definite statements concerning the causal relationship between single characteristics and thus cannot be a substitute for an in-depth analysis. Most importantly, we cannot clarify the exact relationship between sustainability, financial risk management and income without further analysis, as we have, for example, done in respect to normative views (Olbrich et al., 2014).

Altogether, this study is the first to provide a characterization of Namibian commercial cattle farms in respect to risk, management and sustainability. It furthers the understanding of the system and provides the basis for more in-depth analyses. Finally, it highlights issues that may warrant close attention and may ultimately contribute to the development of policies that promote sustainability of commercial cattle farming in Namibia.

Conflict of Interests

The authors have not declared any conflict of interests.

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Shape and size relationships of *Araucaria angustifolia* in South Brazil

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Studies on morphology and occupancy area of trees provide knowledge on features and functions of forest ecosystem, especially in terms of competition and growth of trees. The main purpose of this work was to develop models for shape and size relationships of *Araucaria angustifolia* in natural forest remains of species. Dendrometric and morphometric variables from 210 trees from three sites were used. Results showed that the species present different shape and size, vigor and productive capacity in evaluated sites. Fitted models indicated that there was transition in competition mode (symmetric or asymmetric) for resources, which is result of available growing space for trees. Relationship between shape and size is derived from slope of regression line and regarded as an indication of need for silvicultural interventions to reduce competition, which is a key information for obtaining better practices in forest management.

Key words: Araucaria forest, forest measurements, growth.

INTRODUCTION

Biometric principles of size, shape and growth of trees in forest, and changes of these variables over time are important factors on an individual scale, in forest and ecosystem dynamics. Conclusions on these relationships and forest-level performance are necessary for forest management, since they help to identify the interactions of competition and its effect on growth over time (Pretzsch and Dieler, 2010).

The study on the growth-size relationship and environmental conditions is of particular interest since growth of trees and forest dynamics are strongly affected by trends of changes in growth conditions and stress events (Spiecker et al., 1996; Jentsch et al., 2007; Matyssek and Sandermann, 2003; Pretzsch et al., 2010).

Studies have demonstrated that competition mode and relation between growth and size may vary spatially over ecological gradients (Pretzsch and Biber, 2010), as well as with time as forest develops. According to same

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authors, forest structure parameters are used to analyze and model its dynamics.

Developing of morphometric variables and changes in forest structure for long periods affects to a large extent, processes such as light absorption, water interception, evapotranspiration, photosynthesis and respiration, and in turn, these processes affect the growth of trees and life cycle of organisms around (Pretzsch, 2009).

Canopy structure is crucial to understand relationships between functionality, structure and environment in pure stands, but more importantly in mixed stands, where different species demonstrate their ability to adapt their structure to capture scarce resources efficiently or deny access to competitors for same resources (Preztsch, 2009).

Shape and size relationships of trees can predict space required by one during its development, inferring to its competitors and allowing conclusions on stability, vitality and productivity of each individual, acting as a practical tool in forestry interventions, especially when age of the plants is not known (Durlo, 2001).

Therefore, developing accurate models of morphometric relationships for tree species in its natural area of occurrence allows identifying trends for sustainable forest management, ensuring ecological and structural sustainability of forests, and related benefits.

The purpose of this study was to evaluate morphometric characteristics and shape and size relationships in individual trees, developing models to compare effect of site on trees to assist in forest management strategies and silvicultural interventions in natural patches with *Araucaria angustifolia* (Bertol.) Kuntze in Southern Brazil.

MATERIALS AND METHODS

Study area

The study was done in natural occurrence region of *Araucaria angustifolia*, Southern Brazil. Three sites were evaluated: São Joaquim (1,353 masl); Painel (1.145 masl); and Urupema (1.245 masl) counties (Figure 1).

Araucaria angustifolia is an evergreen species. The shape crown shape has cone to hemispheric form, and at maturity stage, it takes umbel shape. Due to Brazilian Legislation, which has forbidden this species management, at present, Araucaria Forest remains are not subject to management and silvicultural intervention for 40 years, presenting an increased competition.

A total of 210 trees were sampled, 70 from each site. Sampling intensity was evaluated accordingly to Sanquetta et al. (2009), assuming a maximum sampling error of 10%. Dendrometric characteristics of sampled trees are shown at Table 1.

Climate classification of the region according to Koppen is predominantly characterized as Cfb, or temperate. The annual mean temperature is 15.5°C, and minimum mean temperatures range between 5 and 8°C, maximum mean between 22 and 31°C and minimum absolute of -12°C, with annual mean rainfall of 1,400 mm (EPAGRI, 2002).

Predominant vegetation type in the region is the Araucaria Forest (IBGE 2012), which is the typical vegetation in the Southern Brazilian Plateau, it has floristic disjunctions in refuges located in mountain ranges from Serra do Mar and Serra da Mantiqueira. In the past, the species had a distribution even northward, since the Araucariaceae family is believed to have paleogeographic dispersion, suggesting different occupation from the present (IBGE, 2012).

Data collection and analysis

In each study site, sample area was defined and sampled trees were label and their positions were established with GPS. The following variables were measure in each tree: diameter at breast height (d), using a diameter tape; the insertion height of crown (*hic*); total height (*ht*); and crown radius, taken in four directions (North, South, East and West). Height variables and crown radius were measured using a clinometer. Based on the four radius measured, crown mean radius values: $\bar{rc} = \sum_{i=1}^{n=4} \frac{rc}{4}$ was obtained. Multiplying mean radius, crown diameter: $Dc = 2 * \bar{rc}$; crown projected area: $Ac = \pi * \bar{rc}^2$; crown length: $C = ht - hic$; and crown proportion $pc\% = \left(\frac{cc}{ht}\right) * 100$ were obtained.

In this study, the hypothesis that morphometric indexes and their variation are indicators of past competition was assumed, which had caused changes in shape-size relationships and can be express by regression functions (Cunha and Finger, 2013). Therefore, considering two trees with same diameter at breast height, that one with smaller crown diameter is one under more competition.

Using sampled data, morphometric variables were calculated and fit of equations of shape and size relationships was carry out. A covariance analysis was performed using morphometric variables as dependent, and their variability explained by interaction with site and diameter as a continuous and independent variable. Thus, difference in level and inclination of regression line was evaluated from the relation between insertion height of crown (*hic*), crown proportion (*pc%)* and crown diameter (*dc*), as a function of diameter at breast height (*d*) in studied sites, aiming to assess whether a single equation could be used for both sites or multiple equations would be required.

Residuals from regression were tested according to regression assumptions, as proposed by Schneider et al. (2009). The goodness of fit was evaluated by the coefficient of determination (R^2), standard error of estimate (Sxy) and graphical analysis of residuals.

RESULTS AND DISCUSSION

Biometric and morphometric adjustments

Sample size assessment indicated that 59 trees would be required at the São Joaquim site, 28 trees at Urupema and 20 trees at Painel, in order to accurately represent the populations. Therefore, the sample composed by 70 trees from each site is considered sufficient. Table 2 shows the mean morphometric values from the 70 sampled trees in their respective sites.

Results indicate that trees from São Joaquim and Painel have larger mean diameter, higher mean total height and higher mean insertion height of the crown. Consequently, these trees have shorter crown and lower crown proportion, which empirically allows one to conclude that, regarding the crown pattern of Araucaria, sampled trees in these sites are older than those from

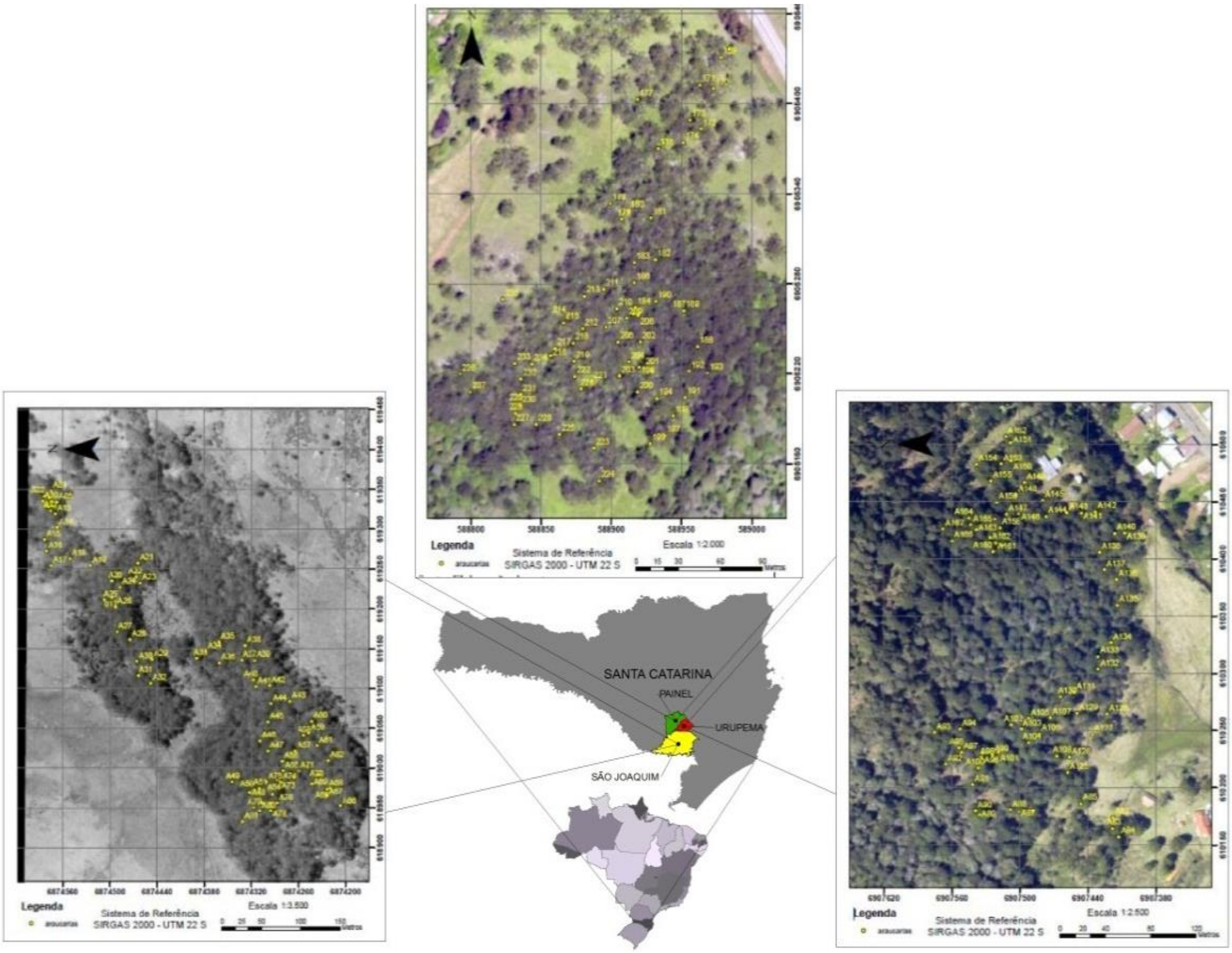

Figure 1. Location map of the sites showing the distribution of the 210 sampled trees in Araucaria Forest remains in Santa Catarina State.

Table 1. Dendrometric variables of sampled trees. Trees from three different sites were sampled and their mean dendrometric variables were presented.

Site	Specie	Strata	hmn	hmx	$\bar{h}$	*d*mn	*d*mx	$\bar{d}$	*a.a* (ha)
				(m)			(cm)		
SJQ			12.3	25.1	18.9	41.1	106.6	71.5	4.1
PNL	*Araucaria angustifolia*	Canopy	12.3	22.6	18.4	30.2	86.6	60.2	4.3
URU			11.5	22.8	16.9	34.4	89.4	54.8	2.2

hmn: Minimum height; hmx: maximum height; $\bar{h}$: mean height; *d*mn: minimum diameter at the breast height; *d*mx: maximum diameter at the breast height; $\bar{d}$: mean diameter at the breast height; *a.a*: sampled area (ha).

Urupema. Durlo (2001), studying *Cabralea canjerana* also observed a higher insertion height of the crown and crown diameter as the trees grow. However, this increase in morphometric variables is also associated with space, competition and density of individuals.

Trees from Urupema presented larger mean crown length, indicating that for this site, trees have more growth space and less competition between individuals,

Table 2. Mean morphometric values of Araucaria at different sites in Santa Catarina State.

	Morphometric variable						
	RCM	**DCM**	**ACM**	**CCM**	**PCM**	**HTM**	**HICM**
São Joaquim	5.4[a]*	10.7[a]	95.0[a]	3.4[a]	17.9[a]	19.0[a]	15.6[a]
s	1.22	2.43	40.8	1.10	5.58	2.69	2.55
Urupema	4.7[b]	9.5[b]	73.8[b]	6.2[b]	37.12[b]	16.9[b]	10.7[b]
s	0.97	1.94	31.6	1.86	10.7	2.22	2.63
Painel	4.5[b]	9.1[b]	66.8[b]	2.9c	15.5c	18.4[a]	15.5[a]
s	0.75	1.51	21.85	1.33	6.94	2.08	2.12

RCM: Mean radius of the crown (cm); DCM: Mean diameter of the crown (m); ACM: Mean area of the crown (m); CCM: Mean length of the crown (m); PCM: Mean crown proportion (%); HTM: Mean total height (m); HIC: Mean insertion height of the crowna media (m); s: standard deviation. * Means followed by the same latter in the columns do not significantly differ by the Tukey's test at 95% of probability.

since competition effect implies directly the crown length and, consequently, crown proportion. These variables might be regarded as measures of vigor (Assmann, 1970), which are required for models of mortality, growth and yield (Weiskittel et al., 2011).

Wink et al. (2012), studying *Eucalyptus* sp. Plantations, also noted that proportion of the crown decreases as trees age. According to the authors, crown proportion was significantly different between young stands (20 months) and intermediate stands (44 months), and the late was not different from mature stands (240 months).

It is understood that the greater the crown length, the higher the proportion of the crown, while the inverse relationship is also true. Therefore, the higher the proportion of the crown, the greater will be the photosynthesis capability, and possibly, better growth rates and less age. Santos et al. (2012) pointed out that trees crown is composed by several elements, and it is responsible for the processes of growth and production. Thus, parameters such as area, diameter and crown length are strongly correlated with these physiological processes.

In these cases, the ability to take up space available for the expansion of branches, along with the maintenance of a crown above the space occupied by the stem appears to be important in inter-crown competition situations (Santos et al., 2012).

Table 3. Analysis of covariance for the insertion height of the crown in araucaria over the studied sites.

	SV	**DF**	**SS**	**MS**	**F**	**Pr>F**
hic	Model	5	1344.48	268.90	54.61	0.0001
	Site	2	1112.10	556.05	112.93	0.0001
	*d**site	3	232.38	77.46	15.75	0.0001
	Residual	204	1004.48	4.92		
	Totl	209	2348.96			
	FV	**DF**	**SS**	**MS**	**F**	**Pr>F**
dc	Model	5	349.86	69.97	24.67	0.0001
	Site	2	101.32	50.66	17.86	0.0001
	*d**site	3	248.54	82.85	29.21	0.0001
	Residual	204	578.55	2.84		
	Total	209	928.41			
	FV	**DF**	**SS**	**MS**	**F**	**Pr>F**
pc%	Model	5	20299.14	4059.82	64.74	0.0001
	Site	2	19688.82	9844.41	156.99	0.0001
	*d**site	3	610.31	203.44	3.24	0.0230
	Residual	204	12792.67	62.71		
	Total	209	33091.82			

SV = Source of variation; DF = degrees of freedom; SS= sum of squares; MS mean square; F = test F; Pr>F = significance; d = diameter at breast height (cm).

Covariance analysis and shape and size relationships

The fitted models presented here aimed to identify and explain relations between shape and size and do not have prediction purposes. Covariance analysis (Table 3) evidenced the presence of differences between inclination levels of regression lines for *hic*, *dc* and *pc%,* thus indicating that the shape and size relationships between sites, morphometry of trees, productivity rates, age and vigor varies with tree's diameter and characteristics, such as competition and social position.

A significant result of the analysis of covariance indicate that the range of variation in shape of trees is regarded to the variation in trees size, as well as to the sort of competition levels at which trees were subject in the forest throughout their development. Such characteristics demand different management practices and morphometric models for the sites, as presented in Table 4.

Insertion height of the crown and crown diameter were positively correlated with diameter at breast height,

Table 4. Coefficients and statistics of the fit for the insertion height of the crown (*hic*), crown diameter (*dc*) and proportion of the crown (*pc*%) as a function of the diameter at breast height (*d*) of araucarias in South Brazil.

Sites	Coefficients *hic*(m)		Statistical criteria	
	Φ_0	Φ_1	S_{yx}	R²adj.
São Joaquim	11.20753	0.06144**d*		
Urupema	3.57887	0.12976**d*	2.21	0.57
Painel	15.1239	0.00715**d*		
Locais	Coefficients *dc*(m)		Statistical criteria	
	Φ_0	Φ_1	S_{yx}	R²adj.
São Joaquim	5.94898	0.06686**d*		
Urupema	3.53678	0.10872**d*	1.68	0.38
Painel	4.48975	0.07651**d*		
Locais	Coefficients *pc%*		Statistical criteria	
	Φ_0	Φ_1	S_{yx}	R²adj.
São Joaquim	19.11804	-0.01770**d*		
Urupema	50.84313	-0.25031**d*	7.91	0.61
Painel	9.65855	0.09718**d*		

Where: *hic* = insertion height of the crown (m); *dc* = crown diameter; pc = crown proportion; *d*: diameter at breast height; Φ_0= intercept; Φ_1 = slope; S_{yx} = Standard error of estimate; R²adj = coefficient of determination adjusted.

which explained 57 and 38% of the variability in the dependents variable, respectively. For proportion of the crown, the regression line presented a negative slope and diameter at breast height accounted for 61% on its variability.

The fit of equations can be seen in Figure 2, which presents the difference in the level and slope of the shape-size of araucaria. Urupema trees have smaller mean diameter and younger ages, as well as the highest crown proportion (37.2%), which implies larger photosynthetic area and higher growth rates.

In São Joaquim and Painel, trees are larger and older, which contributes to the increase in the insertion height of the crown. Such trees present, therefore, shorter crown and lower growth rates, indicating that they have reached maturity and are in the upper strata of the forest. This means that in these sites, environmental conditions and forest dynamics contributed to accelerate growth and development of forest structure over the past decades (Pretzsch et al., 2014).

The fitted equation for the estimate of *hic* shows that as araucaria grows and ages, the crown decreases in length, while its diameter increases, which is common for species that in the early stages of development have higher competitive capacity, fast leaf expansion, higher height and root expansion (Zanine and Santos, 2004).
Regression fit indicates that as trees grow in diameter, insertion height of the crown and crown diameter increase, providing an increased usable bole and indicating that trees were able to stand out from competition in the past and expanded their crown. However, despite the increase in crown diameter, crown proportion decreases, as results of ontogenetic patterns on the species growth. Such reduction shows that growth rates tend to decline with age and reduced crown proportion.

It is understood that trees in an active and accelerated growth phase are shorter and smaller (younger), which present the highest crown proportion as compared to those higher (older) (Wink et al., 2012), varying from 26.2 to 76.7% in this study, for the older and the younger individuals, respectively. The amplitude of the crown proportion is the result of different degrees of competition to which the trees are submitted to and may also be associated with the size of individuals (Roman et al., 2009).

Correlation between morphometric variables of araucaria refers to the individuals position in the canopy, competition (density), size and time. The inverse relationship between diameter at breast height and crown proportion is an indication that as the height of trees stabilize, in large and old trees, there is higher mortality of lower branches, reducing, consequently, crown proportion.

Results show that the relationships in trees' size are strongly related to the growth in height, diameter and site characteristics. Such information can be helpful to build structure scenarios, to be used in morphometric and environmental models in order to define the size, stock and density of individuals (Pretzsch et al., 2014).

Determination of this variable is very important because it allows the projection of the space to be reserved for a tree to have successful development, as it grows. Knowledge of the demanded space for each individual, in turn, allows one to predict the number of individuals to be selected and conducted up to the end of rotation, when a target diameter is established.

Since the studied forests are composed by a great amount of large individuals, one can assume that it is an indication that in the initial process of forest formation, trees were able to grow fast, taking priority in the use of environmental resources (Gustafson et al., 2004). Therefore, the predominance of old individuals indicates the necessity of interventions to allow the developing of young individual, for the success of forest succession.

Positive correlation in the relationship shape-size can be regarded as an indication of trees ability to compete, since individuals will develop their crown structure faster in order to intercept light, growing higher and occupying sooner the forest canopy. Thus, crown structure is a key factor influencing competition for light and species coexistence patterns (Peltzer and Kochi, 2001).

Such growth pattern in the relationship between shape and size is expected in fertile sites, where light is the most limiting factor to tree growth. This study also shows that the competition patterns and the relationship between shape and size can spatially vary across ecological gradients and with the stage of forest

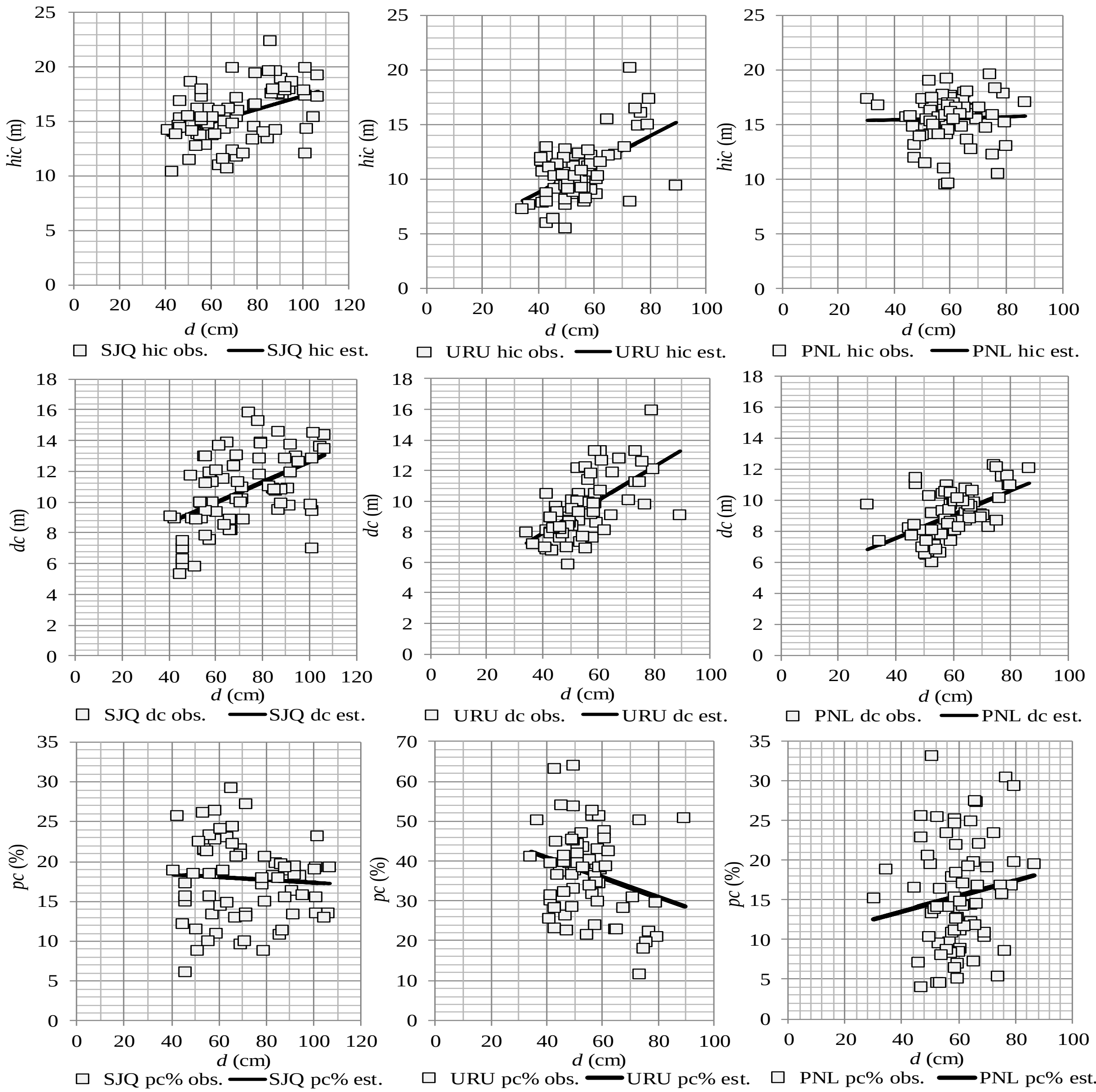

Figure 2. Slope of the regression between insertion height of the crown (hic), crown diameter (dc) and crown proportion (pc%) as a function diameter at breast height (d) of araucaria in South Brazil. Squared dots represent observed values in: SJQ = São Joaquim; URU = Urupema and PNL = Painel. Continuous black line represents the fitted equation. For *hic*, R^2 adj = 0.57, *dc* R^2 adj. = 0.38 and *pc%* R^2 adj.= 0.61.

development (Pretzsch and Dieler, 2010).

Conclusions

Trees from São Joaquim and Painel sites presented larger crown diameter and crown proportion, higher total height and higher insertion height of the crown, indicating that trees from these sites have reached maturity.

A significant result of the analysis of covariance indicate that the range of variation in shape of trees is regarded as the variation in trees size, as well as the sort of competition levels at which trees were subject in the forest throughout their development. The study of morphometric relationships with shape and size of trees may allow the identification of the need for intervention in the forest.

Results from this work are helpful in understanding resources distribution, diametric growth in forest populations, as well as the changes in the structural dynamics with different patterns of resource availability in time.

Conflict of Interests

The authors have not declared any conflict of interests.

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Factors influencing smallholder crop commercialisation: Evidence from Côte d'Ivoire

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In this study, we analysed factors that influence crop output commercialisation among smallholder farmers in Cote d'Ivoire. Unlike previous studies, we correct for sample selection bias by using the Heckman maximum likelihood sample selection model with village fixed effects. We rely on a unique and detailed dataset that covers 3,393 smallholder farmers. The dataset was gathered from the 2014 National employment survey collected by the National Institute of Statistics (INS) Côte d'Ivoire. Results from the study suggest that cooperative membership and land tenure security raise the level of marketed outputs of Ivorian farmers. Female headed households sold lower proportions of their outputs than their male counterparts. Labour shortage is a major constraint to crop output commercialisation. From a policy perspective, the Government should revive its interest in collective actions such as cooperatives, facilitate farmer's access to credit, improve food crop productivity and enhance mechanization.

Key words: Crop commercialisation, Côte d'Ivoire, smallholder farmers, agriculture.

INTRODUCTION

Smallholder farming activities continue to be a dominant livelihood activity in most low- and middle-income countries. Most of them, in regions such as West Africa rely on subsistence farming for their livelihood. Participating in crop market commercialisation usually requires a long transformation process from subsistence to semi-commercial and then to fully commercialised agriculture (Pingali and Rosegrant, 1995). In recent years, The World Bank has listed Africa among the fastest growing regions in the world. As an illustration, Côte d'Ivoire has recently had a stable economy and is currently growing at an approximate rate of 8.3% according to the African Development Bank. As the economy of a country grows, households shift away from subsistence goals to the commercialisation of agricultural products.

In recent years, smallholder farmers in many African countries have been selling a portion of their outputs on

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the market. For rural development and poverty reduction, promoting commercialisation of agricultural products appears to be an essential process. Pender and Alemu (2007) using a survey of 7,186 farm households in Ethiopia, prove that net buyers and autarkic households are poorer in many respects than net sellers. It is therefore important to understand the factors that are more likely to affect the extent of commercialisation. Significant research efforts have been made and are still underway to investigate farmer's ability to switch from a mostly subsistence farming to commercialisation, a process that could help improve their livelihood.

Martey et al. (2012) found that output price, farm size, households with access to extension services, distance to market and market information determine the extent of commercialisation in Ghana. Pingali and Rosegrant (1995) show that, in Asia, irrigated lowlands by their nature are inherently more market oriented because of their ability to generate a surplus and because of better transport infrastructure. Osmani and Hossain (2015) used a Probit model to explore the factors that affect the decision of farmers to participate in output markets to sell their products. Findings from their study suggest that variables such as farm size, household labour and farm income are likely to increase the probability of farmers participating in output markets. However, the probability decreases when a farmer has income from livestock. While many studies have been devoted to this issue, investigating the driving force at household level in Cote d'Ivoire is yet to be explored.

Our objective is to determine the factors that influence smallholder farmer's crop commercialisation in Côte d'Ivoire. The commercialisation issue is closely related to the employment issue in Cote d'Ivoire, which is fully in line with the Ivoirian government's agricultural policy. Our study is similar to that of Martey et al. (2012) and Rahut et al. (2015). They use the Tobit regression analysis. Such econometric specification rests on the basic assumptions of homoscedasticity of variance and no selection bias. However, given the nature of our sample, a Tobit specification may lead to biased estimates since The Breusch-Pagan test indicates that the null hypothesis of homoscedasticity should be rejected. Therefore, we control for selection bias by using the Heckman two stage procedures. We rely on a unique and detailed dataset that covers 3,393 smallholder farmers for the whole agricultural sector of the year 2014. Our estimations yield a number of predictions.

The rest of the paper is organized as follows. First is our conceptual and empirical framework, followed by a presentation of the data used as well as some descriptive statistics. Thereafter, the empirical results along with conclusion and policy implications are presented.

CONCEPTUAL AND ECONOMETRIC FRAMEWORK

Following Strasberg et al. (1999), we used a household commercialisation index (HCI) to measure the intensity of smallholder farmers' engagement in the market. The household commercialisation index is defined as the ratio of the gross value of all crop sales and the gross value of all crop production

$$\text{HCI} = \left[\frac{Gross\ value\ of\ crop\ sales\ (in\ XOF)}{Gross\ value\ of\ all\ crop\ production\ (in\ XOF)}\right] \times 100 \qquad (1)$$

It could be seen as a measure of a household's market orientation. The larger the index the higher the degree of commercialisation or market orientation. A value of zero signifies no market participation—the household only produces for its own consumption; that is, full subsistence.

In this paper we aim at exploring the determinant of both the probability and the intensity of the level of commercialisation. The advantage of this approach is that commercialisation is treated as a continuum thereby avoiding crude distinction between commercialised and "non-commercialised" households. One approach to achieve our objective is to use a Tobit model which has an advantage over other discrete models in the sense that it reveals both the probability and the intensity of the level of commercialisation. Most empirical studies on smallholder agricultural commercialisation use the Tobit model (Holloway et al., 2000; Martey et al., 2012; Rahut et al., 2015). However, the validity of a Tobit model is based on the assumption of normality and homoscedasticity. Our diagnostic checks in our empirical work clearly reject both the assumptions of normality and homoscedasticity at 1% level and 5%, respectively. Furthermore, an OLS regression of HCI will lead to biased and non-convergent estimates, because the sample (Selling households) is unrepresentative of the population we are interested in (farming households).

There is an evidence of a sample selection problem. As a result, a Tobit specification would lead to biased estimates. To overcome this issue, we rely on Heckman's approach to analyse the determinants of commercialisation.

Our approach is closed to Alene et al. (2008) who employ the Heckman selection model to analyse the effects of transactions cost on smallholder marketed surplus and input use in Kenya. However we differ from them by estimating the Heckman two step method simultaneously. Heckman (1976, 1979) treated the selection problem as an omitted variable problem. The Heckman sample selection model has two features such as the two-step estimator and the full information maximum likelihood. However, Puhani (2000) showed that in the absence of collinearity problem, the full information maximum likelihood estimator is preferable to the two-step method of Heckman. Since there is no collinearity among the independent variables that we used in the empirical estimation, we adopt the full information maximum likelihood estimator of Heckman. Following Heckman (1979), we model the determinant of crop output commercialisation as follows:

$$Y_{1i}^{*} = X_{1i}^{'}\beta_1 + u_{1i} \quad (1)$$

$$Y_{2i}^{*} = X_{2i}^{'}\beta_2 + u_{2i} \quad (2)$$

The selection equation could be written as:

$$Y_{1i} = \begin{cases} 1 & if \quad Y_{1i}^{*} > 0 \\ 0 & if \quad Y_{1i}^{*} \leq 0 \end{cases} \quad (3)$$

Heckman (1976, 1979) has proposed a simple practical solution for such situations, which treats the selection problem as an omitted variable problem.
The outcome equation is as follow:

$$Y_{1i} = \begin{cases} Y_{2i}^{*} & if \quad Y_{1i}^{*} > 0 \\ - & if \quad Y_{1i}^{*} \leq 0 \end{cases} \quad (4)$$

The Model (1) is a Probit-type selection equation describing the probability of selling crop output in the market. The variables Y_1^* and Y_2^* are not observed whereas Y_1 and Y_2 are observed. In another note, one of the X_1 variables may be number of people in the household. For example, we could be interested in the effect of an extra household member on the level of commercialisation. We will not observe such effect for households who do not sell. This is expressed in Equations 3 and 4. It is commonly assumed that the correlated errors are jointly normally distributed, that is,

$$\begin{bmatrix} u_1 \\ u_2 \end{bmatrix} \square \left[\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \begin{bmatrix} \sigma_1^2 & \sigma_{12} \\ \sigma_{12} & \sigma_{22}^2 \end{bmatrix} \right] \quad (5)$$

Given that assumption, the likelihood function for the model (2) can be written (Cameron and Trivedi, 2010):

$$L = \prod_{i=1}^{n} \left\{ \Pr(y_{1i}^{*} \leq 0)^{1-y_{1i}} \right\} \left\{ f(y_{2i} \mid y_{1i}^{*}) X \quad \Pr(y_{1i}^{*} > 0) \right\}^{y_{1i}} \quad (6)$$

Where the first term is the contribution when $Y_{1i}^{*} \leq 0$, because $Y_{1i}^{*} = 0$, and the second term is the contribution when $Y_{1i}^{*} > 0$. For the subsample with positive Y_1^* the conditional expectation of Y_1^* is given by

$$E(y_{1i}^{*} \mid x_{1i}, y_{2i}^{*} > 0) = x_{1i}^{'}\beta_1 + E(u_{1i} \mid u_{2i} > x_{2i}^{'}\beta_2) \quad (7)$$

Given the normality assumption, Puhani (2000) showed that the conditional expectation of Y_1^* in Equation (7) can be rewritten as:

$$E(y_{1i}^{*} \mid x_{1i}, y_{2i}^{*} > 0) = x_{1i}\beta_1 + \frac{\sigma_{12}}{\sigma_2} \frac{\phi(-(x_{2i}^{'}\beta_2 / \sigma_2))}{1 - \Phi(-(x_{2i}^{'}\beta_2 / \sigma_2))} \quad (8)$$

Where $\emptyset(.)$ and Φ (.) denote the density and cumulative density functions of the standard normal distribution, respectively. The inverse Mills ratio in the two-step Heckman estimates is represented by:

$$\lambda(x_{2i}^{'}\beta_2 / \sigma_2) = \frac{\phi(-(x_{2i}^{'}\beta_2 / \sigma_2))}{1 - \Phi(-(x_{2i}^{'}\beta_2 / \sigma_2))} \quad (9)$$

And the Probit model is estimated by the Equation 10:

$$y_{1i} = x_{1i}^{'}\beta_1 + \frac{\sigma_{12}}{\sigma_2} \lambda(x_{2i}^{'}\hat{\beta}_2 / \sigma_2) + \varepsilon_1 \quad (10)$$

Our estimation consists of a set of covariates these include the gender of the household head (*Gender*), age of the household head (*Age*), age of the household head squared, education level of household head *(Educ*) grouped into three categories (primary, secondary and tertiary); marital status (*Status*); household size (*Hsize*); land operated per adult in the household (*Land*); land tenure security (*Tenure*); cooperative membership (*Coop).* The use of hired labour (*Hlabor*), the use of unpaid or relatives labour (*Ulabor*) typically through mutual labor exchange arrangements; the use of other inputs such as organic fertiliser (*Orga*); inorganic fertiliser (*Inorga*) and pesticide (*Pest*); household access to off-farm income (*Offincome*) and village dummies variables (*Dvillage*). For the education variables groups, we used no formal education as reference category while the Southern region is used as a reference for residency variables. We expect male-headed households to commercialise more crops than female-headed households. The higher the household head is educated, the better he may be aware of new agricultural practices toward commercialisation. Cooperatives usually provide various services including transportation, packaging, distribution, and marketing of farm products. Therefore, being member of cooperative is expected to be positively correlated with household market participation. Many studies in the literature on consumption (e.g., Omiti et al., 2009; Aderemi et al., 2014) have used the distance to market variable which is found to have significant impact on output commercialisation. However, since our data lack information on the distance to market, we used village dummies variables to remove the distance to market effect (assuming that the distance to market is essentially the same for all households in a village). Therefore, the remaining determinants of commerciali-sation are based on within-village comparisons across households.

Table 1. Description of the explanatory variables used in the regression.

Variables	Description	Measurement
Female headed	Gender of household head	Dummy (1=female; 0=male)
Age	Household head age	Number of years
Age squared	Household head age squared	Number of years
HH head has primary education	HH head has primary education	Dummy (1= if head has primary education; 0=Otherwise
HH head has secondary education	HH head has secondary education	Dummy (1= if head has secondary education; 0=Otherwise
HH head has tertiary education	HH head has tertiary education	Dummy (1= if head has tertiary education; 0=Otherwise
HH is married	Marital status	Dummy (1=if married; 0=Otherwise
Household size	Number of household member (head count)	Number of person
HH land operated size per adult	Ratio of household farm land operated size per number of adults in the household	Hectare
Land tenure security	Farm land with land title or sale attestation	Dummy (1=if yes, 0=Otherwise)
Cooperative	Membership of cooperative	Dummy (1=if yes, 0=Otherwise)
HH used hired labour	Household used hired labour	Dummy (1=if yes, 0=Otherwise)
HH used relatives labour	Household used relatives labour	Dummy (1=if yes, 0=Otherwise)
HH Used organic fertiliser	Household used organic fertiliser	Dummy (1=if yes, 0=Otherwise)
HH Used inorganic fertiliser	Household used inorganic fertiliser	Dummy (1=if yes, 0=Otherwise)
Share of off-farm income in total HH income	proportion of off-farm income in total annual household income	Ratio
$Dvillage_j$	Household in a particular village	Dummy (1=if yes, 0=Otherwise)

Thus the intensity of market participation is estimated with the following equation (Outcome equation).

$$Y_2^* = \beta_0 + \beta_1 Gender + \beta_2 Age + \beta_3 Age^2 + \sum_{i=2}^{4} \beta_{4i} Educ_i + \beta_5 Status + \beta_6 Hsize + \beta_7 Land + \beta_8 Tenure + \beta_9 Coop + \beta_{10} Hlabor + \beta_{11} Ulabor + \beta_{12} Orga + \beta_{13} Inorga + \beta_{14} Pest + \beta_{15} Offincome + \sum_{i=2}^{194} \beta_{16j} Dvillage_j \quad (11)$$

Where Y* is the household commercialisation index specified in equation (1). As recommended by Cameron and Trivedi (2010), for more robust identification, it is important to impose exclusion restriction to the model. This requires that the selection equation has an exogenous variable that is excluded from the outcome equation. More specifically, in specifying such a model, we need at least one variable that explains the decision to participate in output market while not affecting the resulting marketed output, which provides an exclusion restriction by which the model can be identified. We used the number of children under two years old in the household as exclusion restriction variable. Economic and social shocks and stresses are more likely to increase the probability of market participation by a farmer at a certain point in time. Rural households that have very young children have higher levels of vulnerability. For example, children under the age of two are usually more prone to being affected by diseases, than adults. The presence of very young children in the household makes women more likely to leave the output market. We expect the number of children under the age of two to negatively affect the decision. However, we assume that having children under the age two will not have incidence on the quantity of marketed output. In fact, very young children do not constitute a part of workforce in the household. Table 1 presents the description of the explanatory variables used in the regression.

DATA AND DESCRIPTIVE STATISTICS

Data

This study relies on comprehensive primary data collected by Côte d'Ivoire National Institute of Statistics (INS) between January and February 2014 as part of the National employment survey. The

Table 2. Agricultural household main characteristics.

Variable	Mean	Standard deviation
Male headed	0.852	0.355
Female headed	0.148	0.355
Age of household head (year)	44.59	15.72
Marital status		
Married Monogamous	0.664	0.472
Married Polygamous	0.112	0.315
Single (never married)	0.125	0.331
Divorced/Separated	0.025	0.155
Widow	0.075	0.263
Household head education		
[1] None	0.590	0.492
[2] Primary	0.261	0.439
[3] Secondary	0.142	0.349
[4] Tertiary	0.008	0.090
Household size (Head count)	4.619	2.997
Number of Adults (14 years and above)	2.620	1.584
Child dependency ratio (# of children under 10 years/ # of HH member over 10 years)	1.184	0.330
Dwelling characteristics		
Drinking Water from pipeline	0.120	0.325
Drinking Water from Borehole	0.379	0.485
Main Source of Lighting Electric	0.366	0.482
Flush Toilet	0.081	0.273
Public garbage collection	0.192	0.394
Main Cooking Fuel Biomass (Wood/Dung/Coal)	0.978	0.145
Observations	3,393	

survey focuses extensively on agriculture and offers a wealth of data on the range of agricultural production for the country. Data were collected using household questionnaires in which information was obtained at the individual, household and plot level. Agricultural production data were collected at plot and crop level, with detail on the allocation of production and the use of inputs such as fertilizer, pesticides, hired labour, shared labour and household labour activity.

The survey is nationally representative at the urban, rural and agro-climatic zone level. The final sample consists of 11,971 households, 3,393 of this sample is involved in agriculture. In this study we focus on agricultural households.

Socio-economic characteristics of agricultural households

As showed in Table 2, around 85.2% of agricultural households are male-headed against 14.8 female-headed. The age of the agricultural household head is on average 45 years. Table 2 also shows that the majority of household heads are monogamous (66.4%). However, around 11.2% of household heads are polygamous. Very few household heads are single (12.5%).

Most of agricultural household heads in Cote d'Ivoire have not been to school (Table 2). An average of 59% of household heads has no level of formal education. About 26.1% of them attended primary school, 14.2% attended secondary school and less than 1% has a tertiary level education. That said, the level of education of agricultural household head is in generally very low.

Agricultural household size is around 5 members. The average number of adults (members of working age) per household is around 3 persons accounting for 60% of the total size of the household. The dependency ratio is 1.1 children per household.

Access to infrastructure and basic services is problematic for many agricultural households (Table 2). Only 12% of agricultural household have access to piped water and 38 % through borehole. More than 60% of them do not have access to electricity. Approximatively 8% of agricultural households' report having access to an internal flush toilet and 19.2% have access to a public garbage collection service. Almost all agricultural households use wood or dung or coal as their main source of energy for cooking.

Land holding

Households in Cote d'Ivoire own an average of 2 plots. The average landholding size is 4.75 ha. The average land size per adult in the household is on average around 2.2 ha. Compared to other Sub-Saharan African countries, farm land size in Côte d'Ivoire appears to be large. In fact, using LSMS-ISA data, Carletto et al. (2015) reported an average of 0.9; 2.6 and 2.3 ha respectively for Malawi, Tanzania and Uganda which are far less than what we observed in Côte d'Ivoire.

However, the distribution of land holdings and operation

Table 3. Average land holdings (in ha) by quintiles of land operated.

Quintiles of land operated	Count	Mean	SD
1	687	0.675	0.369
2	663	1.990	0.327
3	688	3.449	0.443
4	619	5.642	0.833
5	736	11.48	3.618
Total	3393	4.488	4.059
Observations	3393		

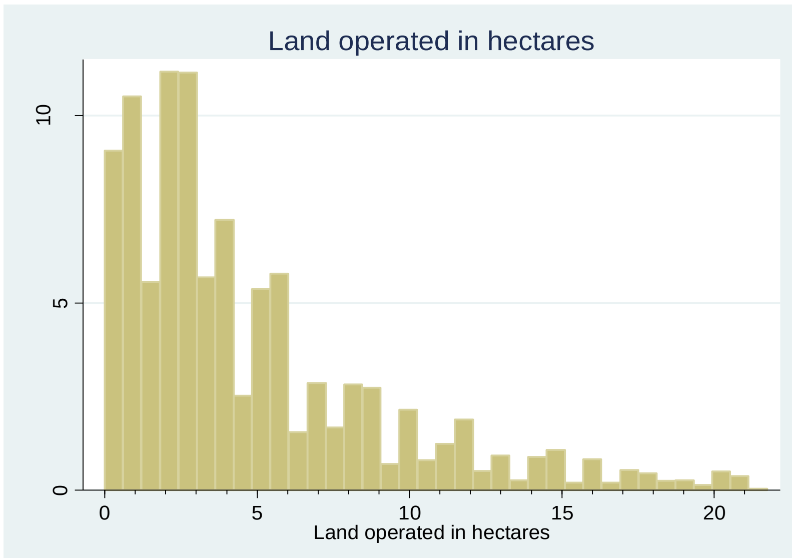

Figure 1. Histogram of area of land operated by households.

in Table 3 and Figure 1 shows the prevalence of smallholder farmers in the country. About 40% of agricultural households operate less than 2 hectares on average. The land holding in the top land quintile appear to be large (averaging 11.5 ha) suggesting that land is concentrated among a small share of household.

Labour and input utilisation

A critical complement to land in the agricultural production process is labour. Households use a combination of family labour and hired labour and also rely on relatives and friends. Our data show that 92% of households used family labour while 48.8% hired agricultural labour and 44.9% benefit from the assistance of relatives and friends to work on their farm (typically through mutual labor exchange arrangements which are especially common in the North). Only 28.1% of the households relied only on family labour.

In addition to employing agricultural labour to increase agricultural production, agricultural households use inputs such as fertiliser, pesticides/herbicides, and manure. Pesticides/herbicides utilisation has the highest rate. Close to 48% of households reported using pesticides/ herbicides. Fertiliser utilisation is reported by 27% of households. Only 18.6% of households reported using manure. Pesticide utilisation rise with increasing area of operated land, from 24.7% in the bottom quintile to 54.9% in the top quintile of land operated.

Fertiliser utilisation in Côte d'Ivoire is very low. Around 27% of the survey household reported using inorganic fertiliser while only 19% used organic fertiliser. Among other factors, the low input utilisation could prevent farmers from achieving higher crop yields.

Crop portfolio

Agricultural households in Côte d'Ivoire diversify their crop production. They grow an average of 3 different types of crop. In Figures 2 and 3 we present the percentage of households that reported growing each type of crop to show the diversification of household crop portfolios. The Figure 2 shows that Cocoa is the predominant crop grown. Cocoa farming accounts for 47% in agricultural households' crop portfolio. Root vegetables (yam, cassava, sweet potato, potato, and cocoyam), cereals and beans, and cashew are equally important. They account for 40, 32 and 21 %, respectively, of the crop portfolio. Very few households are specialised in growing food crops[1] or cash crops[2] (Figure 3). Only 23.6% of agricultural households grow food crops only and about 32.2% of agricultural households grow cash crops only.

[1] Food crops include yam, cassava, sweet potato, potato, and cocoyam, legumes, cereals (corn, rice, sorghum) and beans

[2] Cash crops include cocoa, coffee, cotton, rubber, cashew, ground nut, palm oil, pineapple, mango and avocado

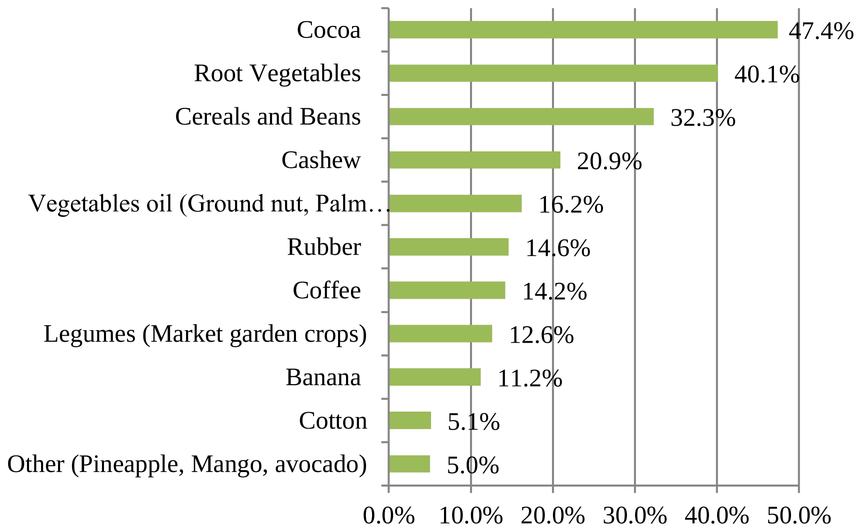

Figure 2. Share of household cultivating each type of crop.

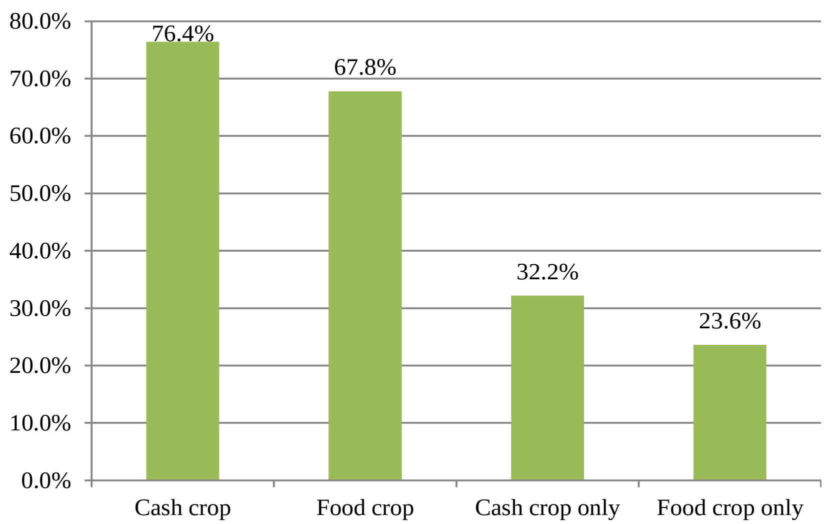

Figure 3. Share of household cultivating each type of crop.

Crop commercialisation

Agricultural households use a large variety of market outlets (Figure 4). The breaking down of the share of households that sold any crop by type of markets they accessed reveals the use of a large variety of market outlet. Approximately, 44% of households reported selling their product to National private operators, while 28% reported having sold in the local market. 19 and 17% of households reported selling respectively to foreign private operators and farmer's cooperatives. National private operators appear to be the main source of access to market accounting for 39% of the overall markets outlets.

Our data show that Cote d'Ivoire is characterised by a high-level of commercialisation. We find that around 80% of households engage in sales (Figure 5). Close to 20% of household reported selling 100% of their agricultural production. This includes the sale of food and cash crops. Indeed, our data suggest that the vast majority of selling households are growing and marketing both cash and food crops while very few of them are specialised in food crops.

As shown in Table 4, the percentage of output actually sold on the market out of the overall harvested production in value terms is around 48.69%, which is very high as compared to the result obtained by Carletto et al. (2015) for Malawi, Uganda and Tanzania, where farming households sold, respectively 17.6, 26.3 and 27.5% of their production. The percentage of output sold is much higher (61.29%) when considering only selling households. Female-headed households appear to commercialise considerably less of their production than male-headed households. The difference of commercialisation index between male- and female-headed households is around 11% points. Even when focusing only on selling households, there is still a large gap between female- and male-headed households. This suggests that female-headed households are less commercially oriented in Côte d'Ivoire.

Not surprisingly, cash crops are more commercialised than food crops. The percentages of output sold are 79.48 and 31.05 respectively for cash and food crops. This suggests that cash crops

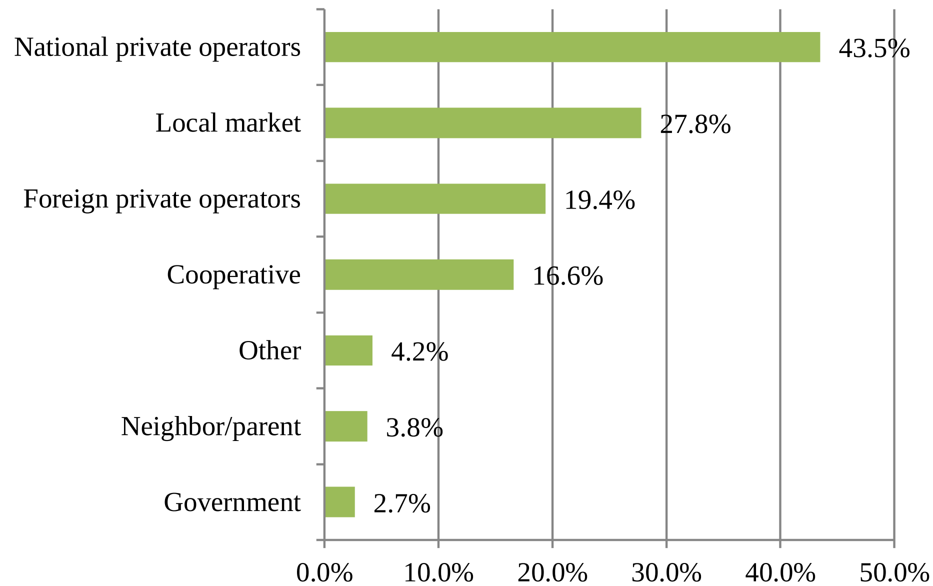

Figure 4. Share of households that sold any crop by type of markets.

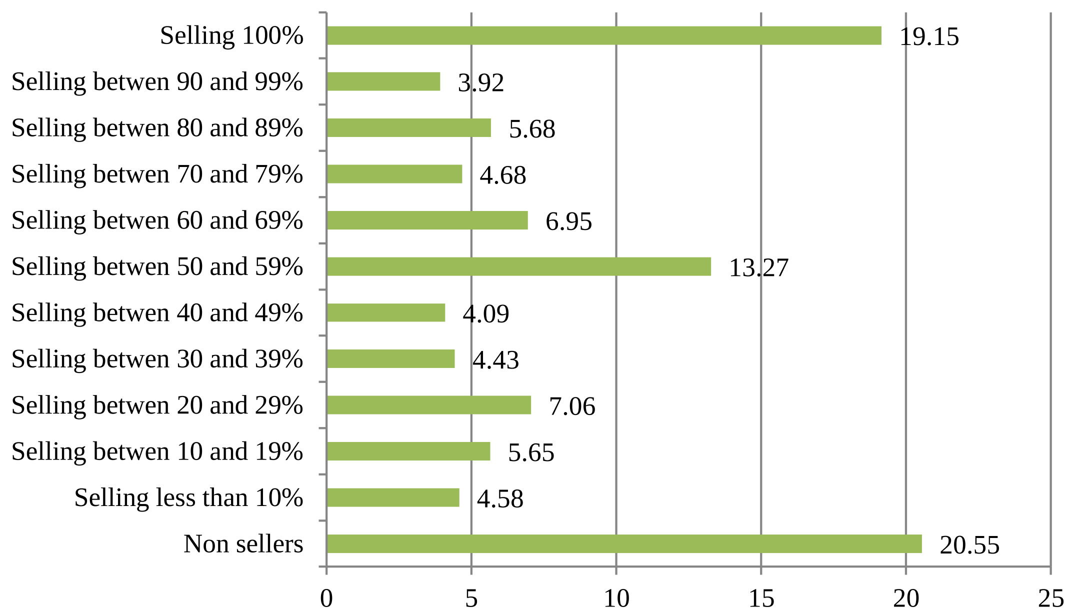

Figure 5. Distribution of households by output commercialisation

adopters are more likely to be market oriented. There is no clear evidence that the degree of commercialisation increases with the farm size (Figures 6 and 7). Compared to the Southern region, smallholder farmers in the other regions and particularly those in Northern and Eastern region are far less likely to sell crop outputs in the market. Of note, the Southern part of Côte d'Ivoire predominantly produces cash crop products while the Northern and the Eastern regions are food producing regions. In addition, national statistics show that poverty is more concentrated in the other regions than in the South with a higher percentage of poverty head count in the Northern and Eastern region. Thus, these regions might be home of subsistence-oriented smallholder farmers.

EMPIRICAL RESULTS

Our estimation results are presented in Table 5. The Wald test has a p-value of 0.0000 and indicates that our model as a whole fits significantly better than an empty model (that is, a model with no predictors). To further check the validity of our model, we perform a likelihood

Table 4. Share of crop output sold by selected characteristics.

Characteristics	Share of crop output sold (%)	Share of crop output sold conditional on sales (%)
Country average	48.69	61.29
Male headed	50.34	61.97
Female headed	39.25	56.69
Cash crops	79.48	
Food crops	31.05	
Head education		
[1] None	46.82	59.72
[2] Primary	51.35	63.64
[3] Secondary	51.05	63.13
[4] Tertiary	58.64	64.10
Land rental market		
Rent in land (No)	50.11	65.85
Rent in land (Yes)	52.46	71.11
Hired labour		
HH uses hired labour (No)	47.95	66.58
HH uses hired labour (Yes)	52.78	65.97
Macro regions		
Southern region	62.92	76.50
Central region	47.47	63.87
Eastern region	39.07	56.80
Western region	52.93	67.30
Northern region	33.22	50.57

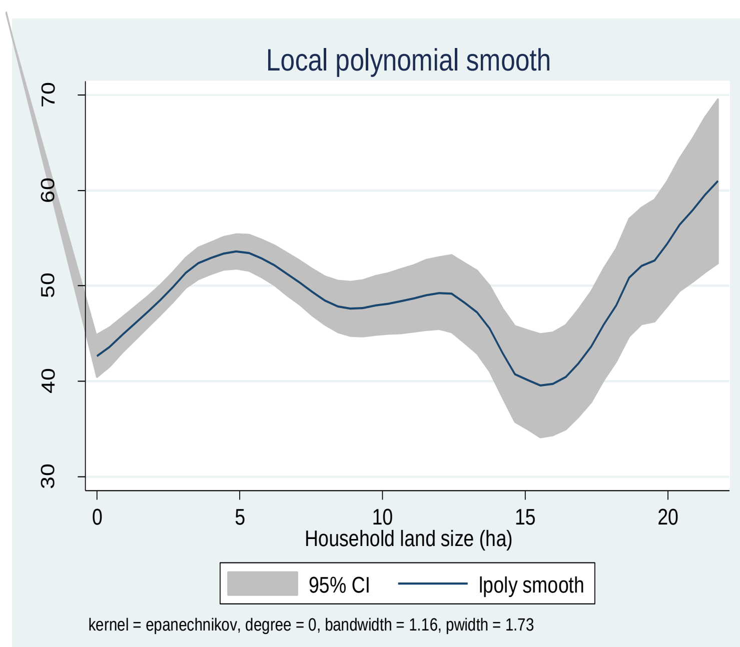

Figure 6. Local linear non-parametric regression of crop commercialisation index by household land-operated size

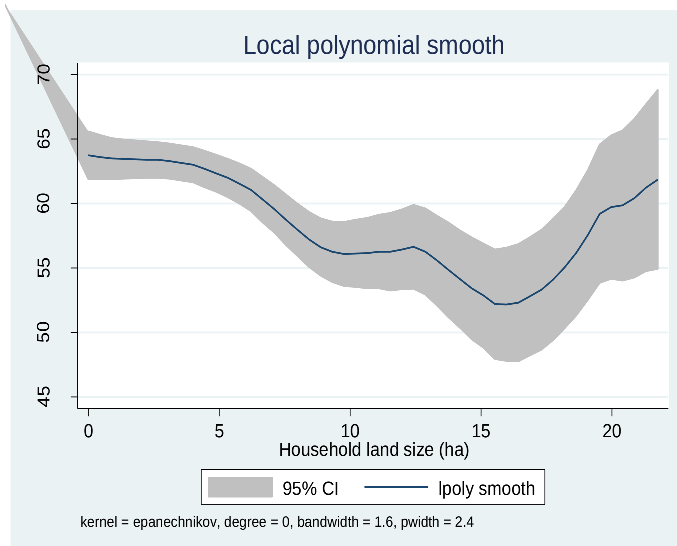

Figure 7. Local linear non-parametric regression of crop commercialisation index (conditional on sales) by household land-operated size.

Table 5. Heckman maximum likelihood estimates (MLE) of the determinants of crop output commercialisation.

Determinant	(1) Probit (1st step)	(2) Benchmark	(3) MLE (2nd step)
Female headed	0.006 (0.135)	-3.437* (1.884)	-3.455* (1.882)
Age of household head (year)	-0.029* (0.016)	-0.173 (0.196)	-0.167 (0.194)
Age of household head squared/100 (year)	0.029*(0.015)	0.236(0.190)	0.232(0.190)
HH head has primary education	0.012(0.109)	0.627(1.439)	0.634(1.439)
HH head has secondary education	0.104(0.141)	0.852(1.872)	0.860(1.872)
HH head has tertiary education	0.246(0.450)	-0.872(5.953)	-0.873(5.953)
HH is married	0.030(0.131)	-3.139*(1.617)	-3.168**(1.610)
Household size	0.009(0.017)	-0.300*(0.250)	-0.324*(0.212)
Household land operated size per adult (ha)	0.019(0.024)	-0.464*(0.277)	-0.467*(0.277)
Land tenure security	-0.187(0.177)	4.270**(2.017)	4.271**(2.017)
Membership of cooperative	0.732***(0.207)	5.283***(1.767)	5.280***(1.767)
HH used hired labor	0.020(0.089)	-1.284(1.181)	-1.280(1.180)
HH used relatives labor	-0.006(0.089)	-2.818**(1.180)	-2.811**(1.179)
HH used organic fertilizer	-0.023(0.131)	-0.380(1.683)	-0.371(1.683)
HH used inorganic fertilizer	0.202(0.135)	0.989(1.738)	0.980(1.737)
HH used pesticide	0.310***(0.105)	0.615(1.405)	0.611(1.405)
Share of off-farm income in HH total income	-2.729***(0.119)	-0.341(3.535)	-0.273(3.513)
# of children under 2 years old	-0.150**(0.072)	0.534(1.144)	
Constant	3.270***(0.537)	78.90***(6.649)	78.74***(6.597)
Village Fixed effects	***YES***	***YES***	***YES***
Athrho		-0.290*(0.182)	-0.293*(0.181)
lnsigma		3.386***(0.014)	3.386***(0.014)
Rho		-0.281(0.167)	-0.284(0.166)
Sigma		29.535(0.419)	29.538(0.419)
Lambda		-8.320(4.996)	-8.414(4.964)
Observations		3393	3393

Standard errors in parentheses; * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$; the reference categories are no education for the educational dummies variables.

ratio (LR) test. The latter test has a p-value of 0.0087 implying that the estimated correlation between the errors is significantly different from zero and the hypothesis of absence of sample selection is strongly rejected. To test the validity of the exclusion restriction variable, we ran the Heckman model by including the number of children under two years old as a regressor in both the selection equation and the outcome equation. The result is presented in columns 1 and 2 in Table 5. The coefficient of the restriction exclusion variables is significant in the Probit model (selection equation) and non-significant in the outcome equation. This demonstrates the validity of our exclusion restriction variable. The third column of Table 5 presents the estimation results of our outcome equation.

Our results are presented in Table 5. The first column of Table 5 presents estimates of market participation while the third column represents estimates of market supply. The result in column 1 shows that cooperative membership and the usage of pesticides are positively correlated with household probability to engage in the market. This result confirms our prediction given that cooperatives reduce the transaction costs of members. The age of the household head, the number of children under the age of two years and the share of off-farm in total household income are the factors that negatively affect the probability of households to engage in the market.

As far as commercialisation intensity is concerned, the estimates indicate that the gender of the household head, marital status, household size, labour constraint, land tenure security, membership of cooperative and the share of off-farm in total household income are significantly correlated with the degree of output commercialisation (Table 5). The regression shows that commercialisation index of female headed households is on average 3.4% less than male headed households, everything being equal.

Married household heads sell an average of 3% less output than non-married household heads. The negative and significant coefficient of the household size variable implies that the bigger the household, the less it is oriented toward the market. This applies to situations where the household has more children below working age, who thus do not contribute to farm labour but significantly increase household consumption (Omiti et al., 2009).

The coefficient of the land-operated size per adult is negative and significant at 1% level. Our descriptive statistic shows that smallholder farmers rely heavily on family labour. As a result, the bigger the land operated size per adult, the higher the constraints faced by the household. Thus, the negative coefficient of the land-operated size per adult implies that households who are facing a labour constraint commercialised less output. An increase of one hectare of farmed land per adult decreases the share of output sold by 0.5%. Since the agriculture sector in Côte d'Ivoire is labour intensive, we argue that labour constraint affects household productivity negatively, which has negative impact otheir commercialisation intensity.

Land tenure security is also a factor affecting the degree of output commercialisation. The estimation shows that having a formal land certificate such as land title or sale attestation is associated with higher commercialisation index. Land tenure security raises the level of household commercialisation by 4.3%. Land insecurity affects household crop choice.

Access to market and extension services through cooperatives is an important factor that increases household level of commercialisation.

Household members of a cooperative sold approximatively 5% more than those who are not members of a cooperative. All things being equal, access to off-farm income does not have any impact on the level of commercialisation after correcting for selectivity bias.

In Table 6, the robustness checks for the determinants of crop output commercialisation are presented. More specifically, two alternative methods are applied, the truncated regression and the Tobit regression. The results are similar and close to those found with the Heckman maximum likelihood estimates. However, the standard deviation of all covariates in the Heckman sample selection model are smaller than those obtained with the other methods. This implies that the Heckman sample selection model yields more efficient estimators.

DISCUSSION

Our findings are consistent with similar studies in the literature. Collective actions appear to be very important factors to agricultural commercialisation. This result confirms findings by Holloway et al. (2000) and by Francesconi and Ruben (2007) who found that cooperative farmers outperform non-cooperative farmers in terms of quantity produced and marketed. Land tenure security has also played a significantly influential role in commercialisation of agriculture in Cote d'Ivoire. The positive sign of the coefficient of land tenure security in our study contradicts the findings of Martey et al. (2012). The contradiction could be explained by the fact that Martey et al. (2012) did not correct for selection bias. In addition, in our sample, households with non-secured land property rights are less engaged in perennial cash crops production such as cocoa, coffee, cashew and rubber, which are more market-oriented.

The use of pesticides has also made an equally important contribution to the probability of a farmer engaging in commercialization. As households usually rely on family labour with very limited options for tractors, the use of pesticides could foster market participation for farmers. The extent of agricultural commercialisation by married head of households is 3% lower than those of

Table 6. Robustness checks for the determinants of crop output commercialization.

Determinant	Truncated regression	Tobit regression
Female headed	-4.164*(2.308)	-3.404(2.079)
Age of household head (year)	-0.226(0.231)	-0.434**(0.216)
Age of household head squared/100 (year)	0.307(0.225)	0.499**(0.211)
HH head has primary education	0.777(1.739)	0.589(1.605)
HH head has secondary education	1.086(2.218)	1.482(2.082)
HH head has tertiary education	-0.677(7.011)	1.258(6.671)
HH is married	-3.624*(1.929)	-1.899(1.802)
Household size	-0.400*(0.260)	-0.234(0.235)
Household land operated size per adult (ha)	-0.562*(0.339)	-0.524*(0.312)
Land tenure security	4.512*(2.332)	1.539(2.269)
Membership of cooperative	6.739***(2.063)	8.820***(2.004)
HH used hired labour	-1.446(1.435)	0.153(1.317)
HH used relatives labour	-3.435**(1.440)	-2.494*(1.319)
HH used organic fertiliser	-0.446(2.045)	0.185(1.891)
HH used inorganic fertiliser	1.434(2.092)	2.869(1.944)
HH used pesticide	1.101(1.673)	3.857**(1.558)
Share of off-farm income in HH total income	-6.330***(2.453)	-46.84***(1.895)
Constant	79.22***(7.768)	84.45***(7.410)
Village Fixed effects	***YES***	***YES***
Sigma	37.26***(0.670)	38.55***(0.515)
Observations	2954	3393

Standard errors in parentheses; * p < 0.10, ** p < 0.05, *** p < 0.01; the reference categories are no education for the educational dummies variables.

unmarried head of households. This finding is consistent with Martey et al. (2012). Similar to Alene et al. (2008), our results suggest that female-headed households have a greater likelihood of participation in markets than male-headed households but supply less marketable output than male-headed households.

As opposed to Nepal and Thapa (2009) and Martey et al. (2012) which use the farm size (in hectares) as a regressor, we use per adult land operated size to highlight the importance of labour constraints in farm commercialization. We find that labour constraints have a negative and significant effect on farm output commercialisation. We argue that labour constraints negatively affect household productivity, which has a negative impact on household commercialisation intensity. The age and the level of education of the household head appear not to be a significant determinant of farm output commercialisation. This result is consistent with previous studies (Aderemi et al., 2014; Rahut et al., 2015). However, it differs from those of Omiti et al. (2009) in Ghana who found that the age and the year of education of the head of the household have a significant positive impact on the degree of crop output commercialisation. Notably, Omiti et al. (2009) did not correct for selection bias either in their estimates which could explain that divergence.

CONCLUSIONS AND IMPLICATIONS

Agricultural households in Côte d'Ivoire diversify their crop production. They grow on average 3 different types of crop with a mix of cash crop and food crops. Selling households have access to a variety of market outlets with national private operators being the main source of access to the market. A small share of households sold their production through farmer cooperatives. However, Cote d'Ivoire is characterised by a high-level of commercialisation. The vast majority of selling households are growing and marketing both cash and food crops while very few of them are specialized in food crops. Our Heckman maximum likelihood estimates underscore the role of household level characteristics in influencing the extent to which smallholders sell their output on market. It emerges from our study that cooperative membership and land tenure security are the factors that positively and significantly affect the level of crop output commercialisation. Female-headed households sell a lesser share of their crop production while unmarried head of households sell more output than married head of households. Labour and capital constraints are major factors preventing households from being more engaged in the market. There is a regional gap in terms of output commercialisation. Farmers in the Southern region where the cropping system is dominated by cash crops are more market-oriented.

As to recommendations, we conclude that policies that target the creation of new cooperatives and reinforcement of existing cooperatives could be effective in reducing cost of market access (costs of information seeking, negotiation and monitoring) for smallholder farmers. Another benefit for farmers belonging to a farmer group (when it exists and is functional) is the increase of negotiation power for better prices, secured market outlets and access to technical assistance (Pingali et al., 2005). Smallholder farmers' education should also be an area of attention by policy makers in order to increase technology adoption and crop productivity. Interventions that increase food crop productivity will be beneficial to the poorest farmers, especially those in the Northern part of the country, who are less engaged in cash crop systems. Relaxing capital constraints by providing smallholder farmers with credit will raise their engagement in the market. The promotion of agricultural mechanization will potentially relax labour constraints that are driving down smallholders' level of output commercialisation.

Conflict of Interests

The authors have not declared any conflict of interests.

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Full Length Research Paper

Effects of rhizobacteria on *Meloidogyne javanica* infection on eggplants

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The effect of two rhizobacteria, *Pantoea agglomerans* and *Bacillus subtilis* on parasitism of the root-knot nematodes, *Meloidogyne javanica* on eggplants was evaluated in laboratory and greenhouse experiments. The impacts of the bacteria application as seed treatment, root dipping, and soil drench on early nematode penetration into plant roots, as well as, on eggplant growth were tested. The number of penetrated second stage juveniles of *M. javanica* was significantly reduced after *P. agglomerans* and *B. subtilis* application at concentration of 10^8 CFU ml^{-1}. *P. agglomerans* increased the eggplant fresh shoot and root weight following seed treatment. In the greenhouse experiment the bacteria were applied alone and in combination with a carbamate nematicide, Oxamyl (Vydate®). *P. agglomerans* was able to suppress *M. javanica* development into plant roots through a first half of eggplant cropping season. At the end of cropping season *B. subtilis* significantly reduced root gall index and number of nematode juveniles in soil and roots. This bacterium applied in combination with Oxamyl was the most efficient against *M. javanica* reproduction. Thereby, *B. subtilis* might be considered as a good candidate for biological or integrated control of the root knot nematodes.

Key words: *Bacillus subtilis*, *Pantoea agglomerans*, biological control, plant growth, gall index, root knot nematode.

INTRODUCTION

Root-knot nematodes are one of the main problems for protected crops, especially in south-eastern countries of Europe where climatic conditions favour their development. Species of *Meloidogyne* have a wide range of plant hosts and cause severe damage to vegetable crops. Crop losses due to *Meloidogyne* exceed 32% on tomato, 30% on melon and 20% on eggplant (Netscher and Sikora, 1990). Eggplant (*Solanum melongena* L.) is a traditional vegetable crop grown in Bulgaria. One of the most frequently found root-knot nematode species on eggplant is *Meloidogyne javanica*, present alone or in combination with other *Meloidogyne* species. In Bulgaria annual crop losses due to *M. javanica* largely depend on vegetable crops, their resistance to the nematode and the methods of control that have been used (Samaliev and Baicheva, 2010; Masheva et al., 2016). Present strategies for nematode management involved some cultural practices such as crop rotations and resistant

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varieties. Crop rotation is widely use but is not effective when applied for control of polyphagous pests. Due to the lack of resistance genes in many vegetables, resistant varieties are not readily available (Dias-Arieira et al., 2012). During the last ten years, a series of field studies employed throughout the world demonstrate that fumigant and non-fumigant nematicides are still efficient for the control of the root-knot nematodes (Giannakou and Anastasiadis, 2005; Choudhary et al., 2006; Hadian et al., 2011). However, the nematicides are usually toxic to highly toxic and there is much concern about their residual effects on the environment and human health. For this reason the interest in biological control as an alternative to chemical control of *Meloidogyne* has increased.

Bacteria associated with roots and rhizosphere of many plant species have been extensively tested for the control of various soil borne pathogens (Haseeb et al., 2006; Vasebi et al., 2015) including plant parasitic nematodes (Kluepfel et al., 1993; Insunza et al., 2002; Aballay et al., 2013). Currently, *Bacillus spp.* and *Pseudomonas spp.* are the most studied bacteria as biological control agents of root-knot nematodes (Hallmann et al., 2009). Other rhizosphere bacteria expressing antagonistic potential against *Meloidogyne* include, *Burkholderia, Paenibacillus*, *Pantoea* and *Seratia* (Duponnois et al., 1999; Oliveira et al., 2007; Abd-Elgawad and Kabeil, 2010). Control of nematodes by rhizosphere bacteria is achieved by mechanisms such as: direct antagonism through the production of secondary metabolites; interference with plant-nematode recognition; competition for nutrients; plant growth promotion; and induced systemic resistance (Tian et al., 2007). The low level in consistency of control of nematodes by many bacteria under field conditions is most likely due to the variability of the soil properties (physical and chemical), microbial activity in the soil as well as due to other environmental factors (Kerry, 2000). Thus, achieving efficient and consistent performance of biocontrol agents requires a more knowledge of effective screening techniques, and development of appropriate formulation and application techniques. The objectives of the present studies were: (i) to determine the effect of two rhizobacteria on early root penetration and gall formation of *M. javanica* into eggplant roots; *(*ii) to observe the influence of the bacteria on the plant growth; to examine the effect of bacteria alone or in combination with an organophosphate nematicide under greenhouse condition.

MATERIALS AND METHODS

Strains of rhizobacteria

Rhizobacteria were isolated in Bulgaria from rhizosphere of tomato plants. Two selected strains of the rhizobacteria, *Pantoea agglomerans* and *Bacillus subtilis* (collection of LMBT, Agricultural University-Plovdiv) which can significantly reduce incidence of galls of nematodes on tomato were used in this study.

Bacterium culture and identification

The strains of *P. agglomerans* and *B. subtilis* were grown in the dark for 48 h at 24°C on tryptic soy broth agar (TSBA). For inoculum production a loop of the bacteria was transferred into 100 ml of TSB and allowed to multiply for 48 h on a rotary shaker (160 rpm) at the same temperature. Bacterial suspensions were centrifuged at 4000 rpm for 20 min, and the bacterial pellet was resuspended in sterile ¼ strength Ringer's solution (Merck). The bacterial suspension was adjusted to a final concentration of 10^8 CFU ml^{-1} by dilution with Ringer's solution. The bacterial strains identifications were determined by FAME Analysis, following by BIOLOG Analysis for *P. agglomerans*.

Nematode culture and sterilization

M. javanica was obtained from cultures derived from single egg masses maintained on tomato (*Solanum lycopersicum* L., cv. Ideal) in a greenhouse at 24 to 26°C. Mature egg masses of *M. javanica* were hand-picked, using a sterilized needle and forceps from heavily infested tomato roots. These egg masses were sterilized in streptomycin sulphate (0.1%) for 45 min and rinsed in sterile distilled water (SDW) before being used as inoculum in experiments. Second stage juveniles (J2) of *M. javanica* were extracted from infested tomato roots following the procedure described by Stetina et al. (1997). Galled roots with egg masses were washed free of soil, cut into small pieces, placed in 1.5% NaOCl and homogenized at 8000 rpm (T 18 digital ULTRA-TURRAX) (Hussey and Barker, 1973). The suspension was poured onto cotton-wool filter, incubated at 24 to 26°C and hatched J2 were collected every 24 h. The second stage juveniles were also sterilized in streptomycin sulphate (0.1%) for 15 min and rinsed in SDW before being used in experiments.

Effect of rhizobacteria on the penetration rate of *M. javanica* juveniles

The bacteria were applied as follows:

1. Seed treatment: The eggplant seeds, cv. Lych were soaked in the suspensions of *P. agglomerans* and *B. subtilis* for 20 min and then planted into pots containing 500 ml soil/sand mixture (1:1, v/v). Each pot received 1 seed. After four weeks, the plants were inoculated with 2500 J2 of *M. javanica* per pot. The inoculation of nematodes was carried out by drenching 5 ml suspension of J2 in distilled water into the potted soil arround the roots. The control treatments received 5 ml distilled water;
2. Root dipping: Roots of three-week-old eggplants were dipped for 20 min into the bacterial suspensions and then planted into pots containing 500 ml soil/sand mixture (1:1, v/v). After a week, the plants were inoculated with 2500 J2 of *M. javanica* per pot.
3. Soil drench: Ten milliliter of bacterial suspensions was pipetted onto the soil surface around three-week-old eggplants. Plants were inoculated with 2500 J2 of *M. javanica* one week after bacteria application. The inoculation of nematodes was carried out by drenching 5 ml suspension of J2 in distilled water into the potted soil arround the roots. The control treatments received 5 ml distilled water. Plants were kept in a growth room with following conditions, 28±1°C temperature, 70±5% relative humidity (RH) and 16:8 (L:D) photoperiod. All the experiments was replicated eight times, end terminated two weeks after nematode inoculation.

At the end of the experiments eggplant fresh shoot and root weight was measured and the penetration rate of *M. javanica* was recorded. Penetrated J2 of *M. javanica* into eggplant roots was determined after staining the roots with red food color (33,3% (v/v) solution of acid fuchsine available in ROTH®) following the method described by Thies et al. (2002). Stained roots were washed with tap water and homogenized at 8000 rpm. The number of J2 extracted from the root tissue was counted under a stereomicroscope.

Greenhouse efficacy experiment in eggplant production system

The experiment was conducted in a commercial greenhouse near Svilengrad, Southern Bulgaria. No nematicides had been applied in the greenhouse for at least 2 years prior to the experiment. Plots were 20 m^{-2} (2 m × 10 m) each. The treatments were arranged in randomized complete block design with four replications. One week before planting of the eggplant seedlings all plots were irrigated with 13 L of water m^{-2} and ploughed with rotary cultivator to ensure moisture uniformity. The distances between and within rows were respectively 0.64 and 100 cm. The greenhouse temperature during the cropping period was 18 to 43°C (March-June). Plants were irrigated every three days with a drip system and fertilized every week with compound fertilizer (N: 15 %, P: 15%, K: 15%).

Two weeks eggplant seedlings, cv. Lych were transplanted in the greenhouse on 15 March, 2014. Before planting, the soil into the band had been infested with *M. javanica* at a rate of 5000 eggs and J2 per plant. The experiments included the following treatments: 1. Control with nematodes; 2. Susspension of *P. agglomerans* at dose 10 ml per plant (per treatment) on 1th, 8th and 15th day after transplanting; 3. Susspension of *B. subtilis* at dose 10 ml per plant (per treatment) on 1th, 8th and 15th day after transplanting; 4. Oxamyl (Vydate® 10L) at dose 1 ml plus *P. agglomerans* at dose 10 ml per plant (per treatment) on 8th and 15th day after transplanting; 5. Oxamyl (Vydate® 10L) at dose 1 ml plus *B. subtilis* at dose 10 ml per plant (per treatment) on 8th and 15th after transplanting; 6. Oxamyl (Vydate® 10 L) at dose 1 ml per plant (per treatment) on 1th, 8th and 15th day after transplanting.

The following observations were made: 1. During the cropping season - numbers of females of *M. javanica* (45th day after transplanting the eggplants); 2. At the end of cropping season (94th day after transplanting) - root gall index, numbers of eggs and J2 in the soil (g), and numbers of eggs and J2 in the roots (g). The soil samples on 45th day were taken by means of an auger (2 cm/d) at a distance 10 cm from the plant stem, upon which the roots were separated, washed, stained in acid fuchsine and the numbers of females were counted by direct examination of the roots using a stereomicroscope and determined per gram of fresh roots. At the end of cropping season, the nematodes were extracted from soil samples using a modified Baermann funnel technique (Southey, 1986). Eggs were extracted from roots samples according to hypochlorite procedure (Hussey and Barker, 1973). Root gall index of eggplants was assessed according to a 0 to 10 scale (Bridge and Page, 1980).

Statistical analysis

Obtained data were subjected to one way analysis of variance (ANOVA) and the treatment means were compared with the control plants, according to the Dunnet's test (P<0.05).

RESULTS

Effect of rhizobacteria on the penetration rate of *M. javanica* second stage juveniles

The experiments showed that both tested rhizobacteria influenced the penetration of J2 of *M. javanica* into the eggplant roots (Table 1, P < 0.05). Both, *P. agglomerans* and *B. subtilis* significantly reduced the number of penetrated J2 applied either as a root dipping or soil drench. *B. subtilis* significantly decreased the number of J2 in the roots when was applied as a seed treatment. Reduction of juveniles penetration following seed treatment, root dipping and soil drench ranged to 32.4, 32.0 and 44.6% for *P. agglomerans* and with 38.8, 27.9 and 66.8% for *B. subtilis* compared with the control treatments (Table 1, P < 0.05).

Both, *P. agglomerans* and *B. subtilis* slightly enhanced the eggplants growth. Statistically, differences in both shoot and root weight were not significant neither for *P. agglomerans* nor for *B. subtilis* when applied as a seed treatment, root dipping and soil drench (Table 2, P<0.05). Overall, the eggplants with *P. agglomerans* application showed a better performance in plant growth parameters compared with those treated with *B. subtilis*.

Greenhouse efficacy experiment in eggplant production system

At the mid-season (45th day) plants treated with the rhizobacteria alone or in combination with Oxamyl had significantly lower number of females present in the roots than the plants in the control plots (Table 3, P<0.05). The lowest number of *M. javanica* females was observed in the treatment *B. subtilis* plus Oxamyl (52). *Pantoea agglomerans* plus Oxamyl, as well as Oxamyl applied separately reduced the number of females (78 and 67, respectively) compared with the control (168). Both, *P. agglomerans* and *B. subtilis* affected the development of *M. javanica* J2 and the number of reproductive females was 128 and 111, respectively. At the end of the cropping season, the gall index varied from 5.2 for the plants in the control plots to 1.9 for the plants treated with Oxamyl - *B. subtilis* combination. Significantly fewer galls were also observed on the plant roots in the plots treated with *P. agglomerans* plus Oxamyl (3.0). *Bacillus subtilis*, as well as Oxamyl decreased the number of eggs and J2 in the soil and in the roots, but there was no statistical difference between the treatments. Further, there was no significant difference between *P. agglomerans* and the control in all three parameters of assessment - gall index, eggs and J2 in the soil and eggs and J2 in the plant roots (Table 3, P<0.05).

DISCUSSION

During the last ten years numerous scientific articles have acquainted with achievements of successful *Meloidogyne* control using rhizobacteria (Mendoza et al., 2008; Vetrivelkalai et al., 2010; Majzoob et al., 2012; Bonaterra et al., 2014). In general, our study has also

Table 1. Effect of the rhizobacteria *Bacillus subtilis* and *Pantoea aggromelans* on root penetration of *Meloidogyne javanica* second stage juveniles

Treatments	Seed treatment	Root dipping	Soil drench
P. agglomerans	438.7[a]	426.8[a]	388.1[a]
B. subtilis	397.2[b]	452.5[a]	322.4[a]
Control	649.1[a]	627.6[b]	701.01[b]

Means followed by different letters in the column differ by Dunnet's test ($P<0.05$).

Table 2. Effect of the rhizobacteria *B. subtilis* and *P. aggromelans* on root and shoot fresh weight of eggplants.

Treatments	Seed treatment		Root dipping		Soil drench	
	Fresh root weight (g)	Fresh shoot weight (g)	Fresh root weight (g)	Fresh shoot weight (g)	Fresh root weight (g)	Fresh shoot weight (g)
P. agglomerans	9.58[a]	13.81[a]	8.72[a]	12.91[a]	8.21[a]	12.17[a]
B. subtilis	8.22[a]	11.82[a]	8.83[a]	12.43[a]	8.04[a]	12.12[a]
Control	8.07[a]	12.01[a]	8.19[a]	12.18[a]	8.02[a]	11.57[a]

Means followed by different letters in the column differ by Dunnet's test ($P<0.05$).

Table 3. Effect of the rhizobacteria *B. subtilis* and *P. aggromelans* alone and in combination with Oxamyl on numbers of *M. javanica* females, root-gall index, numbers of J2 soil and root in greenhouse experiment.

Treatments	At 45^{-th} day after transplanting	At the end of cropping season		
	Females g^{-1} root	Gall index	Eggs and J2 g^{-1} root	Eggs and J2 g^{-1} soil
Control	168[a]	5.2[a]	9567[a]	256[a]
P. agglomerans	128[b]	4.9[a]	8994[a]	231[a]
B. subtilis	111[b]	4.0[b]	6982[b]	157[a]
Oxamyl + *P. agglomerans*	78[c]	3.0[c]	6548[b]	148[a]
Oxamyl + *B. subtilis*	52[d]	1.9[d]	3947[c]	103[c]
Oxamyl	67[cd]	3.9[b]	6787[b]	171[a]

Means followed by different letters in the column differ by Dunnet's test ($P<0.05$).

demonstrated the efficacy of the rhizobacteria as biological control agents of *M. javanica* on eggplants. In laboratory pot experiment, *P. agglomerans* and *B. subtilis* caused a reduction of penetration of J2 into the roots up to 44.6 and 66.8%, respectively, following soil drench application. In the same experiment reduction of juvenile penetration was also observed when the bacteria applied as a root dipping. However, the number of J2 in the eggplant roots at this treatment was higher than the number of J2 at the soil drench treatment. Application of *B. subtilis* as a seed treatment resulted in significantly lower number of juveniles in the root systems compared with the control and *P. agglomerans* treatment. Although, the fresh root and shoot weight of eggplants treated with *P. agglomerans* and B. subtilis were higher compared with the control the differences were not significant. Amellal et al. (1999) reported that *P. agglomerans* is a competent colonizers of the rhizosphere and therefore a promising candidate for biological control. Plant-beneficial effect of *P. agglomerans* was observed by Majzoob et al. (2012) and Bonaterra et al. (2014) on cucumber and tomato, both infested with *M. javanica*. Several *Bacillus* strains have been assessed for their potential as a biological control agent of *Meloidogyne* species. Mendoza et al. (2008) reported *in vitro* activity of a *Bacillus firmus* strain against eggs and J2 of *M. incognita*. Strains of *Bacillus megaterium*, *Bacillis pumilus* and *Bacillus mycoides* reduced the number of egg masses of *M. incognita* on tomato by 31, 30% and 39% respectively (Mekete et al., 2009). The results obtained in the current experiments indicate that the effects of rhizobacteria treatments were similar to those described above. Our results also support the finding of Munif et al. (2013), who reported that *P. agglomerans* reduced *M. incognita* J2 root penetration by 31% following soil drench application. In addition, the authors discussed that application of endophytic bacteria with root dipping and soil drench is more effective for suppressing the penetration of nematode juveniles compared with seed treatment application of (Munif et al., 2013).

According to Thies et al. (1992) biological control of root-knot nematodes usually has not been a stand-alone practice in control of these nematodes. Our results on the other hand, showed that *B. subtilis* can potentially reduce *M. javanica* population in a greenhouse up to the end of the cropping season. The suppressive effect was observed within 45 days after transplanting eggplants and continued through the end of the greenhouse experiment. In addition, the obtained data from this experiment indicate that the chemical nematicides such as carbamates are more effective at the beginning of cropping season, and their efficiency is higher in combinations with the tested bacteria. Furthermore, *P. agglomerans* applied separately does not provide long-lasting protection of plants. However, in the plots treated with *P. agglomerans* plus Oxamyl, final *M. javanica* population was significantly lower than in the control plots. Suppression of the *M. javanica* populations throughout the plant growth is probably due to the successful colonization of the plant rhizosphere and good multiplication rates of the *B. subtilis* and *P. agglomerans*. This is consistent with previous findings reporting successful control of root-knot nematodes using bacteria under greenhouse condition (Giannakou et al., 2004). These authors reported that *B. firmus* significantly reduced the root-knot index on cucumber plants in a greenhouse in Greece. Similarly, Majzoob et al. (2012) stated suppression of *M. javanica* reproduction levels on greenhouse cucumbers in Iran.

It is important to note that although the rhizobacteria reduced the gall index the effect was not uniform, and eggplants within individual plots showed certain variation in the gall index. Moreover, the heavily galled plants suffered from secondary infection by soil-borne fungi (data not presented). This might be the reason for a few dead plants observed at the end of cropping season. Hence, the application of bacteria and chemicals, whose efficacy is limited to nematodes, should be accompanied by additions of fungicides to prevent infestation by soil-borne fungi, such as *Fusarium* sp. and *Verticillium* sp.

Conclusion

The rhizobacterium *B. subtilis* showed promising results in reduction of *M. javanica* reproduction in eggplant and could be consider as a good non-chemical alternative for the control of root-knot nematodes. The superior performance of the *B. subtilis* in combination with an organophosphate nematicide (Oxamyl) in comparison with their separate application, suggests that this bacteria may be successfully included in an integrated scheme for the control of root-knot nematodes.

Conflict of Interests

The authors have not declared any conflict of interests.

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Rice development and water demand under drought stress imposed at distinct growth stages

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This study aimed to establish a comparison for theoretical water demand between rice plants grown under flooding and under different levels of water stress, imposed at distinct crop stages, in terms of plant morpho-physiology and phenology. The experiment was installed in a greenhouse, using complete randomized design and factorial scheme 3 × 4 + 1, with four replications. Factor "A" was defined as the growth stage when water stress was imposed on the treatments, these stages being (1) vegetative, (2) reproductive 1, and (3) reproductive 2; factor "B" was composed of four levels of water stress (0 to 200 kPa). The additional treatment consisted of a flooded check. Water was replenished back to saturation every time the threshold stress level was reached. There is damage to rice growth and development in water tensions greater than 30 kPa when applied between tillering start and anthesis. Main damage was observed as reduced rates of culm growth; leaf area tended to be maintained. Water luxury consumption by rice plants grown under flooding seems to be about 23% of the total demand, compared to the other irrigated treatments. The rice field should be irrigated back to saturation when soil water tension is between 10 kPa and 30 kPa. Overall, theoretical crop coefficient (K_c) for rice under sprinkler irrigation is about 20% lower than that observed for the flooded check.

Key words: Water consumption, planting system, *Oryza sativa*.

INTRODUCTION

Rice is a staple food for nearly half the world's population, being cultivated in 112 countries, with 90% of the world's production concentrated in Asia. In Brazil, about 3 million hectares are cultivated every year and rice is traditionally present in Brazilian meals, regardless of social class. The southern region of the country supplies approximately 65% of Brazilian rice (Gomes and Magalhães Jr., 2004). The demand for water in flooded rice cultivation is considerably higher than the water requirement of crops traditionally sprinkler irrigated, such as soybeans and corn. Physiologically, rice is a sub-aquatic plant adapted to a flooded environment (Correll and Correll, 1975), and may be grown without flooding if the water is managed properly. Early recommendations stipulated the need for

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up to 17,000 m^3 of water per hectare per cycle for flooded rice (Pérez, 1992), including both irrigation and rainfall. In the Brazilian state of Rio Grande do Sul, rice is predominantly grown under continuous flooding (Silva et al., 2015). To meet the water demand it is estimated that, with current technology, an average of 8,000 to 10,000 m^3 of water per hectare is necessary to supplement rainfall in an irrigation period of 80 to 100 days (SOSBAI, 2014). Almost 100% of this amount is supplied by pumping from rivers or ditches. This amount of water is very high when compared to other crops, and not every farmer is able to meet this estimated demand; there are losses in water capture, storage, pumping and transport. These losses are unique to each farm. In fact, real mean water demand for flooded rice may be much higher than that estimated by SOSBAI (2014).

Globally, several alternatives are being studied for improving water use efficiency in rice fields; among them, intermittent irrigation, furrow irrigation and center pivot (sprinkler irrigation) technologies have been emphasized. For these systems, reductions in both productivity and grain quality have often been reported; on the other hand, production costs also fall, which might improve net economic profitability. Research to date supports the evidence that each of the above-mentioned systems are better-suited to specific locations and management styles, and the proportion of water saved will depend greatly on local edaphoclimatic characteristics (Petrini et al., 2013; Londero, 2014). Sprinkler irrigation by pivots and linears has been, and continues to be, tested for rice cultivation, and there are claims for 50% water savings when rice grown under pivot irrigation is compared to continuous flooding (Parfitt et al., 2011). This seems to be the case mainly when the system is installed in uneven areas or in fields with significant slope, as well as where water is scarce. Supposing this economy is confirmed, farmers who grow rice under pivots would have a surplus of water which could be used either to increase rice acreage or to irrigate crops on additional fields.

In order to establish the real water savings by growing rice under sprinkler irrigation compared to flooded systems, there is need to characterize the water demanded for rice plants and the issues which could arise from water limitation in distinct stages of rice plant development. There is little information to date regarding crop coefficients to be used for managing irrigation of rice under pivots in high–yield conditions. These coefficients should be estimated under a controlled environment as a first step for estimating field crop coefficient values. Actual field-scale coefficients for rice under sprinkler irrigation would also have to consider the smaller run-off and percolation losses. These losses are most present in flooded fields, and the resulting water demanded for satisfying these losses should not be confused with crop demand. This study aimed to establish a comparison for theoretical water demand between rice plants grown under flooding and those grown under different levels of water stress, imposed at distinct stages of the crop growth cycle, in terms of plant morpho-physiology and phenology.

MATERIALS AND METHODS

The experiment was installed in a greenhouse at Embrapa Clima Temperado, Pelotas-RS, Brazil, during the traditional rice growing season. A complete randomized design was used with plots arranged in a factorial scheme, 3 × 4 + 1, with four replications. The rice variety was BRS-Querencia, with a medium duration growth cycle (Embrapa, 2005). Factor “A” was comprised of the growth stage when water stress was imposed on the treatments, being (1) vegetative (tillering start through panicle differentiation), (2) reproductive 1 (panicle differentiation through anthesis), and (3) reproductive 2 (anthesis through ripening start). Factor “B” was comprised of the four levels of water stress imposed on the plants. The additional treatment consisted of a constantly flooded treatment. Although the reproductive stage in rice starts at panicle initiation (SOSBAI, 2014), this stage is very difficult to identify; as a result, farmers generally use panicle differentiation as the start of the reproductive stage for nutrient management. As panicle initiation (PI) and panicle differentiation (PD) are spaced only about 4 days (Carli et al., 2016), we decided to use panicle differentiation in the present study. From emergence to the beginning of tillering, all plots were maintained with soil water tension under 10 kPa, including plots which would be flooded from tillering onward. Every time the treatment reached the threshold level of water deficit, it was irrigated back to saturation. Treatments which were not at the developmental stage when the stress was applied were maintained under 10 kPa. Treatments are listed in Table 1. Experimental units consisted of black plastic pots, each with capacity of 12 L, filled with 10 kg of previously corrected and fertilized soil. The soil used at the experiment was collected in agriculture-free natural areas near rice fields at Terras Baixas Experimental Station, Capão do Leão, RS, Brazil. Soil was fertilized with N-P-K and corrected for pH 6.0 with ground limestone. In rice fields, pH is usually not corrected because the water layer is enough to correct the pH after flooding is established, but as most plots of the trial were not going to be submitted to flooding, we decided to correct soil pH in order to guarantee equal soil pH conditions for all plots.

Water stress was monitored by using sets of Watermark electro-tensiometers (Irrometer Co.), with a single sensor installed in each experimental unit (pot), at depth of 10 cm (from soil surface to the center of the sensor), at the radial center of the pot. All sensors were connected by wire to a nearby Watermark data logger, which was programmed to record water tension in kPa at one hour intervals. Sensor readings were automatically corrected by the datalogger as a function of the mean temperature registered inside the plots, and for that, two Watermark temperature sensors were installed in each block of the experiment. Temperature data from these sensors were used by the datalogger to correct soil water tension readings of the corresponding plots. Temperature sensors were also installed at a depth of 10 cm. Soil water tension for all plots was read and recorded manually, twice a day (09:00 am and 04:00 pm), seven days a week. When it reached the threshold level, the water needed to adjust soil water tension back to saturation was added after reading. The amount of water to be added to each plot was determined by using a soil moisture retention curve, which relates water tension (kPa) with water content (%). The water tension curve was determined especially for the experiment, after the soil was corrected and fertilized, so no error in the curve would be attributed to differential soil density or structure. The water retention curve for the soil used in the experiment is supplied in Figure 1.

The daily maximum and minimum temperature and air humidity in

Table 1. Treatments studied at the greenhouse trial at Embrapa.

Treatment	Description / Details
Flooded	Flooded with 7cm of water at tillering start and kept flooded until ripening start. At ripening start water was not removed, but we just stopped re-filling back to 7cm of water layer. Water remained for some days before these plots were dry
water stress (kPa)	**"V" – under treatment between tillering start and panicle differentiation**
10	Irrigated back to the saturation every time water tension reached 10 kPa
30	Irrigated back to the saturation every time water tension reached 30 kPa
100	Irrigated back to the saturation every time water tension reached 100 kPa
200	Irrigated back to the saturation every time water tension reached 200 kPa
	"R1" – under treatment between panicle differentiation and anthesis
10	Irrigated back to the saturation every time water tension reached 10 kPa
30	Irrigated back to the saturation every time water tension reached 30 kPa
60	Irrigated back to the saturation every time water tension reached 60 kPa
130	Irrigated back to the saturation every time water tension reached 130 kPa
	"R2" – under treatment between anthesis and ripening start
10	Irrigated back to the saturation every time water tension reached 10 kPa
30	Irrigated back to the saturation every time water tension reached 30 kPa
60	Irrigated back to the saturation every time water tension reached 60 kPa
130	Irrigated back to the saturation every time water tension reached 130 kPa

In fact, treatments submitted to 10 kPa (V, R1 or R2) were under this water tension during all the cycle, because all treatments were kept under between saturation and 10 kPa, when out of the developmental stage they were supposed to be under treatment.

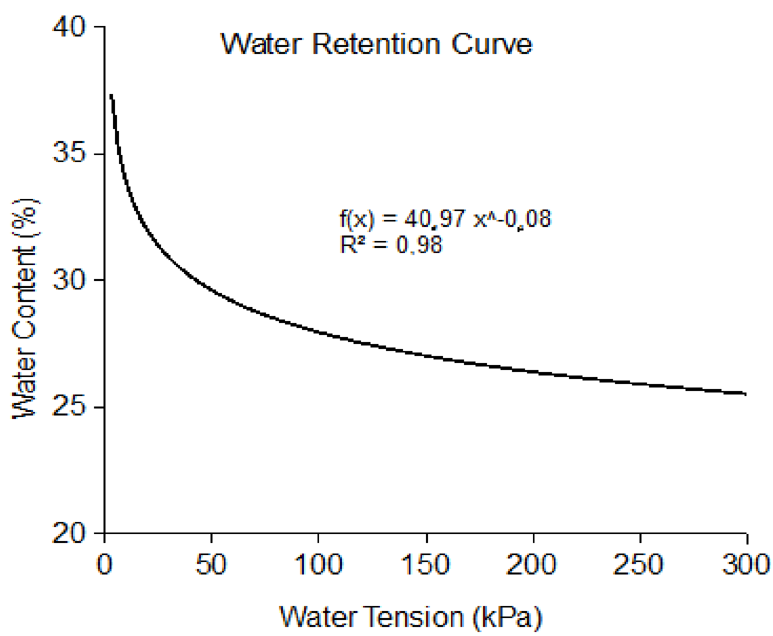

Figure 1. Water retention curve for the soil used at the experiment under controlled environment. Embrapa Clima Temperado, Pelotas-RS, Brazil, 2016.

the greenhouse during the trial are shown in Figure 2a and b, respectively. The evapotranspiration (ET_0) was calculated as an auxiliary method to the tensiometers to help estimate when the plots would reach the threshold water stress level. ET_O was calculated using the Hargreaves equation (Figure 2c), based on daily maximum and minimum temperatures (Figure 2a). At the end of the experiment, the volume of water demanded by each treatment (from rice planting to harvest) was obtained and compared to the additional treatment (flooded) as a percentage.

The impact of the distinct water restriction levels on rice was studied by production of dry mass of culms and leaves as well as total shoot dry mass (excluding the panicle). Based on these data, a

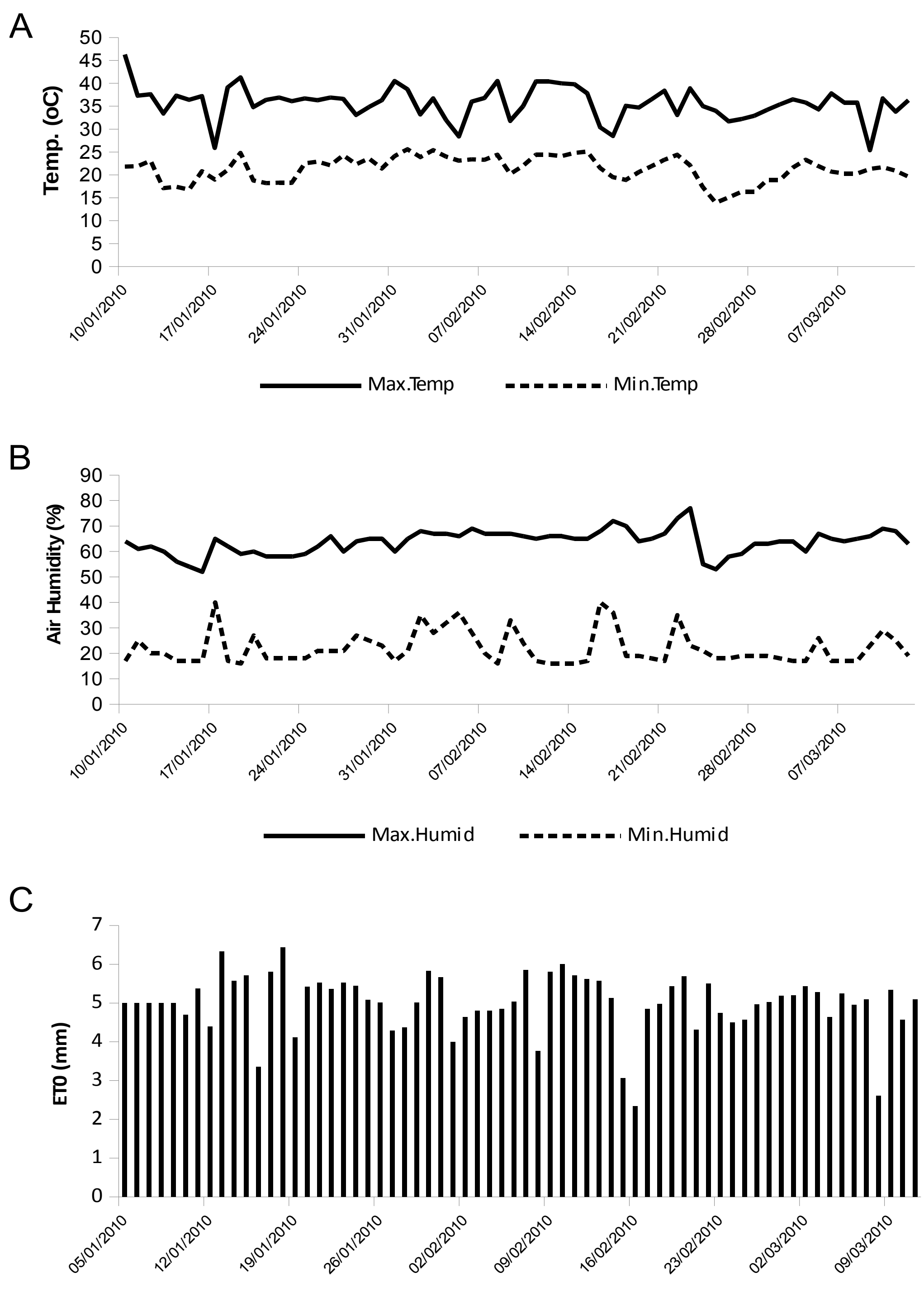

Figure 2. (A) Daily maximum and minimum temperatures collected inside the greenhouse for ETo estimation; (B) maximum and minimum air humidity into the greenhouse throughout the experimental period; (C) Eto estimation by the Hargreaves formula based on maximum and minimum daily temperatures. Embrapa Clima Temperado, Pelotas-RS, Brazil, 2016.

brief plant growth analysis was done by calculating the Specific Leaf Area (SLA), Leaf Weight Ratio (LWR) and Leaf Area Ratio (LAR), according to Gardner et al. (1985) and Parmar and Chanda (2002), using their instantaneous formulas. The number of days from emergence to anthesis (for treatments grouped "V" or "R1") in the rice growth cycle were also determined, as function of water tension. For "R2", stress was imposed at anthesis.

The crop coefficient (Kc) is a property of plants used in predicting water demand by evapotranspiration (Gardner et al., 1985), and as consequence the water demand. This value was also determined weekly for all treatments. The values of Kc were compared to the flooded treatment as a percentage. Data were analyzed into the “R” statistical environment (R Core Team, 2016). Before any analysis, data sets were verified for normality and variance homogeneity by the tests of Shapiro-Wilk and Bartlett, respectively, being transformed by $\sqrt{(x+1)}$ when needed. These were then submitted for analysis of variance by the F-test at 5% probability. Data were explored according to significances of the interactions, being presented in graphical form. Data graphically presented are original; transformed data were used only for the parametric tests.

RESULTS AND DISCUSSION

The dry mass of rice plants (Figure 3A) was affected when the water stress was applied at the “V” (tillering start through panicle differentiation) or at the “R1” (panicle differentiation through ripening start) growth stages. At these treatments leaf dry mass was equivalent to that of the flooded check (approximately 4 g plant^{-1}), but culm dry mass was reduced compared to plants under flooding (12 g plant^{-1} under flooding and approximately 8 g plant^{-1} for “V” and “R1” treatments) (Figure 3A).

These values are reasonable, according to the literature, where the shoot of a single rice plant under field conditions averages about 9 g plant^{-1} (Paranhos et al., 1995), or about 1200 g m^{-2} (Mauad et al., 2011). Under controlled environment, however, plants reached about 18 g plant^{-1} (Figure 3a) due to the lower intraspecific competition (lower plant density) and lower levels of other stresses besides those imposed by treatments (Radosevich et al., 2007).

For treatments grouped under “R2” (water stress between anthesis and ripening start), there was no difference in dry mass compared to the flooded check (Figure 3A). Plants in this group, however, weighed more than the ones reported at “V” and “R1”; this is expected because rice plants do not stop growing at panicle differentiation but at heading (panicle emission) (Moldenhauer et al., 2013), which occurs some days before anthesis (flowering). The Specific Leaf Area (SLA) varied greatly among treatments (Figure 3B), averaging 0.06 m^2 g^{-1} for most treatments. This is comparable to Nagai and Makino (2009), who reported about 0.03 m^2 g^{-1} for Japanese rice varieties. Water tensions of 100 and 200 kPa applied at the “V” stage resulted in SLA of about 0.2 m^2 g^{-1}, most probably as consequence of the severe effect of drought on the growth of rice culms when rice is at the vegetative stage (Figure 3B). Rice did not actually increase leaf area under severe drought stress, but reduced culm growth, while trying to maintain minimum increase in the leaf area, which resulted in disproportionate SLA. Lonbani and Arzani (2011) reported that triticale and wheat mostly tended to keep or increase their leaf area when under moderate levels of water stress; a similar behavior could be present in rice. The leaf weight (LWR) and area (LAR) ratios (Figure 3B) also seem reasonable, according to Nagai and Makino (2009), who found values of about 0.30 and 0.010, respectively, for Japanese rice varieties. In this study, values averaged 0.28 and 0.007, respectively for LWR and LAR. In general terms, SLA and LAR increased when severe water stress was imposed at the “V” stage (Figure 3B) while LWR was little affected.

According to the damage to rice growth as shown in Figure 3, the rice reproductive cycle was lengthened when water stress was imposed at “V” or “R1” stages (Figure 4), with no obvious effect when stress was imposed in “R2” since rice plants had already stopped growth before treatment imposition. Drought effect was most effective in lengthening rice cycle when imposed at the “V” stage, where 46 days were needed to reach anthesis at 10 kPa compared to 55 days and 64 days, respectively, for tensions of 100 and 200 kPa (Figure 4). When drought was imposed in “R1”, days to anthesis were 50 and 54, respectively, for 60 and 130 kPa (Figure 4). When water stress was imposed in “V” or “R1”, there was no difference in days to anthesis among the flooded check and treatments with water tensions up to 60 kPa (Figure 4). This conclusion is based on the confidence interval (data not shown), according to the observed data for dry mass (Figure 3A) and growth analysis (Figure 3B). The main effect of water stress on any reproductive stage is believed to be a reduction in grain yield as a consequence of the reduction in fertile panicles and filled grain percentage (Sarvestani et al., 2008), which was not the focus of the present study.

Some consequences may arise from the delay in rice cycle and anthesis timing in the presence of stress. As an example, in high latitude areas where rice is planted, a delay in crop cycle may subject the field to environmental stresses such as cool weather in anthesis, lack of rains at the proper time and problems in harvest scheduling, similar to those observed for delayed planting (Gomes and Magalhães Jr., 2004). In addition, delays in rice growth stages could result in issues with remobilization and distribution characteristics of photoassimilates between plant organs, as well as reduced photosynthesis rates at the critical stage of grain filling (Liu et al., 2015).The water used by evapotranspiration (Figure 5) declined as water stress increased. While 839 mm (equal to 8,390 m^3 ha^{-1}) were consumed throughout the cycle for the flooded check treatment, only 655, 618 and 644 mm were demanded when rice was grown under 10 kPa of water tension (Figure 5A), which represents an average of 23% theoretical potential water savings by simply changing from flooding to sprinkler irrigation in rice (Figure 5B).

These savings are theoretical since the plots used at the trial are impermeable and free from water losses by runoff or percolation; thus, under field conditions, water savings by growing rice under sprinkler irrigation, compared to the traditional flooded system, would likely be more than the recorded 23%. In addition, it could be said that the “luxury” water consumption by rice when

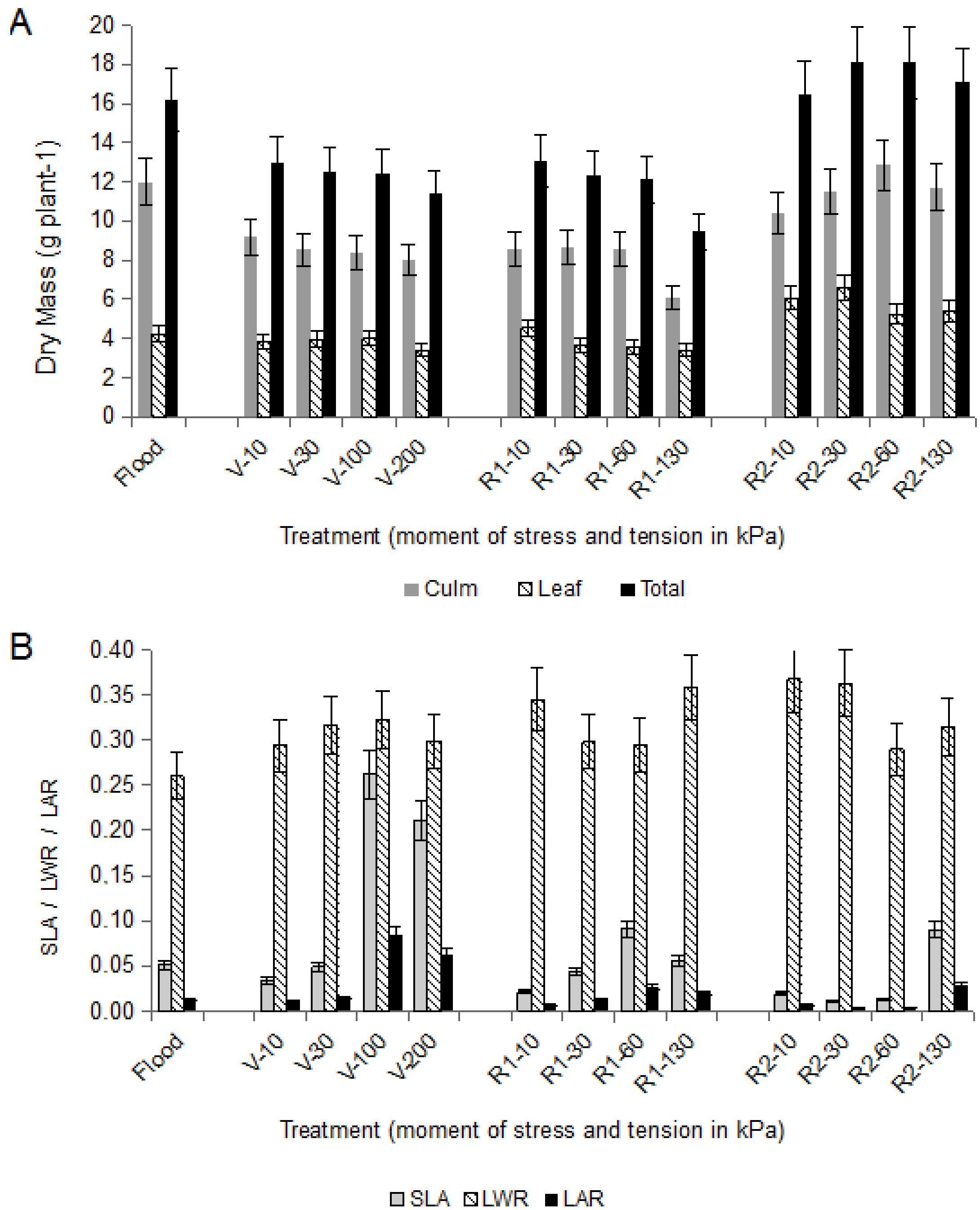

Figure 3. (A) Dry mass of culms, leaf and total (shoot), and (B) growth parameters for rice plants of the variety BRS-Querencia grown under increasing water stress levels applied at distinct developmental stages. V = vegetative stage (from tillering start to panicle differentiation); R1 = reproductive 1 (from panicle differentiation to anthesis); R2 = reproductive 2 (from anthesis to ripening start). Embrapa Clima Temperado, Pelotas-RS, Brazil, 2016.

grown under flooding (compared to sprinkler irrigation systems) equals about 23%. Bacon (2009) reported that rice is the "king of the plants" regarding luxury water consumption; the author remarks that this crop demands about half the available water resources. This shows what a great worldwide impact on water savings could be achieved by improving rice water use efficiency. For the "V" stage, there was no significant reduction in water consumption from V-10 kPa to V-30 kPa, but the demand fell for treatments under 100 and 200 kPa (Figure 5). For stress imposed in "R1", tensions up to 130 kPa did not reflect in lower water demand throughout the cycle

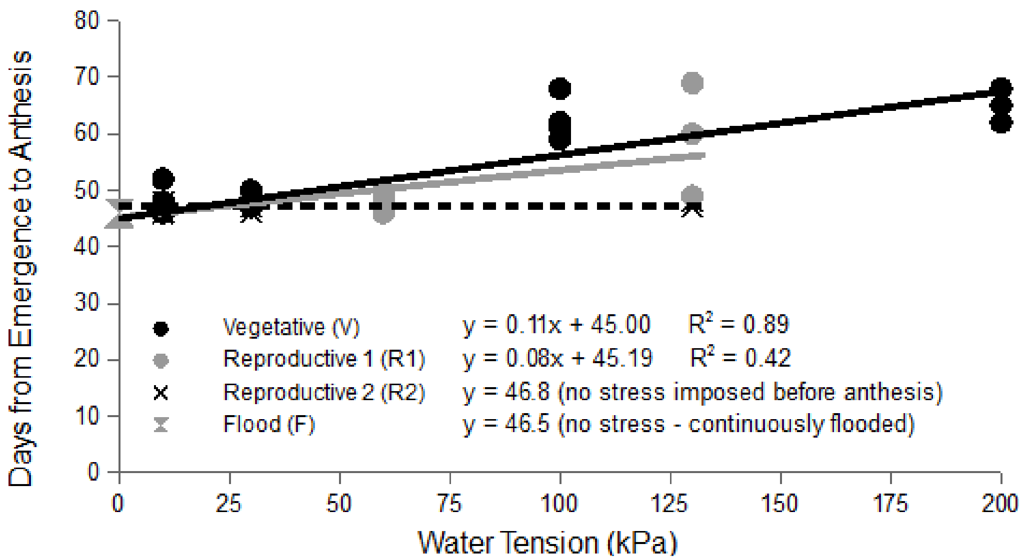

Figure 4. Days from rice emergence to anthesis for variety BRS-Querencia grown under increasing water stress levels applied at distinct developmental stages. V = from tillering start to panicle differentiation; R1 = from panicle differentiation to anthesis; R2 = from anthesis to ripening start. Embrapa Clima Temperado, Pelotas-RS, Brazil, 2016.

compared to R1-10 kPa. However, injury to rice was observed for R1-60 and R1-130 kPa (Figures 3 and 4). For treatments applied in “R2”, there was no significant reduction in water demand for any treatment compared to R2-10 kPa.

According to the data presented in Figures 3 and 4, water tension up to 30 kPa did not cause significant damage to rice growth. Considering this threshold level for water tension, and considering also that water stress at “R1” could result in reduced number of grains per panicle (Sarvestani et al., 2008), when aiming for maximum yield, it seems to be prudent to irrigate rice every time the soil water tension is between 10 and 30 kPa. The 30 kPa value seems to be the limit for avoiding water-related problems in rice growth. In fact, Silva et al. (2015) concluded that there was no damage to rice growth or grain yield when soil water tension was kept below 20 kPa; they reported problems with water tensions of 40 kPa. Our results support the idea that soil water tensions up to 25 or 30 kPa would not damage rice under sprinkler irrigation, but there was no significant water saving when treatments were irrigated back to saturation from 30 kPa (compared to 10 kPa, as seen in Figure 5B). As a practical application, a farmer, considering irrigation capacity, labor and hardware available, could choose to irrigate every time soil water tension reaches 25 - 30 kPa. Irrigating back to saturation at 10 kPa does not result in water savings compared to irrigation applied at 30 kPa, and could demand additional labor or equipment resources with higher flow rates to meet demand.

The resulting crop coefficients (Kc) for each treatment, estimated on a weekly basis, are shown in Figure 6, presented both in original form as well as a percentage of the K_C observed for the flooded treatment. In general terms, the higher values of Kc were observed for the flooded treatment, whose values often stayed between 3.0 and 3.3 (Figure 6). In order to compare Kc between treatments, differences of more than two standard deviations (2SD) were established as the threshold level for differentiation, according to Cumming et al. (2007) and Peternelli and Mello (2011).

Considering the above-determined criterion for differentiation, there was no significant difference in Kc between flooding and 10 or 30 kPa, when these treatments were imposed at the vegetative (“V”) or at the reproductive 1 (“R1”) stages (Figure 6). In these situations, the lower Kc for the higher two water tensions in each stage resulted in serious damage for rice morpho-physiology (Figure 3) and phenology (Figure 4). The lower values of Kc observed for 60 and 130 kPa applied to “R2”, would probably result in little to no crop grain yield (Sarvestani et al., 2008).In general terms, the comparison between sprinkler-irrigated and flooded treatments showed that for the stress level of 10 kPa applied to “V”, “R1” or “R2”, the Kc for irrigated treatments averaged about 80% of that observed for the flooded check in the same week (Figure 6). The water tension of 30 kPa presented similar behavior to the observed for 10 kPa, but irrigating at 30 kPa could be an issue if labor is limited, so it is wise to irrigate rice back to saturation earlier. This reduction of 20% in Kc correlates to the 23% average reduction in water demand when the tension of 10 kPa was compared to flooding (Figure 3B). There is evidence that average water consumption by a farmer's flooded rice in Southern Brazil, estimated by SOSBAI

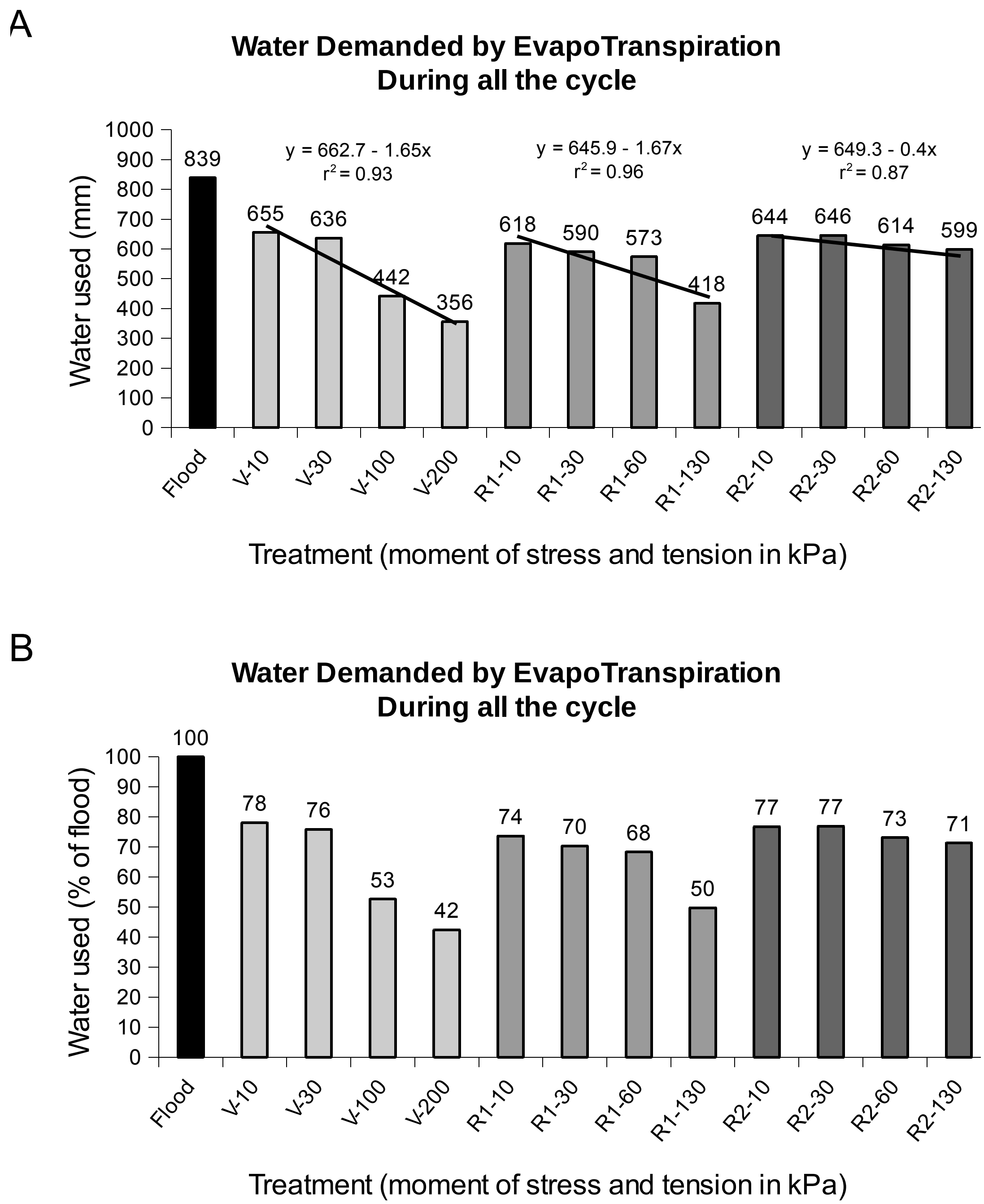

Figure 5. Water demanded by evapotranspiration in mm (A) and percent of the observed for the flooded check (B) for rice plants of the variety BRS-Querencia grown under increasing water stress levels applied at distinct developmental stages. V = vegetative stage (from tillering start to panicle differentiation); R1 = reproductive 1 (from panicle differentiation to anthesis); R2 = reproductive 2 (from anthesis to ripening start). Embrapa Clima Temperado, Pelotas-RS, Brazil, 2016.

(2014) as being between 8,000 and 10,000 m^3 ha^{-1}, may be a little underestimated for real field conditions. There is need to measure real consumption, measuring pumping and evapotranspiration. Our results also supply evidence that the claimed 50% water savings by growing rice under sprinkler irrigation compared to continuous flooding (Parfitt et al., 2011) is feasible and may be achievable under field conditions. Further studies will aim to determine field-scale water losses by runoff and percolation in field trials, as a way to understand the nature of the additional 27% savings when rice is grown under sprinkler irrigation. This represents the difference

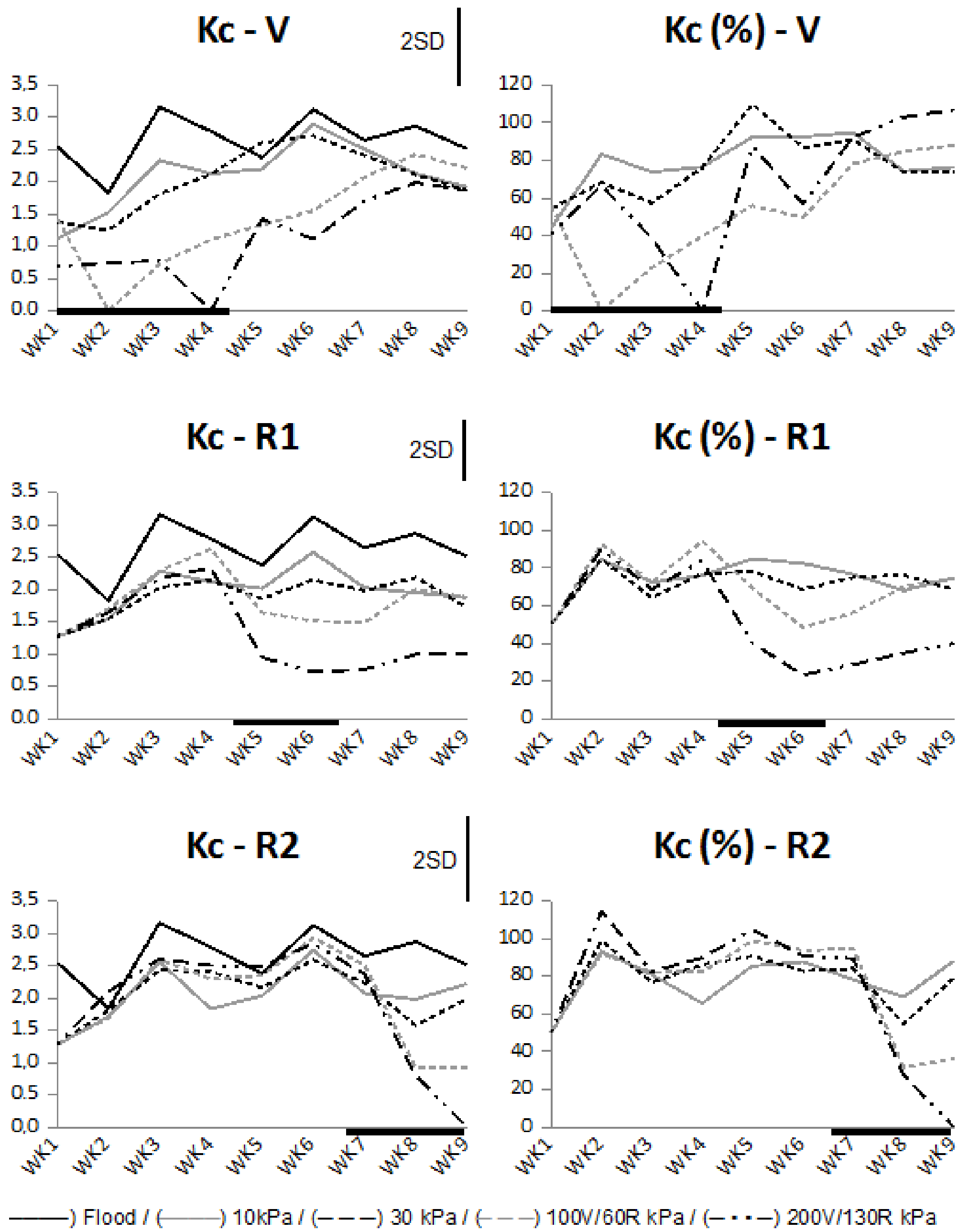

Figure 6. Weekly crop coefficients (Kc's) in absolute values (left) and percentage of the Kc observed for flooded treatment in the same period (right) for the greenhouse trial with the variety BRS-Querencia, estimated by dividing the amount of water added to each plot in the week by the ETo calculated for the same period. Thick line section (——) at the X-axis represents the period when the stress levels were applied to the group of treatments. V = vegetative stage (from tillering start to panicle differentiation); R1 = reproductive 1 (from panicle differentiation to anthesis); R2 = reproductive 2 (from anthesis to ripening start). Embrapa Clima Temperado, Pelotas-RS, Brazil, 2016.

between our results and those reported by Parfitt et al. (2011).

Conclusions

1. There is damage to rice plant growth and development in soil water tensions beyond 30 kPa from tillering start to anthesis. Main damage was observed as reduced rates of culm growth; leaf area tended to be maintained;

2. For the period between anthesis and ripening, no damage to rice growth was observed since rice plants had already naturally stopped growth. Serious damages for yields, however, are frequently reported in the

literature;
3. Water luxury consumption by rice plants grown under flooding seems to be about 23% of the total demand, compared to the other irrigated treatments;
4. When using sprinkler irrigation, rice should be irrigated back to saturation when soil water tension is between 10 and 30 kPa;
5. Overall, theoretical crop coefficients for rice under sprinkler irrigation are about 20% lower than that observed for the flooded check;

Conflict of Interests

The authors have not declared any conflict of interests.

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Full Length Research Paper

Evaluation of the gross and net calorific value of residues of wood pine and araucaria from reforestation

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The objective of this study was to assess the energy value of waste timber in the form of sawdust. Two types of wood: Araucaria (*Araucaria angustifolia*) and Pinus were evaluated with no defined species (*Pinus* sp). The sawdust was collected from a timber that receives wood from reforestation of these species in Southwestern Paraná, Brazil. The material collected was evaluated with a calorimeter bomb to determine the gross and net calorific value. The main results obtained led to the conclusion that the sawdust of *A. angustifolia* showed gross calorific value of 17.32 MJ.kg^{-1} and net of 17.00 MJ.Kg^{-1}, respectively, and *Pinus* sp. gross calorific value of 17.23 and net of 16.91 MJ.Kg^{-1}, respectively.

Key words: Wood energy, conifer of reforestation, gross calorific value.

INTRODUCTION

Forest biomass is a low cost and abundant energy source (Almeida, 2010). When compared with the other non-renewable sources, it has storage advantage, because it can be stored for later use during periods when it becomes necessary (Fowler, 2009).

Used for energy production, biomass can be classified into: Primary- from the forest or agriculture cultivated with energy purpose; Secondary- resulting from primary biomass, including agricultural, forestry and byproducts residues (Carneiro, 2012).

Forest residues are those tree parts such as stems, bark, stumps, leaves which are damaged and unmarketable in the timber manufacturing industry (Karaj et al., 2010). Residues from agriculture and silviculture (including timber processing) apart from being a sustainable source of alternative energy for rural development, can also serve as future supply of bioenergy which do not direct or indirectly have negative impacts on the environment (Scarlat, 2011). However, on the feasibility of projects involving biomass, one must consider the availability of these resources at regional and local levels, in addition to identification and

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evaluation of the energetic potential of different forest species, a fact that is already being regarded in developed regions around the world, with the aim of replacing fossil fuels (López-Rodriguez, 2009).

The term biomass refers to all organic material from plant species that capture and store solar energy, producing photosynthesis. Biomass energy, or bioenergy, is the conversion of biomass into useful forms of energy such as heat, electricity and liquid fuels (Akpinar et al., 2008).

Forest biomass, mainly in the form of firewood, is currently regarded as essential, particularly in developing countries. In India, 70% of energy consumption for cooking food comes from this biomass, according to the Ministry of New and Renewable Energy of India - MNRE (2009) and Abbasi and Abbasi (2010). In rural areas of Turkey, firewood is the fifth largest energy source, and its fuel consumption average amounts to 0.75 m^3 man^{-1} $year^{-1}$ (Akpinar et al., 2008). According to the same author, there is a shortage of this input for domestic use as a result of indiscriminate deforestation, slow forest regeneration in the country and increasing population pressure. In Brazil, this source along with other traditional forms of energy, totals 12.5% of the total need, despite being among the countries with more advanced programs, especially when it comes to modern biomass (Lora et al., 2009).

The importance of the use of residual biomass is due to several factors, such as prevention of forest fire, due to the removal of this biomass from the plots, preventing damage to the local economy. It also contributes to the development of bioenergy crops and provides jobs and income in rural areas (López-Rodriguez, 2009).

Wood residues from sawmills can be used for power generation. Thus, the raw material from these locations, such as tree bark, slabs, sawdusts can be transformed into electricity through combustion (Demirbas et al., 2009).

Pérez et al. (2008) evaluated forest biomass residues from Spain, characterizing them from the energetic point of view. They found that the leaves were the part of the tree with biggest calorific inferior value and among the different species, *Eucalyptus* spp. residues showed higher values of about 65,000 MJ ha^{-1} $year^{-1}$.

Comparing the residues of *Eucalyptus globulus* with *Eucalyptus nitens* in young and adult phases of the species during a year, Pérez et al. (2006) found that *E. nitens* has a higher calorific value during adulthood for all residues except seeds, due to higher concentration of volatile components and essential oil. The author also analyzed that waste collected during the autumn season showed higher calorific value for both species, due to lower moisture samples at harvest. In comparing the residual samples, the bark is the part that has smallest calorific value.

The calorific value of a material is expressed by the content of energy that is released when the material is burned in air. Therefore, the heat generated during combustion of forest species or different timber residues may vary depending on their physical, chemical and anatomical possessions (Almeida, 2010). This phenomenon is divided into two: gross and net calorific value.

According to Kollmann et al. (1968), the net calorific value can be obtained indirectly by the following equation:

$$NCV = GCV - (600 \times 9.h)/100$$

Where: NCV (net calorific value) (Kcal/kg); GCV (gross calorific value (Kcal/Kg); H = hydrogen content (%).

According to the chemical composition of the elementary, wood can assume hydrogen content of 6% (Silva, 2001).

The objective of this study was to compare the energy values of sawdust of *Araucaria angustifolia* and *Pinus* sp., by determining the gross and net calorific power, for use as an environment friendly energy source.

MATERIALS AND METHODS

Localization of the experiment

The experiment was conducted in the soil laboratories of the State University of Paraná West, in Cascavel City, Paraná. The sawdust samples were acquired from Biasin Timber in Realeza City, Paraná, located at approximately 528 km from the capital Curitiba. The timber is used to manufacture doors and windows. The company possesses productivity ranging between 54 and 55 m^3 of sawn timber per day. The main forest species used in this process are *Eucalyptus* sp. *Pinus* sp. and *Araucaria angustifolia* from reforestation.

For this work, the wood residues used were the *Pinus* sp. and *A. angustifolia* from commercial plantations. The samples were available without mixtures, under the same conditions they were in after processing, and in this condition, can be used as fuel. They remained stored in the laboratory until the day of the tests.

Collection of residues of biomass

The residue samples were collected randomly from the timber industry, the total amount of waste was produced in the processing of woods, collecting approximately 1 kg of each material. The waste used in the experiments were characterized as that of sawdust of *Araucaria angustifolia* and sawdust of *Pinus* sp. (Figure 1), resulting from the processing of the planer molding.

Characterization of materials

The residues obtained in the timber were sent to the Soil Labs of the State University of Paraná West, where they were given the calorific value of the residues by bomb calorimetry. Four replications were made for each sample biomass.

Determination of the calorific value

The determination of gross calorific value was done according to

Figure 1. Shavings of wood used in the experiment: *A. angustifolia* (a) and *Pinus* sp. (b).

Figure 2. Isothermal bomb calorimetry used.

ABNT/NBR 8633 (1984) (charcoal/determination of calorific value).

In this procedure, the samples which were previously dried *in natura* were placed in a calorimeter bomb isothermal E2K model (Figure 2), for analysis of the gross calorific value (GCV) to be released by the sample. For each sample, four repetitions were made. The transformation of the values for the GCV to net calorific value (NCV) was performed using the equation Kollmann et al. (1968), already mentioned, with the percentage of hydrogen present in the material as 6%.

Data analysis

To understand the range of values obtained in the experiment, spreadsheets and graphs were used with Broffice calc for the purpose of evaluating the contrast and comparison of mean values for the energy aspects and analysis of immediate shavings of *A. angustifolia* and *Pinus* sp.

RESULTS AND DISCUSSION

Gross calorific value (GCV)

The average values for the higher calorific value of 17.32 were MJ.Kg^{-1} for *A. angustifolia* and 17.23 MJ.Kg^{-1} for *Pinus* sp. mean values from conifers, but which nevertheless exhibit discrepancy observed in the ranges of values between one species and another (Figure 3).

Net calorific value (NCV)

The net calorific value found by indirect method was 17.00 MJ.Kg^{-1} for *A. angustifolia* and 16.91 MJ.Kg^{-1} for *Pinus* sp. (Figure 4).

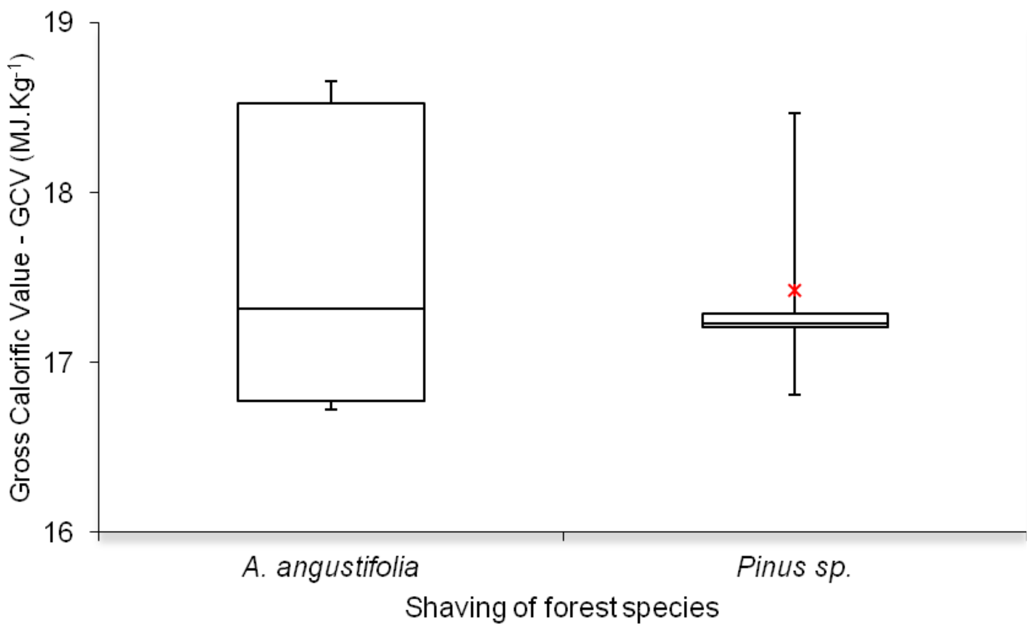

Figure 3. Gross calorific value (GCV) shavings of *A. angustifolia* and *Pinus* sp.

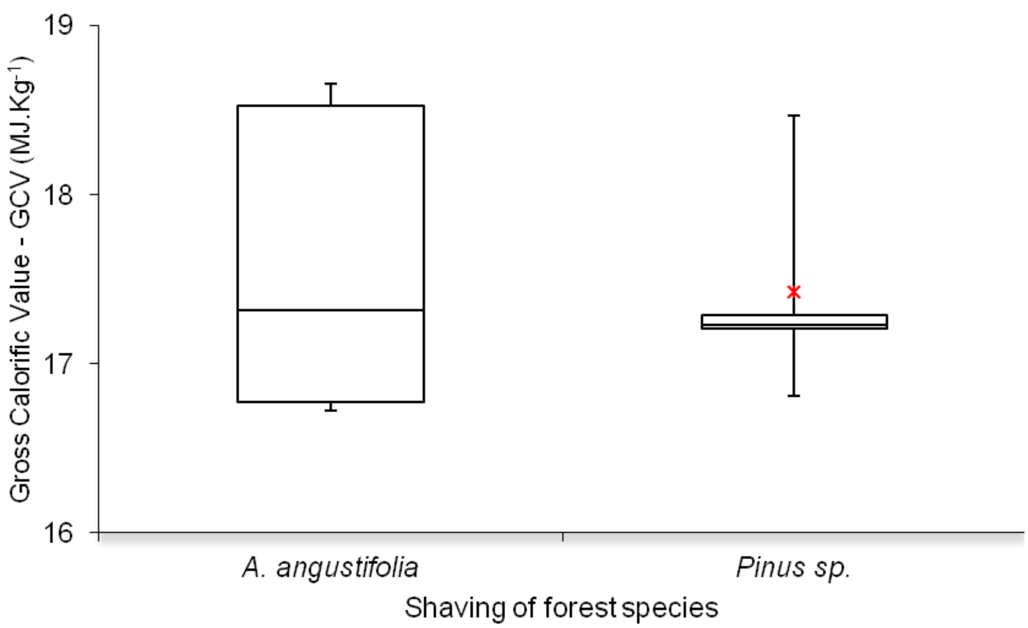

Figure 4. Net calorific value shavings of *A. angustifolia* and *Pinus* sp.

The GCV indicates the amount of energy released during the transfer of heat related process, that is, the higher the GCV, the more the efficiency (Vieira, 2012).

When comparing the results with residues from other species, such as shavings of *Cedrelinga catenaeformis*, which has a gross calorific value of 20.63 MJ.Kg^{-1} (Vale et al, 2007), values similar to those found by Quirino et al. (2004) 20.63 MJ.Kg^{-1} and below those found by Gabardo et al. (2011) for the same conifers, GCV of 27.99 MJ.Kg^{-1} in Araucaria and 32.05 MJ.Kg^{-1} to Pinus was obtained.

Mattos et al. (2006) featured another timber residue, sawdust *A. angustifolia* from commercial plantations with 38 years of age. The residue showed a calorific value of 46.70 MJ.Kg^{-1}, also higher than that found by other authors.

The values found for the NCV from the resulting value of the gross calorific value, discount the energy used to evaporate the hydrogen in fuel formation, in the form of water (Nascimento, 2006). Thus, Cordeiro (2011) evaluated the potential of bagasse energy malt from breweries in Pernambuco and obtained NCV ranging from 23.32 to 47.01 MJ.Kg^{-1}, an amount that increased with decrease in moisture content. Smaller values were described by Brand et al. (2004), analyzing residues of *Eucalyptus* spp. newly produced ranging from 15 to 25 MJ.Kg^{-1}.

Conclusion

From the results obtained in the experiment performed with the shavings of *A*. *angustiflolia* and shavings of *Pinus* sp., it can be concluded that the energy potential of shavings of *A. angustifolia* was higher than that of *Pinus* sp, while the values shown for GCV and NVC from wood shavings of *A. angustifolia* were 17.32 and 17, 00 MJ.kg^{-1}, respectively, while for the residue of shavings of *Pinus* sp., the GCV and NVC were 17.23 and 16.91 MJ.kg^{-1}, respectively. The residues of both species are given for energy purposes.

Conflict of Interests

The authors have not declared any conflict of interests.

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Multiple uses of forest resources in small and medium farms in the tropics: Economic and social contributions

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In complex systems, small anthropogenic changes of the initial conditions could lead to profound changes in the entire system. In this sense, the present literature review has surveyed several studies related to the multiple uses of forest resources and sustainability in small and medium-sized farms in the tropics. In 1985, Food and Agriculture Organization of the United Nations (FAO) published a work addressing multiple uses of forests in the tropics. Since then, despite the technological advances, multiple practices in forest management have not expanded as expected. The Forest Principles from 1992 emphasizes that forests should be managed to meet social, economic, ecological, cultural and spiritual needs of present and future generations. In many tropical countries, multiple use management of forest products and services has traditionally been neglected or it is not well known by policy makers and farmers. Laws are usually written with narrow objectives and tend to decrease social inclusion because of the limited cross-sector dialogue. In spite of these issues, several success stories are reported around the world.

Key words: Forestry enterprises, natural resources management, sustainable use of forest resources, land use, multiple use.

INTRODUCTION

Society and the global economy are dependent and closely linked to forests. Data from the Food and Agriculture Organization of United Nations (FAO, 2015) show that more than 1 billion people depend on forests for their livelihood and forest ecosystems play a critical and essential role in climate stabilization and consequent improvement of quality of life, protection of water sources, food supply, timber and medicinal products, while maintaining much of the world's biodiversity. However, deforestation has led to damages on water sources and silting of rivers around the world.

Climate change and increased variations in temperature might have widespread economic, social and environmental repercussions. Addressing these challenges requires changes and adjustments in forest management strategies, either in native or planted

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forests, aiming to adapt to climate change and, thereby, mitigate its effects (FAO, 2010).

Since the forest sector needs to keep up with development, it is necessary to adapt. This involves changes in management practices, aiming to reduce forest vulnerability to interventions, which will reduce impact on livelihoods communities that depend on forest resources. Although, deforestation rates are declining in some regions, several forest ecosystems are still under threat worldwide. In Brazil, they are concentrated in Amazon, especially in the States that make up the Brazilian Legal Amazon (Amazônia Legal), that is, Mato Grosso, Amazonas, Rondônia and Pará.

Toledo (2003) concluded that, in general terms, rural development in the humid tropics has been a catastrophic process accompanied by deforestation all over the world, with serious implications for wetlands, reducing biodiversity and displacing productive strategies for management of tropical forests. The natural consequence of this situation is the bioecological, economic and social impoverishment of land, biota and people.

Modernization had an undesirable effect from the environmental perspective (Tudela, 1989), which led to high rates of deforestation and a significant reduction in mature tropical forests to almost 10% on the original geographic distribution (Masera et al., 1997).

Also, according to FAO et al. (2012), in face of the alarming fact that there are no substitutes for environmental services provided by natural forests, efforts are being made to create and restore forest areas, in order to convert net losses of forest cover into net gains.

Ehrlich (1988) reported that the increase in human population and its activities have resulted in destruction, degradation and fragmentation of habitats, to the point that this process is now the leading cause of decline on biodiversity. Therefore, this review aimed to assess the progress in sustainable forest management by knowing the current state and trends of socio-economic benefits from the forests.

MATERIALS AND METHODS

This manuscript is based on a literature review related to multiple uses of forests in small and medium farms in the tropics around the world. The selected manuscripts show the current practical aspects as well as the economic and social contributions of forest utilization.

RESULTS AND DISCUSSION

Multiple-use forestry around the world

Among the numerous trials of implementing multiple uses forests, in Table 1, are listed the major cases which are discussed in this text. It can be noticed that in all experiences reported in the case studies and published papers, adoption and/or implementation of multiple use of forests brings economic, social and environmental impact, improving quality of life, adding income and, especially, contributing to the maintenance of the forest ecosystem. These aspects meet what is defined as sustainability, with emphasis on economic, environmental and social balance.

Multiple-use forest in the tropics

After the UNO Conferences on Environment and Sustainable Development, with highlight on Eco-92, there were major changes related to environmental awareness, making the world to look more closely at the potential risks of impacts caused by man on ecosystems. Since then, there has been research on more sustainable solutions, considering not only environmental but also social and economic aspects of human activities.

Costa and Scariot (2003) claimed that the removal of forests for various purposes, such as agricultural expansion, roads and hydropower dams, among others, lead to fragmentation of important habitats in small or medium areas that support only a small number of species. The authors point out that this process has its roots in the perception of early European settlers that resources from natural forests were there to be exploited without a long-term perspective.

This fragmentation highlighted by Costa and Scariot (2003) is consistent with Viana (1995), who showed that the fragmentation process is present through land use by farmers in Central Brazil. The value of multiple nature of forests has been appreciated and used by people who depend on forests in the tropics. The goal of multiple use forest management is included in laws of many countries, as well as the guiding principles of sustainable forest management, became an integral part of laws following the Earth Summit in Rio in 1992 (Sabogal et al., 2013). There are several countries where forest production is limited only to wood, prevailing specialization in forest use, which does not help to achieve the goals of maximum land yields for the benefit of the community as a whole.

For purposes of sustainability, the ideal is the adoption of multiple use of forests, understood by Mcardle (2011) as a term that prevails when there is no abundance of natural resources, that is, in times of shortage and many people in need of these resources. This aspect pointed out in the past represents the current scenario.

CNI and BRACELPA (2012) also highlight the importance of the adoption of forest certification, which began to develop internationally in the 1980s as a result of initiatives aimed at environmental conservation, reducing deforestation and sustaining development of

Table 1. Experiences on multiple uses of forestry around the tropics.

Article titles	Author(s): and synopsis of the article	Site of the study and year of publication
The Contribuiton of Multiple Use Forest Management to Small Farmers´ Annual Incomes in the Earstern Amazon	Sist et al. (2014) The article reports the implementation experience of multiple use of forests by family farming communities.	Amazon Brazilian (2014)
Issues of Conservation and Livelihood in a Forest Village of Assam (India)	Sharma and Indrani (2014) This article discusses the application of Multiple Use of Forests in a location India.	Forest village in Assam region – India (2014)
The Multiple Use of Tropical Forests by Indigenous Peoples in Mexico: the Case of Adaptive Management	Toledo et al. (2003). This article presents the experience of adopting Multiple Use of Forest by indigenous People in Mexico.	Mexico (2003)
Multiple Use Forest Management in the humid tropics: Opportunities and challenges for sustainable forest management.	Sabogal et al. (2013). This article brings the FAO researches experience in the implementation of Multiple Use of Forests in humid tropical forests.	Amazon Basin, Congo Basin and Southeast Asia (2013)
Multiple-use forestry vs forestland-use specialization revisited	Zhang (2003) This article provides a counter argument to the adoption of Multiple Use of Forests, including a case study to support the argument.	United States (2003)
Multiple Use forest management: an alternative to the extinction of the Araucaria Forest?	Rosot (2007) This article reports a case study of applying of Multiple Use Forest Management as an alternative to prevent extinction of Araucaria, in Parana, Brazil.	Southern Brazil (2007)
Biodiversity and Social Carbon	Rezende and Melin, (2005) This book report a case Surrounding communities of Bananal Island, in the state of Tocantins, in 1999, from wich arises the concept of Social Carbon, according to the social benefits generated for the local community.	Bananal Island, Tocantins, Brazil (1999)

forests in the world, through rational use of forest resources to ensure their existence in the long run. Gradually, forest certification grew in importance for marketing timber and products from forests in the global market**,** as a way to ensure access and permanence in tighter markets and to introduce new products, maintaining jobs and paying back investments.

In this context, certification constitutes an important instrument because it enable consumers to be sure that best practices (legal, social, labor) with less environmental impact area adopted.

Multiple-use forest: An alternative for sustainability

In 1954, Mcardle defended the multiple use (Mcardle, 2011) as an alternative to sustainability, when, in the opening speech of the V World Forestry Congress, stated that competition for land use is growing worldwide. This dispute will increase as the world population increases. It is important to remember that the author's approach occurs in a context, at a time**,** when the world population was about 3 billion people. The need for multiple uses becomes more pressing in the current scenario in which the world's population is more than doubled.

Taking Mcardle's concern as a premise, currently, the world's population is approximately 7.6 billion people and the forecast of global organizations (UNO, FAO etc.), is that, in 2050, the world population will reach 9.6 billion. Therefore, concern with depletion of forest resources is now much more latent than it was in 1954 and it will be even greater in 2050.

According to FAO (1984), in the past, very low population densities and limited demand for products allowed obtaining multiple benefits from humid tropical forests, without conscious effort. Currently, population growth and consumption is required for multiple use forest management**,** which is essential for management of forest resources, especially in tropical forests, which are carbon sinks and important source of products and environmental services essential to life. According to research from World Resources Institute (WRI, 2015)*,* 30% of global forest cover have been removed, while 20% have been degraded. In addition, a high proportion has been fragmented, with about 15% intact.

Despite reports stating that since 1890, there have been multiple indications of forest use practices of multiple uses in parts of British India and Malaya (Rawat et al., 2011), the development of the practice started in North America and Europe (Sabogal et al., 2013). Nix (2015) referred to the practice as: land or forest management for more than one purpose, such as timber production, water quality, wildlife, recreation, landscape or clean air. It is a concept of forest management that combines two or more goals, such as production of timber or wooden products, fodder and livestock, adequate environmental conditions for wildlife, effects of landscape, protection against flooding and erosion, recreation and protection of water sources.

Sabogal et al. (2013) appraises the multiple use of forest as the deliberate administration of a particular forest area for a certain period, aiming at various goods and services. This definition implies diversification of uses in spatial and temporal terms and covers both, diversification and integration as well as support capacity.

Several authors in different decades produced their particular concepts of multiple use of forests (Ridd, 1965; Panayotou and Ashton, 1992; Vincent and Binkley, 1993; Boscolo, 2000; Campos et al., 2001; Zhang, 2003). Common and final point of the authors is that the practice promotes the sustainability of life on the planet, with the rational use of the forest, combined with market demand for ecosystem services, such as ecotourism, water and soil protection, biodiversity conservation and carbon sequestration.

In this context, it is possible to infer that multiple uses can be understood as the deliberate and carefully planned integration of various uses, so that they interact with each other, saved the appropriate limitations of each system established.

In 2011, came the Bonn Challenge to restore 150 million hectares of deforested and degraded lands by 2020. This ambitious goal was strengthened during the UNO Climate Summit in 2014 in New York, when more than 130 governments, business, civil society and indigenous peoples supported the restoration of more than 350 million hectares of forests and farmland by 2030.

Under the light of this overall goal and the emerging ambitious of national commitments, it is essential to develop methods and low cost techniques for landscape restoration. The most used methods, such as planting the total area with native species seedlings are often expensive and not feasible on the scale needed to meet the targets set. Thus, other strategies are required. Several case studies show that natural regeneration significantly reduces the cost of restoration also for degraded areas.

Native species recolonize on their own or with some assistance, producing rapid biomass increments due to adaptability to local conditions. Strategies based on natural regeneration also offer low-cost opportunities for biodiversity conservation and interaction of species, carbon fixation and watershed protection. Despite these economic and environmental benefits, natural regeneration is often neglected when policies and restoration programs are designed.

On the other hand, global warming, caused by the increase of greenhouse gases emissions due to human activities, is one of the main environmental problems today. Scientific studies commissioned by the United Nations (UNO) warn that changes in climate can cause serious environmental, economic and social impacts.

According to scientists, there are two ways to fight global warming: reduce pollution and remove carbon dioxide (CO_2) released in the atmosphere. Some authors argue that planted forests are great allies of the planet towards the second alternative.

Reforestation for industrial purposes, being deployed around the world, specifically in regions with vast degraded areas and available land, is one of the examples showing that multiple use of forests is most promising alternative for preservation and sustainability.

In this scenario, according to CNI and BRACELPA (2012), the use of planted forests for industrial purposes is relevant to environmental conservation, as the trees provide raw material in a renewable basis, while they protect biodiversity, conserve soil and water and help to reduce climate change.

CNI and BRACELPA (2012) also highlight that planted forests contribute to recovering degraded areas; increase efficiency on agriculture; optimize the use of areas disturbed through human occupation; absorb and store large amounts of carbon; support farmers without jeopardizing food production; promote biodiversity conservation; prevent erosion and silting of rivers, as well as appropriate extensive degraded areas unattractive for other crops. Some examples of multiple uses of forests in the tropics are shown in Tables 2. Environmental or ecosystem services are those that man gets from ecosystems and can be divided into 4 (four) classes, as shown in Table 3.

Among the evaluated ecosystem services, 60% have been used in a non-sustainable way (such as pure water,

Table 2. Non-timber forest products (NTFPs) and by-products related to multiple uses of forests in the tropics.

NTFP	Products	Byproducts
Barks	Ornamental Medicinal Food Religious Handcraft and natural fertilizers.	Tannins Medicinal active ingredients Cosmetics Dyes Vegetable Fibers
Leaves	Decoration Handcraft Fodder for Medicinal Food Animals Religious and Construction	Vegetable fibers Medicinal Cosmetics Waxes Natural Fertilizers Dyes
Fruits	Handcraft Food Medicinal Fodder Seed lings production Decoration (landscaping)	Vegetable oils Water Purification Food Manufacturing
Seeds	Handcraft Religious Food Decoration Fodder	Oils (biofuels, pharmaceuticals etc.) Gums Natural biocides Seedlings food
Roots	Food religious Medicinal	Natural biocides food Colorants
Flowers	Decoration Food crafts religious	Dyes honey production Flavouring cosmetics
Branches	Handcrafts Household items Religious	Firewood Resins Dyes Lates
Trunks (stems)	Resins dyes Latex and essential oils	Food Handcrafts (from lianas)
Latex	Medicinal Waterproofing and varnishes	Rubbers
Resins	Medicinal varnishes	Wood glues repellents Flavoring products
Tannins	Natural biocides Watter treatments Protectors and tanning	Plant resins
Oils	Food (for frying food) medicinal and Reppellents	Medical Cosmetics
Dyes	Food Paintings for Ritualistic purposes Fabrics dyeing	Food

Source:Valverde et al. (2015).

Table 3. Classification of ecosystem environmental services.

Types of ecosystems services	Ecosystems services
Provision of services	Food, Water Timber
Regulatory services	Climatic, Hidrological Flows and Disease Control
Cultural services	Recreation, Scenic beauty and Spiritual
Support services	Soil Formation Nutrient Cycling

Source: adapted from Valverde et al. (2015).

catch fishery and climate regulation), and many have deteriorated as a result of actions to enhance the delivery of others, such as food (Millennium Ecosystem Assessment, 2005). In their turn, degradation costs are passed on from a group of people to another or to future generations, falling disproportionately on poorer populations, increasing socioeconomic inequalities.

Multiple-use forest in small and medium properties

Mcardle (2011) stated that multiple uses would always have less applicability to smaller private farms. However, the author explained that many small and medium owners, in time and according to their own interests, find some way to practice, to some degree, the multiple uses. This assumption has proved to be consistent with the reality over time and, especially in the tropics.

Experiences of multiple uses of forests have been implemented around the world, successfully recovering landscapes aiming at sustainability, as has already occurred in Africa. Pretty (2014), presents results from the *Foresight Program* from the United Kingdom Government. The author examined 40 projects in 20 countries in Africa, from a program through which more than 3 million hectares of land were rehabilitated and are now productive. Besides providing jobs for thousands of Africans with the implementation of sustainable agriculture, this has enabled increase in yields through combination of new varieties with new management practices for agroecological farming as well as plant breeding, among others. This experience had as main result a larger diversity of trees and crops, which has helped to reduce leaching soil runoff and, thus, increase groundwater reserves.

A study conducted by Sist (2014), in the Brazilian Amazon, showed that until recently, large farms accounted for 75% of deforestation, while 25% were caused by smallholders. On the other hand, recent satellite imagery analysis showed that deforestation in smaller plots has increased significantly in recent years.

Toledo (2003) reported the experience of multiple use implementation of forests by indigenous community in Mexico, which can be considered a case of adaptive management and can be considered as one of the most successful cases of rainforest utilization in terms of biodiversity conservation, resilience and sustainability.

According to reports from Alcorn (1990), managed or "artificial" forests are masses of vegetation where the useful non-native species are introduced and manipulated. As in the rest of the Neotropical region, managed forests in Mexico, from primary or mature forests that have been enriched with some non-native species to turn into plantations where a single species of tree or shrub (such as, coffee or cocoa) is planted in association with some native species. Thus, it is possible to have a range of managed forests, from those almost entirely dominated by native tree species to those dominated by non-native trees.

Finally, in smallholdings, the multiple uses of forests is complemented with vegetables gardens and where water bodies are present, it is also possible to integrate their use. As in other areas of the humid tropics of Latin America, there are agroforestry systems, which are usually located next to the house, being managed by women (Alcorn, 1990). Aside from the Lacandones (inhabiting the southern border of the Mexican territory), gardens are found in all the reviewed studies on indigenous management of natural resources. In short, the sustainable multiple uses consolidates itself in the creation of a diversified production system, where crop farming, livestock, forestry and others are implemented in an equitable manner, keeping a set of production units. Even the *Tzeltal indigenous* communities, who settled the lowlands of the Lacandona forest in Chiapas, Mexico, have a subsistence strategy that is based on multiple uses of natural resources (Toledo and Carrillo, 1992).

This landscape diversity has a dynamic based on cycles of forest-crop farming-forestry, which is the result of permanent tension between regenerative natural forces from forest against human forces that transform forest ecosystems. The indigenous multiple use strategies, as the experience from Toledo (2003), also in Mexico, involves six main production units: corn, crop fields, vegetable gardens or solariums, livestock areas, vanilla orchards and secondary and mature forests. As a result, indigenous farmers in Mexico are a case of success in production, both for consumption and for marketing, thus

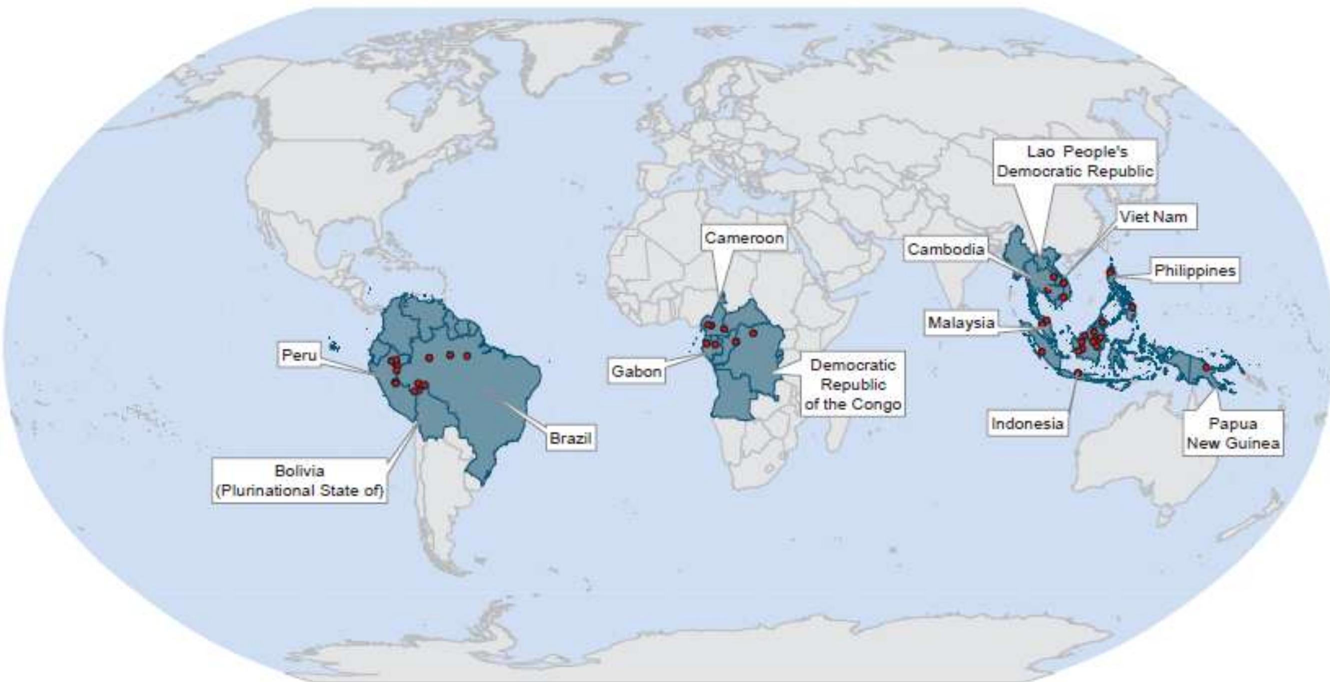

Figure 1. Location of identified multiple-use forest management initiatives in the three tropical rainforest regions. Source: Sabogal et al. (2013).

achieving an economy where self-sufficiency is complemented by excess.

Thus, Toledo (2003) concludes, like Holling et al. (1998) and Toledo (2001), that contemporary scientists, academic institutions and rural development agencies involved in the search for sustainable management systems of natural resources in the humid tropics, should pay attention to the lessons from indigenous socio-ecological systems or to productive and innovative local systems.

The experience of multiple use of forests by indigenous people in Mexico, reported by Toledo (2003) was for many years the most commented and quoted, being considered the single case in tropical forest in South America and in the southern hemisphere. But, in recent years, several papers have been published by Brazilian researchers and other countries, as well as by FAO, with cases of multiple use of tropical forests in Brazil and also in Africa, with reports of success.

Other implementation experiences of multiple use of forests were presented by Sabogal (2013), in surveys carried out in countries located in the tropics with wetlands, among which, three evaluations were carried out with information on the Amazon Basin, Congo Basin and Southeast Asian. In these regions, information was collected through interviews with experts, managers and foresters. Additionally, a questionnaire was applied, identifying in 13 countries (Figure 1), a range of 46 initiatives in progress or completed. Of the surveyed initiatives, timber production is the predominant objective, followed by production of non-timber forest products. Also found by the survey, there were activities of economic, importance in at least some (21%) of the surveyed initiatives, including fishing, ecotourism, forest conservation, and firewood and charcoal production and ecosystem services.

Sabogal (2013) concluded that more effort is necessary to eliminate unfair competition from traders whose sole goal is to extract timber, with little or no concern in adding value to the practice of multiple uses. Thus, the forestry component through silvicultural treatments would lead to a more appropriate management of areas with forest cover.

Relevant study in tropical forests was carried out in the Brazilian Amazon by Sist (2014), in which the author found that small holders in the Brazilian Amazon hold possession of more than 12 million hectares of permanent forest reserves, equivalent to 60% of the public forests in the region. It evaluates economic performance and the management system in a multiple-use forest in a settlement of small farmers and provides information on its potential and limitations.

Sist (2014) has also assessed the potential income for farmers generated by multiple use forest management and compared it with the potential income from six other uses of arable land. The author pointed out that within the communities using familiar forest management, multiple use of the forest has been considered as a possible way to increase income from forests, while preserving the ecological function of forest ecosystems.

The study revealed that within the Amazon, forest management for multiple uses has a high potential, since more than 40% of wood species are also included as non-timber products, some considered as the main product for the market, such as andiroba oil (*Carapa guianensis* Aubl.), cumbaru seeds (*Dipteryx odorata* Aubl. Willd), copaiba oil *(Copaifera* spp.) and Brazil nuts (*Bertholletia excels* Humb. & Bonpl), among others. This scenario shows that the prospects for use of different species in many tropical environments are feasible, with possible compatibility between the use of wood and seeds, especially those producing oil for energy production or in different combinations of these two uses. On the other hand, considering the conditions of small farmers or communities with low investment capacity, lack of knowledge on forestry techniques and reduced connectivity to wood markets, the legislation is undoubtedly more favorable to mechanization for selective logging practiced by forestry companies than to use at small local scale.

Sist (2014) concluded that the average annual economic benefits of multiple use of forests in the Amazon are well below the regional and international levels, representing only 25% of the annual income from the most productive system. These numbers reveal the limits of multiple uses of forests when compared with income from agriculture. However, although the income generated by logging can be considered low when calculated on an annual basis and as compared to the income generated by agriculture, payment in cash after extraction represents a significant amount of financial resources. These could be used in the implementation of more intensive production systems, changing or improving current practices by adopting more sustainable farming techniques, with technical and legal public support, aiming to integrate forest management into sustainable agricultural production systems.

Another key issue that should be highlighted with regard to sustainable forest management is the perception that its success lies not only in the adoption of appropriate technical and silvicultural practices, but that it depends largely on external factors such as market, policies and interests of multiple stakeholders (Louman and Camino, 2004). In this case, the multiple use of forests for carbon sequestration, creating a market in the stock exchanges around the world, reducing deforestation around water sources and maintaining the water table among others can be highlighted.

From other activities of economic importance, in at least some of the initiatives surveyed for multiple use of forests, were found fishing, ecotourism, forest conservation, firewood and charcoal production and ecosystem services. The dominant model of logging, however, is jeopardized in some regions by the arrival of investors interested in agro-industrial activity or mining projects, due to higher financial benefits as compared to those associated with sustainable logging.

According to BRACELPA (2010), in Brazil, companies operating in the logging industry, specifically the pulp and paper industries, invest in alternatives to the practice of multiple use of forests at small farms. It is worth noting the Forest Development Program from Klabin, created in the 80's, in partnership with the Brazilian Federal Government, the National Bank for Economic and Social Development (BNDES), and institutions linked to forest and environment preservation. It is active in the state of Santa Catarina and arose from the company's need to integrate itself with local communities. This program provides support to development areas, incorporating them into the productive process of the company, increasing the company's forest base. Program participants are also involved in other practices, such as forestry (both, pine/eucalyptus and native species), enrichment of secondary forests, organic farming, ecotourism and livestock husbandry (BRACELPA, 2010). With this practice, farmers do not need to abandon their traditional activities, pine and eucalyptus plantation do not use areas occupied by the major activities of the farmer. The program can, therefore, be classified as multiple-use of forests, contributing to the sustainability environmental, since it brings the following benefits to farmers:

a) Environmental conservation and protection;
b) Social inclusion and improved quality of life;
c) Empowerment of rural development;
d) Promotion of planned and ordered occupation of rural landscape;
e) Encouraging agroforestry systems to obtain certifications;
d) It creates opportunities for employment and income;
g) Expands knowledge through exchange of experiences;
h) Encourages preservation and monitoring of fauna, flora and water resources.

Funding for multiple-uses of forest program implementation

The world, about to collapse, seeks alternatives for sustainability in all its dimensions. To achieve the much-desired balance that will lead to sustainability, the main obstacle is funding for improvement of environmental management. Actions for implementation require high volumes of financial resources with public and private contributions, which are not always available. Ideally, sustainable forest management should be self-financed through sales of forest goods and services (Panayotou and Ashton, 1992).

Each country, in its own way, faces the challenge of seeking the best way to finance sustainable forest management; however, if the profits from the use of resources are not enough, there is a great tendency to replace timber production by agriculture.

According to FAO (2010), alternatives for financing are being developed and tested in many countries. They include a wide range of schemes, such as concessions for conservation, debt for nature swaps, payments for environmental services, including "green funds" (payments for carbon offsets), and compensatory payments, to name a few.

The most complex task is the identification of the most suitable financing alternatives for sustainable forest management, since roles, priorities and needs of the various funding bodies are not quite clear to many people and entities.

The economic contributions related to forests in its different environments refer to rural development, poverty reduction and other sectors of the economy that have received increased attention in recent years. Although, bids and payments associated with carbon sequestration and sources of clean water may represent a potential source of significant funding for sustainable forest management, market development based on Payment for Environmental Services (PES) is still in its early stages.

Obtaining additional funding for sustainable forest management is essential, increasing the level of understanding and awareness on traditional and innovative financing options. Policies, regulatory and administrative constraints limit efforts for identification and diversification of funding sources, as well as the legal and institutional reforms that create obstacles to actions to be undertaken.

Final considerations

This century will witness in-depth debate on the limits of sustainability. The global agenda lists issues such as: water conservation, climate change, biodiversity, renewable energy, food security and safety, among others. The conceptual basis for multiple uses in forest management for timber and non-timber products in tropical forests was established almost 20 years ago. Since then, only a few multiple-use forest management systems, some of them discussed in this article, were implemented in the tropics. The most referred examples are those from Guatemala and Mexico.

If multiple use of tropical forest is a desirable alternative, it is still a distant goal, usually ignored as a management alternative by stakeholders in the forestry sector. Government, private and non-profit institutions and other stakeholders involved with sustainability that have multiple use of forests as alternative for sustainability, should establish partnerships with international entities public and/or private, to support implementation of new projects around the world.

Governments have a fundamental role to play in creating favorable environments. Non-governmental organizations and financial institutions are also key to actively establish or support strategies and measures to overcome the economic (market), financial, social and technical barriers for multiple uses, in particular for communities and small holders, as sustainability is the product of joint actions for the common good, mainly the binomial: forests and water.

Conclusion

Therefore, this work concluded that there are laws on forest management; however, they have narrow goals and tend not to favor social inclusion due to a limited inter-sector dialogue when establishing them. Nevertheless, this work concludes that there are promising perspectives on the subject, with success cases in the tropics with a tendency to expand in this area. They prove to be social inclusive for local communities of smallholders that use forest resources in a sustainable way. They achieve conservation of native species with social and economic benefits that reflect in their livelihoods.

Conflict of Interests

The authors have not declared any conflict of interests.

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